Special Report 242

CURBING GRIDLOCK

Peak-Period Fees To Relieve Traffic Congestion

VOLUME 2

Commissioned Papers

Committee for Study on Urban Transportation Congestion Pricing

Transportation Research Board

Commission on Behavioral and Social Sciences and Education

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The report has been reviewed by a group other than the authors according to the procedures approved by the Report Review Committee, consisting of the members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

In response to the growing interest in congestion pricing, the Federal Highway Administration and Federal Transit Administration requested that the Transportation Research Board and the Commission on Behavioral and Social Sciences and Education of the National Research Council conduct a study of this tool for congestion management. The study committee would

- Assess and synthesize available research and experience on congestion pricing,
- Commission papers on critical issues raised by congestion pricing to be presented at a national symposium, and
- Develop recommendations on the potential role of market pricing principles as a tool for congestion management, guidelines for the assessment of the impacts of congestion pricing experiments, and fruitful areas for further research, demonstration, or experimentation.

To conduct this study, the National Research Council appointed a committee with expertise in economics, political science, transportation planning, geography, transit and highway agency management, civil engineering, and government. The committee's deliberations were supplemented by liaison representatives from several groups concerned about the benefits and costs of congestion pricing. (Liaison representatives were invited to participate in the committee's discussion and review and comment on report drafts, but did not vote on recommendations.) After a review of the literature, and drawing from its expertise, the committee commissioned papers on a variety of topics. These papers were presented and discussed at a symposium held in Washington, D.C., in 1993. The

papers, as revised by their authors after the symposium, are contained in Volume 2 of this Special Report. Volume 1 contains the committee's overview of the material contained in the commissioned papers, its conclusions, and recommendations regarding the potential of congestion pricing, the need for evaluation of early demonstrations, and other research needs.

Several of the members selected for this study committee and several of the authors of commissioned papers reside in California. There is good reason for this representation. Congestion pricing as a concept and proposal has been more extensively studied in California in recent years than elsewhere in the United States, and the only experimentation with congestion pricing moving forward at the time of this writing is occurring in California.

The report was reviewed by an independent group of reviewers in accordance with National Research Council report review procedures.

The report was performed under the overall supervision of Robert E. Skinner, Jr., Director, Studies and Information Services, Transportation Researach Board, and Susanne A. Stoiber, Director, Division on Social and Economic Studies, Commission on Behavioral and Social Sciences and Education. Stephen R. Godwin served as study director and, under the guidance of the committee, drafted the report.

The final report was edited and prepared for publication under the supervision of Nancy A. Ackerman, Director, Reports and Editorial Services, Transportation Research Board. Naomi Kassabian was the editor for the report. Frances E. Holland provided word processing support and, along with Marguerite E. Schneider, provided assistance in meeting logistics and committee correspondence.

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VOLUME 1: Committee Report and Recommendations

Congestion Trends in Metropolitan Areas

PETER GORDON AND HARRY W. RICHARDSON
University of Southern California, Los Angeles

In the absence of road pricing, congestion has become the dominant rationing mechanism. The consequences include political pressures for officials to do something about perceived congestion. In response, they implement expensive transit investments, development restrictions, highway capacity expansions, and more recently a spate of intelligent vehicle-highway system (IVHS) research projects. Expenditures on these investments are part of the social cost of *not* pricing. Moreover, they have the effect of diverting the attention of policy makers from the pricing option.

The purpose of this paper is to present evidence showing that in U.S. cities suburbanization has been the dominant and successful mechanism for coping with congestion. Suburbanization has shifted road and highway demand to less-congested routes and away from core areas. All the available recent national survey data on self-reported trip lengths, durations, or both corroborate this view.

How can road congestion be measured? Whereas self-reported travel times and distances (and speeds) provide only indirect evidence, there are few alternative methods of measuring congestion. Hanks and Lomax (1992) present estimates based on ratios of traffic counts to available lane-miles. Their metropolitan area congestion index rankings (Table 1) are computed from the ratio of vehicle miles of travel (VMT) per lane-mile (for freeways and principal arterial streets) versus a standard deemed to equal congested conditions. The benchmark is applied equally to all areas regardless of local conditions. These synthetic descriptors correlate poorly with self-reported average worktrip (p.m. peak) speeds [from Nationwide Personal Transportation Study (NPTS) data]; the rank-order correlation coefficient is just 0.09, not significantly different from zero.

TABLE 1 Comparison of TTI Congestion Index with NPTS Trip Speed: Rankings of Metropolitan Areas

Metro Area[1]	TTI Congestion Index[2]	NPTS PM-Peak[3] Work Trip Speeds[4]
Los Angeles	1	10
San Francisco	2	9
Miami	3	11
Chicago	4	12
Seattle	5	4
Houston	6	5
New York	7	3
Boston	8	6
Detroit	9	8
Portland	10	16
Philadelphia	11	2
Denver	12	17
Milwaukee	13	15
Cleveland	14	13
Cincinnati	15	14
Hartford	16	1
Pittsburgh	17	7

(Rank-order correlation = 0.09)

Notes: [1] TTI used PMSAs and reported 1989 results for fifty of them; NPTS reports 1990 data for CMSAs; NPTS labels responses by place of residence (inside or outside central city) of respondents; inside central city respondent data are shown here; only those places common to both sources are included in this Table; Dallas-Fort Worth is left out since there is a TTI entry for both PMSAs.
[2] Highest ranking denotes worst congestion.
[3] Trips beginning 4-7 PM.
[4] Calculated from self-reporting trip durations and distances; highest ranking corresponds to slowest speed; only trips by private vehicles are included.

1 mph = 1.6 km/hr

The Highway Performance Monitoring System (HPMS) data assembled by FHWA and reported for urbanized areas since 1989 include several indexes that describe road conditions. These include total miles of freeway, total freeway daily VMT (DVMT), percent of total mileage serving as freeways, percent of total DVMT served by freeways, annual average daily traffic on freeways, total estimated freeway lane mileage, and average daily traffic per freeway lane. As expected, indexes that compare demand with capacity (such as average daily traffic per freeway lane) correlate with the Texas Transportation Institute (TTI) index. And, as with the TTI index, demand/capacity indexes do not necessarily covary with vehicle speeds. The lack of covariance should not be surprising. Consider Figure 1, which repeats the standard analysis of roadway congestion: VMT is measured on the horizontal axis, cost (1/speed) is on the vertical axis, and capacity is the third dimension and is represented by shifts to the right in the average cost curve, from *AC* to *AC′*. Given any capacity, average cost increases as VMT grows and speeds decline. Given any demand schedule, higher speeds are available as higher capacity allows greater VMT (moving from *A* to *B* on the graph). In the longer run, demand growth is responsible for still more VMT, with the final equilibrium speed (Points *C*, *C′*, or *C″*) indeterminate (greater than, equal to, or less than the original speed at *A*).

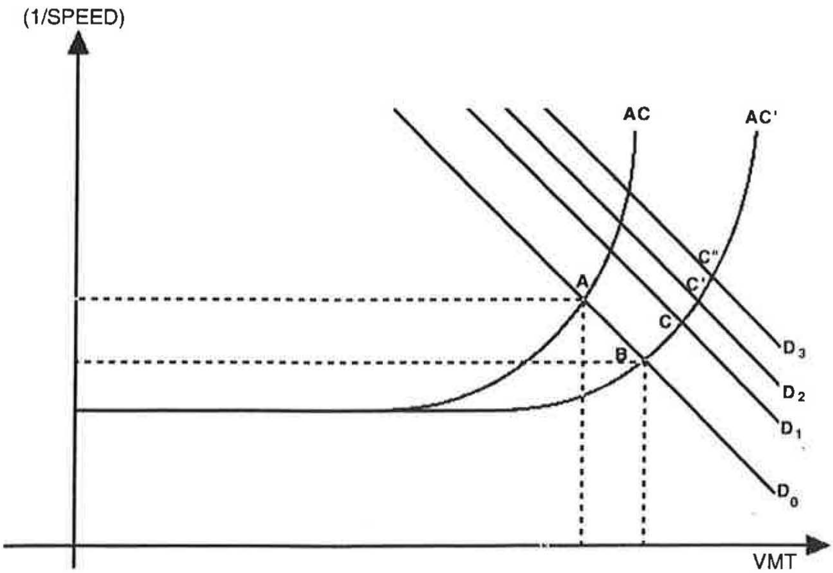

FIGURE 1 Road use equilibrium.

An alternative approach to the study of congestion, unpopular these days because of its high cost, is to follow cars in traffic and monitor directly the congestion they experience. An early example is the General Motors chase car study (Chang and Herman 1978). Instrumented vehicles were used to follow randomly chosen cars in the streets to reproduce the speed-time history of the followed car. Average speeds in heavy traffic for Los Angeles and New York, respectively, were 12.9 and 7.5 mph (20.8 and 12.1 km/hr) for the downtown area, 21.5 and 14.8 mph (34.6 and 23.8 km/hr) for urban roads, and 43.1 and 38.1 mph (69.3 and 61.3 km/hr) for freeways. Speeds were faster as traffic densities dropped, but not by very much except in the downtown area (up to 60 percent faster in Los Angeles). Another measure is the percentage of time the cars were stopped, which was up to 20 percent in Los Angeles urban traffic and almost 37 percent in Manhattan heavy traffic; trip time was a linear function of stopped time (2.17 + 2.157 stopped time). The ratio of the coefficient of variation of speed to average speed could be expressed as a negative exponential function [1.35 exp (−0.0343 average speed)] estimated across nine metropolitan areas. These data are from the 1970s, and there are no recent studies to evaluate temporal trends along these lines. However, these data represent an interesting and very different approach to measuring congestion. From the planner's point of view, however, the method is too episodic, and sheds insufficient light on the congestion costs experienced by all metropolitan travelers.

The implication of contained *areawide* average speeds comes from the "commuting paradox" discussed by Gordon et al. (1991). They reported:

> The commuting paradox reflects the apparent contradiction between perceptions of worsening traffic congestion and evidence of either declining or stable commuting times. However, not only is there no contradiction but the two phenomena are causally related. Rational commuters will, sooner or later, seek to escape congestion by changing the location of their homes and/or their jobs. This type of adjustment is easier to make in large, dispersed metropolitan areas with alternate employment subcenters and a wide variety of residential neighborhoods. The process is facilitated by the decentralizing location decisions of firms seeking to move closer to suburban labor pools. (Gordon et al. 1991)

THE EVIDENCE

Evidence favoring the foregoing view comes from seven major national self-reported travel surveys. The findings from large-scale household

surveys present a consistent story of the containment of metropolitan area commuting times. Evidence from NPTS surveys (1977, 1983, 1990), a commuting questionnaire included in the American Housing Survey (AHS) (1985, 1989), and the last two decennial censuses (1980 and 1990) all help to make the same point.

1977 NPTS

Research using the 1977 NPTS data was reported by Gordon and Wong (1985). They focused on a cross section of metropolitan area trips and found that trip durations did not increase with city size. Since the same survey did not indicate that city size was associated with greater ridesharing (though it showed some greater transit use) or peak spreading, it was likely that the more-dispersed nature of the large cities was responsible for the lack of increase in trip times. This view contradicted the popular idea at that time that city growth and suburbanization would increase average trip lengths and supported the notion that jobs were decentralizing almost as fast as the population, allowing many people to avoid commuting to crowded core centers.

1980 Census

Pisarski came to similar conclusions in his study of 1980 census commuting data (1987). He called attention to the "suburban boom" and to "the fact that suburb-to-suburb worktrips are 50 percent shorter than suburb-to-center city worktrips." Since the former are the fastest growing, the national average work-trip length should fall. He reported the average commuting time in 1980 as 21 min. Table 2 elaborates on Pisarski's analysis by adding data on flows to and from central business districts (CBDs). The shortest trips are those from suburb to suburb (Column 6), and they are the most prevalent. The longest trips, which constitute the smallest number, are from suburb to CBD (Column 4).

1983 Versus 1977 NPTS

Gordon et al. (1989a) compared metropolitan area commuting times and distances from the 1977 and the 1983 NPTS surveys. They found that com-

TABLE 2 Work-Trip Travel Times in U.S. Urbanized Areas, 1980, by Origin-Destination Categories (DOT 1985)

Living:	Inside Central City			Outside Central City		
Working:	CBD	Ins. CC	Outs. CC	CBD	Ins. CC	Outs. CC
ALL Urbanized Areas	24.9 (5.5)	20.0 (32.7)	26.4 (8.6)	35.1 (3.3)	27.2 (15.3)	18.8 (36.6)
25 LARGEST Urbanized Areas	33.4 (4.5)	25.5 (24.7)	29.9 (6.8)	42.1 (3.7)	33.0 (14.3)	19.5 (45.7)

Note: The 'overall' averages were 22.2 minutes for all UAs and 25.4 minutes for the largest 25 UAs, a difference of 14 percent.

(trip durations in minutes; percent of total in parentheses)

muting durations did not deteriorate with city size nor did they worsen over the 6-year time span. In related work (Gordon et al. 1989b) the authors determined that an analysis of men only yielded similar results, refuting the argument that short overall work-trip averages primarily reflect the effect of more working women, who typically have shorter commutes.

1985 AHS Versus 1980 Census

The 1985 AHS included questions on commuting. Fortunately, identical wording was used in the 1980 census commuting questions, which made 1980–1985 comparisons for metropolitan areas possible. Gordon et al. (1991) reported the findings for the top 20 Primary Metropolitan Statistical Areas (PMSAs). The results (Table 3) again corroborated the earlier data: in 18 cases average automobile commuting times were shorter in 1985; in 9 of these cases the difference was statistically significant at the 99 percent level, whereas in 6 others the difference was significant at the 95 percent level. The two trip-length increases (Dallas and Phoenix) were not statistically significant.

1990 Versus 1983 NPTS

Reporting on the 1990 NPTS, Hu and Young (1992) note:

> The average commute trip length increased by 7 percent from 1983 to 1990, from 9.9 miles to 10.6 miles. Yet, the commute time declined by 3

TABLE 3 Changes in Work-Trip Travel Times, 1980 to 1985: Largest U.S. Metropolitan Areas

	1980			1985		
	All	Auto	Transit	All	Auto	Transit
New York	35.6	28.1	47.6	34.0	26.3*	46.2
Los Angeles	24.3	23.7	40.5	22.8	22.1**	39.0
Chicago	28.2	25.4	45.9	26.4	23.9**	44.0
San Francisco	25.3	23.1	39.4	24.4	21.3*	33.2
Philadelphia	25.6	23.7	43.4	24.2	21.9**	39.6
Detroit	23.3	23.1	40.9	19.9	19.9**	44.5
Boston	23.5	22.0	37.7	23.2	20.4*	40.0
Dallas	22.8	22.6	38.1	23.2	22.7	40.7
Washington, D.C.	28.5	26.9	41.7	26.2	25.0**	38.4
Houston	26.6	26.5	46.1	24.0	24.0**	42.0
Miami	23.7	22.9	42.3	21.0	20.6**	33.2
Cleveland	23.4	22.1	38.3	19.8	19.5**	37.0
Atlanta	25.9	24.7	42.8	24.0	23.3*	42.1
St. Louis	23.0	22.6	37.1	21.1	20.9*	31.9
Seattle	23.1	22.0	37.4	21.1	20.5*	37.8
Minneapolis	20.1	19.6	31.0	17.8	17.6**	27.0
San Diego	19.6	20.3	38.9	19.6	19.5	39.5
Baltimore	26.5	25.7	41.6	25.9	24.7	41.2
Pittsburgh	23.1	22.2	37.0	22.4	21.5	37.1
Phoenix	21.7	21.8	42.2	22.6	22.4	38.3

Note: ** decrease in auto commuting time is significant, 0.01 level
* decrease in auto commuting time is significant, 0.05 level

Sources: 1980 U.S. census and 1985 American Housing Survey. See Gordon, Richardson, and Jun (1991) Journal of the American Planning Association, 57.

> percent during the same period. This observation might be partially due to the fact that a greater number of suburban and exurban residential areas and employment centers were developed. The resulting commutes are longer but are travelled at faster speeds. The decline in travel time is also influenced by changes in commuting modes, with a decrease in transit and carpooling and an increase in driving alone. (Hu and Young 1992, 24)

In this study, some of the mode-choice effects were controlled for by studying private mode trips only.

Tables 4 and 5 show average trip durations and distances for the two most recent NPTS surveys (1983, 1990). As before, trips were aggregated by purpose (work and other), place of residence of the respondent [inside central city or outside central city (only metropolitan area residents are included in these compilations)], time of day [peak periods 6:00 to 9:00 a.m. and 4:00 to 7:00 p.m. (weekend trips are included with off-peak trips)], and metropolitan area size class. *Nonstop* work trips were studied only in order to remove the possible effects of increased trip chaining. Table 6 summarizes the comparisons between the two NPTS surveys. The data suggest a mixed picture of net time and distance improvements and deteriorations. For inside-central-city residents, trip durations improved during the morning peak for three of the five PMSA-size groups (including the over-3-million group). There were also trip-time improvements for three of the five groups for the afternoon peak. For outside-central-city residents, trip durations improved for two of the five groups. For the p.m. peak, work-trip times are down in three of the five cases.

To the extent that sample sizes permit, it was possible to test the popular idea that the decentralization of employment works only to the advantage of whites (the spatial-mismatch hypothesis in which job decentralization leaves inner-city minorities unable to access expanding job locations). Table 7 shows that no disadvantage for blacks was found. Black-versus-white comparisons were made, holding income and metropolitan size constant. Of the 24 comparisons, most did not show significant differences in travel distances or durations between the races. Of the seven instances in which there were significant differences, five indicated *shorter* trips for blacks. In only two cases did blacks take significantly longer-duration trips, yet in both cases the associated distances were not significantly longer.

The pooled survey results on durations and distances were converted to data on trip speeds. The latter are more likely to be normally distributed and therefore more appropriate for standard statistical testing. Data on trip

TABLE 4 Mean Trip Times and Distances, 1983 and 1990, by Trip Purpose, Time of Day, and Metropolitan Size: Inside Central Cities (Private Vehicles)

MSA Population Size			AM-Peak[a]		PM-Peak[a]		Off-Peak	
			Work	Other	Work	Other	Work	Other
Residing Inside Central Cities								
Below 250,000	T[b]	1983	15.2	15.7	17.2	12.2	13.6	16.0
		1990	15.0	11.5	16.8	13.6	13.0	14.3
	D[b]	1983	6.7	7.6	7.6	5.0	6.2	7.8
		1990	7.8	6.4	9.6	7.3	7.0	8.3
250,000-499,999	T	1983	15.1	13.9	15.2	11.7	15.7	13.3
		1990	14.8	10.1	15.7	11.8	14.2	14.8
	D	1983	6.1	6.0	7.7	5.0	7.5	5.6
		1990	7.6	3.7	7.7	5.6	7.8	8.8
500,000-999,999	T	1983	17.3	17.9	20.8	12.3	14.9	17.2
		1990	17.9	12.5	17.9	14.1	16.1	14.8
	D	1983	8.5	8.5	9.3	5.0	6.9	9.0
		1990	10.2	5.7	9.2	7.5	9.2	8.0
1-3 Million	T	1983	18.3	16.4	20.8	14.0	17.9	15.1
		1990	19.5	12.4	21.3	14.1	17.8	14.8
	D	1983	8.7	-	8.3	5.5	8.7	6.8
		1990	10.4	6.1	11.1	7.1	9.7	8.0
Over 3 Million	T	1983	28.8	15.1	29.4	17.8	23.0	17.3
		1990	22.9	15.7	24.6	14.7	21.7	16.1
	D	1983	12.7	5.3	12.3	6.7	10.4	7.4
		1990	11.7	7.4	11.8	6.9	12.1	8.5

Source: Computed from 1983 and 1990 NPTS data.

1 mi = 1.6 km

[a] In this and subsequent tables, the AM peak is defined as 6-9 AM; the PM peak is 4-7 PM.

[b] T refers to time in minutes, and D to distance in miles.

TABLE 5 Mean Trip Times and Distances, 1983 and 1990, by Trip Purpose, Time of Day, and Metropolitan Size: Outside Central Cities (Private Vehicles)

MSA Population Size			AM-Peak [a]		PM-Peak [a]		Off-Peak	
			Work	Other	Work	Other	Work	Other
Residing Outside Central Cities								
Below 250,000	T[b]	1983	18.4	9.8	20.2	12.9	16.6	13.3
		1990	19.1	19.5	20.0	17.5	20.4	17.5
	D[b]	1983	9.9	4.3	9.9	6.6	8.8	6.9
		1990	11.7	12.3	12.2	11.1	13.2	11.4
250,000-499,999	T	1983	19.2	18.2	19.7	14.9	16.9	14.1
		1990	19.3	13.1	21.9	12.5	19.4	17.2
	D	1983	10.6	12.4	9.9	7.9	8.8	7.6
		1990	12.0	6.9	13.6	6.5	12.5	10.2
500,000-999,999	T	1983	22.5	17.9	25.5	13.5	21.7	15.8
		1990	21.1	16.9	23.0	13.3	20.8	15.9
	D	1983	12.1	10.4	13.2	6.5	11.1	8.6
		1990	13.1	10.3	13.9	7.5	13.2	9.8
1-3 Million	T	1983	22.1	14.9	23.2	17.7	19.5	16.1
		1990	21.5	13.2	22.8	15.1	21.0	16.6
	D	1983	11.2	7.4	11.2	9.3	10.7	8.8
		1990	12.5	7.2	12.1	8.1	12.9	10.5
Over 3 Million	T	1983	22.3	15.9	25.5	14.1	18.3	17.3
		1990	24.3	13.2	26.4	14.3	21.7	15.9
	D	1983	11.2	7.6	11.5	6.9	9.3	9.0
		1990	13.5	6.8	14.0	7.1	12.9	9.0

Source: Computed from 1983 and 1990 NPTS data.

1 mi = 1.6 km

[a] In this and subsequent tables, the AM peak is defined as 6-9 AM; the PM peak is 4-7 PM.

[b] T refers to time in minutes, and D to distance in miles.

TABLE 6 Comparison of Mean Trip Times and Distances, 1983 and 1990, by Trip Purpose, Time of Day, Metropolitan Size, and Place of Residence (Private Vehicles)

MSA Size			AM-Peak[a]		PM-Peak[a]		Off-Peak	
			Work	Other	Work	Other	Work	Other
Residing Inside Central Cities								
Below 250,000	T[b]	83-90	Down	Down	Down	Up	Down	Down
	D[b]	83-90	Up	Down	Up	Up	Up	Up
250,000-499,999	T	83-90	Down	Down	Up	Up	Down	Up
	D	83-90	Up	Down	n/c	Up	Up	Up
500,000-999,999	T	83-90	Up	Down	Down	Up	Up	Down
	D	83-90	Up	Down	Down	Up	Up	Down
1-3 Million	T	83-90	Up	Down	Up	Up	Down	Down
	D	83-90	Up	-	Up	Up	Up	Up
Over 3 Million	T	83-90	Down	Up	Down	Down	Down	Down
	D	83-90	Down	Up	Down	Up	Up	Up

(continued on next page)

TABLE 6 *(continued)*

Population Size			AM-Peak[a]		PM-Peak[a]		Off-Peak	
			Work	Other	Work	Other	Work	Other
Residing Outside Central Cities								
Below 250,000	T[b]	83-90	Up	Up	Down	Up	Up	Up
	D[b]	83-90	Up	Up	Up	Up	Up	Up
250,000-499,999	T	83-90	Up	Down	Up	Down	Up	Up
	D	83-90	Up	Down	Up	Down	Up	Up
500,000-999,999	T	83-90	Down	Down	Down	Down	Down	Up
	D	83-90	Up	Down	Up	Up	Up	Up
1-3 Million	T	83-90	Down	Down	Down	Down	Up	Up
	D	83-90	Up	Down	Up	Down	Up	Up
Over 3 Million	T	83-90	Up	Down	Up	Up	Up	Down
	D	83-90	Up	Down	Up	Up	Up	n/c

Source: Computed from 1983 and 1990 NPTS data.
1 mi = 1.6 km

[a] In this and subsequent tables, the AM peak is defined as 6–9 AM; the PM peak is 4–7 PM.
[b] T refers to time in minutes, and D to distince in miles.

TABLE 7 Racial Comparisons: Work-Trip Distances and Durations by MSA Size and Income (Private Vehicles)

MSA Size	Income Group	Blacks	Whites	Significantly Different at 95% Confidence*
< 250,000	< $ 30,000	8.73 mi 17.13 mins	9.67 mi 17.22 mins	NO NO
	$ 30,000 - $ 54,999	6.27 mi 14.14 mins	11.22 mi 18.08 mins	YES YES
	> $ 55,000	NA** NA**	10.23 mi 16.66 mins	--- ---
250,000 - 499,999	< $ 30,000	10.71 mi 18.34 mins	8.95 mi 15.84 mins	NO NO
	$ 30,000 - $ 54,999	8.76 mi 18.91 mins	11.61 mi 19.23 mins	YES NO
	> $ 55,000	NA** NA**	11.48 mi 18.43 mins	--- ---

(continued on next page)

TABLE 7 *(continued)*

500,000 - 999,999	< $ 30,000	6.97 mi 16.74 mins	10.28 mi 17.95 mins	YES NO
	$ 30,000 - $ 54,999	10.72 mi 16.31 mins	12.46 mi 20.24 mins	NO YES
	> $ 55,000	NA** NA**	11.78 mi 19.92 mins	--- ---
1 - 3 million	< $ 30,000	9.17 mi 20.63 mins	10.52 mi 18.87 mins	NO NO
	$ 30,000 - $ 54,999	10.17 mi 19.59 mins	11.32 mi 20.35 mins	NO NO
	> $ 55,000	10.48 mi 18.95 mins	12.95 mi 22.23 mins	NO NO
> 3 million	< $ 30,000	10.89 mi 25.48 mins	11.72 mi 20.04 mins	NO YES
	$ 30,000 - $ 54,999	13.04 mi 26.77 mins	13.12 mi 23.09 mins	NO YES
	> $ 55,000	13.65 mi 29.02 mins	14.80 mi 26.66 mins	NO NO

Source: Computed from 1990 NPTS data tapes, U.S. DOT; (i) - (iv) as above; * Two-tailed t-tests;
** NA means that sample size is < 20.
1 mi = 1.6 km

speeds are shown in Table 8. For 59 of the 60 comparisons between 1983 and 1990, speeds for 1990 are higher, 57 of them by statistically significant amounts.

ANOVA tests were also conducted on the null hypothesis that average trip speeds were independent of city size. Table 9 shows *F*-values and significance levels for the 12 categories (two possible places of residence, three time slots, two trip purposes) for which the tests were conducted. Whereas the null hypothesis that city size makes no difference when comparing average trip speeds was not rejected (at the 95 percent confidence level) for 1983 work trips (although sustained for 1983 nonwork trips), the findings for 1990 are somewhat different. Table 9 shows that city size makes no difference for inside-central-city a.m.-peak and off-peak work trips but is significant for the 10 other categories.

However, inspection of Table 10, in which 1990 NPTS data for the 20 reported Consolidated Metropolitan Statistical Areas (CMSAs) are given, shows that there is no simple relationship between trip speeds and metropolitan area size. The middle-sized cities often show the highest speeds (as in 1983), with generally slower speeds seen in the larger and the smaller metropolitan areas. Whereas the five smallest CMSAs show the shortest commuting times, the relationship between metropolitan area size and trip duration is at best weak. More important, relative or absolute CMSA population growth does not correlate with commuting times. The large metropolitan areas appear to absorb large numbers of newcomers without significant decreases in average commuting times. The p.m. period work trip for central-city-based residents is used in Table 10 because some observers think that this is the trip type that is most vulnerable to congestion in conditions of growth; however, analysis of other trips yields similar results. Yet CMSAs with substantial population growth (including Los Angeles, which increased by more than 3 million during the decade) fared about as well as the other metropolitan areas. It is likely that spatial adjustments helped. The Los Angeles CMSA ranked eighth in (24-hr) work-trip speeds by central city residents and tenth in (24-hr) work-trip speeds by suburban residents. A comparison of data for Los Angeles with pooled data for the rest of the top 10 CMSAs (Table 11) showed higher speeds for Los Angeles in five of six cases, two of them significantly higher.

Pisarski (1992a) cites 1985–1989 AHS comparisons that show that the recent decline in work-trip carpooling has been greater than the decline in transit commuting. In order to control for this effect, the 1983–1990 analysis was extended by studying drive-alone cases only. Table 12 sum-

TABLE 8 Comparison of Mean Trip Speeds, 1983 and 1990, by Place of Residence (Private Vehicles)

MSA Population Size		AM-Peak		PM-Peak		Off-Peak	
		Work	Other	Work	Other	Work	Other
Residing Inside Central Cities							
Below 250,000	1983	25.0	20.6	22.9	20.3	24.6	20.9
	1990	29.6*	26.4*	31.4*	26.8*	30.2*	27.4*
250,000-499,999	1983	23.5	19.3	25.0	23.1	24.9	21.2
	1990	29.9*	22.1**	28.7	26.0*	31.5*	28.8*
500,000-999,999	1983	27.4	19.4	25.4	21.0	25.4	23.0
	1990	31.6*	24.2*	29.3**	26.6*	32.4*	27.1*
1-3 Million	1983	27.6	31.7	24.2	20.5	27.5	22.4
	1990	30.7*	24.3	30.4*	26.8*	31.7*	27.7*
Over 3 Million	1983	25.9	15.9	25.5	18.0	25.9	19.2
	1990	30.0*	23.3*	28.0	25.0*	30.6*	26.5*

(continued on next page)

TABLE 8 *(continued)*

Population Size		AM-Peak		PM-Peak		Off-Peak	
		Work	Other	Work	Other	Work	Other
Residing Outside Central Cities							
Below 250,000	1983	30.3	20.9	27.3	24.5	28.2	25.8
	1990	35.2*	30.3*	34.1*	29.6*	36.6*	32.6*
250,000-499,999	1983	30.7	24.8	27.7	24.6	28.4	27.1
	1990	34.8*	28.3**	35.1*	29.4*	34.9*	30.7*
500,000-999,999	1983	30.6	24.5	29.6	26.3	28.6	25.9
	1990	35.2*	30.6*	34.9**	30.7*	35.9*	31.5*
1-3 Million	1983	28.4	23.1	27.0	25.3	29.9	28.3
	1990	33.5*	26.6*	30.7*	28.5*	34.7*	31.0*
Over 3 Million	1983	28.1	20.9	25.8	23.8	27.3	23.7
	1990	31.8*	25.5*	30.7*	27.3*	33.1*	31.8*

* Significantly greater than 1983 at the 99% confidence level.
** Significantly greater than 1983 at the 95% confidence level.
Source: Compiled from 1983–84 and 1990 Nationwide Personal Transportation Study data.
1 mph = 1.6 km/hr

TABLE 9 ANOVA *F*-Values for Null Hypothesis That City Size Does Not Affect Average Speeds (Private Vehicles)

Residence	AM-Peak		PM-Peak		Off-Peak	
	Work	Other	Work	Other	Work	Other
Inside Central Cities 1990	1.05 (0.3797)[a]	3.70 (0.0052)	2.65 (0.0321)	2.71 (0.0287)	1.48 (0.2067)	10.74 (0.0001)
Outside Central Cities 1990	8.11 (0.0001)	11.61 (0.0001)	9.00 (0.0001)	10.16 (0.0001)	5.77 (0.0001)	72.35 (0.0001)

Source: Compiled from 1990 Nationwide Personal Transportation Study data.

[a] Significance levels are shown in parentheses.

marizes these comparisons. As before (Table 8), average trip speeds increased. Of the 30 work-trip speed comparisons made, trip speeds were higher in all cases, in 26 of them by statistically significant amounts.

1989 Versus 1985 AHS

Table 13 shows commuting data for 1985 and 1989 as reported by the AHS. The results show no change in metropolitan area median trip times (all modes). The same table demonstrates that just 9.0 percent of all urban commuters took trips that were longer than 45 min in 1989, down slightly from the 9.1 percent who did so in 1985.

Table 13 provides some evidence for the debate on spatial mismatch of jobs. The below-poverty population has shorter median commutes than the general population; their median commute declined from 18 to 17 min in the 4-year interval. Blacks had a longer median commute, which became longer in 1989; Hispanics showed no change, being even with the general population in 1989. This is a complex picture, but not one that corroborates the spatial-mismatch hypothesis.

1990 Versus 1980 Census

Preliminary 1990 census data have been reported by Pisarski (1992b). He notes that U.S. average commute times increased by 40 sec (from 21.7 to 22.4 min) in the 1980s. Yet even this moderate increase may be a statistical

TABLE 10 Work-Trip Durations and Speeds (Private Vehicles) Compared with CMSA Growth (1980–1990)

CMSA	1990 Pop. (000)	Pop. Change (000) 1980-1990	% Pop. Change 1980-1990	Central City PM Peak Work Trip Duration, 1990 (min.)	Work Trip Duration, 1990 (mins.) Residing		Work Trip Speed, 1990 (mph) Residing	
					Inside Central City	Outside Central City	Inside Central City	Outside Central City
Los Angeles	14,532	3034	26.4	25.5	23.7	26.0	31.7	33.6
Dallas	3,885	954	32.6	25.5	21.0	18.8	33.0	36.1
San Francisco	6,253	885	16.5	16.6	19.7	21.9	29.6	33.9
Houston	3,711	611	19.7	24.7	20.2	24.5	29.2	33.9
Miami	3,193	549	20.8	19.8	19.7	23.5	32.8	28.6
New York	18,087	547	3.1	26.1	23.0	23.4	26.7	31.5
Seattle	2,559	466	22.3	19.8	20.1	30.1	32.3	29.5
Denver	1,848	230	14.2	24.7	21.2	20.5	31.6	32.2
Philadelphia	5,899	218	3.8	22.3	22.6	22.1	34.8	30.8
Boston	4,172	200	5.0	24.3	21.3	20.8	26.9	33.2

(continued on next page)

TABLE 12 Comparison of Mean Work-Trip Speeds, 1983 and 1990, by Place of Residence (Private Vehicles, Drive-Alone Only)

MSA Population Size		AM-Peak	PM-Peak	Off-Peak
Residing Inside Central Cities				
Below 250,000	1983	25.81	23.23	24.77
	1990	29.82**	31.57*	30.64*
250,000-499,999	1983	23.71	24.86	24.60
	1990	29.67*	29.30	32.27*
500,000-999,999	1983	28.05	26.93	25.27
	1990	30.95	28.50	32.99*
1-3 Million	1983	27.21	23.71	28.28
	1990	31.25*	30.80*	32.13*
Over 3 Million	1983	25.89	26.19	26.71
	1990	30.38*	28.38	30.40**

MSA Population Size		AM-Peak	PM-Peak	Off-Peak
Residing Outside Central Cities				
Below 250,000	1983	30.34	27.50	26.56
	1990	35.38*	35.00**	36.46*
250,000-499,999	1983	30.88	27.88	28.58
	1990	34.98*	35.08*	35.39*
500,000-999,999	1983	30.99	29.34	29.16
	1990	34.98**	35.07**	36.32*
1-3 Million	1983	28.42	27.02	30.15
	1990	33.60*	30.64*	34.60*
Over 3 Million	1983	27.40	26.36	27.44
	1990	31.76*	30.75*	33.28*

* Significantly greater than 1983 at the 99% confidence level.
** Significantly greater than 1983 at the 95% confidence level.

Source: Compiled from 1983-84 and 1990 Nationwide Personal Transportation Study data.

1 mph = 1.6 km/hr

TABLE 13 Travel Time from Home to Work, 1985 Versus 1989 (Bureau of the Census 1991, Table 1–5; 1992, Table 1–5)

All workers	Less than 15 minutes		15 to 29 minutes		30 to 44 minutes		45 to 59 minutes		1 hour to 1 hour, 29 min.		1 hr, 30 min. or more		Works at home		Median	
	1985	1989	1985	1989	1985	1989	1985	1989	1985	1989	1985	1989	1985	1989	1985	1989
Total Occupied Units	35.82	34.66	33.84	33.83	14.10	14.11	5.01	5.06	3.15	3.26	1.25	1.21	2.96	2.57	19	20
Tenure Owner	35.02	33.80	33.89	33.77	14.21	14.35	5.14	5.11	3.15	3.29	1.28	1.20	3.29	2.89	20	20
Renter	37.55	36.50	33.76	33.94	13.86	13.62	4.73	4.97	3.15	3.22	1.19	1.24	2.25	1.89	19	19
Characteristics Black	28.53	28.12	37.24	36.26	18.60	17.27	5.98	6.22	4.32	4.97	1.38	2.19	.74	.70	22	23
Hispanic	34.42	32.91	35.52	34.69	15.21	15.78	4.66	4.83	3.65	3.56	1.32	1.42	1.35	1.48	20	20
Elderly (65+)	36.25	34.70	29.35	31.13	13.41	13.29	3.90	4.39	4.09	2.47	1.64	1.21	6.83	4.90	19	19
Moved in past year	36.82	35.30	34.34	34.56	14.09	14.87	4.83	4.90	3.14	3.15	1.20	1.23	1.74	1.68	19	20
Below poverty level	36.20	37.64	30.89	30.60	12.60	10.93	3.87	4.30	2.99	2.81	1.48	1.22	6.69	5.45	18	17
In (P)MSAs Central cities	34.66	34.46	36.73	36.14	14.09	13.78	4.53	4.53	3.41	3.22	1.12	1.12	1.97	1.74	20	20
Suburbs	31.46	29.90	35.15	35.43	16.20	16.11	5.86	5.83	3.41	3.60	1.28	1.28	2.52	2.39	21	21
Urban Total	36.83	35.96	34.08	34.13	14.06	13.80	4.81	4.69	3.12	3.15	1.16	1.13	2.09	1.97	19	19
Outside (P)MSAs	63.77	63.48	19.47	18.63	5.44	6.01	2.50	2.24	1.03	1.71	.94	.76	2.82	2.41	15-	15-
Regions Northeast	32.60	32.01	31.78	31.67	15.60	16.01	6.07	5.96	5.74	4.87	2.18	2.11	2.80	2.29	21	21
Midwest	39.91	38.88	33.42	33.11	12.13	12.13	3.76	4.28	2.19	2.53	.82	.76	4.12	2.95	17	18
South	35.03	33.85	35.23	35.20	14.40	14.71	5.06	4.82	2.44	2.78	1.05	.95	2.42	2.23	19	20
West	35.43	33.59	34.22	34.58	14.49	13.62	5.37	5.52	2.82	3.35	1.16	1.27	2.59	2.93	19	20

TABLE 14 Person-Trips by Mode and Purpose, 1983 and 1990 NPTS (Hu and Young 1992)

Purpose	Private 1983	Private 1990	Public 1983	Public 1990	Other[a] 1983	Other[a] 1990	Total 1983	Total 1990
Earning a Living	44,560 (87.1%)[b]	49,116 (91.2%)	2,302 (4.5%)	2,100 (3.9%)	4,298 (8.4%)	2,639 (4.9%)	**51,160 (100.0%) 22.80%[b]**	**53,855 (100.0%) 21.58%**
Family & personal business	70,020 (87.9%)	96,061 (92.6%)	876 (1.1%)	1,006 (1.0%)	8,762 (11.0%)	6,626 (6.4%)	**79,658 (100.0%) 35.5%**	**103,693 (100.0%) 41.5%**
Civic, educational & religious	14,800 (55.9%)	17,564 (61.9%)	1,244 (4.7%)	1,075 (3.8%)	10,433 (39.4%)	9,736 (34.3%)	**26,477 (100.0%) 11.8%**	**28,375 (100.0%) 11.4%**
Social & recreational	50,287 (81.2%)	53,348 (86.3%)	991 (1.6%)	742 (1.2%)	10,652 (17.2%)	7,727 (12.5%)	**61,930 (100.0%) 27.6%**	**61,817 (100.0%) 24.8%**
Other	4,319 (83.7%)	1,483 (81.4%)	41 (0.8%)	35 (1.9%)	800 (15.5%)	304 (16.7%)	**5,160 (100.0%) 2.3%**	**1,822 (100.0%) 0.7%**
All purposes	**183,986 (82.0%)**	**217,572 (87.2%)**	**5,454 (2.4%)**	**4,958 (2.0%)**	**34,945 (15.6%)**	**27,032 (10.8%)**	**224,385 (100.0%)**	**249,562 (100.0%)**

Values are in millions.

Notes: [a] Includes trips by bicycle, walking, school bus, taxi, airplane, Amtrak, moped and other modes.
[b] Trip purpose share.

(work trips and work-related trips in the survey) declined from 22.8 to 21.6 percent, whereas family and personal business person-trips (the category that includes shopping) are up from 35.5 to 41.5 percent in the United States in the 7 years between the two latest surveys (Tables 14 and 15). In sum, greater numbers of individuals have had greater access to destinations (many of them during peak periods) at higher speeds. This overwhelming improvement in welfare is in sharp contrast to the doomsday rhetoric so often heard in discussions of U.S. urban transportation.

Another important point brought out by these trends has to do with Downs' law of peak-hour expressway congestion (actually, the Wardrop network flow equilibrium principle): the wide array of proposed nonpricing work-trip reduction policies is likely to be a wasted effort because any unused capacity made available by these programs will quickly be absorbed by expanding nonwork travel.

SUBURBANIZATION OF JOBS

Results from sources other than the travel surveys corroborate the extent of faster suburban commuting. Recent empirical research (Gordon and Richardson 1991) shows that the decentralization of economic activity (as measured by more rapid employment growth rates at peripheral compared with central locations) is characteristic of recent trends in almost all U.S. metropolitan areas (Table 16) and is neither a unique phenomenon (e.g., the peculiarity of Los Angeles) nor a regional phenomenon (the

TABLE 15 Person-Trips by Purpose (DOT 1990)

Purposes	1977	1983	1990
Work	19.5%	20.7%	19.8%
Work Related Business	3.6	2.4	1.4
Shopping	17.1	18.2	18.9
School/Church	12.2	11.9	11.4
Doctor/Dentist	1.3	1.3	1.1
Other Personal Business	12.7	16.1	21.6
Vacation	0.1	0.3	0.2
Visiting Friends/Relatives	9.9	10.9	9.6
Pleasure Driving	0.6	0.6	0.3
Other Social/Recreational	13.7	15.5	14.5
Other	9.3	2.3	1.2
All Purposes	100.0	100.0	100.0

TABLE 16 Sectoral Employment Trends in 12 Major CMSAs, 1982–1987 (Gordon and Richardson 1992, Tables 4 and 5)

Sector	Central City			Ring I			Ring II			CMSA
	1982 Share	1987 Share	Annual Growth Rate 1982-87	1982 Share	1987 Share	Annual Growth Rate 1982-87	1982 Share	1987 Share	Annual Growth Rate 1982-87	Annual Growth Rate 1982-87
Manufacturing	0.302	0.258	-0.0388	0.349	0.377	0.0075	0.349	0.365	0.0012	-0.0078
Retail	0.281	0.258	0.0215	0.368	0.379	0.0454	0.351	0.364	0.0468	0.0394
Wholesale	0.377	0.319	-0.0029	0.336	0.360	0.0445	0.287	0.321	0.0535	0.0304
Services	0.416	0.361	0.0397	0.300	0.327	0.0885	0.284	0.313	0.0904	0.0698

Includes New York, Los Angeles, Chicago, Philadelphia, San Francisco, Detroit, Houston, Miami, Cleveland, Milwaukee, Cincinnati, Seattle

spatial structure of automobile-oriented Western metropolitan regions). The research also shows that downtown job growth has been either negative or modest in all major sectors in the larger metropolitan areas since the mid-1970s (Table 17). It is likely that these long-standing employment decentralization trends will continue and may even accelerate. Expanded telecommunications networks and continuously improving information processing and exchange technologies suggest that, in future

TABLE 17 Annual Average Downtown Job Growth Rates by Major Sector, 1976–1980 and 1980-1986

Sector	1976-1980			1980-1986		
	Top Ten*	2nd Ten**	60 Major CBDs	Top Ten*	2nd Ten**	60 Major CBDs
Manufacturing	-0.0010	-0.0157	-0.0083	-0.0375	0.0215	-0.0279
Retail	-0.0020	0.0119	-0.0017	0.0027	0.0216	0.0008
Fire & Services	0.0164	0.0300	0.0266	0.0309	0.0435	0.0352
Total	0.0061	0.0177	0.0111	0.0116	0.0311	0.0117

* Includes New York, Los Angeles, Chicago, Philadelphia, Dallas, San Francisco, Boston, Detroit, Washington, D.C., Houston

** Includes Anaheim, Newark, Atlanta, Minneapolis, Denver, San Diego, Phoenix, San Jose, St. Louis, Pittsburgh

Source: Computed from the Wharton Urban Decentralization Project Database.

TABLE 18 Ten-Year Growth in Mileage on U.S. Urban Roads and Highways (Harrington and Bradley 1992)

	1980	1990	1980-1990 Average Annual % Change
Interstate	9,219	11,527	2.3
Other Freeways & Expressways	6,713	7,670	1.3
Other Principal Arterial	44,338	51,987	1.6
Minor Arterial	66,581	74,656	1.2
Collector	68,213	78,248	1.4
Local	428,168	533,275	2.2
Total Urban	**623,232**	**757,363**	**2.0**
Total U.S.	**3,856,858**	**3,880,151**	**0.1**

1 mi = 1.6 km

years, greater numbers of firms and households will be "footloose" than ever before.

CONCLUSIONS

In the 1980s, U.S. population grew by almost 10 percent and the urban population grew by almost 12 percent. Urban VMT in the decade grew by almost 50 percent whereas miles of urban roads grew by just over 21 percent (Tables 18 and 19). Yet the average commute increased by only 40 sec and these census results have to be qualified by the trip-chaining effects, only identifiable with NPTS data. Clearly a process of accommodation was at work. Was it peak-spreading? Earlier work (Gordon et al. 1990) showed that peak-spreading in metropolitan areas had been modest in the years 1977–1983. Table 20 updates this analysis. It shows that the six peak hours (6:00 to 9:00 a.m. and 4:00 to 7:00 p.m.) accounted for similar proportions of *all* departures in 1977 (39.1 percent), 1983 (37.2 percent), and 1990 (38.3 percent). What about work-trip departures? AHS comparisons for 1985–1989 (Table 13) show that departures during the heaviest morning peak hour, 7:30 to 8:30 a.m., were 28.2 percent of all work trips in 1985 versus 27.9 percent in 1989, an insignificant change.

The common perception of congestion is to conceive of it as route congestion on particular roads. Leaving aside the problem that measuring congestion along individual roads requires expensive longitudinal studies,

TABLE 19 Ten-Year Growth in U.S. Urban VMT

	1980	1990	1980-1990 Average Annual % Change
Interstate	159,347	278,404	5.7
Other Freeways & Expressways	88,328	127,431	3.7
Other Principal Arterial	227,123	335,687	4.0
Minor Arterial	172,356	235,036	3.2
Collector	82,623	103,756	2.3
Local	123,146	196,778	4.8
Total Urban	**852,923**	**1,277,092**	**4.1**
Total U.S.	**1,530,409**	**2,147,501**	**3.5**

1 mi = 1.6 km

TABLE 20 24-Hour Distributions of Trips for MSAs over 3 Million Population, 1977, 1983, 1990, All Purposes, All Modes

Time of Departure	1977	1983	1990
12pm - 2am	5.46%	1.40%	1.28%
2 - 4 am	0.60%	1.16%	0.44%
4 - 5 am	0.26%	0.73%	0.35%
5 - 6 am	1.15%	1.18%	1.24%
6 - 7 am	**3.53%**	**4.04%**	**3.24%**
7 - 8 am	**7.84%**	**6.95%**	**6.52%**
8 - 9 am	**6.68%**	**6.19%**	**5.87%**
9 - 10 am	4.71%	4.62%	4.64%
10 - 11 am	4.80%	5.28%	4.92%
11 - 12 am	4.27%	6.67%	5.58%
12am - 1pm	0.64%	7.17%	6.28%
1 - 2 pm	8.95%	6.10%	5.79%
2 - 3 pm	7.57%	7.72%	8.04%
3 - 4 pm	8.03%	7.44%	8.45%
4 - 5 pm	**9.05%**	**7.66%**	**8.45%**
5 - 6 pm	**7.15%**	**6.44%**	**7.86%**
6 - 7 pm	**4.86%**	**5.96%**	**6.34%**
7 - 8 pm	4.14%	4.16%	5.08%
8 - 9 pm	2.71%	3.32%	4.02%
9 - 10 pm	2.60%	3.08%	2.84%
10 - 12 pm	5.00%	2.73%	2.77%

Note: The six hours of peak-period traffic (boldface type) accounted for 39.1% of all trips in 1977, 37.2% of all trips in 1983 and 38.3% of all trips in 1990.

Source: Computed from 1977, 1983-84 and 1990 NPTS data tapes, U.S. DOT.

the authors believe that discussions of whether or not congestion is getting worse make sense only at the metropolitan-wide level. They further believe that synthetic physical measures of congestion (e.g., the ratio of VMT to some measure of capacity) are also misleading. This explains the emphasis given in this paper to mean travel times and speeds across all metropolitan residents (disaggregated only by central city or suburban residence).

The weight of the evidence suggests that modern cities have avoided worsening congestion by spreading out. Cities remain competitive by avoiding high land costs (and high export prices) and by taking advantage of agglomeration economies that are apparently available at comparatively low densities and throughout each metropolitan area. Congestion exists (as it must in the absence of pricing), but spatial structure adjustments stave off most of the traffic calamities that many have predicted for the largest U.S. cities.

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ABBREVIATION

DOT U.S. Department of Transportation

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Alternative Methods for Measuring Congestion Levels

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The perception that congestion is worsening in major U.S. metropolitan areas is widespread (Meyer 1990). Whether this congestion is real or otherwise, much of the transportation planning that occurs in the United States focuses on relieving congested facilities. However, even if these plans were put in place, regional and local officials would be hard pressed to state that congestion had been reduced, mainly because there is currently no consistent measure of congestion that has been used by metropolitan planners to monitor system conditions. This deficiency will be remedied during the next several years as federally mandated congestion management systems are implemented in major metropolitan areas. Two of the important elements of these systems are the identification of a target transportation system or geographic area that will be the focus of monitoring efforts and the identification of performance measures. Both of these elements will permit transportation planners and decision makers to monitor system performance consistently over time.

However, as federal, state, and local policy makers begin examining innovative strategies for better managing the transportation system, there is a need for past and current data on demand for transportation services and the capability of the system to respond. For example, the success of applying congestion pricing techniques in congested corridors or other locations in a metropolitan area will very much depend on the levels of congestion that are occurring (and thus the motivation to use the priced facility). Several authors have recently suggested that congestion is not a serious problem and that system performance data over time will show a general improvement in congestion levels. Others suggest that highway

performance data will show a general worsening of system congestion. The purpose of this paper is to explore different measures of congestion that could provide some insight into what has really happened to congestion levels over time. In addition, do the available data suggest where the problems are greatest (e.g., suburbs, exurbs, around activity centers, central city)?

This paper is based on data collected from several sources. Thirty metropolitan planning organizations (MPOs) were contacted to discover what data were available on congestion levels in their urban areas. Several state departments of transportation (DOTs) were contacted to determine whether any systematic monitoring was being performed concerning congestion on the state highway system (besides the typical traffic counting programs). Numerous state and metropolitan transportation plans and corridor studies were reviewed, as were several environmental impact statements for highway projects.

All the evidence found in the limited time available is presented here. One of the key observations that needs to be made at the outset is that very few planning agencies or state transportation agencies monitor congestion data. None of the project studies and environmental impact statements reviewed provided data on how traffic volumes have changed over time. Instead, they mainly provided base-year traffic counts that were then compared with forecast-year traffic to determine the severity of projected congestion. The state DOTs contacted, even those that use the Highway Performance Monitoring System (HPMS), did not conduct any operating performance measurements. In most cases the roads were rated by the level of deficiency of their physical condition. To put it bluntly, there is very little information on which to judge whether congestion levels are increasing or decreasing. Those data that are available most often do not provide a fine enough disaggregation to monitor congestion levels for different hours of the day or for that matter for different travel patterns.

POSSIBLE MEASURES OF CONGESTION

Congestion, the effects of congestion, and measuring congestion levels have been of interest to transportation professionals for many years. In the mid-1950s, for example, as major highway improvements were being contemplated around the United States, engineers and planners were interested in the economic effects of congestion (Gibbons and Proctor

1954). Suggested measures of congestion during this period focused on three major factors (Rothrock 1954):

• Operational characteristics of traffic flow, which include speeds, delays, and overall travel times;
• Volume-to-capacity characteristics, which require comparison of actual volumes to road capacity; and
• Freedom-of-movement characteristics, which require a determination of the percentage of vehicles restricted from free movement and the durations of such restrictions.

As noted by Pignataro (1983), several types of congestion indexes surfaced from this early work:

1. The ratio of the actual travel time a vehicle occupies a section of roadway to the optimum travel time (Rothrock and Keefer 1957),
2. Simple travel time to traverse a specified section of roadway (Hall and George 1959; Deen 1960; Haley 1963),
3. Reduction in speed that occurs at high volumes without corresponding changes in volume (Athol 1965),
4. Relationship of average overall speed to speed changes and frequency of speed changes per mile (Greenshields 1961; Platt 1963), and
5. Relationship of time loss to driver inconvenience and discomfort (George 1961).

Much of this earlier work, of course, resulted in the method of highway capacity analysis and level-of-service (LOS) determination that is common to transportation engineering today. In addition, this earlier work focused exclusively on specific facility characteristics, with little attempt to develop a regional or subregional measure of congestion. This pioneering work, however, should not go unnoticed in the exploration for alternative measures of congestion for the 1990s.

More recently, the transportation profession has begun to reexamine how congestion should be measured. Kraus et al. (1976) estimated a model of the welfare cost of congestion, concluding that congestion cost the United States approximately 10 percent of the gross national product at the time that their article was written. Lindley (1987) published a more practical approach that addressed congestion on urban freeways only and used as the primary source of data the 1984 HPMS survey of approximately 50 percent of the freeway sections in the United States in urban

areas with a population of more than 50,000. Congestion was defined as occurring whenever the volume-to-capacity ratios for the HPMS section rose above 0.77, the breakpoint between LOS C and D. The cost of congestion was estimated as a function of vehicle miles of travel (VMT) under congested conditions, including some measure of delay costs for recurring congestion. Cost of nonrecurring congestion was estimated in similar fashion on the basis of flow rates past incidents of various types and their probable frequencies.

In 1989 the General Accounting Office (GAO) published a report on traffic congestion that surveyed efforts in the United States to measure congestion. None of the measures cited by the GAO were as useful as the Lindley approach, although a number are likely to yield necessary input data in any effort to estimate the prevalence and costs of congestion. These measures included traffic density, average travel speed, maximum service flow rate, volume-to-capacity ratios, average daily traffic volume, and daily VMT.

Schrank et al. (1993) of the Texas Transportation Institute (TTI) have undertaken one of the more systematic approaches to measuring congestion in U.S. cities. In an approach similar to Lindley's, these researchers assumed that "congested" facilities were those that experienced performance above some threshold value. The value selected was 13,000 daily VMT per lane-mile (20 917 VKT per lane-kilometer) on freeways and 5,000 daily VMT per lane-mile (8045 VKT per lane-kilometer) on principal arterials. Much of the data for this assessment came from the national HPMS data base. This approach toward congestion measurement will be discussed more fully in a later section.

In another much broader study using the HPMS data base, Hartgen and Krauss (1992) examined 14 data items associated with each of the 50 state DOT program characteristics and resulting performance data. The performance data from the HPMS sections that are of most interest here are the change over time in the percentage of urban Interstate and other freeways that were congested. For example, the proportion of urban Interstate HPMS sections considered congested increased from 36.8 percent in 1984 to 52.6 percent in 1989. However, in 1990, the percent congested increased only slightly, to 52.8 percent. The authors concluded, "In summary, the 1990 statistics show continued improvement, but with a leveling off of congestion increases."

Finally, other efforts to assess changing congestion levels have relied on national data that come primarily from the U.S. census journey-to-work data. Perhaps the most interesting use of these data was made by Gordon

et al. (1991), who compared 1980 journey-to-work data with the results of the 1985 American Housing Survey for the top 20 metropolitan areas in the country. The authors found that the work-trip travel times decreased or remained almost constant over this time period. Commuting times tended to be shorter in cities experiencing rapid growth. On the basis of this analysis, Gordon et al. suggest that the phenomenon reflected in the data is one in which individuals and firms adjust rationally (economically) to adverse changes in physical and economic conditions such as long travel times by relocating their activities and residences so as to keep commuting times within tolerable limits. Congestion mitigation is thus nothing more than the process of making rational location decisions and of not placing restrictions on the way in which this land use pattern occurs.

This preliminary discussion of congestion measures provides two important points of departure for the discussion that follows. First, identification of different approaches toward measuring congestion has been important in the transportation profession for many years. Most of the measures that were identified almost 40 years ago are still the major ones considered today, although, as was mentioned earlier, they have little application in the metropolitan areas of the country.

Second, the discussion of congestion measures must necessarily begin with the identification of the target market. For the operators or owners of the road system, there are clear operations-based measures that relate performance to traffic volume and speed characteristics, as well as system-based measures that relate traffic levels to system capacities. For the users of the road system, there are different measures that reflect actual trip patterns and trip characteristics. For operations reporting the desired measures would rely on the traditional tallies taken in every metropolitan area, for example, traffic counts, screenline counts, toll counts, boarding counts for transit. For systems monitoring the measures would need to identify changes both in breadth and depth of congestion, where breadth could be defined as the percent traffic affected and depth would be the total time (in minutes or hours) of delay. User-based monitoring would identify the differences between system measures and individual measures, such as changes in average travel times for specific origin-destination pairs taken within a context of known average trip lengths and mode-split data for a metropolitan area. One of the reasons for some discrepancy in the results of the congestion studies is precisely the difference in the target market–characteristics of the individual trip (e.g., average trip time) versus those of the system or facility (e.g., average speed on a facility segment).

In the following sections efforts that have been undertaken in the United States to quantify system performance as it relates to congestion are discussed.

METROPOLITAN AREA EXAMPLES

At the outset of this study, the MPO was considered to be a major source of information on system performance at the metropolitan level because it has been the responsibility of these organizations since the mid-1970s to coordinate urban transportation planning in metropolitan areas. Therefore, 30 MPOs were contacted that represented every geographic region of the country, with the selection oriented toward metropolitan areas that had experienced high levels of growth over the past 10 years (see box). MPO planners were asked if any systematic effort was currently being undertaken to monitor levels of congestion (or, for that matter, any other system performance indicator) on the metropolitan road network. In particular, information was sought on changes in congestion over time to determine if congestion levels were declining or increasing. Facility-specific data, such as those that might occur in corridor studies, were also solicited. Twenty-two of the 30 MPOs indicated that no congestion performance information was available. Several MPO officials stated that they perceived congestion levels as worsening but that there were no data to support this opinion except traditional traffic counts, which, in most cases, were used simply to monitor traffic volume levels on specific facilities for traffic modeling (i.e., model calibration). Eight MPOs, however, indicated that

METROPOLITAN PLANNING ORGANIZATIONS CONTACTED

Atlanta	Dallas	Memphis	St. Louis
Baltimore	Denver	Miami	San Diego
Birmingham	Detroit	Minneapolis	San Francisco
Boston	Houston	New Orleans	Seattle
Buffalo	Indianapolis	Newark	Tampa
Chicago	Jacksonville	Orlando	Washington, D.C.
Cincinnati	Kansas City	Philadelphia	
Cleveland	Louisville	Pittsburgh	

some efforts have been made to monitor system performance. Four of these—in San Diego, Baltimore, Washington, D.C., and Orlando—were considered interesting enough to merit further attention here.

San Diego

The San Diego Association of Governments (SANDAG) is the designated regional transportation planning and congestion management agency (under state law) for the San Diego metropolitan area. SANDAG produces a report that shows the weekly traffic volumes on selected roads in the metropolitan network. LOS standards are applied to these road segments to provide some measure of performance related to volume-to-capacity ratios, traffic density, and average vehicle speeds. The capacity of each road segment has been estimated using the *Highway Capacity Manual* (TRB 1992), with adjustments for unique local circumstances. For example, capacity increases were credited to locations in which auxiliary lanes existed between freeway interchanges and ramp meters were used because "in the field, there was a demonstrated improvement in traffic flow" where these conditions occurred (SANDAG 1992). The estimated levels of service are based on average weekday peak-hour volumes, which means that congestion levels could actually be worse or better than estimated on some days. The California Department of Transportation has verified the LOS estimates by conducting travel time studies on the selected roadway links, so SANDAG planners can consider these indicators to be representative of what is actually occurring on the road network.

The only temporal comparison available at this time is the difference in congestion levels on the selected road segments between 1985 and 1990 (Tables 1 and 2). As shown in Table 1, in 1985 72 mi (116 km) (37 percent) of the freeway experienced LOS E and F during the morning peak hour, whereas 70 mi (113 km) (35 percent) experienced these conditions during the afternoon peak. Five years later, an additional 23 mi (37 km) (an increase of about one-third) of freeway was experiencing such conditions during the morning peak hour, and an additional 48 mi (77 km) (an increase of more than two-thirds) was added to these LOS categories for the afternoon peak hour.

The summary report prepared by SANDAG concluded the following:

> The regional percentage of freeway miles experiencing LOS "F" almost doubled during the five year period. However, the degree of increase

TABLE 1 San Diego Urban Freeway Mileage by Level of Service, 1985 and 1990 (SANDAG 1992)

		1985 Miles by Level of Service						1990 Miles by Level of Service					
Freeway	Peak Hour	Total Miles[a]	A/B	C	D	E	F	Total Miles[a]	A/B	C	D	E	F
I-5	AM	56.4	11.2	16.9	18.1	6.8	3.4	56.4	4.5	13.5	11.6	12.2	14.6
	PM		6.6	17.8	19.3	10.5	2.2		6.2	5.8	14.8	16.8	12.8
I-8[b]	AM	25.4	3.7	1.8	5.9	7.5	6.5	25.4	3.2	5.8	5.7	5.4	5.3
	PM		3.7	3.0	4.3	4.2	10.2		3.2	2.4	5.1	4.2	10.5
I-15[c, d]	AM	33.9	9.5	9.0	6.2	6.9	2.3	33.9	7.6	5.4	7.8	6.8	6.3
	PM		9.5	12.2	6.1	5.4	0.7		6.2	6.8	1.0	7.8	12.1
SR-52	AM	3.4	0.0	3.4	0.0	0.0	0.0	7.4	1.0	0.0	0.0	6.4	0.0
	PM		0.0	3.4	0.0	0.0	0.0		1.0	0.0	0.0	6.4	0.0
SR-67[b, c]	AM	4.9	1.4	2.4	1.1	0.0	0.0	4.9	3.9	1.0	0.0	0.0	0.0
	PM		1.4	3.5	0.0	0.0	0.0		2.9	2.0	0.0	0.0	0.0
SR-78[c]	AM	16.6	0.0	7.8	2.6	6.2	0.0	16.6	0.0	0.0	9.5	2.2	4.9
	PM		0.0	5.3	1.8	7.7	1.8		0.0	0.0	4.4	1.5	10.7

(continued on next page)

TABLE 1 *(continued)*

Freeway	Peak Hour	1985 Miles by Level of Service: Total Miles[a]	A/B	C	D	E	F	1990 Miles by Level of Service: Total Miles[a]	A/B	C	D	E	F
SR-94[b]	AM	11.9	0.0	1.6	3.3	4.9	2.1	11.9	0.0	0.0	5.5	3.5	2.9
	PM		0.6	1.8	2.6	3.9	3.0		0.0	0.0	1.5	4.0	6.4
SR-125[c]	AM	1.8	0.0	0.0	0.0	1.8	0.0	1.8	0.0	0.0	1.8	0.0	0.0
	PM		0.0	0.0	0.0	0.7	1.1		0.0	0.0	1.8	0.0	0.0
SR-163	AM	11.0	0.0	0.0	0.0	7.9	3.1	11.0	0.0	0.0	0.0	7.8	3.2
	PM		0.0	0.0	4.6	3.3	3.1		0.0	0.0	0.0	7.8	3.2
I-805[b]	AM	28.1	7.3	5.1	3.3	6.4	6.0	28.1	6.7	2.0	6.4	5.8	7.2
	PM		7.0	5.4	3.3	6.4	6.0		3.9	4.8	5.8	8.2	5.4
SR-905	AM	3.2	3.2	0.0	0.0	0.0	0.0	3.2	3.2	0.0	0.0	0.0	0.0
	PM		3.2	0.0	0.0	0.0	0.0		3.2	0.0	0.0	0.0	0.0
TOTAL	AM	196.6	36.3	48.0	40.5	48.4	23.4	200.6	30.1	27.7	48.3	50.1	44.4
	PM		32.0	52.4	42.0	42.1	28.1		26.6	21.8	34.4	56.7	61.1

NOTE: 1 mi = 1.6 km.

[a] Urban area only.

[b] Includes capacity benefits from ramp meters since 1985.

[c] Additional lanes added on some freeway segments since 1985.

[d] Separate HOV lanes (reversible) added since 1985.

TABLE 2 Percentage of San Diego Freeway Mileage by Level of Service, 1985 and 1990 (SANDAG 1992)

		Percent of 1985 Miles by Level of Service						Percent of 1990 Miles by Level of Service					
Freeway	Peak Hour	Total Miles[a]	A/B	C	D	E	F	Total Miles[a]	A/B	C	D	E	F
I-5	AM	56.4	20	30	32	12	6	56.4	8	24	21	22	26
	PM		12	32	34	19	4		11	10	26	30	23
I-8[b]	AM	25.4	15	7	23	30	26	25.4	13	23	22	21	21
	PM		15	12	17	17	40		13	9	20	17	19
I-15[c, d]	AM	33.9	28	27	18	20	7	33.9	22	16	23	20	19
	PM		28	36	18	16	2		18	20	3	23	36
SR-52	AM	3.4	0	100	0	0	0	7.4	14	0	0	86	0
	PM		0	100	0	0	0		14	0	0	86	0
SR-67[b, c]	AM	4.9	29	49	22	0	0	4.9	80	20	0	0	0
	PM		29	71	0	0	0		59	41	0	0	0
SR-78[c]	AM	16.6	0	47	16	37	0	16.6	0	0	57	13	30
	PM		0	32	11	46	11		0	0	27	9	64

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TABLE 2 *(continued)*

		Percent of 1985 Miles by Level of Service						Percent of 1990 Miles by Level of Service					
Freeway	Peak Hour	Total Miles[a]	A/B	C	D	E	F	Total Miles[a]	A/B	C	D	E	F
SR-94[b]	AM	11.9	0	13	28	41	18	11.9	0	0	46	29	24
	PM		5	15	22	33	25		0	0	13	34	54
SR-125[c]	AM	1.8	0	0	0	100	0	1.8	0	0	100	0	0
	PM		0	0	0	39	61		0	0	100	0	0
SR-163	AM	11.0	0	0	0	72	28	11.0	0	0	0	71	29
	PM		0	0	42	30	28		0	0	0	71	29
I-805[d]	AM	28.1	26	18	12	23	21	28.1	24	7	23	21	26
	PM		25	19	12	23	21		14	17	21	29	19
SR-905	AM	3.2	100	0	0	0	0	3.2	100	0	0	0	0
	PM		100	0	0	0	0		100	0	0	0	0
Total	AM	196.6	18	24	21	25	12	200.6	15	14	24	25	22
	PM		16	27	21	21	14		13	11	17	28	30

NOTE: 1 mi = 1.6 km.
[a] Urban area only.
[b] Includes capacity benefits from ramp meter since 1985.
[c] Additional lanes added on some freeway segments since 1985.
[d] Separate HOV lanes (reversible) added since 1985.

varied considerably among freeways and in some cases there was a decrease in the amount of the most severe traffic. . . . Several freeways showed an improvement in the level of service (because) of the addition of lanes between 1985 and 1990. (SANDAG 1992)

San Diego is an example of an area in which one of the more systematic MPO efforts in the country to quantify congestion performance levels has taken place. The information provided by SANDAG indicates that congestion levels on the San Diego freeway system have increased over the 5-year period 1985 to 1990. Efforts to validate these findings (through the use of travel time studies) seem to have been successful.

Baltimore

The Baltimore Metropolitan Council periodically publishes a summary report of the travel characteristics in the Baltimore region. The most recent report used the latest census data and state highway agency traffic counts to compare the changing travel characteristics with the 1980 data (Baltimore Metropolitan Council 1993). Some of the key observations from this report include the following:

- The demand for highway travel within the Baltimore region has increased substantially from 1980 levels, with 1990 volumes almost 45 percent greater than those in 1980 (see Figure 1).
- Demand tends more and more to exceed supply, especially during the commute hours of the day. (No discussion was presented on how capacity was determined.)
- The number of vehicle trips per day has increased from 4.2 million in 1980 to 5 million in 1990.
- Average travel times have changed insignificantly from 26.5 min in 1980 to 25.9 min in 1990.
- For 50 to 60 percent of workers the trip to work is less than 30 min. An additional 30 percent travel from 30 to 60 min.
- In 1980, 60 percent of the work travel was by automobile; in 1990, this proportion had reached 70 percent.

Although average travel times have not changed significantly over the past decade, the report states, "Anyone who travels the roadways within the Baltimore Region is aware that congestion is increasingly becoming an

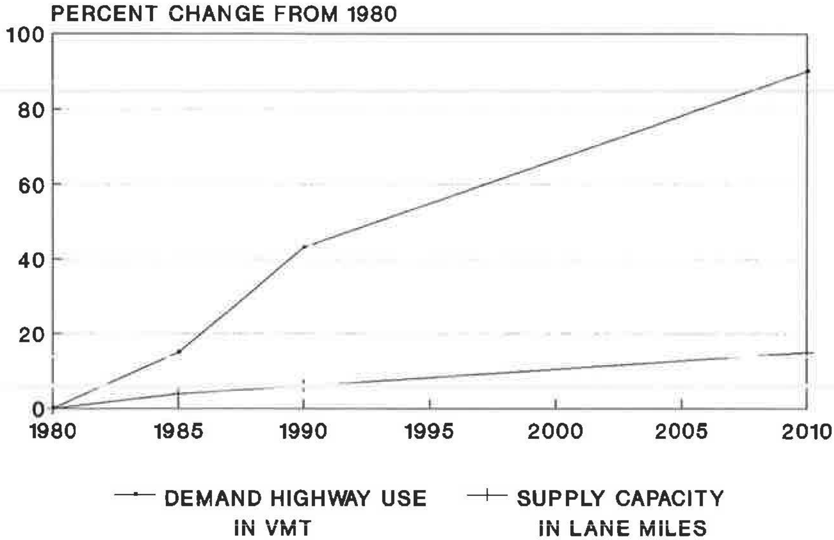

FIGURE 1 Change in highway demand versus supply in Baltimore region (Baltimore Metropolitan Council 1993) (1 mi = 1.6 km).

undesirable part of daily commuting." A planner with the council stated that the region is encountering increasing levels of congestion in some corridors and that where road capacity has been added, congestion levels have declined. Overall, though, this planner believes that local officials have a strong perception that congestion has become worse over time.

Washington, D.C.

The Metropolitan Washington Council of Governments (COG) has conducted several studies of road facilities in the Washington, D.C., metropolitan area that provide useful insights on what has happened to congestion levels over time. Two of these studies will be discussed here—the *1990 Beltway Travel Time Study* (COG 1990b) and the *1990 Arterial Travel Time Survey* (COG 1990a).

Beltway Travel Time Study

The Washington Beltway (I-495) is arguably the most important road facility in the Washington metropolitan area. This 64-mi freeway carries 40 percent of the freeway VMT and 16 percent of the total VMT in the

region. Since 1981 COG has been conducting studies of Beltway travel times and speeds by measuring the travel times between interchanges on the roadway in both directions. A minimum of 16 runs was made in each direction, and the estimated range in error was ±2 mph (±3 km/hr).

The overall findings of the most recent report published (COG 1990b) provide an interesting comparison over time of the performance of a major regional facility. Table 3 shows how average travel speed on the Beltway has changed from 1981. From 1987 to 1990, speeds increased 2 to 3 mph in both directions; this increase in speed was attributed to several factors: improvements to interchanges, widening of the Beltway in some locations, operational improvements such as restricting trucks to the two right lanes, and the introduction of 65-mph (105-km/hr) speed limits on rural freeways, which apparently had a spillover effect on the Beltway (of 152 links in 1987, 16 operated at average speeds of 60 mph (97 km/hr), whereas this number had increased to 29 links by 1990).

Of some interest, COG further disaggregated the speed data by dividing the Beltway into several sectors and comparing the relative performance of each sector (see Table 4); in addition, the speed data at key bottlenecks (in this case, the bridges over the Potomac River) were compared. Not surprisingly, the bottlenecks showed lower average speeds than the rest of the Beltway and also a much greater variation in these average speeds over time. Figure 2 shows the average speed data for the Woodrow Wilson Bridge. As noted in the report, construction activities and limited lane capacity on the bridge have contributed to the wide variation in average travel speeds. (However, as was also noted, data were discarded for travel runs in which there was an accident or unusual inci-

TABLE 3 Overall Travel Speeds on Washington Beltway, 1981–1990 (COG 1990b)

Time and Direction	1981	1985	1987	1990	Change, 1987–1990
AM clockwise	—	45	45	48	+3
AM counterclockwise	—	46	46	50	+4
PM clockwise	53	50	46	48	+2
PM counterclockwise	54	47	46	46	0

NOTE: Values are in miles per hour (1 mph = 1.6 km/hr).

TABLE 4 Average Beltway Speeds by Sector (COG 1990b)

Time and Direction	1981	1985	1987	1990	Change, 1987–1990
Sector 1: US-1 (Virginia) to George Washington Memorial Parkway (Maryland)					
AM clockwise	—	36	43	43	0
AM counterclockwise	—	55	55	56	+1
PM clockwise	54	56	56	54	−2
PM counterclockwise	54	52	49	57	+8
Sector 2: George Washington Memorial Parkway (Maryland) to I-95 (Maryland)					
AM clockwise	—	56	53	51	−2
AM counterclockwise	—	34	31	41	+10
PM clockwise	46	35	32	37	+5
PM counterclockwise	54	45	40	32	−8
Sector 3: I-95 (Maryland) to US-1 (Virginia)					
AM clockwise	—	49	43	51	+8
AM counterclockwise	—	47	53	51	−2
PM clockwise	56	59	52	54	+2
PM counterclockwise	53	44	47	47	0

NOTE: Values are in miles per hour (1 mph = 1.6 km/hr).

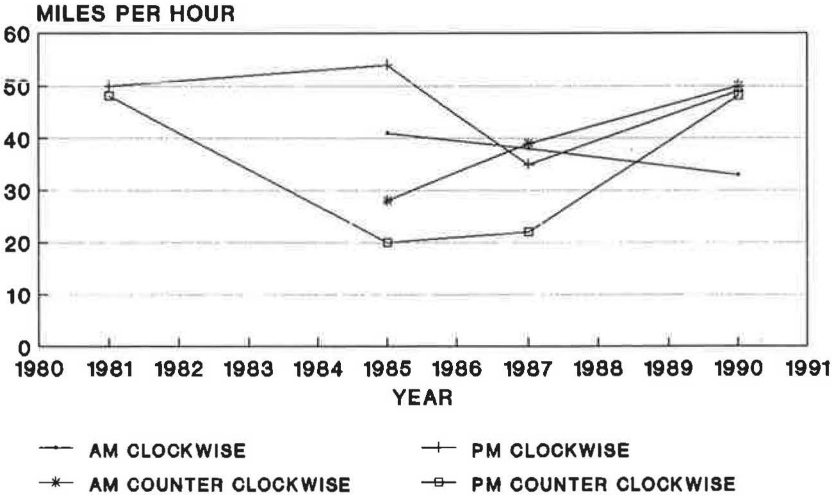

FIGURE 2 Average travel speed on Woodrow Wilson Bridge (COG 1990b) (1 mph = 1.6 km/hr).

dent, which is the type of event that causes high levels of congestion at this location.)

Arterial Travel Time Survey

Given the perception that freeway congestion was worsening in the Washington metropolitan area, COG was requested to assess the potential of principal and minor arterials handling increased volumes (COG 1990a). Sixteen arterial routes were selected for LOS and travel time analysis. These 16 routes represented a cross section of the arterial highway system in Northern Virginia and Prince George's County. The study collected data during the 2-hr p.m. peak, and some of the routes were in relatively undeveloped areas outside the Beltway. The results of this study were somewhat surprising in that 83 percent of the arterial sections representing 90 percent of the arterial miles were operating at LOS A to D. The study concluded that much of the travel time delay experienced on the arterial system could be attributed to a relatively small number of bottlenecks (usually intersections). The congested highway sections were interspersed with sections operating at higher speeds and better levels of service.

Some of the arterial routes in the 1990 study had been studied in 1980 and 1988–1989 as part of another travel time study. Table 5 compares the average speed data for each of these routes for 1980 and 1988–1989. As shown, average arterial speeds between 1980 and 1989 have generally declined on 16 of the 20 routes, declining 20 percent or more on 9 routes. For those routes where average speeds increased, the reasons cited were road improvements that substantially increased capacity.

Orlando

The MPO in Orlando conducted a regional travel time study in 1988 to determine the performance of commuter corridors in the Orlando metropolitan area (Metropolitan Planning Organization 1988). The results of this study were compared with those from a 1984 study to determine the relative change in road performance over time. Eleven major routes were selected, and numerous travel time runs were made during the peak and off-peak hours. As noted in the study report, most of the routes experienced longer travel times and thus slower speeds during the peak periods. Figures 3 and 4 show the comparison of 1984 and 1988 peak and off-peak

TABLE 5 Arterial Travel Time and Speed Comparison in Washington, D.C., 1980 to 1988–1989 (COG 1990a)

Route	Description	Average Travel Time 1980	Average Travel Time 1988–1989	Average Speed (mph) 1980	Average Speed (mph) 1988–1989	Percent Difference in Speed
US-1	Crystal City to I-95	14:43	13:12	17.1	19.0	+11
US-1	I-95 to Mt. Vernon	16:59	17:51	25.7	24.4	−5
VA-7	Alexandria to Seven Corners	19:57	22:23	21.1	18.8	−11
VA-7	Seven Corners to Tysons Corners	16:35	20:17	18.8	15.4	−18
VA-7	Tysons Corners to Seven Corners	15:29	16:35	20.2	18.8	−7
VA-7	Seven Corners to Alexandria	18:43	23:22	22.5	18.0	−20
VA-236	Alexandria to Landmark	9:08	8:41	21.2	22.2	+5
VA-236	Annandale to Fairfax City	12:37	20:57	28.6	17.2	−40
VA-236 to VA-644	Alexandria to Springfield	18:42	27:50	27.0	18.1	−33
US-50	Seven Corners to Fairfax City	16:35	17:36	25.7	24.2	−6
VA-123	Chain Bridge to Tysons Corners	15:25	15:34	28.8	28.5	−1
VA-123	Tysons Corners to Fairfax City	16:28	21:47	22.2	16.8	−24
Wilson Blvd.	Rosslyn to Seven Corners	13:34	12:11	20.2	22.4	+11
MD-5	Curtis Road to Clinton	15:30	20:18	25.9	19.8	−24
US-1 (Md.)	Riverdale to College Park	5:24	7:16	27.2	20.2	−26
US-1 (Md.)	College Park to Muirkirk Road	9:02	11:30	32.3	25.3	−22
MD-193	Langley Park to Greenbelt	13:31	12:37	26.4	28.3	+6
MD-193	Greenbelt to Langham Severn Road	4:31	5:40	35.2	28.0	−20
MD-193	Lanham Severn Road to Greenbelt	4:08	5:34	38.5	28.5	−26
MD-193	Greenbelt to Langley Park	13:32	13:51	26.4	25.7	−3

NOTE: 1 mph = 1.6 km/hr.

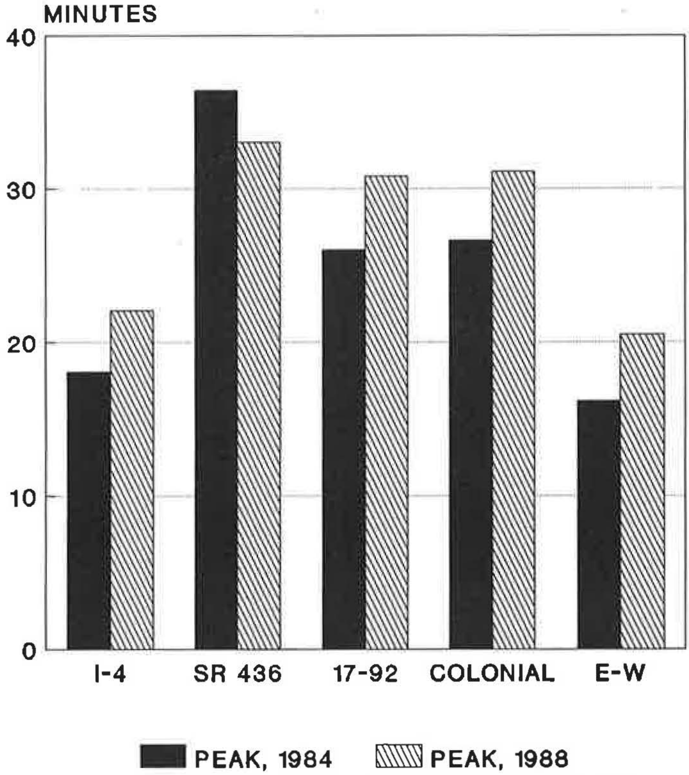

FIGURE 3 Orlando peak travel times, 1984 to 1988 (Metropolitan Planning Organization 1988).

travel times for selected routes in Orlando. Of some interest is the observation that all peak-hour travel times increased except for one route, whereas the off-peak travel times showed mixed results. Although interesting in that it included off-peak travel times, this report is probably not an important indicator of national road performance, especially given the heavy tourist-oriented travel that occurs in the Orlando area and the lack of information on what improvements had been made to the road network.

HPMS-BASED STUDIES

Texas Transportation Institute

As noted earlier, the best-known example of use of the HPMS data base to assess changes in congestion levels in urban areas is the research currently under way at TTI (Schrank et al. 1993). A roadway congestion index (RCI)

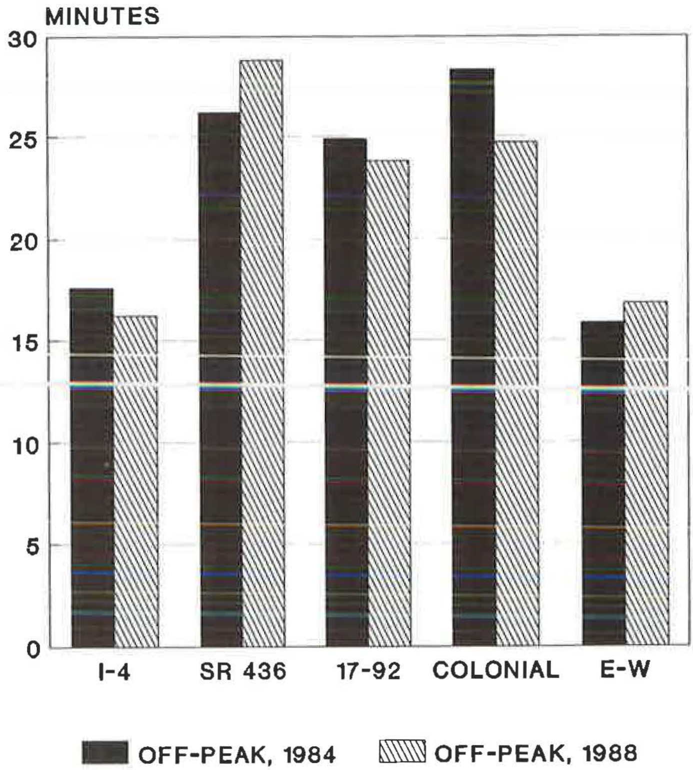

FIGURE 4 Orlando off-peak travel times, 1984 to 1988 (Metropolitan Planning Organization 1988).

was developed and used to measure urban mobility in 50 urbanized areas of the United States. This index is a weighted average based on the proportion of travel on freeways versus that on principal arterials. The average percent of the congestion experienced across all lane-miles in the urban area for each of the two types of facilities is calculated. Thus, if 1 lane-mi (1.6 lane-km) of freeway carried 13,000 VMT/day (20 917 VKT/day) for 5 days a week and nothing for the other 2 days, it would earn a score of 0.71. The average of such scores for all lane-miles of freeway would then be weighted according to the amount of VMT on freeways and combined with the similarly weighted average score for lane-miles of principal arterials. An RCI value of greater than 1.0 indicates that congested conditions exist areawide. This approach is very much an areawide assessment and is not used for site-specific locations.

Using this approach, the TTI research team estimated the changes in congestion levels between 1982 and 1990 (Table 6). According to this measure, San Diego experienced the greatest increase in congestion, 56 percent, during the 9-year period (a validation of the San Diego travel time study discussed earlier). Interestingly, the principal arterial component of the RCI showed that Washington, D.C., had the most congested principal arterials in the country (again, a validation of the arterial travel time survey discussed earlier).

Trends in congestion as they varied by population size and density were also examined in this study. Five population groups were identified as shown in Table 7. As can be seen, the average level of congestion increases as the urban area population increases. In addition, the congestion measure for each population group was examined from 1982 to 1990 with the result that the percent change in congestion for larger cities was greater than that for smaller cities (e.g., an average of 21 percent for the largest cities to an average of 17 percent for the smallest cities). The 50 cities were also categorized by population density. The results show that those cities with the greatest population density had the largest congestion measures, including the greatest increase from 1982 to 1990 (21 percent). In cities that were more spread out, the congestion measures were lower.

On the basis of the RCI and the analysis that serves as its foundation, the TTI study seems to indicate clearly that congestion is becoming worse in many U.S. urban areas.

Federal Highway Administration

The latest analysis based on HPMS data was conducted by the Federal Highway Administration (Cottrell 1993). This study updated previous efforts at monitoring system performance by comparing 1990 HPMS data in urbanized areas with similar data for 1987. The year 1987 was chosen because, beginning in 1986, many states began calculating roadway capacity on the basis of the updated *Highway Capacity Manual* (TRB 1992). To avoid changes in congestion levels because of a different definition in road capacity, a base year of 1987 was chosen for the comparison. Unlike previous studies based on the HPMS data base, the threshold value of congestion was considered to be a *V/C* ratio of 1.0 for freeways and other principal arterials with signal progression or no signals at all and a *V/C* ratio of 0.85 for other principal arterials with fixed-time or traffic-actuated signals.

TABLE 6 Changes in TTI Congestion Index, 1982 to 1990 (Schrank et al. 1993)

Urban Area	Year 1982	1983	1984	1985	1986	1987	1988	1989	1990	Percent Change, 1982 to 1990
Phoenix AZ	1.15	1.16	1.10	1.13	1.20	1.18	1.00	1.03	1.03	−10
Houston TX	1.17	1.21	1.25	1.23	1.21	1.19	1.15	1.13	1.12	−4
Detroit MI	1.13	1.10	1.13	1.12	1.11	1.10	1.09	1.08	1.09	−4
Louisville KY	0.84	0.82	0.81	0.79	0.80	0.88	0.87	0.86	0.86	2
Philadelphia PA	1.00	1.03	1.04	0.90	1.06	1.06	1.07	1.05	1.05	5
Pittsburgh PA	0.78	0.76	0.76	0.78	0.79	0.79	0.81	0.82	0.82	5
Memphis TN	0.86	0.80	0.76	0.75	0.77	0.84	0.85	0.91	0.91	6
Corpus Christi TX	0.67	0.69	0.69	0.71	0.71	0.72	0.70	0.71	0.72	7
Jacksonville FL	0.87	0.98	0.98	0.98	0.95	0.94	0.95	0.93	0.94	8
Orlando FL	0.66	0.68	0.67	0.71	0.71	0.72	0.74	0.72	0.72	9
San Bernardino-Riverside CA	1.09	1.11	1.12	1.11	1.14	1.13	1.16	1.16	1.19	9
Ft. Lauderdale FL	0.86	0.85	0.84	0.84	0.84	0.90	0.90	0.92	0.94	9
Oklahoma City OK	0.72	0.72	0.75	0.74	0.71	0.76	0.78	0.78	0.79	10
Cincinnati OH	0.86	0.83	0.82	0.83	0.84	0.87	0.88	0.94	0.96	12
Tampa FL	0.94	0.91	1.03	1.00	0.96	1.02	1.03	1.03	1.05	12
New York NY	1.01	1.02	0.99	1.00	1.06	1.06	1.10	1.12	1.14	13
San Antonio TX	0.77	0.79	0.82	0.87	0.90	0.85	0.86	0.87	0.88	14
New Orleans LA	0.98	1.00	1.05	1.10	1.11	1.14	1.13	1.13	1.12	14
Charlotte NC	0.67	0.72	0.72	0.73	0.73	0.74	0.73	0.74	0.78	16
Indianapolis IN	0.71	0.66	0.75	0.76	0.80	0.85	0.84	0.85	0.83	17

Hartford CT	0.76	0.79	0.86	0.85	0.85	0.87	0.91	0.89	0.89	17
El Paso TX	0.63	0.64	0.65	0.70	0.75	0.71	0.74	0.74	0.74	17
Boston MA	0.90	0.93	0.95	0.98	1.04	1.04	1.12	1.09	1.06	18
Fort Worth TX	0.76	0.79	0.80	0.82	0.87	0.87	0.87	0.87	0.90	18
Albuquerque NM	0.78	0.83	0.89	0.93	0.88	0.91	0.90	0.91	0.93	19
Milwaukee WI	0.83	0.84	0.87	0.88	0.90	0.95	0.94	0.97	0.99	19
St. Louis MO	0.83	0.87	0.88	0.89	0.93	0.96	0.98	0.96	0.99	19
Kansas City MO	0.62	0.62	0.60	0.65	0.69	0.71	0.72	0.72	0.74	19
Honolulu HI	0.93	0.95	0.97	0.97	1.05	1.07	1.10	1.09	1.11	19
Miami FL	1.05	1.09	1.07	1.13	1.10	1.14	1.18	1.25	1.26	20
Baltimore MD	0.84	0.84	0.85	0.84	0.88	0.90	0.92	0.99	1.01	20
Nashville TN	0.74	0.76	0.83	0.81	0.86	0.88	0.94	0.90	0.89	20
Denver CO	0.85	0.88	0.93	0.96	0.97	0.95	0.99	1.01	1.03	21
Cleveland OH	0.80	0.82	0.83	0.81	0.86	0.89	0.97	0.95	0.97	21
Norfolk VA	0.79	0.77	0.79	0.84	0.90	0.93	0.94	0.95	0.96	22
Columbus OH	0.68	0.71	0.71	0.71	0.75	0.78	0.79	0.82	0.83	22
Austin TX	0.77	0.84	0.89	0.91	0.98	0.96	0.96	0.96	0.94	22
San Jose CA	0.85	0.87	0.90	0.94	0.96	0.98	0.99	1.02	1.04	22
Chicago IL	1.02	1.02	1.05	1.08	1.15	1.15	1.18	1.21	1.25	23
Portland OR	0.87	0.86	0.88	0.93	0.97	1.00	1.05	1.07	1.07	23

(continued on next page)

TABLE 6 *(continued)*

Urban Area	Year 1982	1983	1984	1985	1986	1987	1988	1989	1990	Percent Change, 1982 to 1990
Atlanta GA	0.89	0.94	0.97	1.02	1.09	1.11	1.14	1.14	1.11	25
Dallas TX	0.84	0.89	0.94	0.98	1.04	1.02	1.02	1.02	1.05	25
Minneapolis–St. Paul MN	0.74	0.79	0.81	0.83	0.87	0.87	0.83	0.90	0.93	26
Seattle-Everett WA	0.95	0.99	1.02	1.05	1.09	1.14	1.17	1.21	1.20	26
Los Angeles CA	1.22	1.27	1.32	1.36	1.42	1.47	1.52	1.54	1.55	27
Sacramento CA	0.80	0.84	0.88	0.92	0.95	1.00	1.03	1.01	1.02	27
Washington DC	1.07	1.09	1.12	1.20	1.28	1.30	1.32	1.36	1.37	28
San Francisco–Oakland CA	1.01	1.05	1.12	1.17	1.24	1.31	1.33	1.36	1.35	34
Salt Lake City UT	0.63	0.63	0.65	0.68	0.68	0.70	0.72	0.81	0.85	35
San Diego CA	0.78	0.83	0.91	0.95	1.00	1.08	1.13	1.18	1.22	56
Northeastern avg	0.91	0.92	0.94	0.94	0.99	1.00	1.04	1.05	1.05	
Midwestern avg	0.82	0.82	0.83	0.84	0.87	0.90	0.91	0.92	0.94	
Southern avg	0.85	0.86	0.88	0.90	0.91	0.94	0.96	0.97	0.97	
Southwestern avg	0.82	0.85	0.87	0.90	0.93	0.91	0.90	0.91	0.93	
Western avg	0.94	0.97	1.01	1.04	1.09	1.13	1.16	1.18	1.19	
Texas avg	0.80	0.84	0.86	0.89	0.92	0.90	0.90	0.90	0.91	
Total avg	0.86	0.88	0.90	0.92	0.95	0.97	0.98	0.99	1.00	
Maximum value	1.22	1.27	1.32	1.36	1.42	1.47	1.52	1.54	1.55	
Minimum value	0.62	0.62	0.60	0.65	0.68	0.70	0.70	0.71	0.72	

SOURCE: TTI analysis.

TABLE 7 TTI Congestion Indexes by Population Grouping (Schrank et al. 1993)

Urban Area	Population (thousands)	Roadway Congestion Index	Percent Change in Roadway Congestion Index, 1982 to 1990
First group			
Corpus Christi TX	280	0.72	7
Charlotte NC	450	0.78	16
Austin TX	510	0.94	22
Albuquerque NM	525	0.93	19
El Paso TX	540	0.74	17
Nashville TN	565	0.89	20
Hartford CT	610	0.89	17
Honolulu HI	660	1.11	19
Tampa FL	700	1.05	12
Jacksonville FL	720	0.94	8
Oklahoma City OK	735	0.79	10
Salt Lake City UT	800	0.85	35
Second group			
Louisville KY	810	0.86	2
Orlando FL	850	0.72	9
Columbus OH	850	0.83	22
Memphis TN	860	0.91	6
Norfolk VA	925	0.96	22
Indianapolis IN	945	0.83	17
Portland OR	1,030	1.07	23
New Orleans LA	1,080	1.12	14
Sacramento CA	1,095	1.02	27
Cincinnati OH	1,140	0.96	12
Kansas City MO	1,160	0.74	19
San Bernardino-Riverside CA	1,170	1.19	9
Third group			
San Antonio TX	1,170	0.88	14
Fort Worth TX	1,200	0.90	18
Milwaukee WI	1,230	0.99	19
Ft. Lauderdale FL	1,270	0.94	9
San Jose CA	1,410	1.04	22
Denver CO	1,580	1.03	21
Seattle-Everett WA	1,730	1.20	26
Cleveland OH	1,790	0.97	21
Miami FL	1,850	1.26	20
Pittsburgh PA	1,865	0.82	5

(continued on next page)

TABLE 7 *(continued)*

Urban Area	Population (thousands)	Roadway Congestion Index	Percent Change in Roadway Congestion Index, 1982 to 1990
Atlanta GA	1,875	1.11	25
Phoenix AZ	1,895	1.03	−10
Fourth group			
St. Louis MO	1,960	0.99	19
Baltimore MD	1,990	1.01	20
Dallas TX	1,990	1.05	25
Minneapolis–St. Paul MN	2,010	0.93	26
San Diego CA	2,295	1.22	56
Houston TX	2,880	1.12	−4
Boston MA	2,955	1.06	18
Washington DC	3,100	1.37	28
San Francisco–Oakland CA	3,675	1.35	34
Detroit MI	4,000	1.09	−4
Philadelphia PA	4,220	1.05	5
Fifth group			
Chicago IL	7,510	1.25	23
Los Angeles CA	11,420	1.55	27
New York NY	16,780	1.14	13

SOURCE: TTI analysis and local transportation agency references.

The actual measure of congested conditions in an urbanized area was based on two factors–the number of lane-miles that experienced congestion at some time during the day and the duration of congestion on each congested highway segment. As shown in Table 8, the level of congestion on the selected road segments ($DVMT_F/DVMT$) increased from 1987 to 1990. Cottrell notes that this change represented "substantial increases in freeway congestion in the selected cities." A critique of the FHWA analysis shows that several assumptions were made that erred in being conservative (e.g., no attempt to include congestion due to incidents). The analysis would thus seem to be a reasonable estimate of congestion increases in the selected urbanized areas.

CONCLUSIONS: TOWARD BETTER CONGESTION MEASURES

The evolution of congestion measures has been reviewed and sources of congestion data for areas and facilities have been identified that provide

TABLE 8 Comparison of 1987 and 1990 Roadway Congestion as Determined from National HPMS Data Base (Cottrell 1993)

		$DVMT_F$/DVMT (%)		Growth Rate Ratios	
Population Group	Functional Class	1987	1990	$DVMT_F$/DVMT	$DVMT_F$/LM
> 1,000,000	Freeways	1.5	2.2	5.5	15.7
(13 UZAs)	OPAs	0.8	0.8	0.6	1.6
	Principal arterials	1.2	1.7	5.2	16.9
200,000–999,000	Freeways	0.2	0.4	8.1	23.5
(39 UZAs)	OPAs	0.2	0.3	3.6	5.0
	Principal arterials	0.2	0.4	6.5	13.5
> 200,000	Freeways	1.1	1.7	5.3	15.0
(52 UZAs)	OPAs	0.6	0.6	1.0	1.9
	Principal arterials	0.9	1.3	4.9	12.6

NOTE: DVMT = daily vehicle miles of travel; $DVMT_F$ = DVMT experiencing LOS F; OPAs = other principal arterials; LM = lane miles; UZA = urbanized area. 1 mi = 1.6 km.

mixed indications of congestion trends. National data bases provide useful indicators of trends in the characteristics of trip making for individuals, but their use is based on a number of assumptions that leave their conclusions open to interpretation. This paper is an attempt to report field trend data that conclusively show the performance of specific facilities over time, whether or not the same travelers are using that facility during that time period (and thus experiencing the increase or decrease in congestion). If congestion is occurring and is getting worse, some portion of the traveling public is experiencing it. Especially with regard to congestion pricing, the issue becomes one of whether there is sufficient congestion to warrant pricing of a particular facility.

It is important to note that very little information is available to make conclusive judgments that are generalizable to every city in the United States. The paucity of information on system performance in U.S. metropolitan areas is incomprehensible. When 22 of the 30 largest U.S. MPOs state that they have no idea whether congestion has increased or decreased during the past 15 years, the entire focus of urban transportation planning in this country should be questioned. But perhaps this finding should not be surprising. The traditional emphasis of transportation planning has been on the provision of the necessary infrastructure to accommodate expected demand. Enhancing the capacity of the transportation system was the primary motive of many planning processes. The only need for data in such a planning process was to establish a base year with which to compare forecast volumes.

A general trend in many planning disciplines has been toward maintaining the performance of a particular facility or system by utilizing means other than capacity expansion. In transportation, this means that minimum levels of system performance can be established as target values and a multitude of actions considered to maintain this performance level. Transportation demand management (TDM), for example, is one nonconstruction means of maintaining a certain level of performance while still providing mobility. Both the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Clean Air Act Amendments of 1990 (CAAA) have performance concerns central to this approach. ISTEA, in its requirement for several management systems, is using a performance-based approach. Certainly CAAA defines acceptable performance as the degree to which air quality standards are attained, using the surrogate variable VMT to measure progress. The major implication for planners of this performance perspective is the need for a comprehensive system-monitoring and data-analysis capability.

The major conclusion that can be drawn from the small number of studies that were reviewed for this paper is not surprising, but it is certainly relevant for a discussion on congestion pricing. Is congestion getting worse? In those situations in which traffic growth has occurred (even accounting for the impact of the recession) and no additional capacity has been provided, the answer to this question is yes. In San Diego, Washington, D.C., and Baltimore, the decline in congestion levels was explained primarily by the addition of new road capacity and, in some cases, operational improvements. In addition, congestion levels as measured by average travel time seemed to be most affected by delays at bottlenecks. The remaining portions of the trip were usually made at fairly high speeds.

In conclusion, here are some thoughts on what constitutes a good measure of system performance. A good set of congestion measures has the potential to improve not only the quality and consistency of public transportation policy but also public understanding of the congestion phenomenon, leading to political support for policy improvements and more rational behavior by individual travelers. System monitoring, now required by federal law, has always been an important part of transportation planning (Meyer 1980). However, congestion should be only one part of an overall mobility measurement, albeit an important part. Mobility is the key goal of transportation planning and decision making, with congestion being a constraint that must be overcome to achieve this goal. Even with this, however, congestion measures will probably be the easiest manifestation of system performance. Such measures should

- Have a clear, intuitive meaning, so that they are understandable to professionals in other fields;
- Be acceptable and useful to transportation professionals;
- Be comparable across time and between geographical areas (facilities, corridors, subareas, and metropolitan regions);
- Have a strong functional relationship to the actual costs of congestion, so that direct and indirect costs of congestion can readily be calculated from them;
- Be consistent with the theoretical definition of the social cost of congestion, which already underlies so much of transportation economics;
- Cost less to estimate on a regular basis for all geographic areas of potential concern than it is anticipated to save by improving transportation policy and public awareness;
- Be theoretically and functionally related to other predictable measures (e.g., road performance characteristics), suggesting that congestion measures too might be forecast with some success; and

• Where appropriate, be based on statistically sound measurement techniques.

These characteristics provide a useful starting point toward developing congestion measures to which, it is hoped, planners 10 years hence can refer and that will reveal the performance of the transportation system since system performance monitoring was first required in 1993.

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ABBREVIATIONS

COG	Metropolitan Washington Council of Governments
SANDAG	San Diego Association of Governments
TRB	Transportation Research Board

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Potential of Congestion Pricing in the Metropolitan Washington Region

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The National Capital Region (Figure 1) has become one of the most vital urban areas in the country. It has experienced dramatic economic growth over the past two decades and more. During the same time significant resources have been invested in transportation infrastructure and services, which are regarded as among the best in the country. For the past few years, however, these resources have been stretched beyond their capacity as economic growth has brought ever-increasing traffic and the related problems of increased delays and emissions. The growth in traffic has outpaced expansion in road capacity, and although transit and other high-occupancy-vehicle (HOV) services have been expanded, congestion and related problems have become progressively worse. The small improvements in speeds on the Capital Beltway (I-495) observed in the late 1980s largely appear to have been the result of the cyclic economic downturn during that period, and most observers do not expect them to last further into the 1990s.

The future seems to hold more of the same—continued growth in the economy and accompanying congestion. According to the projections developed by the Metropolitan Washington Council of Governments (MWCOG), the region will continue to experience dramatic growth (MWCOG 1992a). The anticipated regional growth in population, employment, home-based work trips, car occupancy, and vehicle miles of travel (VMT) from 1990 to 2010 is summarized in Tables 1 through 5.

Between 1990 and 2010, the population is expected to grow from 4.4 million to 5.4 million and employment from 2.7 million to 3.8 million

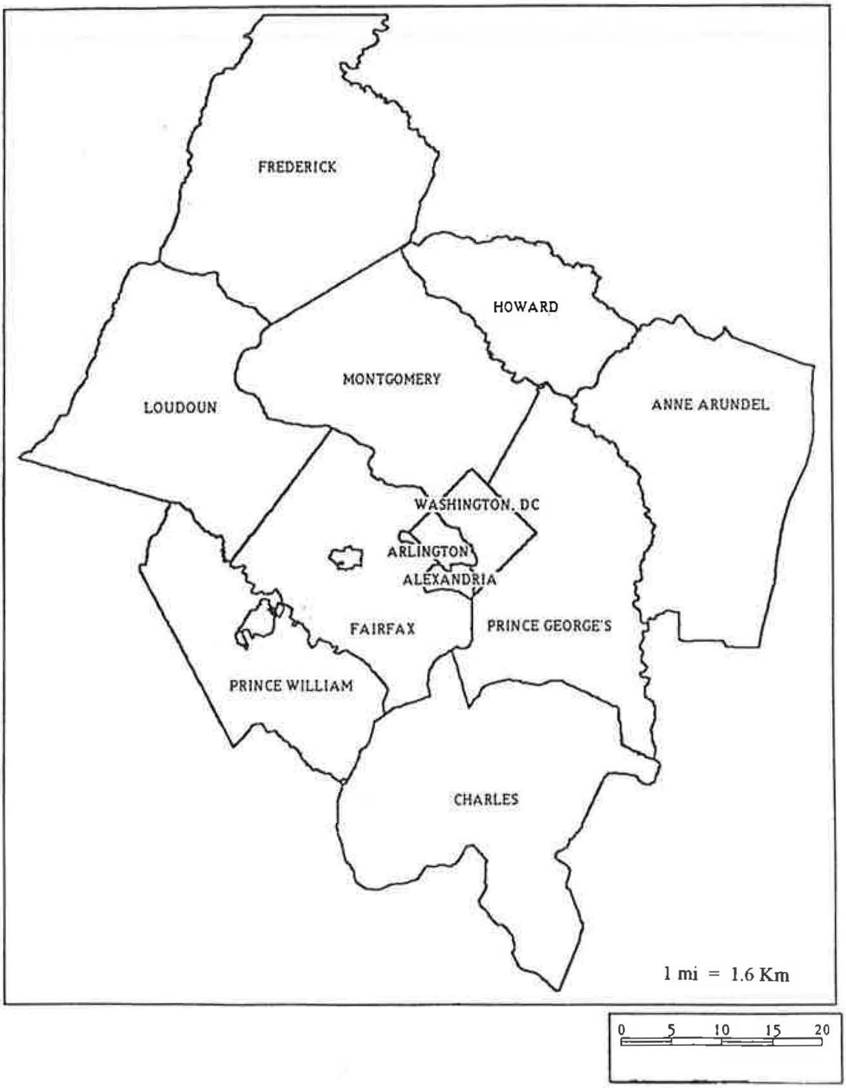

FIGURE 1 Transportation modeling area for Metropolitan Washington Council of Governments Transportation Planning Board (MWCOG 1992b).

TABLE 1 Population and Employment Forecasts (MWCOG 1992b)

Population Forecasts
(MWCOG Round 4.1 in Thousands)

	1990	2010	Change	%
Central Jurisdictions	906	942	36	4
Inner Suburbs	2,254	2,689	435	19
Outer Suburbs	1,217	1,735	518	42
Total	4,377	5,366	989	23

Employment Forecasts
(MWCOG Round 4.1 in Thousands)

	1990	2010	Change	%
Central Jurisdictions	1,030	1,295	265	26
Inner Suburbs	1,179	1,768	589	50
Outer Suburbs	506	780	274	54
Total	2,715	3,843	1,128	42

(much of this in the suburbs). The daily commute trips are anticipated to grow from 4.0 million to 5.7 million, with three-fourths of the growth taking place in the suburbs. Weekday VMT is expected to increase from 96.9 million (156.0 million VKT) to 147.1 million (237.0 million VKT); again much of this growth will be in the suburbs.

In 1991 the Transportation Planning Board of MWCOG adopted a long-range transportation plan. The key elements of the plan are shown in Figures 2 and 3. A large proportion of the highway element and most of the transit element focus on radial travel in the region. Despite these investments (funding for which has not yet been fully established), in anticipa-

TABLE 2 Total Home-Based Work Person Trips, 1990 and 2010 (MWCOG 1992a)

1990 Total Home-Based Work Person Trips

From	To: Core	10-Mile Square	Near Suburbs	Far Suburbs	Total
Core	39,400	15,000	7,800	600	62,800
10-Mile Square	289,000	214,200	115,300	10,900	629,400
Near Suburbs	476,500	371,500	1,164,400	90,200	2,102,600
Far Suburbs	100,600	79,400	308,600	694,000	1,182,600
Total	905,500	680,100	1,596,200	795,600	3,977,400

Core - Downtown Washington, Rosslyn and Pentagon
10-Mile Square - Remainder of Washington, Arlington and Alexandria
Near Suburbs - Fairfax, Montgomery and Prince George's Counties
Far Suburbs - Loudoun, Prince William, Frederick, Howard, Charles and Anne Arundel Counties

Note: Numbers may not sum to total due to rounding.

1 mi = 1.6 Km

2010 Total Home-Based Work Person Trips

From	To: Core	10-Mile Square	Near Suburbs	Far Suburbs	Total
Core	48,600	19,900	10,900	1,000	80,400
10-Mile Square	301,300	247,800	134,300	14,200	697,700
Near Suburbs	593,900	506,300	1,724,500	155,700	2,980,500
Far Suburbs	140,900	122,800	526,500	1,131,200	1,921,400
Total	1,084,700	896,900	2,396,200	1,302,200	5,680,000

Core - Downtown Washington, Rosslyn and Pentagon
10-Mile Square - Remainder of Washington, Arlington and Alexandria
Near Suburbs - Fairfax, Montgomery and Prince George's Counties
Far Suburbs - Loudoun, Prince William, Frederick, Howard, Charles and Anne Arundel Counties

Note: Numbers may not sum to total due to rounding.

TABLE 3 Home-Based Work Automobile Person Trips, 1990 and 2010 (MWCOG 1992b)

1990 Home-Based Work Auto Person Trips
(Includes Drivers and Passengers)

	To				
From	Core	10-Mile Square	Near Suburbs	Far Suburbs	Total
Core	12,500	7,400	5,200	600	25,700
10-Mile Square	127,400	158,000	95,600	10,800	391,800
Near Suburbs	344,100	341,600	1,112,200	90,200	1,898,000
Far Suburbs	88,900	77,300	306,600	693,900	1,116,700
Total	573,000	584,200	1,529,600	795,500	3,482,300

Core - Downtown Washington, Rosslyn and Pentagon
10-Mile Square - Remainder of Washington, Arlington and Alexandria
Near Suburbs - Fairfax, Montgomery and Prince George's Counties
Far Suburbs - Loudoun, Prince William, Frederick, Howard, Charles and Anne Arundel Counties

Note: Numbers may not sum to total due to rounding.

1 mi = 1.6 Km

2010 Home-Based Work Auto Person Trips
(Includes Drivers and Passengers)

	To				
From	Core	10-Mile Square	Near Suburbs	Far Suburbs	Total
Core	15,800	8,900	6,800	1,000	32,500
10-Mile Square	136,300	176,200	109,000	14,200	435,600
Near Suburbs	390,900	437,100	1,642,200	155,700	2,625,900
Far Suburbs	120,800	116,900	521,100	1,130,900	1,889,700
Total	663,800	739,100	2,279,000	1,301,800	4,983,700

Core - Downtown Washington, Rosslyn and Pentagon
10-Mile Square - Remainder of Washington, Arlington and Alexandria
Near Suburbs - Fairfax, Montgomery and Prince George's Counties
Far Suburbs - Loudoun, Prince William, Frederick, Howard, Charles and Anne Arundel Counties

Note: Numbers may not sum to total due to rounding.

TABLE 4 Home-Based Work Car Occupancy, 1990 and 2010 (MWCOG 1992a)

1990 Home-Based Work Car Occupancy

From	To: Core	10-Mile Square	Near Suburbs	Far Suburbs	Total
Core	1.14	1.20	1.21	1.08	1.17
10-Mile Square	1.23	1.20	1.23	1.14	1.21
Near Suburbs	1.46	1.27	1.20	1.14	1.25
Far Suburbs	1.35	1.26	1.20	1.17	1.19
Total	1.37	1.25	1.20	1.17	1.23

Core - Downtown Washington, Rosslyn and Pentagon
10-Mile Square - Remainder of Washington, Arlington and Alexandria
Near Suburbs - Fairfax, Montgomery and Prince George's Counties
Far Suburbs - Loudoun, Prince William, Frederick, Howard, Charles and Anne Arundel Counties

1 mi = 1.6 Km

2010 Home-Based Work Car Occupancy

From	To: Core	10-Mile Square	Near Suburbs	Far Suburbs	Total
Core	1.27	1.13	1.15	1.13	1.20
10-Mile Square	1.25	1.15	1.21	1.15	1.20
Near Suburbs	1.33	1.19	1.18	1.17	1.20
Far Suburbs	1.32	1.25	1.22	1.16	1.19
Total	1.31	1.19	1.19	1.16	1.20

Core - Downtown Washington, Rosslyn and Pentagon
10-Mile Square - Remainder of Washington, Arlington and Alexandria
Near Suburbs - Fairfax, Montgomery and Prince George's Counties
Far Suburbs - Loudoun, Prince William, Frederick, Howard, Charles and Anne Arundel Counties

tion of continued diffuse land uses, growth patterns, travel preferences, and relatively low costs associated with automobile travel, the MWCOG studies expect the single-occupant automobile to continue to be the principal mode of travel. For instance, even if all the elements of the adopted plan are fully implemented, the transit share of commuter trips is likely to remain unchanged at 12.0 percent, and the average commuter automobile occupancy is projected to drop only from 1.23 in 1990 to 1.20 in 2010.

TABLE 5 Vehicle Miles of Travel (in millions), 1990 and 2010 (MWCOG 1992a)

Jurisdiction	1990	2010 TIP	2010 LRP
District of Columbia	8.1	10.4	10.5
Arlington County	3.3	4.0	4.0
City of Alexandria	2.0	2.5	2.5
Montgomery County[1]	16.8	24.5	24.8
Prince George's County	18.4	27.6	27.8
Fairfax County[2]	18.9	28.5	28.3
Loudoun County[3]	1.3	3.3	3.3
Prince William County[4]	4.9	8.5	8.8
Frederick County	4.9	8.9	8.9
Howard County	5.8	9.4	9.2
Anne Arundel County	10.4	15.1	15.1
Charles County	2.1	3.7	3.8
Total	96.9	146.4	147.1

1 mi = 1.6 Km

[1]Includes City of Rockville.

[2]Includes Fairfax City and Falls Church.

[3]Excludes portion west of Route 15.

[4]Includes City of Manassas and City of Manassas Park.

Highway capacity is expected to continue to lag behind demand. For instance, between 1990 and 2010, highway capacity in the region is programmed to increase 14 percent, whereas the VMT would go up 52 percent. In consequence, congestion is expected to become much worse in most corridors and to become systemic within the region. Significantly greater investments than those currently planned might be needed just to maintain the present levels of service in the suburbs.

Figures 4 through 7 provide some measures of expected increase in congestion in the region from 1990 to 2010. Figure 4 shows that in 2010, total demand as measured by VMT will far exceed the total available capacity [expressed as the capacity to accommodate travel at level-of-service (LOS) E or better]. Figures 5 and 6 identify the screen lines in the region with LOS F. In 1990, 8 of 23 screen lines in the region were already at LOS F, but by 2010, 21 of 23 screen lines will show this level of service. Figure 7 shows the anticipated declines in overall average regional speeds. Peak-hour speeds decline from 37 mph (59 km/hr) in 1990 to 34 mph (54 km/hr) in 2010. Although these declines appear small, they represent

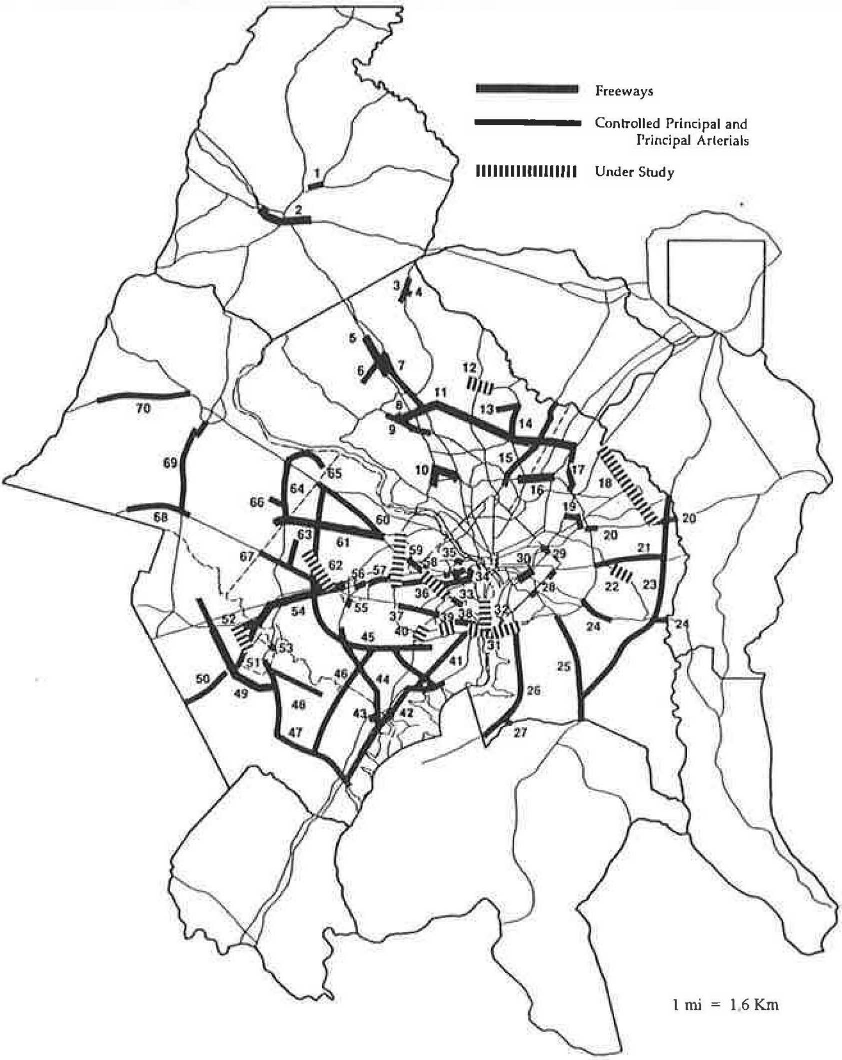

FIGURE 2 Major highway facilities of the long-range plan (updated by TPB Sept. 18, 1991) (MWCOG 1992a).

increased annual delays of tens of millions of hours. Moreover, according to MWCOG, these regional declines mask much larger shifts in corridors where congestion is estimated to increase.

Declines in speed, increases in congestion, and estimated increases in trip lengths during the 20-year period together will result in a significantly reduced quality of travel in the region (MWCOG 1992a).

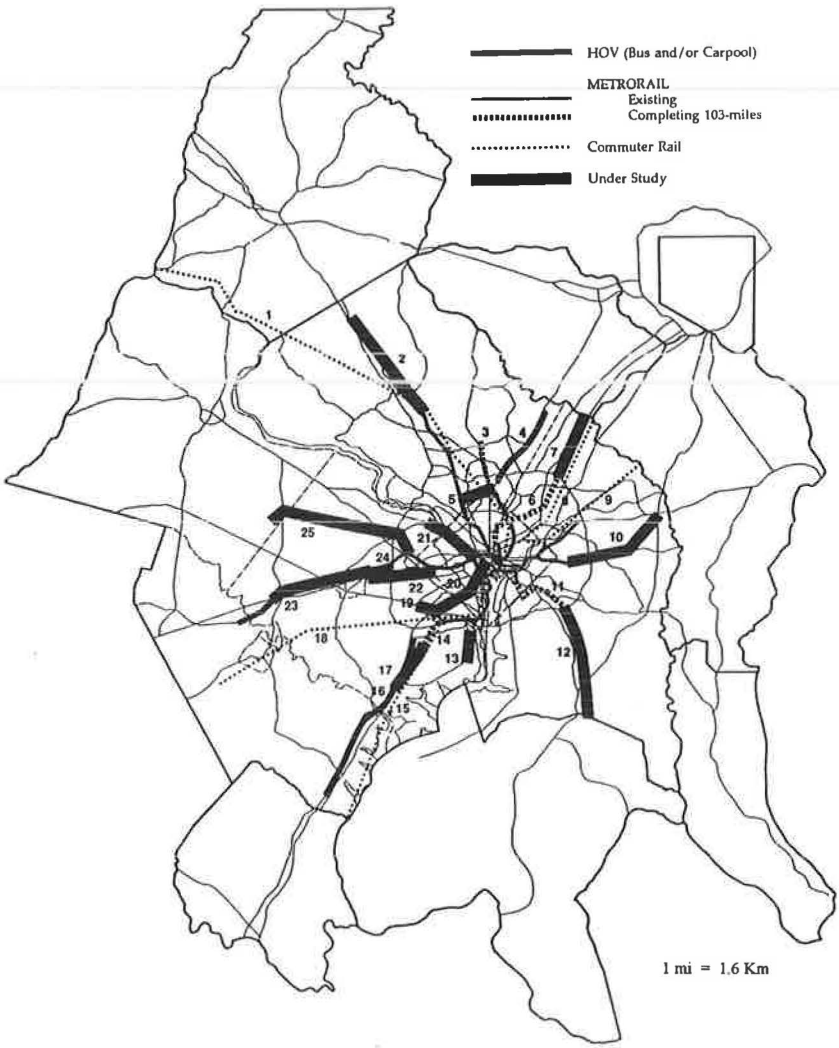

FIGURE 3 Transit facilities of the long-range plan (updated Sept. 18, 1991) (MWCOG 1992a).

Air quality poses another major concern for the region during the next decade and beyond. The region has been classified as a nonattainment area by the Environmental Protection Agency. As a "serious" nonattainment area, the region must attend to these problems more forcefully and quickly than many other regions. Under the 1990 Clean Air Act Amendments (CAAA), the region must achieve a 15 percent reduction in hydrocarbon

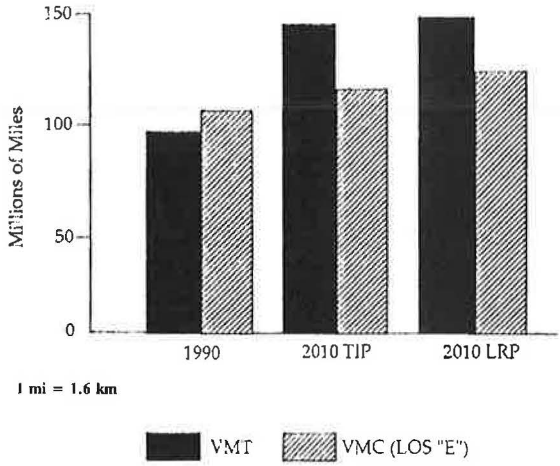

FIGURE 4 Vehicle miles of travel versus vehicle miles of capacity (MWCOG 1992a).

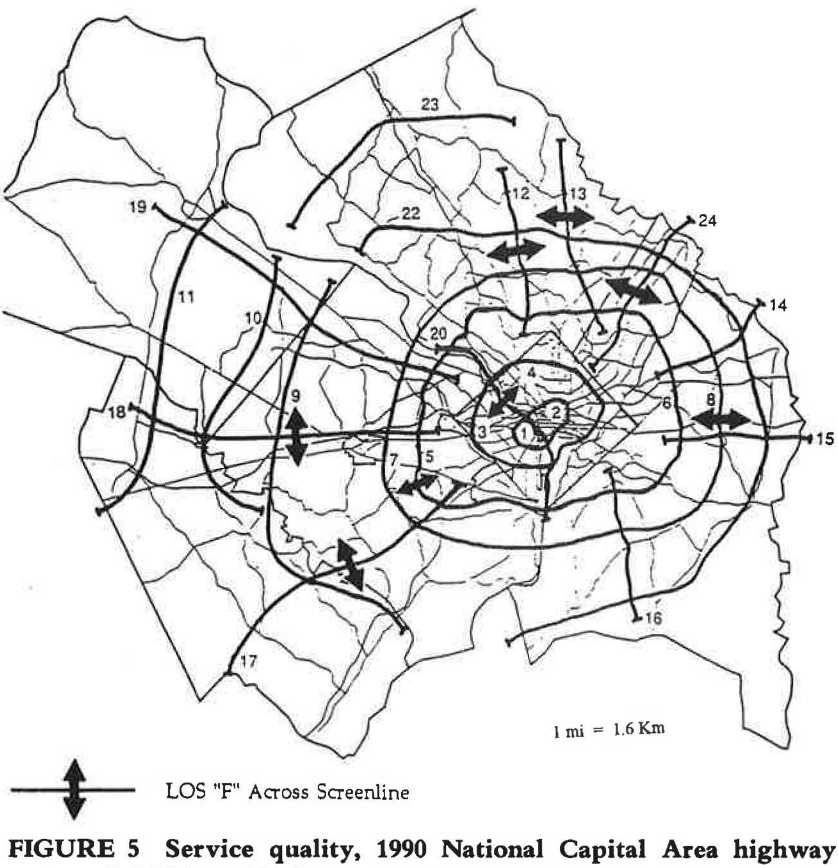

FIGURE 5 Service quality, 1990 National Capital Area highway system (MWCOG 1992a).

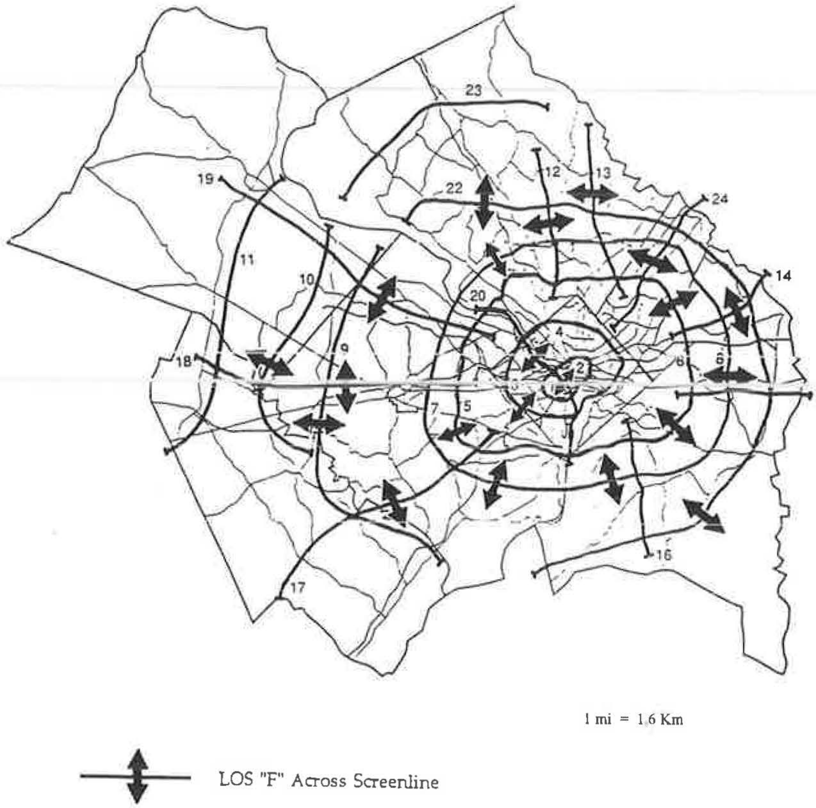

FIGURE 6 Service quality, 2010 transportation improvement plan (MWGOC 1992a).

emissions by 1996 and be in attainment with the national standards by 1999, in addition to a further 9 percent reduction in emissions by that date (WRN 1992).

RECENT TRANSIT AND HOV PROPOSALS TO REDUCE CONGESTION

The growth and travel context summarized above points to three principal long-term problems for the region:

1. Most corridors will have inadequate capacity and high demand (with major problems emerging in suburban areas and circumferential corridors);

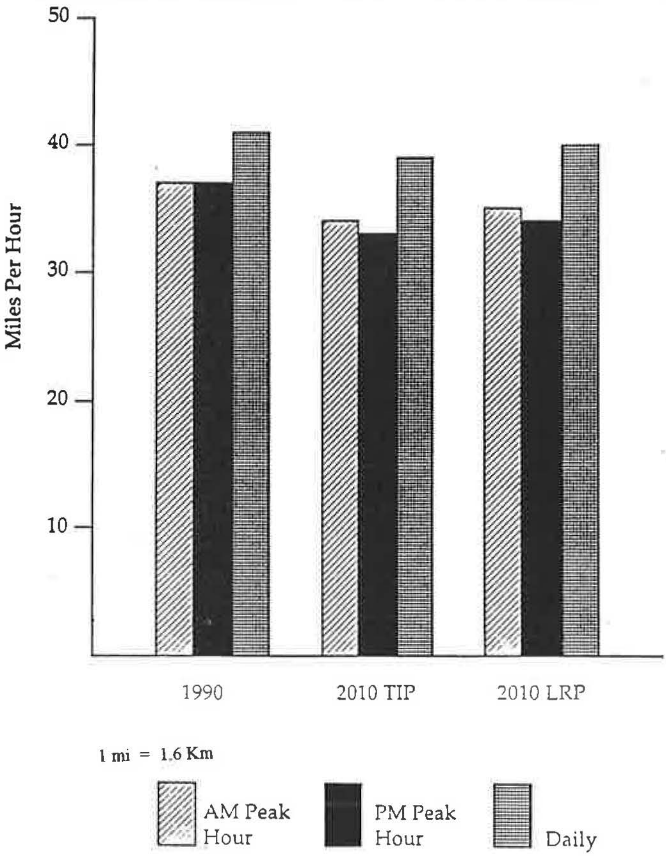

FIGURE 7 Average regional speed (developed as part of air quality conformity) (MWCOG 1992a).

2. Funding for transportation will continue to be very tight (funding for the adopted plan is also not well established, let alone funds for possible additional needs such as circumferential transit or HOV facilities in suburban corridors); and

3. The problem of excessive hydrocarbon emissions in the region will continue to demand vigorous action.

Recognizing the issue of inadequate capacity, the Transportation Planning Board (TPB) of MWCOG recently conducted a study of circumferential transit and HOV facilities (MWCOG 1992b). The study focused on the feasibility of circumferential rail and light rail options and a regional

network of HOV lanes (including lanes along the Beltway). The study found that, although the rail options might be economically feasible in several short corridors inside the Beltway in the inner suburbs (such as the Bethesda-Silver Spring Corridor), such options would not be successful along and outside the Beltway because the projected land uses and relatively low cost of travel by automobile would make it difficult for them to attract sufficient ridership.

An HOV facility along the Beltway connecting with major radial HOV lanes would be costly (because of the need to provide flyover access to inside HOV lanes and thus avoid weaving and merging problems), but could be feasible from the standpoint of usage levels. However, HOV facilities are likely to produce only a small reduction in traffic, if any, along the mixed traffic lanes, and such reductions are likely to last for a short period only until latent demand fills up the roads again. This has been a common phenomenon around the country: latent demand for automobile travel quickly fills up the highway capacity made available by strategies such as road expansion, HOV lanes, transportation demand management (TDM), or parking management.

PRICING TO REDUCE CONGESTION

The severe congestion in mixed-traffic conventional lanes can be reduced only by providing additional capacity for this traffic or by reducing solo driver demand through decreased subsidies for automobile users. Even so, the phenomenon of latent demand suggests that perhaps the hope of sustaining lower congestion over time may not lie in expanding capacity (which is also expensive). Parking-related pricing policies do not address the problem of latent demand adequately either. In this context, congestion pricing perhaps holds good potential to provide long-lasting relief, as well as the promise to be self-financing.

The aim of congestion pricing would be to charge each road trip an amount equal or close to the cost occasioned by that trip, including the costs of vehicle operation, delays inflicted on other travelers, accidents, road damage and maintenance, and pollution. Since road users in congested situations currently pay far less through existing road user charges and taxes than the costs they occasion in a trip, congestion pricing would implement surcharges for the use of congested roads during congested conditions (peak periods). It also would be expected to produce revenues well in excess of implementation costs.

Congestion pricing can reduce congestion significantly by encouraging peak-period travelers to shift to the off-peak period, to high-occupancy modes, to less congested facilities, and even to eliminate certain low-value trips. It promises to increase peak-period travel speeds, to reduce delays and costs to automobile and transit users and to truck movements and other high-value commercial traffic, to enhance transit productivity and reliability, to reduce pollution and energy use, and to make economic activities more productive (KTA 1993). It also is likely to enhance other TDM measures such as telecommuting and compressed work weeks.

APPLICATION OF CONGESTION PRICING IN THE REGION

Which Facilities Could Be Priced?

In the past many localities have considered congestion pricing programs covering local street systems in downtown areas or congested bridge, tunnel, or road segments. However, as described earlier, congestion in the metropolitan Washington region is (and will continue to be) systemic over many corridors, including the core, other areas inside the Beltway, the Beltway itself, and suburban areas within several miles outside the Beltway. Thus, congestion pricing of particular bridges, road segments, or core-area street systems would be neither effective nor equitable. Rather, the aim of the congestion pricing program in the region should be to cover the major area in which congestion is projected to be endemic. This probably would include all the principal travel corridors and activity centers within, say, a 15- to 20-mi (24- to 37-km) radius from the core plus the major activity centers and major congested facilities outside this zone. The purpose of such extensive coverage would be twofold: it would enhance effectiveness by covering most congested corridors and facilities, and it would treat major activity centers and jurisdictions equitably and thus safeguard the existing competition among them. The question of exactly how large an area or which particular facilities to include would need to be examined more carefully in a detailed study.

Although the ultimate goal should be to cover all parts of the region that are congested, it would be prudent to proceed with the implementation in an incremental manner, perhaps starting with congestion pricing at one or two facilities such as the Dulles Toll Road. This incremental approach would show successful use of technology, administration, enforcement,

and other key dimensions and provide an exemplary overview of the regional program to come.

How Could the Charges Be Applied?

In order to be effective and acceptable, congestion pricing would require collection of charges and enforcement of violations without stopping or slowing the vehicles. Since the aim is to avoid delays and unnecessary use of resources, toll booths would be unacceptable. Two mechanisms are possible for administering congestion surcharges:

- *Supplementary Licenses*: Peak-period travelers when traveling in designated congested locations would be required to purchase and display a windshield sticker. Singapore has used such a program with great success since 1975 to reduce congestion in the downtown area (Watson and Holland 1978). Differential pricing by peak and off-peak periods and by location (depending on the level of congestion) is possible to a limited degree by using different colors or shapes, or both, for the supplementary licenses (GLC 1975). Greater differentiation would produce greater efficiency in the system by bringing prices closer to occasioned costs of different trips. A feasibility study in London (GLC 1975) showed that an effective system of enforcement based on randomly placed enforcement personnel and heavy fines can be designed to keep the violations down to acceptable levels. Supplementary licenses could be sold directly to the users by the authorities or through retail outlets for a commission, much like lottery tickets.
- *Automatic Vehicle Identification via Electronic Licenses*: Under this mechanism, vehicles using the priced facilities would need to be fitted with an electronic device that would be monitored by roadside scanners placed along travel routes in congested corridors (200 to 300 roadside scanners could probably cover the major corridors and facilities adequately within a 20-mi radius from the core). This on-vehicle device could be an electronic tag carrying a unique identifier so that the roadside scanner could identify the vehicle's passage and bill the owner by mail much as the telephone company sends a long-distance telephone bill. Such electronic licenses have been tested successfully for road pricing applications in Hong Kong (Harrison 1986). Alternatively, the on-vehicle device could be a prepaid smart card by which the appropriate charge would be deducted automatically in response to a electronic signal from the roadside scanner when the

vehicle went by. The technology for such smart cards is available and is being used extensively for automatic toll collection in the United States and Europe. Electronic licenses would easily allow the prices to vary by level of congestion and other determinants. Thus, complex price schedules achieving a high-efficiency system would be possible, if desired, although it may be preferable to keep the price schedules relatively simple to start.

Advances in microprocessing and intelligent vehicle-highway systems (IVHS) technology hold the promise to keep the costs of electronic licenses low for large regional applications such as the one proposed for the Metropolitan Washington region. Compared with supplementary licenses, they also promise much greater flexibility, automatic collection, easier enforcement, and inexpensive administration. Consequently, over the long run, benefits of electronic licenses are likely to outweigh those of supplementary licenses. Nevertheless, a limited use of supplementary licenses may be required for a while even under the electronic licensing program to accommodate occasional travelers or those from outside the area. Furthermore, in addition to making licenses available through a retail distribution network, it may be desirable to make them available also at rest areas and major intersections along the principal approach roads to the region for the use of travelers from outside the area. Informative signs would be required on approach roads and within the priced region alerting approaching traffic to the program and the need to carry a license, and directing them to an appropriate outlet to obtain the license.

What Are the Enforcement Issues?

As mentioned earlier, success of a congestion pricing program would require enforcement for violators without stopping the vehicles. This could be achieved if violations were mailed. Effective enforcement of a supplementary licensing program would call for monitoring at randomly selected locations and would require 200 or more enforcement personnel, probably aided by mobile photo-radar cameras. A similar method has been used successfully in Singapore and was proposed for London in 1975. For an electronic licensing program, much of the enforcement function could be fully automated. Photo-radar cameras could be permanently mounted near the roadside scanners, which would identify the violation and trigger the camera for mail citation.

In anticipating enforcement operations, a key consideration is the desired level of deterrence, which depends on two factors: the probability

that a vehicle not in compliance will be observed and cited by an enforcement agent and the level of fines for noncompliance compared with the congestion price assessed. The level of deterrence is roughly proportional to the product of the probability of being observed and cited times the cost of the fine divided by the price of the congestion charge. If there is a high probability of paying a fine that is much higher than the congestion charge, compliance can be expected to be very good.

Fines should be at least 10 and preferably 20 or more times the level of the daily congestion charge if the probability of being observed and fined is very close to 1. If the probability of being caught and fined falls below .5, the level of the fine should be at least 20 times the entry fee and preferably at much higher multiples in order to achieve high compliance.

What Impacts Are Likely?

The impacts would depend, among other things, on the prices charged (and the original level of congestion), the traffic affected, and the quality of available alternative modes and routes.

In terms of price elasticities, the literature suggests a range from −0.1 or −0.2 at the low end to −0.3 or −0.4 at the high end, depending on the level of charge, the current costs of travel, and the capacity of alternative roads and transit systems (Urban Institute and KTA 1991; Kane and DeCorla Souza 1992). Opportunity and incentive to shift from the peak to the off-peak period may boost these elasticities higher.

Assessment of travel and related impacts of a regionwide congestion pricing program in the MWCOG area would require considerable effort and resources. For illustrative purposes, a quick and rough estimate of program dimensions and plausible impacts is as follows:

Program Dimension	*Estimate*
Area covered	Major corridors within 700 mi^2 (1814 km^2)
Pricing points	250 to 300
Pricing period	6:30–9:30 a.m. and 3:30–6:30 p.m.
Vehicle trips/day facing prices	4.0 to 5.0 million
VMT/day facing prices	40 to 50 million (64 to 81 million VKT)
Charges (average)	$0.15/VMT ($0.10/VKT)

Impact	*Estimate*
Reduction in daily VMT	4.0 to 12.0 million (6.5 to 19.0 million VKT)
Reduction in average round-trip time	10 to 15 min
Reduction in daily volatile organic compounds	10 to 30 tons
Annual program costs	$80 million to $160 million
Annual program revenues	$1.1 billion to $1.7 billion

For the preceding estimates it is assumed that all congested facilities in the major corridors would be priced during 3-hr morning and afternoon peak periods. It is assumed that this policy would affect 50 to 60 percent of the 4.0 million home-based work trips forecast for 2010. The estimate of total affected trips (4.0 to 5.0 million/day) was derived assuming that work trips make up between 33 and 40 percent of all trips during peak periods and that 75 to 80 percent of these trips would be on priced facilities. Affected VMT was derived assuming average trip length of 10 mi (16 km). Trip time savings assume an increase in average speed for the affected trips from 15 to 20 mph (24 to 32 km/hr) on arterials and from 30 to 40 mph (48 to 64 km/hr) on expressways.

An average congestion charge of approximately $0.15/VMT ($0.10/VKT) has been suggested in recent studies for congested facilities (Urban Institute and KTA 1991; Kane and DeCorla Souza 1992). [This charge is not dramatically different from the average charge of about $0.12/VMT ($0.08/VKT) now being assessed on the Dulles Toll Road.] Optimal charges would vary by level of congestion and type of facility. Over heavily congested expressway segments the marginal costs could be as high as $0.20/VMT ($0.12/VKT) or more and over heavily congested arterials twice this amount. Estimates of VMT reductions are based on shrinkage factors of between 10 and 25 percent as implied by the elasticity ranges presented earlier and the typical perceived automobile driving costs in the region—on the order of $0.20 to $0.30/VMT ($0.12 to $0.19/VKT).

Annual program costs shown above are based on the estimates used by the 1991 congestion pricing study for the Los Angeles region by the Southern California Association of Governments (Urban Institute and KTA 1991). These estimates assume long-term operations and a program covering a large area and vehicle fleet. The program revenues are calculated from the congestion charges and the amount of travel that would

continue under the program and be affected by the charges. Revenues are estimated to be more than 10 times the program costs and thus would allow many collateral and compensatory actions to be funded.

The distributional impacts of a proposed program should be studied in detail. In general, one would expect the following to receive positive benefits from reduced congestion:

- *Existing users of HOV and transit and transit service providers*: A reduction in congestion from the pricing program would significantly increase HOV mode speeds, productivity, and reliability. Existing users would enjoy significantly improved service even before additional resources were put into these modes. The providers of HOV service (e.g., bus operating agencies) would benefit from significant increases in vehicle productivity as speeds increase.
- *Road users shifting from SOV to HOV mode and transit*: Those who are voluntarily attracted to HOV modes because of enhanced service levels (brought on by improved productivity and reliability or by explicit expansion) would realize positive benefits from the opportunity to use a more desirable mode.
- *Road users continuing to drive and placing a high value on their time*: The value of time savings produced by lower congestion and increased speeds would outweigh the increased congestion toll payments for users who value their time highly (including most trucks and other commercial vehicles).
- *Businesses reaping the benefits of more efficient delivery systems*: Businesses where trucking and delivery system costs are a significant proportion of total costs of doing business (e.g., suppliers, supermarkets) would realize large savings in delivery costs.
- *Population segments enjoying cleaner air*: Persons living and working near existing high concentrations of pollutants produced by vehicle emissions would enjoy cleaner air.
- *Major recipients of the revenues generated by the pricing program*: Congestion pricing can generate large new revenues, far in excess of program costs. For instance, if revenues are used to expand HOV modes, the original and new users of these modes would enjoy the benefits. If revenues are used for in lieu reductions in existing taxes such as registration fees, the affected motorists would gain. If revenues are used to compensate particular road users or businesses, they would benefit. Depending on the compensations, such distributions could partly or fully mitigate negative impacts of pricing on these groups.

Despite such benefits, would such a congestion pricing proposal be fair? On the one hand, it can be argued that since the road users would simply be paying for the costs that they occasion (congestion pricing aims only to eliminate or reduce the existing subsidies for automobile users), it would treat everyone equally. On the other hand, there would be losers under the program. These would include

- *Those who do not value their time highly or cannot afford the increased charges, or both*: Those who are forced to pay more than their time savings or to involuntarily shift to other modes of travel or eliminate trips would lose benefits.
- *Certain businesses in the region who might lose competitive posture compared with those in outlying uncongested areas*: Although many businesses might benefit from improved speeds for goods delivery and employee commutes, some businesses would be disadvantaged vis-à-vis competition from outside the priced zone. Again, this picture could be changed depending on how complementary programs and actions were structured.
- *Users of unpriced facilities in the region*: Travelers on certain unpriced facilities might incur increased costs of congestion if traffic is diverted from priced facilities.
- *Neighborhoods*: Certain neighborhoods might be affected by spillover parking or traffic. Collateral programs such as neighborhood parking permit programs and restrictions on through traffic in neighborhoods could be instituted, however, to reduce spillovers.

Collateral and complementary actions would be needed if those losing under the program are to be compensated.

IMPLEMENTATION CONSIDERATIONS

Congestion pricing has not been implemented on roads in the United States except as flat tolls at a few tunnels and bridges. Attempts to use congestion pricing in the past failed because they did not give sufficient attention to concerns about adverse effects on the poor, on businesses, or on those dependent solely on automobiles or to developing a constituency by explaining the benefits and identifying and designing mitigating and compensatory actions.

The key issues identified in the following discussion will need careful consideration before congestion pricing can be seriously considered by decision makers and the public.

Operation and Enforcement

In order to achieve successful implementation, a congestion pricing program requires careful design of charges and boundaries and comprehensive operating and enforcement procedures. The key questions to be answered are as follows:

1. *What facilities should be priced?* In order to maximize benefits and safeguard equity, the geographic scope of the pricing would have to be designed carefully. For instance, it may become necessary to include certain facilities without severe congestion in the pricing scheme if pricing would spill traffic onto these facilities. Although existing congestion levels will help set the optimal price levels, practical considerations of collection, equity, and revenue needs will also play a role in setting final prices. Although careful design at the outset can go a long way toward making a successful and acceptable program, the actual outcomes might turn out to be different from the planning projections. Flexible program boundaries and prices allowing modification as experience accrues would need to be considered. Consequently, it may be more important to start with prices and boundaries that can be easily altered than to start with any rigid design.

2. *What charging mechanisms should be used?* Collection of congestion charges for the facility or areawide approach would require vehicles either to display prepurchased supplementary windshield stickers such as those used in Singapore or to be equipped with electronic licenses [automatic vehicle identification (AVI) transponders] such as those tested in Hong Kong. Each of these mechanisms would require an extensive distribution system and complex enforcement procedures. A commission-based retail distribution system would need to be sufficiently widespread to facilitate purchase of stickers or licenses by the users. It also may become necessary to set up roadside kiosks at approaches to the priced region to serve users. A refund system for unused licenses also might need to be set up. To be effective, pricing programs would need to identify violators and cite them without forcing them to slow down or stop. This could be accomplished photographically, provided that citations could be sent to vehicle owners by mail. This form of enforcement is based on the concept of owner responsibility, which is increasingly being promoted and accepted in the enforcement of moving violations in California and elsewhere.

Legal Impediments

Both the pricing concepts and the proposed operational and enforcement mechanisms might require new legal initiatives and clarifications. The legality of congestion pricing in general needs to be sorted out. Traditionally, federal and state statutes have limited how roads can be priced and how the revenues can be used. However, these statutes have undergone revisions in the last few years, making it more feasible to implement road pricing in certain applications.

Legal hurdles might include the federal statute prohibiting collection of tolls on federally assisted roads (Section 129, Title 23, U.S. Code); state statutes prohibiting owner liability for moving violations, and local court precedents on the level of fines for traffic violations.

Further legal issues surround administrative and enforcement procedures in congestion pricing. For instance, effective enforcement would probably require heavy fines for deliberate violations. Local court precedents might restrict fine levels. Further, effective enforcement of facility or areawide pricing approaches would probably require photographic monitoring of moving vehicles to detect those in violation and later citation of the vehicle owner by mail. This concept of owner liability for a moving violation might require state enabling legislation. Several California communities (including Pasadena) are using such photo-radar and mail procedures for vehicles exceeding speed limits and running red lights. However, the issue of citing the vehicle owner is complex and in need of simplifying legislation.

For facility and areawide pricing, there might also be legal restrictions on the use of revenues generated from the program. Further steps should include soliciting up-to-date legal opinions from the U.S. Department of Transportation and the region's legal counsel.

Feasibility and Acceptance

Pricing proposals might face significant initial opposition simply because congestion pricing is a new concept that proposes increased charges for travel that has enjoyed large subsidies in the past. There is evidence of considerable opposition to charging for driving or parking to relieve congestion and air pollution. Past attempts at implementing pricing in several U.S. cities met serious opposition (Higgins 1986). Reasons for

objections included concerns about possible adverse impacts on businesses and lower-income travelers. Concerns were also raised about the operational requirements of permit systems and the capacity of transit to absorb large volumes of commuters diverted from other modes. Important determinants of feasibility and acceptance that deserve further scrutiny are discussed in the following paragraphs.

Realization of Measurable User Benefits

Many congestion pricing programs can be shown to produce benefits for society. However, pricing proposals would be acceptable only where the resulting benefits are perceived by the users as significant and worth the increased prices. This suggests that in the National Capital Region, particular attention should be given to applications that focus on facilities or areas with heavy congestion.

Mitigation of Adverse Impacts and Compensatory Actions

Given evidence about objections raised by decision makers concerning road pricing, it is clear that acceptability of congestion pricing will also depend on minimizing negative attributes and compensating those negatively affected. For instance, alternative transportation services may need to be expanded to provide mobility for those who are unwilling or unable to pay the congestion charges. Groups perceiving adverse impacts, such as the poor, residents of the pricing zones, and some businesses, might need to be compensated in some manner. This is not to say that businesses would be affected negatively by pricing. Nevertheless, perceived risk to businesses was one of the key factors behind the rejection of proposals by the Urban Mass Transportation Administration (now the Federal Transit Administration) for areawide pricing demonstrations in the 1970s. Another major concern relates to the possibility of spillover traffic to local streets and neighborhoods as users try to avoid the areas with congestion pricing. Coverage of some of these streets in the pricing scheme and neighborhood entry restrictions may have to be implemented as collateral actions to mitigate adverse spillover impacts.

Congestion pricing programs promise large new revenues, which could enable many compensatory and mitigation measures to be financed. For example, the preliminary assessments suggest that regionwide pricing could generate hundreds of millions of dollars annually in revenues. Even programs with more limited coverage could generate tens of millions of

dollars annually. These revenues could pay for significant expansion in alternative-mode service tailored specifically to potentially affected parties. Alternatively, these funds could go toward overall transportation improvements and financing in the region. Another possible use of some portion of the revenues is as an offset reduction in business or other existing taxes. A revenue-neutral program may have some appeal to businesses.

Minimizing Privacy Concerns

Another issue relating to acceptability pertains to the fears about the invasion of privacy, particularly if AVI is used to charge road users. Although privacy issues were not a major concern in areawide congestion pricing proposals of the 1970s (Higgins 1986), these issues were raised in some assessments (Bhatt 1976). Because the time and place at which vehicles traverse pricing points can be identified and an electronic record of travel can be kept, the concern is that such detailed records of public movement may constitute an invasion of privacy. The possible solution is to borrow from the long-distance billing procedures of telephone companies. Each user might opt to receive detailed billing explicitly identifying each trip made, the time, and the charge. Alternatively, the user could be given a chance to protect his privacy by opting to receiving an aggregate monthly bill without details. In this case, after each trip was made and the charge posted, the time and place would be erased from the record. This approach is used for the automatic toll collection system of the Oklahoma Turnpike Authority; most users opt for the detailed billing. With the use of prepaid smart-card technology, this problem would not be encountered.

Organizational, Intergovernmental, and Institutional Issues

The proposed congestion pricing program would have regional implications. Such regional pricing programs would require resolution of many institutional and intergovernmental issues, including responsibility for collection of congestion charges, collateral expansion of alternative modes of transportation, and other possible use of revenues for mitigating perceived or actual adverse impacts of the pricing program.

An institution must be identified as responsible for collecting congestion charges. For the National Capital Region, this would require coopera-

tion of three states and Congress. Depending on the rationale for the program, a regional special agency organized to administer pricing might be most appropriate. Collection responsibility does not imply spending authority. Because the use of revenues is critical to the acceptance of congestion pricing, revenues should be provided to the jurisdictions or to regional agencies implementing the compensatory actions or other collateral improvements. A revenue-sharing agreement might become necessary for an extensive regional pricing program, and a new regional compact might be needed.

It is very important that the responsible agency be chosen appropriately for any pricing application. Ideally, operational and enforcement functions would be centralized and combined with other functions already performed by the agencies. Also, local jurisdictions should not be put in a position to decide on higher tolls for outsiders versus those for residents. Institutions with broader geographic coverage than the areas or corridors affected most likely should have responsibility for a pricing program. Further assessments are necessary to define institutional roles and responsibilities for the proposed program.

NEXT STEPS

As the previous discussion indicates, there are many unanswered questions about congestion pricing in general and its application to the metropolitan Washington region. Although the concept promises to reduce congestion and generate revenues for transportation alternatives and other purposes, several issues have arisen:

- Much more careful assessment of impacts would be desirable;
- Public acceptability is in question;
- There are possible legal impediments, at least with respect to the pricing of federal-aid facilities;
- New legislation may be needed to facilitate enforcement;
- A large-scale distribution system for permits or AVI would be needed, possibly involving both government and retail outlets; and
- New organizations would probably be necessary, at least for application and enforcement of the congestion pricing, and new roles for existing institutions would be necessary for collection and distribution of revenues.

In light of these issues, congestion pricing deserves much more analysis and evaluation before the concept is considered for implementation within the region. One way to gain a better understanding of congestion pricing effects and implementation and policy hurdles is to evaluate possible applications of the concept

- Where opportunities arise for road tolling projects in the region and
- On highly congested facilities where the prospect of traffic spillover is minimized and transit and rideshare options are good.

The long-term goals should be to nurture a constituency for congestion pricing, address opponents' concerns, and develop an incremental program of implementation. If projects such as congestion pricing on existing toll facilities (e.g., the Dulles Toll Road) or parts of the Beltway could be implemented, even as demonstrations, invaluable information about the concept, technology, administration, enforcement, impacts, and legality would become available. Regional congestion pricing would get a boost from the success of these pilot projects.

Once careful assessment of a prototype concept for the region has been completed, a "testing of the waters" should take place with representatives of local business interests; outside agencies such as transit, ridesharing, and air quality; and local government officials and interests. Given past experience with the concept, likely concerns will focus on feasibility of enforcement, equity, alternative modes, compensatory actions to mitigate adverse impacts, revenues, and economic impacts. Depending on the results of detailed evaluations and testing for acceptability, further steps might be taken to flesh out the compensatory actions and implementation steps. Further steps may include

- Research into whether federal funds would be available to implement and evaluate the program,
- Research to design compensatory actions to ensure widespread benefits and monitoring programs that would allow prices and compensatory actions to be adjusted over time,
- Identification and development of the potential roles of various governments in sharing the costs and risks,
- Possible general specifications for the best pricing technology and distribution system, and

• Review of the latest implementation lessons from other sites here and abroad.

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ABBREVIATIONS

GLC	Greater London Council
KTA	K.T. Analytics, Inc.
MWCOG	Metropolitan Washington Council of Governments
WRN	Washington Regional Network for Transportation, Land Use and Air Quality

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Transportation Pricing and Travel Behavior

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The purpose of this paper is to summarize and critically interpret the current status of knowledge about the effects of transportation system pricing on daily activity patterns and travel behavior. The paper is written in the context of heightened interest in pricing instruments as tools for financing transportation investments and for addressing externalities in the transportation system (particularly the highway system). In making judgments about the desirability of pricing and in developing specific pricing policies, it is important to have as much information as possible about impacts on the amount, location, and timing of travel in affected areas, both in total (for determining aggregate revenues and other systemwide impacts) and among specific facilities, jurisdictions, and population subgroups (for evaluating distributional consequences). An assessment of how well the current status of knowledge can address these information needs is made.

TRAVEL DEMAND THEORY

Understanding the impacts of transportation pricing requires an understanding of possible demand responses.

An implicit theory of travel behavior has emerged over the last 40 years through the adaptation of concepts from economics and psychology as well as from practical efforts to forecast travel demand. Critical elements of this theory are the roles of time and cost—and the compensatory relationship between the two—that follow from conventional utility maximization in the face of time and budget constraints. A hierarchy of behav-

iors is suggested ranging from the route choices made as a trip is carried out to the more basic daily or weekly activity choices that set a pattern of desired trip making and the even more far-reaching location and life-style choices that determine a household's living arrangements.

Under this conventional paradigm of travel behavior, price could have noteworthy effects at many levels of the behavioral hierarchy:

- Route Choice: Tolls and congestion fees influence the "impedance" of each route, which will produce changes in path choices as fees are differentially changed and congestion shifts or abates.
- Time of Travel: Fees that vary with congestion will induce some drivers with scheduling flexibility to shift to lower-cost periods and perhaps others with high time values to shift to previously congested periods.
- Mode Choice: Price is a key determinant of modal competition for all types of travel.
- Destination Choice: Differential price increases will cause a spatial shift in destination choices from any given location, and a general price increase could lead to shorter trips overall (although, again, individuals with high time values might make longer trips).[1]
- Trip Chaining: Price increases could induce individuals with low time values to combine trips for more efficient routing, and congestion relief might lead some individuals with high time values to undertake fewer linked trips.
- Trip Frequency and Activity Selection: For nonwork trips, a general price increase could reduce the amount of discretionary trip making among low-time-value households. For work trips, a significant price increase (either differential or general) could foster work-at-home policies, four-day work weeks, or other reduced-trip scenarios.
- Automobile Ownership: By directly or indirectly raising the cost of automobile ownership or decreasing highway accessibility, price increases could reduce the incentive for multiple-automobile ownership among lower-income households. Congestion relief might induce an opposite effect among high-income households.
- Residential and Employment Location: Significant price changes may cause lower-income working households to seek less expensive workplaces or residential locations. Conversely, reductions in congestion may induce higher-income households to locate farther from their workplaces.
- Residential and Commercial Construction: Pricing-induced changes in residential demand or workforce availability might shift the locus of

regional growth or perhaps alter the overall rate of regional demographic and economic change.

The same hierarchy of effects could be postulated for other large changes in the transportation system, such as the cumulative impact of congestion as it increases gradually over a long period.

Accessibility is a common thread running through all affected elements of travel behavior. It has been customary to let travel time (usually by automobile) serve as a proxy for accessibility. But in a situation where the cost of travel is no longer necessarily correlated with time and distance—as would be the case under a serious congestion pricing scheme—cost must be a component in accessibility. Thus a demand analysis for pricing requires models that incorporate price throughout the choice hierarchy. It is not enough to use price alone; since responses to price differ with income, price coefficients should reflect income variations, either by incorporating different coefficients for several income categories or by explicitly estimating a cost coefficient including some transform of income.

In the intense debate over any large change in transportation policy such as congestion pricing, there is pressure to address each potential effect in a meaningful way. It appears likely that some of the listed phenomena are more important than others, but unfortunately the theoretical literature does not offer much help in sorting out the first-order effects. The primary reason why the literature fails to provide more precise guidance is that each phenomenon is highly context specific, with geographic scale of implementation, network topology, magnitude of existing congestion, availability of alternative modes, and social-economic-demographic makeup of the affected population all leading to significant variations in outcome.

It is possible to attempt a typology of price effects for a range of prototypical strategies by reasoning about the basic characteristics of each strategy. However, as Table 1 suggests, such a typology does not do much to simplify the analysis task. In fact, it is difficult to escape the conclusion that an understanding of pricing impacts would require a comprehensive modeling approach in each specific implementation context.

ANECDOTAL AND EXPERIMENTAL EVIDENCE

It has been suggested that actual experience with pricing could provide generalizable evidence of the magnitude of pricing impacts. Indeed, there is a large body of anecdotal and experimental evidence on the effects of

TABLE 1 Potential Traveler Responses to Congestion Pricing

Facilities Affected	Traveler Responses	Speed Impacts
Specific facilities, with no significant alternate routes (e.g., Bay Bridge)	Primary: Time-of-day Mode Secondary: Trip chaining Residential location Workplace location	Higher on priced facilities during the peak (e.g., 30 to 50 mph) Slightly lower on priced facilities during the shoulder of the peak (e.g., 55 to 50 mph) Unchanged on other facilities
Specific facilities, with substitutable unpriced facilities	Primary: Route Time-of-day Secondary (high time value): Trip frequency and destination/activity patterns Automobile ownership Residential location Workplace location	Higher on priced facilities during the peak (e.g., 30 to 45 mph) Lower on parallel unpriced facilities during the peak (e.g., 40 to 35 mph) Uncertain changes during the shoulder of the peak

All freeways, without pricing on arterials that serve as alternate routes	Primary: Route Time-of-day Secondary (all time values): Mode Trip frequency and destination/activity patterns Automobile ownership Residential location Workplace location	Higher on priced facilities during the peak (e.g., 30 to 45 mph) Lower on parallel unpriced arterials during the peak (e.g., 30 to 20 mph) Modest declines in the shoulder of the peak
All freeways and arterials as necessary to achieve LOS standards	Primary: Route Time-of-day Mode Trip frequency and destination/activity patterns Automobile ownership Residential location Workplace	Higher speeds everywhere

NOTE: LOS = level of service. 1 mph = 1.6 km/hr.

transportation pricing in the real world ranging from toll increases on bridges and turnpikes to fuel prices, transit fare changes, employer-based parking fees, and rideshare subsidies.

A few representative examples of the kinds of price changes for which data can be obtained are given in Table 2. Before commenting on the value of evidence such as this, it is important to have a clearer idea of the questions posed.

The first question concerns whether there indeed is price elasticity in urban transportation. Although the answer may seem obvious to students of urban transportation demand, this is an issue that emerges often in discussions with policy makers and the public. There is a popular understanding that many travelers—especially low- and middle-income commuters—do not have realistic options for the trips they now make, and hence will exhibit little or no price sensitivity in a broad range around present prices. Such a view leads to an interpretation of pricing, especially parking and congestion pricing, as primarily a tax on unavoidable behavior.

The second question concerns the nature, magnitude, and distribution of benefits from pricing in general and from the implementation of individual measures in specific contexts. The TRB Committee for a Study on Urban Transportation Congestion Pricing, along with many others, seeks generalizable findings to support policy recommendations.

Regarding the first question, although the range of aggregate elasticities emerging from available evidence is wide and subgroups and locations may be affected differently, it is clear that travelers do in fact respond to prices by changing their travel consumption patterns in a variety of ways. Most lay observers of the transportation system do not appreciate the range of flexibility allowed by the list of behavioral effects in the previous section. But theory suggests and empirical evidence tends to affirm that most elements of travel are responsive to price (albeit inelastically) and that even the most rigidly constrained worker retains some freedom to shift the conditions of travel to avoid an onerous price.

Unlike findings based on theoretical models, which do not resonate with most politicians or other nontechnical decision makers, these real-world cases—however imprecise—make it possible to talk in broad terms in policy forums about the behavioral consequences of some commonly suggested pricing measures. Note, however, that congestion pricing is not one of the measures for which good evidence exists. The most general points about price elasticity are helpful in discussing the potential outcome of congestion pricing, but convincing evidence based on congestion pricing in the transportation system is not available.

TABLE 2 Representative Transportation Pricing Experience

Type of Price Change	Description	Aggregate Demand Elasticity
Bridge toll increase	Tolls on the Golden Gate Bridge were increased from $2.00 to $3.00 to cover earthquake retrofitting costs. A clear drop in traffic was detected, with some diversion to bus and ferry and a residual net decline in corridor trips.	−0.15
Bridge toll increase	Tolls on the San Francisco Bay Bridge were raised from $0.75 to $1.00. A small drop was detectable in the time series of daily volumes, but any long-run effect was indistinguishable from background trends.	<−0.05
Toll road increase	Following a toll increase from $0.50 to $1.00 (about $0.04 to $0.08/mile), the Everett Turnpike in New Hampshire experienced significant diversion to convenient parallel arterials.	−0.1 (automobile) −0.2 (truck) (selected locations only)
Fuel tax increase	Pickrell and others have extracted a fairly consistent set of fuel price elasticities from documentation of experience worldwide.	−0.2 to −0.25 (short-term) −0.05 (long-term)
Transit fare increase	Following the most recent set of BART fare increases, staff conducted an exhaustive review of the reasons for what turned out to be a significant ridership decline. Elasticities were found to vary strongly with trip distance on the BART system and by time of day.	−0.05 (off-peak, short) to −0.4 (peak, long)
Parking price increases	Airport parking elasticities have been studied carefully at San Francisco (SFO) and Boston (Logan). In both cases, the price sensitivity of short-term parkers appeared to be very low, while the price sensitivity of long-term parkers was remarkably high. Both airports have taken revenue-maximizing steps based on this knowledge.	−0.1 (<1 day) to −2.0 (>8 days)
Parking price increases	Under South Coast Regulation 15, some employers have increased parking prices to encourage ridersharing and transit use.	−0.05 to −0.15

NOTE: 1 mi = 1.6 km.

The second question is much more difficult to answer in a positive way. First, few of the examples that can be cited are drawn from structured experiments. Whether this kind of nonexperimental evidence can provide generalizable, scientifically valid insight on the effects of pricing, particularly congestion pricing, is an open question.

More important, as the discussion in the previous section suggests, the wide range of potential behavioral responses complicates the task of generalizing from real-world experience about the more subtle effects of pricing. Not only are important aspects of the spatial, technological, and demographic contexts unknown (to varying degrees) in each case, but evidence of temporal variation is entirely absent. In other words, differences in context make it impossible to generalize in a precise way, and the absence of time-of-day variation means that a key response to congestion pricing—shifting the time of travel—cannot be observed in existing data. Thus, although available evidence is adequate to support arguments about the direction of change under pricing, it yields little insight on the more exacting questions of magnitude, net benefit, and distributional consequences.

Despite all of this, there remains a great deal of value in looking at real-world evidence of pricing effects. The following points are intended to illustrate the range of conclusions that can be drawn from the empirical literature:[2]

1. Reinke's work on Bay Area Rapid Transit (BART) fare elasticity provides strong evidence on the degree of variability with time of day and trip length (Reinke 1988). Contrary to conventional assumptions, BART's off-peak ridership has shown less sensitivity to price than its peak ridership. The likely reason is that express buses and casual carpooling provide higher-quality alternatives in the peak (these options are not available in the off peak). This should serve as a warning that even knowledge as well established as the discretionary, flexible nature of off-peak travel cannot serve as a simple guide in all pricing contexts. Outcomes are highly dependent on the characteristics of the pool of travelers affected and on the quality of the alternatives they face.

Observed BART elasticities also tend to corroborate the theoretical treatment embodied in the logit choice equation (which is the primary tool used in modeling travel demand). According to the logit equation, elasticities should be proportional to the magnitude of the variable in question. BART fares are distance based, and observed BART elasticities show a clear tendency to increase with length of travel (hence fare) on the BART

system. In fact, a retrospective analysis showed that the regional travel demand models provided an accurate picture of the spatial effects of the BART fare increase.

2. Shoup's discussion of parking pricing in another paper in this volume tends to confirm what many have suspected. Although employee parking demand is inelastic with respect to price (e.g., −0.05 to −0.2), elasticities nevertheless are high enough to make parking pricing a significant instrument for influencing travel behavior, and an income supplement to compensate for newly imposed parking pricing apparently does little to diminish its effect.

3. The body of evidence on bridge toll increases requires careful interpretation. There is a mythology that suggests that tolls do not affect volumes on congested urban facilities. Indeed, it is difficult to use available evidence to refute this hypothesis. In some cases, notably the most recent increase in San Francisco–Oakland Bay Bridge tolls, the effect simply is too small to distinguish from other influences on bridge volumes, such as long-term demographic trends, fuel prices, and the condition of the regional economy.[3] Trans-Hudson facilities to Manhattan are also said to exhibit low elasticities. Looking at survey data for the Bay Area, one apparent reason for these low elasticities is that such highly congested facilities serve a pool of high-time-value users who already pay substantial costs for parking and for whom even a $1 daily toll increment would represent a small change in total travel cost. In this situation, actual price elasticities (in terms of the total price of travel) could be quite high and still remain consistent with toll bridge observations.

The common thread running through these examples, and through the entire empirical literature, is the wide variability of possible outcomes from transportation pricing. There clearly is a price response ranging from moderately to highly inelastic in most situations. Equally clear are the reasons for uncertainty and variability of outcomes. They stem from the wide range of potential behavioral responses identified earlier and the way that each set of circumstances can lead to a different mix of responses.

A number of other observations are suggested by a reading of the literature:

1. Evidence based on real-world experience can be useful in an anecdotal, hypothesis-stimulating way. At a minimum, good documentation of empirical evidence is essential for communicating the potential value of pricing to decision makers and the public.

2. Some generalization may be possible where there is extensive experience with price changes (for conventional toll facilities, in particular). However, such evidence does not exist for congestion pricing.

3. The first few congestion pricing experiments in the United States will be of critical importance. However, their usefulness will be limited if results are recorded and reported as aggregate statistics only. A careful experimental design involving detailed before-and-after surveys of affected travelers and thorough statistical analysis is essential in each case.

4. There may also be a role for stated-preference surveys of prospective responses to congestion pricing. However, these should be conducted and interpreted with utmost caution. The difficulty with stated preference is that, without an extremely realistic experimental context, each subject responds from a mental model of his or her own behavior. Yet, in the true situation, behavior results from the (partially subconscious) mediation of parallel responses in different parts of the brain. Cognitive science does not offer much hope that these two processes will produce comparable results (other than serendipitously), at least not in the face of as many behavioral degrees of freedom as have been identified here.

MODEL-BASED EVIDENCE

Short of full-scale experimentation, modeling is the only real way to understand complex interactions among the determinants of choice or to sort out the large number of potential outcomes in a pricing implementation.[4] The extent to which operational travel models are available and reflect a reasonable theoretical treatment of price thus becomes a critical issue.

Among models used by state, regional, and local planning agencies in the United States to study transportation alternatives, virtually none can adequately represent the range of possible demand responses to prices. These models typically incorporate only some elements of the hierarchy of affected choices (e.g., many ignore location and life-style choices) and, with the exception of mode, often omit price altogether from the choice calculus. As a result, most operational models will give highly misleading answers about the overall effects of pricing.

Outside the United States (e.g., in the United Kingdom and the Netherlands), a number of model systems have been developed, with a full hierarchy of travel models and with accessibility (generalized price) and

income appearing throughout. However, the only such model in use in the United States was developed for the San Francisco Bay Area.

Bay Area Model

The Bay Area model was developed in the mid- to late 1970s[5] using data from a 1965 regional home interview survey and from more focused surveys conducted before and after the opening of BART. Some adjustments were made based on a 1981 regional home interview survey, and the Metropolitan Transportation Commission (MTC) contemplates a major update based on a survey collected by MTC in 1990. However, the model described here is an adaptation by this author of the model originally delivered by the consultants.

The Bay Area model system has been adapted for use in a number of pricing studies for California cities. It covers a standard set of trip purposes (work, shopping, social-recreational, and non-home-based) but does so in a manner that accounts for the effects of accessibility through much of the behavioral hierarchy. Since it can be argued that the structural characteristics of the Bay Area model have been essential to carrying out a credible analysis of pricing, it is helpful to describe that model in some detail.

The Bay Area model begins with standard network representations of the regional highway and transit systems. Given interzonal trip tables by purpose[6] and knowledge of peaking characteristics for each trip purpose, network assignment algorithms are used to create peak and off-peak level-of-service (LOS) tables by mode [automobile, transit, and high-occupancy vehicle (HOV)]. Equilibrium assignments are performed for the peak periods.

Computed LOS data are then fed into a hierarchy of probability and demand equations for each trip purpose. For nonwork trips, the hierarchy begins with a joint model of mode and destination choice in which the zone-to-zone accessibility is defined in terms of both travel times and travel costs. Trip frequency is then computed using a nonlinear equation with variables drawn from personal and home zone characteristics, including the natural log of the denominator of the destination–mode choice model.[7] This "logsum" variable captures the effect of overall accessibility from the home zone on trip generation.

Work trips are modeled in a similar way, with mode choice nested under destination choice rather than treated jointly. The logsum from the mode choice model essentially serves as the accessibility measure in desti-

nation choice. Work trip generation is treated exogenously to the travel model (as a fundamental output of the land use modeling process).

Given a full set of travel calculations, automobile ownership probabilities are computed as functions of income, local land use characteristics, and relative accessibility by transit versus automobile. Accessibility is inferred from the denominator of the shopping and work-destination choice models by dividing the composite transit utilities by the composite automobile utilities in each case (work trip accessibility is included only for households with workers).

The four travel model levels—mode choice, destination choice, trip frequency, and automobile ownership—yield new trip tables, which can be integrated and assigned to the networks to generate new estimates of level of service. Technically, it is necessary to repeat the whole procedure iteratively until the travel demand estimates and LOS estimates converge to an apparent equilibrium.

The strength of the Bay Area model lies in its normative treatment of travel demand, that is, as a hierarchical arrangement of interrelated travel choices interconnected by price-dependent measures of accessibility. From the model documentation, it is clear that some of the linkages are significant, whereas others may be less so.[8]

Much less clear is the superiority of the Bay Area specification and structure in comparison with other possible realizations of hierarchical, accessibility-dependent travel choice. In particular, advances in nested choice modeling have been made in the last decade that are not reflected in the Bay Area model because they were not well developed at the time.[9] Also, model development resources did not allow a complete exploration of alternative specifications. Nevertheless, the Bay Area model offers at least a reasonable starting point for the analysis of pricing measures.

A regional land use model, POLIS, is operated by the Association of Bay Area Governments (ABAG). It uses highway LOS data in allocating new development among the cities and towns of the region. In some applications, MTC provides ABAG with revised LOS tables in order to verify that land use allocations would not be affected by large changes in highway accessibility.[10, 11]

Several changes were made to fine-tune the Bay Area model for pricing studies. Because of the practical and administrative difficulties of running the POLIS land use model for multiple scenarios, a Bay Area residential-location choice model previously developed by this author was added to the model system as an alternative procedure. In addition, an ad hoc corridor-level time-of-day adjustment was incorporated based on data that

suggest a simple relationship between work trip departure time and the extent of travel time degradation due to congestion.[12]

Practical Applications of Bay Area Model

A critical demand modeling issue concerns the mechanics of aggregation given available software. Two options were available for practical use of the Bay Area model: standard operation in the Urban Transportation Planning System (UTPS) large-scale modeling framework (MTCFCAST) and nonstandard operation in a household-level simulation framework (STEP).

MTCFCAST reflects an adaptation of the "pure" Bay Area model to the constraints and practicalities of large-scale modeling. There are detailed highway and transit networks, and demand estimates are carried out for a system of about 700 regional zones (average population 9,000). Many elements of the demand models are treated in a simplified way. For example, socioeconomic data are input as zonal averages rather than as ranges that would reflect the variability of the estimation data. Also, some models have been reestimated without accessibility feedback, in the interest of computational tractability.[13] It would be fair to characterize MTCFCAST as a model that achieves great detail in representing infrastructure by reducing its detail in representing demand. (This is true of metropolitan planning organization models in general.)

STEP reflects an application of the "pure" Bay Area model at the household level (augmented by residential location and time-of-day models, and with some additional reestimation not reflected in MTCFCAST). It works with a sample of households from the region, as large and as up-to-date as possible. Base LOS data are supplied exogenously for each zone,[14] along with standard land use and socioeconomic information. (This data ensemble has exactly the same form as a model estimation data set.) STEP reads through the household sample, adding LOS and land use data to each household record as necessary, and calculates all of the household's travel probabilities. Full model specifications are used, and the sampling framework preserves the richness of the underlying distribution of population characteristics.[15] Household totals are expanded to represent the population as a whole and summed in various regional and subregional categories.

With STEP it is possible to test any change in the population or in the transportation system that (*a*) can be represented in terms of the variables of the Bay Area model and (*b*) can be associated with a specific geographic

area or grouping of households by reprocessing the household sample using the new data values. What STEP lacks is a detailed network representation and traffic assignment component, meaning that changes in travel time resulting from changes in demand must be calculated in another way. A simple routine for estimating changes in level of service has been incorporated, but it is intended only as an approximation.[16] It thus would be fair to characterize STEP as a model that achieves great detail in representing demand by reducing its detail in representing infrastructure.

A comparison between the available large-scale and microsimulation approaches suggests that neither is ideal for the analysis of transportation pricing policy. The large-scale model is too expensive to run in an exploratory mode, lacks some potentially important feedback loops, and is incapable of capturing the distributional effects of pricing. The microsimulation model does not allow pricing of individual links and supports disaggregation of outputs only where sample size is adequate. On balance, it was decided to use the microsimulation model (STEP) for pricing studies because of the importance accorded to equity considerations in early Bay Area debates about pricing (Figure 1).

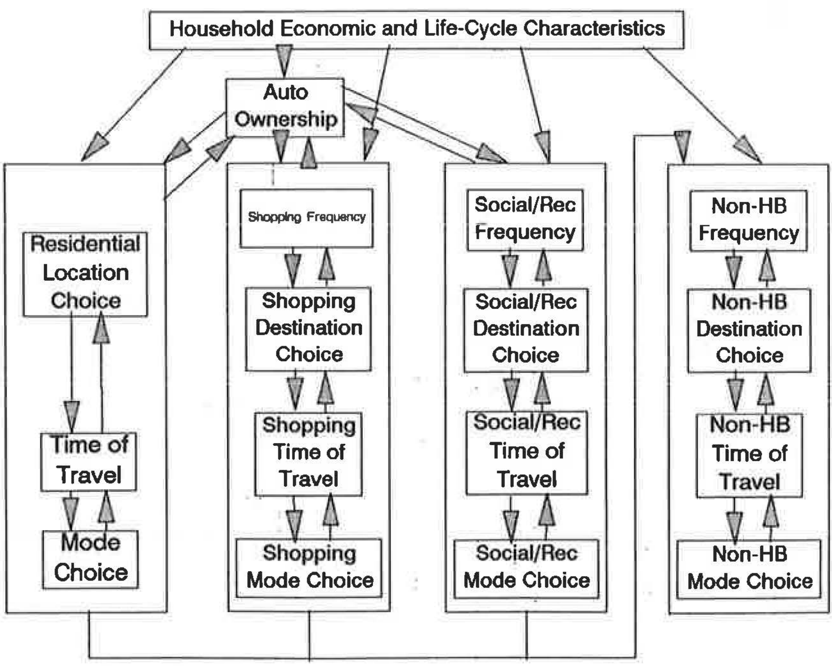

FIGURE 1 Conceptual structure of the STEP model.

The microsimulation methodology fits well with the regional scope of proposed policies.[17] However, a more facility-specific approach to pricing, such as the toll road proposals for the Bay Bridge and Southern California, would require a network-based model (which might, in an advanced form, produce trip tables using a household simulation approach).

Using STEP, four prototypical pricing concepts for the Bay Area and the South Coast Air Basin were studied in some detail.[18] The analysis results are summarized in Tables 3 and 4, and key assumptions are described briefly here:

- Congestion Fees: Congestion was expressed in terms of the ratio of peak to uncongested travel times. Values of this ratio reflecting various LOS ratings were selected. For each LOS rating, STEP was run repeatedly to determine the average per-mile price that would have to be charged in each corridor to reduce highway travel (and increase speed) enough to achieve the required travel time ratio. All models through automobile ownership and residential location were exercised. No effort was made to account for employment allocation effects (i.e., workplaces were taken as given).
- Emissions Fees: The annual smog-based registration fee was represented in two ways. First, an age-based fee was calculated as a proxy for the true smog fee.[19] Data from the California Air Resources Board (CARB) on average emissions and vehicle miles traveled (VMT) by model year were obtained for a 1997 fleet. An informal survey of air pollution experts was conducted to estimate the average annual cost of mobile source pollution in each area.[20] The fleet and pollution cost data were translated into per-mile estimates of pollution costs by model year. These costs then were added to the annual automobile ownership costs of each household according to the makeup of the existing household fleet, and STEP was run with the full set of models. Because no possibility of substitution was allowed, a modest drop in the size of the vehicle fleet was predicted, with the burden falling almost entirely on low-income households. Limited reductions in emissions occurred, however, because most households simply retained their older cars. A vehicle-type choice model would be required to develop a more accurate estimate of this shift.

A second scenario was tested by simply assuming that the emissions fee would result in the replacement of some portion of the vehicle fleet older than 8 years by 8-year-old vehicles (i.e., perfect substitution would occur). The STEP travel demand models were not exercised in this case (i.e., STEP was used only for survey tabulation with emissions calculations).

TABLE 3 Overview of the Bay Area Pricing Study

Strategy	Description	Percent Change from 1997 Mobile Source Baseline						
		VMT	Trips	Fuel	ROG	CO	NO_x	CO_2
Regionwide congestion pricing (level-of-service D/E), average $0.10/mi	An automatic vehicle identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E	−1.8	−2.2	−6.5	−5.5	−7.5	−2.9	−6.5
Regionwide employee parking charge, $3.00/day	All workers in the region would experience a minimum $3.00 (1991)/day charge for parking an automobile, pickup, or van at the workplace	−1.2	−1.5	−1.2	−1.4	−1.4	−1.5	−1.2
Regionwide nonemployee parking charge, $0.01/min	All nonresidential parking lots and on-street spaces in commercial districts would be metered or gated for $0.60/hr operation ($3.00/day maximum) or converted to an equivalent pay-for-time scheme	−4.2	−5.4	−4.7	−4.6	−5.1	−4.5	−4.7
Mileage- and smog-based registration fee (average $125/vehicle)	Fees would be paid annually at the time of registration, based strictly on the calculated annual emissions for each vehicle (derived from the odometer reading and a representative measurement of tailpipe emissions)	−0.2	−0.1	−1.0	−4.5	−4.5	−2.5	−1.0
Gasoline tax increase, $2.00	Fees would be paid at the pump	−8.1	−7.6	−36.0	−7.8	−7.6	−7.8	−36.0
Net for market-based strategies		−14.8	−15.9	−44.2	−21.7	−23.6	−17.9	−44.2

NOTE: VMT = automobile and private transit vehicle-miles traveled; Trips = vehicle trips; Fuel = gallons of fuel consumed; ROG = emissions of reactive organics; CO = emissions of carbon monoxide; NO_x = emissions of oxides of nitrogen; CO_2 = emissions of carbon dioxide. 1 mi = 1.6 km.

TABLE 4 Overview of the South Coast Air Basin Pricing Study

Strategy	Description	Percent Change from 2010 Mobile Source Baseline: VMT	Trips	Fuel	ROG	CO	NO_x	CO_2
Regionwide congestion pricing (level-of-service D/E), average $0.15/mi	An automatic vehicle identification (AVI) scheme would be used to price the regional freeway and arterial system to maintain level-of-service (LOS) D/E	−5.0 [±.7]	−3.8 [±.4]	−9.2 [±.9]	−8.2 [±.8]	−12.1 [±1.0]	−8.4 [±1.0]	−9.2 [±.9]
Regionwide employee parking charge, $3.00/day	All workers in the region would experience a minimum $3.00 (1991)/day charge for parking an automobile, pickup or van at the workplace	−1.5 [±.2]	−1.8 [±.3]	−1.7 [±.3]	−1.7 [±.3]	−2.1 [±.3]	−1.6 [±.3]	−1.7 [±.3]
Regionwide nonemployee parking charge, $0.01/minute	All nonresidential parking lots and on-street spaces in commercial districts would be metered or gated for $0.60/hr operation ($3.00/day maximum) or converted to an equivalent pay-for-time scheme	−3.5 [±.2]	−4.3 [±.4]	−3.5 [±.5]	−4.0 [±.5]	−4.2 [±.4]	−3.8 [±.5]	−3.5 [±.5]
Mileage- and smog-based registration fee (average $110/vehicle)	Fees would be paid annually at the time of registration, based strictly on the calculated annual emissions for each vehicle (derived from the odometer reading and a representative measurement of tailpipe emissions)	−0.4 [±.2]	−0.7 [±.2]	−2.7 [±.4]	−4.1 [±.4]	−4.5 [±.4]	−5.0 [±.5]	−2.7 [±.4]

(continued on next page)

TABLE 4 *(continued)*

Strategy	Description	Percent Change from 2010 Mobile Source Baseline						
		VMT	Trips	Fuel	ROG	CO	NO_x	CO_2
Deregulated private transit	Regulatory changes would remove legal restrictions on private shared-van transportation services. Private operations would emerge to provide access to the largest employment centers in the region, and in other heavily-used corridors	−1.8 [±.3]	−2.0 [±.3]	−1.9 [±.3]	−2.2 [±.3]	−2.2 [±.3]	−2.1 [±.4]	−1.9 [±.3]
Net for market-based strategies		−11.6 [±1.4]	−12.0 [±1.2]	−17.3 [±1.3]	−18.8 [±1.7]	−23.0 [±1.9]	−18.9 [±1.8]	−17.8 [±1.8]

NOTE: VMT = automobile and private transit vehicle-miles traveled; Trips = automobile vehicle trips; Fuel = gallons of fuel consumed; ROG = emissions of reactive organics; CO = emissions of carbon monoxide; NO_x = emissions of oxides of nitrogen; CO_2 = emissions of carbon dioxide.

Each value represents the midpoint of the estimated range of effect. Numbers in brackets indicate variation above and below the midpoint, based on sensitivity tests of key parameters related to pricing (such as the travel cost coefficients). Accuracy of the estimates will depend as well on other uncertainties that are inherent in any travel forecasting exercise, such as in regional and subregional growth projections and in assumptions about future infrastructure investments.

The results reported in Tables 3 and 4 were for the first analysis scenario. It is quite likely that this approach understates the true potential of an emissions fee, however. Even a modest substitution under the second scenario produces higher estimated emissions reductions.

• Parking Fees: All worker drive-alone parking fees were set to a minimum of $3.00 per day,[21] and worker transit fares in affected districts were set to zero. STEP was run with the full set of models to estimate the combined effect of parking and transit incentives.

• Gasoline Taxes: The effect of a gasoline tax was studied in a very simple way. The automobile operating cost per mile was increased under varying assumptions about improved fleet mileage, and STEP was run with the full set of models. Figures reported in Table 1 assume fleet improvement to 40 mph (64 km/hr), reflecting a substantial demand pull for more efficient vehicles.

If the gasoline tax also covered insurance, as some have suggested, it might not be so easy to reduce the fee by purchasing a more efficient vehicle.[22] Under this scenario, the effects of a gasoline tax might be substantially higher.

STEP is currently being used in a study of the equity impacts of transportation pricing for the Environmental Defense Fund and on an extension of the analyses in Tables 3 and 4 to the entire state of California for CARB, funded by a consortium of federal, state, and local agencies.

Some initial results of these studies are shown in Table 5 and Figures 2 and 3. The pricing scheme represented here is a simple fee based on VMT, assumed to be collected so that travelers perceive it as an out-of-pocket cost. Congestion pricing, parking pricing, and other measures that affect mobility in less overt ways will also be analyzed but are not shown here.

The main purpose of this material is to illustrate the level of distributional analysis made possible by the household simulation approach of STEP. The hope is that a repetition of the analysis for the four large metropolitan areas of California will lead to some general observations about the magnitude of impact for various pricing measures and about the extent to which distributional problems can be addressed within the overall scope of a pricing policy.

How well would these analyses withstand an objective critique? Simply put, the household simulation approach based on the STEP application of the Bay Area model system addresses (*a*) the need for appropriate price, income, and time variables; (*b*) the need for structural completeness and feedback through automobile ownership; and (*c*) the advantages of disag-

TABLE 5 South Coast Air Basin 1991 Base Case: Equilibrated Daily VMT with Respect to Cost per Mile

VMT Fee	Time	Income Quintile					
per Mile	per Mile	1	2	3	4	5	Total
−9	2.32	51.1	65.4	67.9	80.9	94.8	360.2
−8	2.28	47.2	62.8	66.5	80.0	94.8	351.4
−7	2.24	43.6	60.3	65.0	79.1	94.8	342.8
−6	2.21	40.3	57.9	63.5	78.2	94.6	334.5
−5	2.18	37.3	55.5	62.0	77.2	94.5	362.5
−4	2.14	34.5	53.2	60.6	76.2	94.2	318.7
−3	2.11	31.9	51.0	59.1	75.1	93.9	311.2
−2	2.09	29.6	48.9	57.7	74.1	93.6	303.0
−1	2.06	27.5	46.9	56.2	73.0	93.2	296.8
0	2.03	25.5	45.0	54.8	71.9	92.8	290.0
1	2.01	23.7	43.1	53.4	70.8	92.3	283.4
2	1.99	22.1	41.3	52.0	69.7	9.19	277.0
3	1.97	20.7	39.6	50.7	68.6	91.3	270.8
4	1.95	19.3	37.9	49.3	67.5	90.8	264.8
5	1.93	18.1	36.4	48.0	66.4	90.2	259.0
6	1.91	17.0	34.9	46.8	65.2	89.6	253.4
7	1.89	16.0	33.4	45.5	64.1	89.0	245.0
8	1.87	15.1	32.1	44.3	63.0	88.3	242.8
9	1.86	14.2	30.8	43.1	61.9	87.7	237.7
10	1.84	13.5	29.5	41.9	60.8	87.0	232.7
11	1.83	12.8	28.4	40.8	59.7	86.3	228.0
12	1.82	12.2	27.3	39.7	58.7	85.6	223.3
13	1.81	11.6	26.2	38.6	57.6	84.9	218.9
14	1.79	11.1	25.2	37.5	56.5	84.2	214.5
15	1.78	10.6	24.2	36.5	55.5	83.4	210.3
16	1.77	10.2	23.3	35.5	54.5	82.7	206.2
17	1.76	9.8	22.5	34.6	53.5	81.9	202.3
18	1.75	9.5	21.6	33.6	52.5	81.2	198.4
19	1.74	9.2	20.9	32.7	51.5	80.4	194.7
20	1.73	8.9	20.1	31.9	50.5	79.7	191.1

NOTE: VMT in millions. 1 mi = 1.6 km.

gregation. On the other hand, STEP does not address employment allocation[23] or absolute regional growth, and treats time of day in a simplified way. However, given the status of knowledge and the scope of available models, it would be difficult to carry out a more thorough analysis of pricing without improving the Bay Area demand models and integrating the resulting model system into a fully detailed network model. Such an

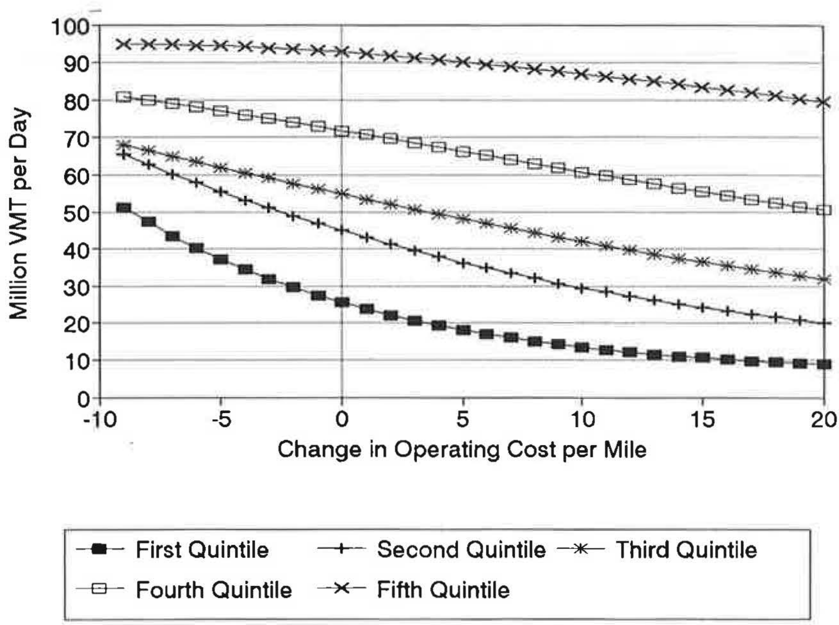

FIGURE 2 Effect of South Coast Air Basin VMT fee on operating cost per mile.

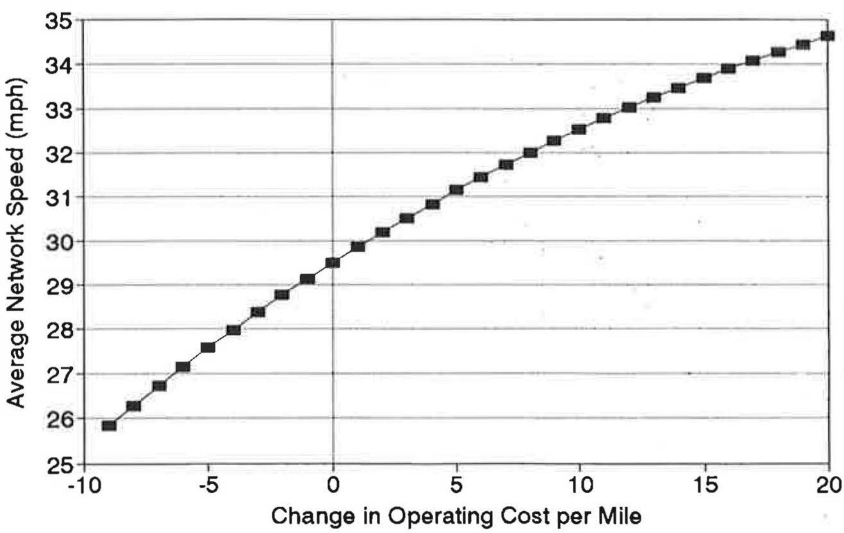

FIGURE 3 Effect of South Coast Air Basin VMT fee on speed.

effort is well beyond the scope of the funding that has been available to date.[24]

UNCERTAINTIES

A central theme in this paper is the difficulty of forming precise, generalizable conclusions about the net effects of pricing.

One major factor is the inherent imprecision of anecdotal evidence.

Another major factor is that no available model—not even the Bay Area's—is complete enough or has been scrutinized adequately by the professional community to support definitive conclusions (especially about effects of pricing on time of day and land use).

Another major factor is that travel behavior has so many degrees of freedom, each of which responds to different locations and individual characteristics, that net responses from pricing and other transportation policies are highly context specific. At a particular location and time, the aggregate price elasticity will depend on

- The income distribution of affected travelers;
- The price base (including parking, tolls, and other out-of-pocket expenses);
- The a priori pattern of delay in the transportation system;
- The network configuration for the affected mode, particularly the presence or absence of competitive routes;
- The availability of competitive alternative modes; and
- The flexibility of travelers to change the timing of their activities (e.g., nonwork trips often are more "discretionary" than work trips).

A final factor, which is major or minor depending on one's point of view, stems from disagreements over the theoretical underpinnings of travel demand analysis. For example, some have argued that more explicit recognition of travel as a phenomenon derived from the demand for activity participation would lead to different conclusions about the role of travel price (which may be small in the face of benefits from activity participation). Alternatively, some researchers have found support for a critique of the simple compensatory mechanism that lies at the heart of conventional travel models. According to this critique, there may be thresholds of response or sequential (e.g., lexicographic) aspects of cognition that lead to highly nonlinear price responses.

Despite all of these caveats, the fact remains that well-crafted travel demand models—such as the Bay Area's—have provided reliable estimates of price effects in realistic settings (such as those for transit price increases). These results suggest that although the phenomena may be complex, a comprehensive, locally crafted conventional model can provide a good approximation of the first-order effects.

It is important to develop a better understanding of the conditions under which a complex model of urban travel such as the Bay Area's can be a useful tool for pricing studies. However, experience with the Bay Area model has been constructive enough to argue for the refinement and extension of that model as a tool for pricing studies and, possibly, to suggest the development of such tools for other parts of the country.

RESEARCH NEEDS

The following research needs are perceived:

1. A thorough review and cautious interpretation of existing evidence on price sensitivity.
2. Accelerated implementation and evaluation of carefully designed congestion pricing experiments (particularly to learn about time-of-day and land use effects).
3. Possibly a program of stated-preference experiments to study the same issues as those in item 2.
4. Peer review and accelerated development of new-generation household travel simulation tools patterned on the Bay Area's STEP program.

NOTES

1. The behavioral process is quite different for work and nonwork trips. In the non-work-trip case, travelers have the option to shift locations of discretionary activities. In the work-trip case, travelers have fixed origins (residences) and destinations (places of employment) in the short run, but can change either or both in the long run.
2. The focus here is on the broad conclusions that are apparent from a careful reading of the literature.
3. The toll was increased from $0.75 to $1.00 (in the westbound direction only). Previous modeling studies indicated an elasticity of about -0.1, so the expected decrease in volume was about 3 percent, close to the average annual increase in Bay Bridge volume over the past two decades. In other words, taking into account long-term trends along with measurement variability and

all the other potential influences, there is little reason to think that a 33 percent increase in toll would have a distinguishable effect on Bay Bridge volume. It does not follow that more significant toll increases, say, to $2.00 or $3.00, would also have unmeasurable effects.

4. Even with a full-scale experiment, modeling is necessary to sort out the overlapping influences of various changes in travel behavior. One builds a model capable of replicating the result of an experiment, then tests the performance through a priori analysis of the next experiment, then refines (or replaces) the model to incorporate what is learned from the actual outcome of the new experiment.
5. Model development was carried out by Cambridge Systematics with support from researchers at the University of California, Berkeley.
6. Note that trip tables are both an input and an output of the modeling exercise. The process begins with a "guess" about what the final trip tables will look like (usually based on factored versions of previously calculated trip tables). This initial set of tables is used to produce initial level-of-service (LOS) estimates, which in turn are used to calculate new trip tables. Then new trip tables are used to produce new LOS estimates, and the demand estimation process is repeated. An iterative procedure is required to achieve consistency between LOS assumptions and estimated demand.
7. For a logit discrete choice model, the log of the denominator is an exact measure of the expected utility from the choice depicted by the model.
8. For example, in standard statistical terms, the influence of nonwork trip accessibility on trip generation and automobile ownership is supported by coefficients with the correct signs and *t*-statistics in the range 12.31 to 15.21 (for sample sizes of about 1,300).
9. These developments might affect the precise form of accessibility in the automobile ownership model, for example.
10. Transit accessibility could be added to the POLIS framework, but the resources to do so have not become available.
11. POLIS is an optimization model showing a significant effect of highway accessibility on location decisions but also reflecting the constraints on development imposed by existing zoning maps. When POLIS is run without releasing zoning constraints, the location effects of accessibility changes are quite muted. If land use constraints were released, the location effects would be much greater.
12. Evidence on time responses in the Bay Area 1981 household sample was studied. For example, a.m. start times were determined for all workers beginning their jobs between 5:00 and 11:00 a.m. The mean and standard deviation of work start time were calculated for ranges of the peak-to-off-peak time ratio (1.0 to 1.09, 1.1 to 1.19, etc.) The mean start time did not vary significantly with the peaking ratio (approximately 7:55 a.m. in all cases). The standard deviation did not vary for values of the peaking ratio up to 1.8. Above 1.8, the standard deviation rose dramatically (from about 0.8 to 1.1 hr). A possible interpretation is that a.m. peak spreading has two components: as congestion builds, workers change trip start times but do not change work start times; when congestion reaches a critical point (apparently related to the presence of

LOS E/F conditions over much of the commute), workers also shift work start times. The same process was assumed to occur with peak cost. The price of the automobile trip was converted to equivalent time using the mode choice model's value of time. True peak spreading was introduced when the combined time/cost measure exhibited a peak ratio greater than 1.8. Similar procedures were developed for p.m. peak work trips.

13. Specifically, nonwork trip generation was decoupled from destination and mode choice, not from lack of statistical significance but from its relative unimportance to investment policy (as an off-peak phenomenon that does not impinge on capacity requirements). Standard cross-classification models were substituted. The automobile ownership linkages to destination and mode choice were not altered.
14. Interzonal LOS tables typically would obtained from large-scale model output and used as the STEP base case.
15. For example, households in the lowest income quintile are addressed in STEP but lost in the higher zonal average incomes of MTCFCAST.
16. The simplified LOS model uses peak and off-peak travel times and base-case demand estimates to "calibrate" a Bureau of Public Roads (BPR)-type supply function for appropriate spatial groupings of trips (e.g., trips in broadly defined corridors). For each change in demand, the calibrated function can be used to compute a new "equilibrium" in the corridor. This technique has been documented by Harvey (1983).
17. It has a secondary value as well. Microsimulation fundamentally is a survey tabulation technique employing sophisticated data transforms. In the Bay Area studies, much use was made of the ready-at-hand survey tabulation capability implicit in STEP. For example, Bay Area surveys contain detailed vehicle data, so that exact use patterns by model year or vehicle type can be determined. Using STEP, these were correlated with personal and household characteristics to yield useful information about low-income dependence on old vehicles.
18. Analyses for the South Coast Air Basin were carried out with the Bay Area models adapted to a Southern California data base. Households, networks, and zonal data all came from the Los Angeles region. Constant terms and other "calibration" coefficients were adjusted so that STEP base-year projections would replicate patterns in the South Coast data. This approach in effect transfers a model structure and key behavioral coefficients from the Bay Area, but applies them to a distribution of independent variables representing the South Coast Air Basin. Such a model transfer is less desirable than using locally-developed models of the same quality, but may be necessary for California studies because the Bay Area is the only place in the state with variation in prices, transit service, and land use sufficient to support the development of a reliable hierarchical model.
19. The work of Stedman (1991) and others has shown that vehicle age is an imperfect predictor of emissions rate.
20. Transit accessibility could be added to the POLIS framework, but the resources to do so have not become available.

21. Existing fees higher than $3.00 were not changed, and no fee was assumed for HOV users.
22. Because aggregate insurance costs would be relatively independent of (or might even rise with) fuel efficiency, the per-mile tax component for insurance would have to stay about the same in order to recover full insurance costs.
23. Previous work with the POLIS model suggests that allocation effects would be limited without some relaxation of land use constraints. Of course, many pricing advocates expect that congestion prices would produce political pressure for such a change.
24. A hybrid approach in which trip tables from MTCFCAST are adjusted according to interim results from STEP has been employed for Transportation Implementation Plan conformity studies in the Bay Area. This method requires further refinement, but holds promise for pricing studies in which fine-grained network characteristics are of critical importance.

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Peak Pricing Strategies in Transportation, Utilities, and Telecommunications

Lessons for Road Pricing

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Prices are signals. In a market economy they are used to contribute to the solution of balancing wants and resource scarcity. They indicate to demanders how much they will have to give up in order to have or consume a (economic) good or service.[1] To the supplier, the price provides a signal of what the producer will receive from the market for supplying the good or service. Although every good in the economy has a cost, not every good has a price. Just because a good is distributed at a zero price to the recipient and is called "free," however, it is not so plentiful as not to be scarce. Distributing scarce goods "free" paradoxically makes their scarcity even greater. All goods in the economy from automobiles to refrigerators to restaurant meals to telephone calls to transportation infrastructure can be regarded as scarce because their production and continued maintenance require the use of scarce resources.

There are essentially two approaches for allocating resources and goods and services. One is to use various nonmarket mechanisms such as administrative rationing, random allocation, or queueing. In these cases some authority must decide how to allocate available goods or services to competing users. However, since there is no efficient method of inducing users to reveal their preferences, the authority has no way of accurately knowing who values a given good or service more and thus may end up providing it to those who do not value it the most. If road use is underpriced, for example, excess demand may send the false signal that there is

too little capacity and thus the authority would invest in even more capacity. This can lead not simply to economic inefficiency but to significant waste.

The other approach for allocating resources is a market approach, which uses the price system to establish a set of user fees to ensure that existing capacity is used in a way that provides the highest value to the community owning the infrastructure.

Prices in a market economy perform two functions. In the short run with available capacity of production fixed, they act as a signal to ensure that scarce goods and services are allocated to those who value them the most. The value is established by willingness to pay. This ensures that social benefit from utilization of the fixed capacity, measured by the aggregate value of the good or service to all consumers and producers of it, is maximized. In the longer term, prices provide a signal to the capital market to move capital into those activities that yield the highest return and thus ensure optimal investment in capacity. In the end, the "efficient market" will provide what people want when they want it and at the least possible cost and in the desired proportions.

These notions seem quite acceptable to the bulk of Americans for the majority of goods and services in the economy. Food, clothing, and shelter, all regarded as the basics of survival, are allocated through pricing mechanisms. There are some goods and services, however, that are regarded as public types of goods—national defense and police and fire protection, for example—and that are provided by the government and paid for indirectly through the tax system. There is an enormous economic literature that provides the economic rationale as to why some goods should or should not be provided by private markets and why some should be priced to reflect their scarcity.

An interesting class of good is one for which demand varies over time and prices change to reflect that demand. Seasonal demand for vacation facilities results in rising and falling prices; hotel rooms in Miami carry a higher price in the winter than in the summer. Seats on aircraft carry a different price depending on the demand by hour, day, and month; for example, seats to Europe are priced lower in the winter than in the summer. A phone call made between Washington, D.C., and San Francisco has a higher price at midday than in the late evening. The differences reflect in part the differences in the demand for telephone facilities during the day. The St. Lawrence Seaway has a "peak load" charge for ships to reflect the higher demand placed on the system and to encourage ships to shift their demand for use of locks to lower-demand periods and thus

reduce the waiting costs of congestion. Perhaps the most interesting, and seemingly least noticed, characteristic of these markets is that "time-of-use" pricing is an accepted practice by both consumers and producers across a number of goods and services.

Roads represent one of the best examples of a good that is subject to demand variability and congestion. Economists have long argued that to give roads away "free" simply exacerbates the problem (Gillen and Oum 1992). However, road pricing is an enigma. There is perhaps no other policy tool on which there has been such broadly based agreement among the academic community, that it solves the problem of congestion on U.S. streets, highways, and urban expressways and on which at the same time there has been unanimous and continuous rejection of its solution to the congestion problem by policy makers, government bureaucrats, and politicians.

A number of reasons may explain this lack of support for pricing transportation infrastructure (Gillen 1992a, 1992b). First, there is the misconception that since pricing will not eliminate congestion, it is not worth introducing. The problem here of course is the failure, particularly on the part of academics and other experts, to convey the fundamental idea that the optimal amount of congestion is not zero. It would be impossible to provide sufficient capacity to eliminate congestion. Rather there is an amount of congestion that is just worth what it costs.

Second, in past decades there has generally been sufficient excess capacity on the roadway system that congestion was not a problem. However, this has led to an attitude among policy makers and the general public that excess capacity is a public good. It is somehow deemed desirable to build roads and runways and air traffic control systems that will satisfy the maximum demand thereby leaving large amounts of excess capacity at other times.

Third, the public argues that it has paid for the roads and should not have to pay for them again. Although there is considerable debate as to who has picked up the bill for the infrastructure in the different modes, this attitude fails to distinguish the allocation of road use from the payment for the capital stock and it clearly indicates that people are myopic regarding their contribution to the congestion problem.

Fourth, proponents of road pricing have presented it as a demand management tool independent of other policy decisions. This has unfortunately led to criticisms by those users who may be priced off a facility, who legitimately ask, "What am I supposed to do?" Pricing is not a stand-

alone strategy and should be introduced in conjunction with other policy tools as a management package.

Fifth, the proponents of road pricing have in the past failed to provide some measure of the benefits arising from the use of this tool rather than some other. They have traditionally tried to sell road pricing on the basis of economic efficiency yet the public had no understanding of the concept. Economic efficiency did not provide a meaningful measure of benefits in the eyes of the public. It is only recently that the sizable welfare gains have been quantified and that the real economic benefits arising from efficient pricing and investment in transportation infrastructure have been made accessible to a broader public audience.

Finally, and perhaps the strongest argument used against road pricing, is the claim that it is inequitable, that it discriminates against the poor. Although this may appear to be the case if one considers only road pricing, it is not true when consideration is given to the expenditure of the revenues collected from the imposition of the congestion price. Indeed, it has been shown that low-income drivers can be better off.

Work undertaken in Britain (Jones 1991) has reported that public acceptability of road pricing rests on the following concerns:

1. Road pricing will not work and people will still drive. This is tantamount to saying that demand for road use is completely inelastic and that there are no substitutes in the eyes of road users.
2. The technology is not reliable.
3. The system is an invasion of privacy because it provides information that can, in effect, trace individuals' vehicle movements at all times.
4. Road pricing inflicts significant harm on the poor.
5. Road pricing schemes cause boundary problems; when is the price a peak price and when is it not?
6. Road pricing is simply another form of taxation. This is a widely held view, one that has gained prominence with the current fiscal problems of government. The fear is that once such a scheme is in force, there will be no stopping the insatiable tax-and-spend government.

The objections to road pricing cited by policy makers, politicians, and the public and the reasons for rejecting road pricing could apply equally well to other "utility-like" goods or services such as telecommunications, transit, and electricity. In telecommunications, for example, pricing does not completely eliminate queueing, there has been excess capacity in the past, the network has been paid for, and there are few substitutes. High

peak prices also discriminate against the poor. But peak-period premiums and off-peak discounts have become common or are being experimented with, and consumers seem to accept this with equanimity. What explains the acceptance of these situations? What analogies and contrasts among and between these situations help explain the acceptance and use of peak-period charges when they are applied, and what does this imply about the potential for use of congestion pricing on the roads in the United States? The answers to these questions are discussed in this paper. In separate sections, telecommunications, airports, transit, and electric utilities are examined for their institutional features, economic characteristics, and pricing strategies. The final section provides an assessment of the analogies and contrasts and a compendium of potential lessons to be learned for introducing peak pricing of roads.

TELECOMMUNICATIONS PRICING

The telecommunications market is perhaps the richest in the development and application of sophisticated pricing of any market. There has been a high and continuous increase in productivity due mostly to the rapid technological change and innovation. The new technology has resulted in lower maintenance costs and an increased ability to offer more products. It also provides a rich chronicle of the basis for peak pricing, the institutional setting that facilitated and promoted this practice, and the mechanisms used to address social and equality issues.

In the past, regulators supported the notion of transferring revenue from long-distance service to local service. The object was to maximize penetration on the basis of the positive externalities of a larger network. When penetration was almost universal and an increasing disparity between long-distance rates and falling costs for trunk service was evident, the revenue transfer lost any justification. Regulators and politicians took the view that it was politically important to develop target subsidies to assist groups who would have been disadvantaged. This resulted in the creation of the social and lifeline tariffs to subsidize access and usage for low-income users and the elderly. The emergence of strong competition in the long-distance markets placed significant pressure on all industry participants to improve efficiency and productivity. The focus was more demand-side driven, with a sensitivity to customer needs and a differentiation of services and rate structures. The rebalancing of the rate structures and the establishing of a fixed entry fee for access to the network accord

with the structure of telecommunications cost. The change was facilitated by the development of the lifeline tariffs and sophisticated pricing structures.

Economic Characteristics

Telecommunications resembles in some respects economic services delivered through networks, like roads. The network, components, and facilities are located in relation to the final consumer, production is capital intensive, the independent network components are frequently common resources for several outputs, and the output cannot be stored in inventory to buffer the difference between the timing of production and time of demand. There are differences. The telephone network has a well-defined capacity, costs are almost independent of the flow of services through the facilities, most materials and energy costs are independent of use, and therefore variable costs are small and different parts of the system capacity contain different levels of technology. The diversity of this system allows the network to exploit scale economies at different volumes of transport. However, telecommunications is not a natural monopoly in the long-distance market, but it does exhibit some scale and scope economies at low levels of output.

Demand in telecommunications has many similarities to road demand. Communication, as with travel, is real time and nonstorable, demand has a regular daily and weekly pattern, and with no storage and variable costs a peak-load situation is created. Off-peak telecommunications services have an almost zero marginal cost. When demand is greater than capacity, output is rationed by queueing or rejecting calls.[2] As with transportation, demand is distributed across a broad number of distinct markets and user classes.

Tariff Developments

Of most interest is the development of telephone tariffs. Telecommunications was characterized in the 1980s by substantial growth, industrial and regulatory restructuring, and the rise in effective competition. In this industrial setting, firms have introduced new pricing structures and have revised others that have been in place for a substantial period of time. There are significant differences between local and long-distance markets. The latter is highly competitive with a number of providers. The standard rate

structure has been in place for many years and there is a price per call and minutes of duration according to distance and time of day. Over time and primarily through technological change, the evolution has been to fewer distance bands and smaller differences between peak and off-peak rates. There has been significant innovation in the rate structure for large users, and rates have been tailored to volume of use.

For basic U.S. rates telephone calls are priced according to broad calling area categories. At the local level, exchange rates under state regulation vary considerably from one state to the next. The reasons for the variance include both cost and demand conditions. At the local level, residential rates are most all flat rates; New York and Chicago have a measured service rate structure. Businesses are generally billed under measured service rates (monthly fee plus a fee for each local call), which is mandatory. Different rates is illustrated in Table 1. There have been two types of rate innovation in the local exchange. First, social tariffs or lifeline rates were established to offer lower priced access to the network and lower-priced local calling to a select group of customers. A variety of lifeline

TABLE 1 Average Monthly Local Telephone Rates from 95 Cities, October 1990 (Mitchell and Vogelsang 1991)

		Business, per line	
	Residential	One Line	Three Lines
Flat Rate (unlimited calls)	$12.40	$33.20	$45.80
Subscriber line charge	$3.55	$3.69	$5.72
Touchtone	$1.31	$2.18	$2.27
Taxes	$1.83	$4.94	$6.92
Total	$19.09	$44.01	$60.71
range w/o Touchtone	$8.14 - $27.11		
Measured service	$8.46	$16.22	$20.96
usage	(includes 50 calls)	$16.09 (for 200 calls)	$15.99 (for 200 calls)
Subscriber line charges	$3.55	$3.55	$4.91
Touchtone	$1.31	$2.43	$2.69
Taxes	$1.48	$4.46	$5.05
Total	$14.80	$42.75	$49.60
Marginal price, 5 min. call	$0.090	$0.093	$0.093
Lowest monthly rate	$5.66		
subscriber line charges	$3.55		
Taxes	$1.14		
Total	$10.35		

approaches exist across the different states. Second, many local exchanges are introducing some form of per-call or per-minute price for most local calls for business as a substitute for the standard fixed charge.

Long-distance service can be intrastate or interstate, and rates are regulated through price-cap regulation. In the past, rate-of-return regulation was used. Entry may or may not be restricted at the intrastate level and is not at the interstate level. Intrastate rates are differentiated by distance, time of day, weekend period, and first minute or additional minutes of duration. Levels of intrastate rates vary widely in the United States.

Elasticity Estimates

The decision by regulators to transfer revenue from long-distance to trunk service was based on the explicit objective of wanting to maximize penetration and implicitly on assumptions regarding the value of demand sensitivity. In particular, demand must be sufficiently inelastic in the long-distance market to generate the revenues to transfer to local exchange markets. There are also a number of other elasticities to consider—access and usage elasticity segmented by the service options available. Griffin (1982) estimates the long-run income elasticity of demand for long-distance service as 1.32 and a price elasticity of -0.60.

Park et al. (1983) derived estimates for price elasticities (Table 2) for local calls on the basis of experimental data. The total decrease in single-party use is the full reduction in single-party calls caused by a price change. Substitution is that part of the total decrease offset by an increase in multiple-party use and repression is the difference between the total reduction in single-party use and the increase in multiple-party use. The elasticities are quite small in all cases. Local usage does not fall significantly with an increase in either a charge per call or a charge per minute.

TABLE 2 Estimated Price Elasticities for Local Telephone Calls, Experimental Prices, December 1979 (Park et al. 1983)

	Repression Elasticity		Substitution Elasticity	
Charge	calls	minutes	calls	minutes
per call charge	-0.076	-0.086	-0.002	-0.005
per minute charge	-0.055	-0.109	-0.014	-0.034

Furthermore, the substitution elasticity is also quite small, which means that multiple-party calls are not a close substitute for single-party calls. Thus far the elasticity evidence is consistent.

Taylor and Kridel (1990) estimate access elasticities from a sample of 80,000 households from the 1980 public use sample. The elasticities must be calculated from the estimates and some assumed pricing scenarios. The first important result is that the elasticity of access with respect to the number of lines (a measure of the network externality) is small, 0.027. This value provides, as Taylor and Kridel note, no support for the large access subsidies that have characterized telecommunications pricing in the past and to some extent currently. The impact of higher access charges on consumers is evaluated on the basis of alternative scenarios and assumed socioeconomic characteristics. The conclusion is that the access repression elasticity is small but not zero. This result is consistent with the previous cited evidence and offers little support for the contention that local rates must be subsidized since in the absence of a subsidy universal access would be threatened. Taylor and Kridel's estimated impacts of higher access charges on different socioeconomic groups illustrates that some groups fare worse than others. But this would be precisely the target group for the lifeline rates.

Train et al. (1987) use a nested logit model to develop elasticities of demand for local service option, number of calls, average duration, and revenues with respect to the fixed monthly charge and usage charges for calling under each option. A significant conclusion is that there are moderate price elasticities of number of calls with respect to usage charges for households subscribing to measured service. Raising usage charges has a negligible impact on revenues since a large number of households are on or convert to flat-rate service in response to higher usage charges. There is a high degree of substitution among service options. The empirical results of the research by Train et al. (1987) are reported in Tables 3 through 5. Tables 3 and 4 describe the characteristics of the service options available, and Table 5 contains the values for the elasticities calculated for each of the option combinations.

The general results by Train et al. (1987) show that own-price elasticities for the monthly fixed charges of each service group are fairly high, indicating a high degree of substitutability among services. Increasing the fixed charges for measured service shifts customers to flat-rate service, under which they make more calls since the marginal price is lower. Conversely, increasing the fixed charge of flat-rate service reduces the

TABLE 3 Telephone Service Options (Train et al. 1987)

Service	Availability	Charges for calls to Nearest Zone	Charges for Calls to Other Zones
Budget Measured	Available to all customers	each call charged 7¢	Each call charged at rate that varies with time, distance and duration of call
Standard Measured	Available to all customers	$4.00 worth of calling at no additional charge, each added call is charged as under budget measures service	
Local Flat rate	Available to all customers	No extra charge	Each call charged at rate that varies with time, distance and duration of call
Extended Local Flat-rate	Available to customers in only some exchanges	No extra charge	No extra charge for calls to some exchanges, charged as under local flat-rate service for calls to other exchanges
Metropolitan Area Flat-rate	Available to non-rural customers	No extra charge	No extra charge

amount of calling as customers shift to measured service, under which additional calls are relatively expensive.

Increasing the cost for marginal calls shifts customers from measured to flat-rate service. The elasticities are fairly low, however. The own-price elasticity of Zone 1 calls for customers with budget measured service is −0.41 (Table 5). For customers with standard measured service the elasticity is −0.26.

The work by Train et al. (1987) provides a comprehensive set of elasticity estimates of how consumers respond to price changes for service options and calls. Households facing a price increase in their current plan can substitute either other calling patterns or other service plans. For those on flat-rate service the greater tendency is to substitute other calling patterns than service options. Households faced with positive prices for calls respond to a price increase by a moderate reduction in the number of calls (elasticity around one-half), and there is some shifting to other calling plans that allows calling at no added charge. The elasticity of the number of calls with respect to calling charges is quite small. The cross-elasticity between option plans is relatively high. As prices for one service plan

TABLE 4 Telephone Time-Zone Categories (Train et al. 1987)

Zones		Times	
Number	Description	Time of Week for which Different Rates are Charged for Calls to that Zone	Rates During that Time
1	Zone immediately surrounding household residence	9 A.M. - 9 P.M. Monday - Sunday	Full tariffs
		7 A.M. - 9 P.M. and 9 P.M.-Midnight, Monday-Sunday	50% off
		Midnight - 7 A.M. Monday - Friday	86% off
2-6	Geographic bands successively more distant from household residence	9 A.M. - 9 P.M. Monday - Friday	Full tariffs
		All other times	50% off
7	Specific exchange outside of zones 1-6, applicable only to households in certain exchanges within a metropolitan area	9 A.M. - 9 P.M. Monday - Friday	12% off, on average
		7 A.M. - 9 A.M., 9 P.M.-Midnight, Monday - Sunday	48% off, on average
		Midnight - 7 A.M. Monday-Sunday	60% off, on average
		9 A.M. - 9 P.M. Saturday-Sunday	56% off, on average
8	Remainder of metropolitan area in which household resides, applicable only to households in certain exchanges within a metropolitan area	9 A.M. - 9 P.M. Monday - Friday	12% off, on average
		7 A.M. - 9 A.M., 9 P.M.-Midnight, Monday - Sunday	48% off, on average
		Midnight - 7 A.M. Monday-Sunday	60% off, on average
		9 A.M. - 9 P.M. Saturday-Sunday	56% off, on average

increase relative to others, customers make substitutions and at an increasing rate.

Wenders (1987) reports values for price and income elasticities of demand for access and use. He estimates that the residential access demand elasticity is approximately -0.39. If customers have a measured service option, this elasticity falls by two-thirds. Wenders finds that access elasticity varies across households by income level and head of household and that the access demand with respect to fixed fee ranges from -0.2 to -0.3, depending on these two parameters. The income elasticity is approximately 0.5, implying that telephone access is a necessity.

Wenders's estimates for usage elasticities were price elasticities of -0.27 in the short run to -0.38 in the long run and income elasticities of usage of approximately 1.0. These compare with results that Wenders reports from Taylor (1980), which are as follows:

TABLE 5 Estimated Price Elasticities for Service Options and Calls (Train et al. 1987)

No. of Households Choosing	Monthly Fixed Charge for Service (initial shares in parentheses): Budget Measured [.05]	Standard Measured [.15]	Local Flat Rate [.74]	Extended Local Flat rate [.01]	Metro Area Flat rate [.05]	Charge for Calls to Zone 1	Charge for 1st Min. calls to Zone 2-8	Charge for Addl. Mins. for calls to Zones 2-8
Budget Measured	-1.06	0.16	1.52	0.02	0.11	-0.41	-0.04	-0.04
Standard Measured	0.05	-1.38	1.36	0.01	0.14	-0.26	-0.04	-0.03
Local Flat	0.07	0.25	-0.46	0.01	0.11	0.08	0.00	-0.01
Extended Local Flat	0.11	0.11	0.45	-0.91	0.34	0.08	0.06	0.06
Metro Flat	0.04	0.22	1.07	0.04	-2.19	0.07	0.21	0.21
No. of calls	0.14	0.14	-0.29	0.00	-0.06	-0.02	0.00	0.00
Average Duration	0.00	0.00	0.00	0.00	0.00	0.00	0.01	-0.01
Total Revenues	0.04	0.18	0.56	0.01	0.02	0.05	0.07	0.06

Item	Elasticity Range	Mean
Usage with respect to price		
Short run	−0.03 to −0.44	−0.21
Long run	−0.22 to −1.04	−0.67
Usage with respect to income		
Short run	+0.05 to +1.08	+0.39
Long run	+0.28 to +2.72	+1.33

The most recent elasticity estimates are by Chen and Watters (1992). They estimate a model of the demand for long-distance usage and provide own-price and cross-price elasticities for time-of-day usage based on data from Southwest Bell. Their model can be used to predict customer telephone usage shifts between rate periods as a result of tariff changes. Their estimated time-of-day usage elasticities were as follows:

	Elasticity		
Time-of-Day Period	d	c	n
Day (d)	−0.56	0.35	0.21
Evening (c)	0.37	−0.46	0.09
Night/weekend (n)	0.31	0.40	−0.45

As is evident, all elasticity values are less than 1 and all rate periods are substitutes. Daytime usage has the largest price elasticity as well as the largest cross-elasticity. However, within two discounted periods there is a relatively small cross-elasticity, suggesting less substitution. The larger own-price elasticities for discounted periods relative to cross-price elasticities mean that customers adjust their overall level of usage in response to a price change rather than shift between the discounted services.

From the results of Chen and Watters (1992), it appears that customers are more sensitive to daytime price changes and will transfer usage to a discount period when daytime prices change. The relative price changes between discount periods cause overall usage to change, but there is relatively little shifting between discount periods. These results are important for two reasons. First, they provide some evidence that it is important to get the peak, off-peak rate structure correct and have relatively fewer discount periods because people switch between peak and off-peak periods and less within the off-peak period. Second, aggregate elasticities can be misleading because they fail to distinguish time periods. Significant shifts can occur between rate periods. Therefore, knowing the time-of-day elasticities is vital in designing and implementing a pricing strategy.

Assessment

The presence of regulators and the ability of users, customers, and interest groups to intervene are important characteristics of this industry. The rates charged reflect an economic efficiency, profit maximizing, or a corporatist orientation. Regulators have some sense of economic efficiency. There is a distancing from government and politicians, and therefore rates are not viewed in the same way as road taxes or licensing, that is, as a tax. Furthermore, the move from rate-of-return regulation to price-cap regulation suggests a sensitivity to efficient markets.

In telecommunications, there also seems to have been a linkage of pricing theory and practice, much more so than in any other industry or market. This linkage can be attributed to many factors, including significant research on linear and nonlinear price schedules, greater experience with more complex pricing schemes than consumers find in other markets, relatively rapid technological change that allowed prices to fall and make most consumers better off, and changing industry structure. A substantial force in changing rate structures and focusing on efficient pricing has been the social tariffs and lifeline rates, which are particularly important features of telecommunications pricing and provide an important lesson for road pricing.

In looking at the evolution of efficient prices and normative considerations in pricing, innovations tended to be Pareto-improving rather than merely *potentially* Pareto-improving. This is an important point, because it means that if it is not possible to demonstrate welfare gains from a shift to a new pricing structure, the old prices will continue. More than simply demonstrating that new tariffs will have broad economywide impacts, narrow and specific interest groups must be considered, because they affect the implementation of new pricing structures.

During the last decade there have been numerous pricing innovations and these have generally brought lower prices and a larger set of service choices. However, these innovations have not come at a zero cost. In particular, there are now higher transactions costs to consumers for ordering these integrated services. The rebalancing between local and long-distance markets can be attributed to several factors: the differential rates of technological change, the divided authority between federal and state governments, the breakup of American Telephone and Telegraph (AT&T), and particularly the growing procompetitive policy of regulators and policy makers.

The lessons from telecommunications can be found in a number of places. First, the benchmark for tariffs is marginal costs. The telecommunications industry recognized the simplicity of marginal-cost-based prices and their ability to mask conceptual difficulties, measurement problems, and potential line efficiencies. However, that was the starting point, and thus the position is one of efficient pricing. Marginal-cost-based pricing evolved in telecommunications into Ramsey pricing, a robust concept, which is able to adapt to situations of interdependent demands, competitive circumstances, and both positive and negative externalities. The next evolution was to nonlinear, nonuniform pricing. These nonlinear prices can improve on Ramsey prices yet allow the firm to satisfy revenue constraints. The disadvantage lies in the informational requirements. This last evolution has meant moving from a traditional "fully distributed" costing approach to pricing to more modern concepts of more cost-based prices, which are sustainable and subsidy free. A driving issue has been the comparability of prices and costs justified by issues of fairness and competition. The fully distributed cost-pricing approach is fragile in situations of competitive entry, has limited fairness properties, and is completely unrelated to efficiency. These were all important issues in telecommunications tariff setting.

Another interesting feature introduced into telecommunications pricing that may have some value in road pricing is "customer class" pricing, which classifies customers on institutional grounds. A customer class can be based on size of consumption, demand sensitivity, time pattern of consumption, or geographic pattern of consumption. Using customer classes reduces the burden of certifying eligibility by replacing it with self-selection. The correlation between income and demand for specific services is used as a means of price discrimination. Institutional affiliation also makes customer separation easier to achieve and eliminates the problem that pricing based on "means testing" can trigger behavioral changes at thresholds.

Summary

Although there appears to be much to be learned for road pricing from the telecommunications market, there are caveats. Local exchanges were regulated by public utility commissions at the state level even before the breakup of AT&T. Local exchange rates do not vary systematically at the local level. There have been technological change and increases in capacity,

but calls are queued rather than being rationed by price as in the long-distance market.

The last two decades have witnessed significant progress in the research, design, and implementation of public utility tariffs. This has also been true in the road pricing literature, but the result has been exactly the opposite to what has happened in telecommunications. The fatal flaw may have been the failure of road pricing proponents to develop a treatment for the normative issues as the telecommunications industry has.

The normative framework was established for telecommunications tariffs and objectives of tariff setting. The major objective was to consider fairness, the three characteristics of which were the economic right to telecommunications and the dimensions of this right defined in terms of service and source of financing,[3] the maintenance of utility levels, and the establishment of user charges based on some cost concepts.[4]

Social concerns were introduced into telecommunications pricing through the lifeline programs, which had two goals—to encourage universal access and to alleviate financial hardship. The first goal relates to network externalities and to telephone access as an economic right and the second goal relates to customer class pricing and discriminating two-part tariffs. The lifeline program was established as a federal program in 1985 and Link-up-America in 1987. Both are subsidy programs, targeted at different populations and seeking to accomplish different goals. The access subsidies are targeted at marginal consumers in order to increase subscribership,[5] whereas the usage (hardship) subsidy is aimed at low-income groups. The two goals mean that the relative importance of each will affect the design of an effective lifeline program. This is a particularly important point that must not be lost on proponents of road pricing schemes. There are costs to these social tariffs. These include the direct administrative costs of implementation and management and secondarily the allocative inefficiency arising from how the program is funded.

AIRPORT RUNWAY PRICING

Efficient airport runway pricing in the presence of congestion has almost as rich a literature as road pricing. The end result is the same, however. Runway pricing has not been adopted in the United States although it has been in Europe, specifically by the British Airports Authority, which has implemented peak-period pricing at all of its seven airports. At major

airports such as London's Heathrow, the peak-period landing and terminal fees are about five or six times higher than the off-peak fees.

There are several reasons for not having peak, off-peak pricing at U.S. airports. First, it is claimed to be currently against the law that states that revenues must equal expenditures and that airports cannot discriminate in pricing. However, price differences do exist at the three major New York airports. The law must therefore mean that aggregate revenues and expenditures must balance and not those for particular user classes. Second, there is a belief among airport officials that the elasticity of demand for airport use is zero or very nearly so. This may be true for large commercial aircraft, but it is highly unlikely for commuter or general aviation (GA) aircraft. The conclusion of these same officials is that peak pricing would do nothing to solve the problem. Third, the Air Transport Association (ATA), which represents airline interests, is against peak, off-peak differentials because they see it as the beginning of gouging the airlines. Their position is not nearly as strident as that of the Aircraft Owners and Pilots Association (AOPA), which has campaigned against any such pricing policy and has taken the position that GA aircraft are overcharged now. Fourth, the method of financing airports in the United States can, in some cases, give the airlines power over runway and terminal fees. With a residual-cost approach (57 percent of U.S airports), airlines collectively assume financial risk by agreeing to pay any costs of running the airport that are not allocated to other users or covered by nonairline sources of revenue. With this financial responsibility come majority-in-interest (MII) clauses, which allow airlines to affect airport costs and investment, prevent any change in the basis of runway or terminal pricing, transfer property rights, and create barriers to entry. In many cases the airlines have long-term agreements with the airports, which clearly inhibit any shift in the basis of establishing landing and terminal fees.

There have been two attempts at introducing congestion fees at U.S. airports, the outcomes of which have been radically different. In 1968 the Port Authority of New York (PANY) imposed surcharges for peak-hour use by small aircraft of Newark, Kennedy, and LaGuardia airports. The takeoff or landing fee for aircraft with fewer than 25 seats was raised from $5 to $25. The peak hours were defined as 8:00 to 10:00 a.m. Monday through Friday and 3:00 to 8:00 p.m. all days of the week. Larger aircraft did not have to pay the added fee and their landing fee continued to be weight based.

The PANY surcharges provide two important lessons. First, they demonstrate that peak, off-peak pricing differentials are administratively feas-

ible. Second, they brought about significant efficiency improvements. With the landing fees, GA activity fell by 19 percent overall and by 30 percent in the peak hours. The percent of aircraft operations delayed more than 30 min fell significantly (Congressional Budget Office 1992).

An attempt by the Massachusetts Port Authority (Massport) to introduce peak pricing had a very different conclusion (Massachusetts Port Authority 1987). In 1988, Massport proposed a new formula for establishing landing fees, moving away from a fee system based solely on landing weight to a two-part system. The new fee formula had a base charge of $88 plus a variable charge of $0.47/1,000 lb (453 kg), whereas the previous fee system simply had a $1.31/1,000-lb base with a minimum of $25. Several organizations, states, AOPA, and the U.S. Department of Transportation filed suit against Massport claiming the new formula discriminated against small aircraft. The court found the fee to be discriminatory and contrary to federal statute.

Massport, in early spring 1993, proposed a new peak-hour pricing plan. The structure of the plan would be to charge jet aircraft $50 per operation plus a $0.60/1,000-lb weight charge for each landing during off-peak hours. Aircraft that were not jets would pay less. During peak periods, all aircraft would pay the off-peak rate when they landed as well as an additional peak-hour capacity charge of approximately $100 to $120. Massport claimed that the pricing plan would reduce peak-hour demand by approximately 10 percent, which would reduce delay time due to congestion. The benefit claimed is that a 5 percent reduction in airfield use would lead to a 20 percent reduction in average expected flight delays.

The fees charged by BAA are shown in Table 6. The peak, off-peak differential has been in force for several years. American carriers have tried unsuccessfully to have the fee system scrapped. The impact of the fee system has been to spread the shoulders of the peak at Heathrow and to divert smaller aircraft, charters, and some domestic traffic to airports other than Heathrow. There has been somewhat limited success in spreading the peak for two reasons. First, Heathrow serves predominately international flights, many of which originate in eastern or western time zones, so there are limited opportunities for substitution of other flight times. Second, Heathrow cannot expand runway capacity, so the peak charge acts as a rationing mechanism between high-value and relatively lower-valued flights.

Unlike telecommunications or electric utility demand analysis, there have been no attempts to estimate the demand for airport use, and there-

TABLE 6 Landing Fees at BAA's London Area Airports (*Air Transport World* 1991)

Airport	Peak	Off Peak	Weighted Average
Heathrow			
B 757	1680	658	844
Shorts 360	654	153	318
B 747	6259	1747	3336
Gatwick			
B 757	1122	450	634
Shorts 360	444	111	211
B 747	4866	1867	2709
Stansted			
B 757	734	365	507
Shorts 360	123	71	88
B 747	3807	1806	2810

Note: All figures are in 1991 U.K. pounds. The Boeing 757 seats 140 passengers and is a Stage III aircraft and thus has a lower noise charge. The Shorts 360 seats 22 passengers. The Boeing 747 seats 270 passengers and is a Stage II aircraft, which carries a higher noise charge (*Air Transport World* 1991).

fore direct elasticity estimates are not available. The impact of peak-period pricing on period and airport substitution is assessed from partial and anecdotal information such as PANY and BAA experience. One attempt at indirectly establishing elasticity estimates of the demand for runway use with respect to landing fees found, as expected, that the elasticity was quite low (Gillen et al. 1989). The elasticity estimates were developed from airline cost functions in which airport fees were included as an input cost. It was possible to derive input demand functions, but it was not possible to determine the shift from peak to off-peak.

Using the derived elasticities, Gillen et al. (1990) developed efficient prices for runway use for Pearson International Airport, Toronto, Canada. The fees were to reflect both congestion and noise externalities. Furthermore, they were designed to be revenue neutral so the airport did not collect any additional revenue from the introduction of efficient pricing. The results are shown in Table 7. They reflect what is evident in the BAA pricing policy, namely, that large aircraft are currently being overcharged and smaller aircraft undercharged. Also the relatively high elasticity for GA aircraft, -0.58, will yield a result similar to that found in New York.

The airport pricing literature makes it quite clear: the failure to introduce landing fees that more closely reflect the real costs of usage and externalities of the facilities has generated significant economic waste. This waste is measured in real resource costs to carriers who use crew time, fuel,

TABLE 7 Comparisons Between Social Marginal Costs and Current Landing Fees for Select Aircraft at Pearson International Airport, Toronto, Canada (Gillen et al. 1989)

	B747-200	DC10-40	B737-200	Dash 8	Business Jet	Piston
Current Fees						
Domestic	$521	$355	$80	$12	N/A	$ 0
Int'l	$769	$524	$85	$15	N/A	$ 0
Social Marginal Cost						
High Month:						
high-peak	$426	$376	$269	$213	$211	$161
low -peak	$246	$196	$154	$ 98	$105	$ 55
Low Month:						
high-peak	$271	$221	$170	$114	$120	$ 70
low -peak	$226	$176	$142	$ 86	$ 93	$ 43
Off-Peak	$206	$156	$129	$ 73	$ 81	$ 31
Price Elasticity	N/A	-0.068	-0.075	-0.086	N/A	-0.58

and capital in congested facilities. It is also measured in wasted time to travelers. These delay costs can amount to billions of dollars. Winston (1991) provides an estimate of $11 billion (1988 U.S.) in annual welfare gains associated with efficient pricing and runway investment in the U.S. airports:

	Annual Economic Effects, $ U.S. billions (1988)	
Item	*Efficient Pricing and Runway Investment*	*Efficient Pricing with Current Runway Investment*
Consumer surplus change from landing and takeoff fees	1.10	12.53
Reduced delay to travelers	7.91	3.62
Carriers' operating cost savings	2.77	1.23
Airport revenues less costs	0.77	11.5
Total welfare change	11.01	3.82

Summary

A number of lessons emerge from the narrow evidence of congestion pricing at airports in Britain, New York, Canada, and elsewhere. First, the

experience of both PANY and BAA have illustrated that such pricing is administratively feasible. Second, there are clear efficiency gains. Although the evidence from New York is piecemeal, Winston's estimates show a clear net welfare gain. There are other lessons, however. Congestion fees must be set to reflect market conditions at the airport. Not all airports, indeed relatively few, in the United States have significant congestion problems and need to adopt congestion pricing. If runway pricing is to be broadly introduced into the system, it is clear that the law governing balancing revenues and expenses will have to be changed. Similarly, the interpretation of the courts as to what is discriminatory, as the Massport fee formula was, will require legislative changes.

The lessons for road pricing are few but important. First, peak-period pricing has been introduced in those cases in which there is a concern for efficient use of resources and the recognition that there are real gains to be made. Second, BAA moved to efficient pricing at the time it was moving through corporatism and to privatization. Like telecommunications the BAA is currently regulated via price-cap regulation. This change in institutional structure was important. Third, the new pricing approach was accompanied by service improvements and there was a redistribution of the cost burden to more closely reflect cost causality, as also with telecommunications.[6]

TRANSIT PRICING

Since 1970 more than 30 transit systems in the United States have introduced time-of-day pricing in which adult fares vary by time on weekdays. Twelve of these systems discontinued such pricing for different reasons. Time-of-day pricing has been applied to a number of different transit technologies, including bus, rapid rail, and dial-a-van, and in cities ranging in population from fewer than 25,000 to over 4 million (Cevero 1984, 1990).

To evaluate the behavioral response to transit pricing it is necessary to examine the objectives and the rationale behind specific fare programs. Transit agencies pursue a number of different objectives and in different combinations. These include cost recovery, revenue generation, improved service quality for users, promotion of equity objectives, and encouragement of mode shifts.

The time-of-day pricing options were introduced for a number of reasons in the different systems. The major rationale was that average and

marginal costs are different between peak and off-peak periods because of increased staffing requirements, labor rules, and increased overhead (Cevero 1986). A second justification was the desire to increase farebox revenue from the inelastic peak demand. In some cases the argument was made that there was a desire to shift discretionary trips from the peak to the off-peak period when there was some excess capacity. There was an opportunity to increase off-peak ridership since it was relatively elastic.[7]

The motivation for introducing time-of-day pricing determined the form in which it was introduced. The systems using peak, off-peak fare differentials in the United States were about evenly split among off-peak discounts (motivation to shift discretionary trips to the off-peak period and increase off-peak utilization), peak-period surcharges (motivation to increase farebox revenues to cover a greater proportion of costs), and programs involving differential rates of fare increases between peak and off-peak periods.

Transit Demand Sensitivity

Transit riders have been found to be generally insensitive to fare levels, structure of fares, or form of payment. Studies have found that the elasticity of demand with respect to time is twice that of fare. This provided compelling arguments for operating higher-quality express systems or routes at a higher fare. Such systems can be and have been supplemented with vouchers to handle the adverse impact on the poor.

Research has shown that the common practice of charging flat fares is inequitable and penalizes short-distance and off-peak users. Free-fare programs, however, have proved to be quite expensive, ineffective, and attractive only to marginal riders. Free-fare programs that were geographically contained, as in downtown areas, have met with more success. Pass-fare programs, fare reduction and fare-differential programs, and midday discounts with the introduction of new transit programs and services have also met with some success.

As a general rule, the own transit fare elasticity is said to lie between -0.22 and -0.33 (Cevero 1990). Research has shown, however, that the elasticity varies significantly in different contexts. The sensitivity of a fare increase is larger than that of a corresponding fare decrease. The elasticity rises with the fare level and varies with the length of time between fare increases. An increase in fare will elicit a large short-run response, but this dissipates over time. The fare elasticity is also defined by the class of user.

For example, the own transit fare elasticity is −0.32 for those less than 16 years old, −0.22 for those between 17 and 64, and −0.14 for those older than 64. The fare elasticity also increases with income, with a value of −0.19 for those earning less than $5,000 annually to −0.28 if income exceeds $15,000. Automobile ownership results in a fare elasticity of −0.41, whereas those who have no car exhibit a fare elasticity of −0.10. Work trips have fare elasticities of between −0.1 and −0.19 and shopping trips, −0.32 and −0.49. Off-peak fare elasticities have been estimated to lie in the range of −0.11 to −0.84, and peak fare elasticities lie in the range of −0.04 to −0.32. Short trips of less than 1 mi (1.6 km) exhibit a high fare elasticity, around −0.55, whereas longer trips, 3 mi (4.8 km) or more, have been estimated to have an elasticity of −0.29. The fare elasticity also varies with the density of the population.

Service elasticities tend to be much higher. Average headway and speed elasticities are found to be twice as large as fare elasticities, and elasticity of transit use with respect to travel time has been estimated to be in the range of −0.59 to 1.16. Schedule reliability elasticities have been found to be high; transit patrons, particularly for the work trip, plan their arrival at pickup points to minimize waiting (or down) time.

Research has also shown that user-side subsidies such as vouchers or discount passes are more suitable than subsidies to transit firms because the former help those whom they are designed to help—the poor—and because average costs of delivery decrease and productivity rises as transit competes with other modes such as taxi. An important research finding has been that higher-price, higher-quality service supplemented with discount passes and vouchers is preferred to low-price, low-quality service.

Research has found that transit ridership is more sensitive to a change in the automobile price than is the automobile to a change in transit fare; the cross-elasticity of transit use with respect to a change in automobile costs is greater than the cross-elasticity of automobile use with respect to a change in transit fare. The empirical evidence is that the elasticity of transit with respect to automobile tolls is between +0.32 and +0.41 and with respect to a change in the gasoline price is between +0.08 and +0.80. Service cross-elasticities are larger than price cross-elasticities. The elasticity of bus use with respect to automobile travel time is +0.36 to +0.42, and the elasticity of automobile use with respect to a change in in-vehicle bus or transit time is +0.02 to +0.14. The conclusion from all of the own and cross-price elasticity measurements is that automobile disincentives are

more effective than transit incentives in shifting people from automobile to transit.

Transit Fare Structures

The combination of the objectives of the transit agency and the elasticity characteristics of the market determines the fare structure to a large extent. The most common system is the flat fare, which is used, transit officials claim, because it is the simplest to implement and the easiest for users to understand. Some transit agencies that had differential pricing switched back to the simpler fare system because of problems with implementation, particularly defining time and distance boundaries; Portland, Oregon, and Allentown, Pennsylvania, are good examples. Most analysts conclude that flat fares are inequitable, result in cross-subsidy to peak users, and discourage short-distance, off-peak travel.

Time-of-day prices vary in form from peak-hour surcharges to off-peak discounts. Evidence that ridership is more sensitive to off-peak discounts than it is to peak-hour surcharges is shown below:

Type of Fare Charge	*No. of Transit Systems*	*Mean Estimated Fare Elasticity (SD)*
Off-peak discount	6	−0.667 (0.25)
Differential increase	5	−0.295 (0.12)
Peak surcharges	6	−0.268 (0.20)

In those cities that introduced discounts, ridership increased by an average of 10 percent in the first year of the program. By contrast those cities that introduced a peak-hour surcharge experienced an 8 percent reduction in ridership, on average, in the first year. Clearly, discounts result in less revenue but increased ridership, whereas peak surcharges have precisely the opposite effect.

Several studies have examined the time-of-day transit pricing impacts (Oram 1988). Generally, there has only been a modest ridership shift from peak to off-peak period. This results from making the peak-period boundary too wide, which reduces the time substitution opportunities or increases the transaction cost of substitutes. Also, riders had fewer substitution alternatives such as flex time. Midday discounts were found to induce latent trips rather than to induce riders to switch from peak to off-peak periods. Revenues were found to increase with the use of peak-period surcharges, whereas they fell with the use of midday discounts.

Implementation Issues and Attitudes

The success of time-of-day pricing programs depended on a number of factors. First, disputes as to when certain fares were in force and others were not was an important issue. The use of run based rather than time based fare collection was considered effective in eliminating fare disputes, a major issue in time-of-day pricing schemes. Second, the pricing program required marketing and promotion for awareness and understanding. Submarkets have to be carefully analyzed so product prices can be set at a level that will sustain the service.

Transit officials' attitudes ranged from benign indifference to skepticism. Skeptics were soon won over with smooth operations and success at achieving transit agency objectives. Interestingly, transit boards members perceived the time-varying prices as more businesslike and were quite willing to accept them. This attitude was echoed by riders in a number of locations. Two factors can explain this: first, marketing and promotion were aggressive and service quality was improved; second, the peak, off-peak differential was relatively small. This promoted the perception that the higher peak charge was cost reflective rather than an attempt by the transit agency to gouge peak-hour riders.

Assessment

There are a number of lessons for road pricing from the application of peak pricing in public transit systems, but they must be placed in the context of the motivation for introducing peak pricing. Unlike road pricing, time-of-day pricing in transit was introduced to raise farebox revenue or to increase ridership in the off-peak period, the latter resulting from some discretionary trips in the peak and increased use of excess capacity in the off-peak. To these ends the transit pricing has been successful. There are some but not large efficiency gains to be had, but this was not a prime motivation to begin with.[8] The introduction of peak, off-peak fee differentials was found to have improved financial and operating performance. It was also found to have had no impact on the size of the labor force or vehicle requirements. There were therefore only minor efficiency improvements in a few instances. Cost savings would generally not be of much significance since most shifting would occur at the shoulders of the peak, not at the heart. The lack of efficiency gains should not be transferred to the context of roads.

It has been shown that it is quite possible to have time-of-day pricing in a network and to have it accepted by consumers. To the riding public a wide spectrum of services and price combinations is preferred to more limited choices. This approach has worked well in both the airline and telecommunications industries. To the extent that fares can be set to reflect service quality and costs, urban transport is better off. A similar position may apply to road pricing; users need choices, not only to provide substitutes, but to better be able to match their wants and needs to price and quality combinations in the same spirit that nonlinear tariffs perform this function in telecommunications.

The design of a time-of-day pricing program provides lessons in a number of dimensions. The width of the peak time band can affect the success of the program. A wide band discourages peak, off-peak shifts, whereas a narrow band may result in a secondary peak, revenue losses, and a greater probability of fare disputes. The peak, off-peak fare differential must be carefully calculated to avoid having peak riders switch modes rather than travel time. The objective of the transit firm will be reflected in the form of the price variation. If increased revenues are desired, a peak surcharge would be introduced, whereas increased ridership would call for midday discounts. In neither case would there be significant intertemporal shifts. Peak fares will tend to discourage trip making and will shift non-work trips out of the peak hours.

ELECTRIC UTILITY PRICING

Unlike many parts of Europe, the United States uses a flat or block rate price structure rather than a time-of-use (TOU) structure for electric, gas, and water utilities. It is therefore generally not possible to say a great deal regarding demand response to changing prices. However, over a period of 6 years the U.S. Department of Energy has engaged in a cooperative program of residential TOU rate experiments involving time-of-day or seasonal variation of prices. The experiments were in response to the Public Utility Regulatory Policy Act of 1978, which stated that rates should not be applied if they were not cost-effective. Much effort was therefore expended on determining whether the benefits of placing consumers on TOU pricing outweighed the transactions cost of implementation. As of 1985, 15 experiments were completed or ongoing. The main goal of these experiments was to see if TOU rates would yield sufficient alterations in the residential customer load curve to justify implementing

such rates. The justification involved determining three specific effects: the revenue impact on the utility, the current capacity reduction implied, and the change in consumer welfare. The welfare measure considered losses from higher prices and higher transactions cost and any reductions in capacity investment requirements. These experiments are particularly interesting for students of road pricing with regard to the measures of demand elasticities, the design of the experiments, the transferability of the experimental elasticity estimates, and what constitutes success in terms of efficiency gains or welfare improvements.

The design of the experiments had a significant effect on the usefulness of the data, particularly the amount of variability built in for the peak, mid-peak, and off-peak prices. Many of the early experiments, and even some of the later ones, had only one set of TOU prices, and therefore the inferences available were limited to a single statistical comparison between the control group and the experimental household. The design also limited the transferability of the results, because they are not applicable to situations in which the TOU prices differ from those used in the experiment. The experiments were carried out in the following states: Arizona, Arkansas, California (Los Angeles), California (Southern California Edison), Connecticut, New Jersey, New York, North Carolina (Blue Ridge Electric), North Carolina (Carolina Power & Light), Ohio, Oklahoma, Rhode Island, Vermont, and Wisconsin and in Puerto Rico (Aigner 1985).

The early demonstration projects did not have guidance with regard to statistical sampling, experimental design, and degree of price variability. In assessing the projects' suitability for price elasticity estimation, the key factor in the experimental design was the degree of independent price variation offered to customers [see paper by Hirschberg (1989)]. Without price variation the impact of TOU prices on customers could not be established. Aigner (1985) reports the following for each experiment: those for Arizona, California (Los Angeles), New Jersey, and Wisconsin were well designed with wide variation in the price treatment; those for Arkansas, Connecticut, New York, and Ohio had too little price variation and had only two different TOU rate structures and were therefore of limited use. The new group of experiments included California (Southern California Edison), North Carolina, Oklahoma, Puerto Rico, and Rhode Island, and these had good price variation but contained some additional flaws, for example, sample households were protected from paying more in the experiment than they would have otherwise. There were also issues of mandatory versus voluntary participation in the pricing project. A voluntary program may well discourage those who would be prime

candidates for inclusion unless they could be assured that their bills could be lowered by shifting a sufficient amount of usage out of the peak period (Aigner 1985).

Elasticity Measures

The elasticity results are reported in Tables 8 and 9, which summarize all the TOU experiments. The estimates exhibit a wide variation, as well they might since they are taken from different experiments with different designs and from different areas. Generally the own-price elasticity of the midpeak (the period between peak and off-peak) is greater than the elasticity of the off-peak, which is greater than the elasticity of the peak. All studies found a reduction in usage with TOU prices during the peak period. However, this reduction was not accompanied by a statistically significant increase in base-period usage. This implies that total usage has either decreased or remained the same across the various projects. Peak-day usage shifts and average-day usage shifts were found to be about the same. The peak-period elasticity estimates ranged from -0.2 to -0.8 and the off-peak estimates from -0.1 to -0.8. The cross-elasticity measures varied widely in sign and magnitude across the various experiments.

Caves and Christensen (1980) undertake to provide summary measures of consumer responses to TOU prices. They develop measures of elasticity of substitution and price and income elasticities, all of which are useful in assessing consumer responses; a subset of their estimates is contained in Table 10. In their estimates they consider differences in the ratio of peak to off-peak prices and the length of the peak. Their results show that consumption can be shifted away from the peak periods but only to a limited extent because the cross-elasticities are quite small. Peak and off-peak consumption of electricity are substitutes, but the two commodities are complements with respect to total income.

In a 1984 paper, Caves et al. use the Wisconsin experimental data to examine the two types of peak charges used in the TOU pricing experiments. First, they assess charges on the basis of energy used when the price is established on the basis of whether consumption takes place in the peak or off-peak period. This is the energy-by-time-of-use (ETOU) rate; that is, the price paid depends upon whether electricity is consumed in the peak or off-peak. The amount paid depends on how much energy is consumed. The second rate, demand by time of use (DTOU), also assesses energy charges but differentiates by time of use by assessing an additional charge

TABLE 8 Uncompensated Partial Own-Price Elasticities of Electricity Demand by Time of Day

	Connecticut		Arizona		Wisconsin	
	Narrow Peak 4 hours	Broad Peak	Narrow Peak 3 hours	Broad Peak (5-8 hrs)	Narrow Peak 6 hours	Broad Peak (9-12 hrs)
Peak Period			-0.41		-0.41, -0.66	-0.48, -0.84
Summer			-0.18		-0.81	-0.81, -0.83
			-0.64	-0.69, -0.79		
Winter	-0.24, -0.50					
Mid-peak Period						
Summer			-0.26, -0.24			
			-0.47			
			-0.7	-0.38, -0.58		
Winter	-0.24, -0.50					
Off-peak Period						
Summer			-0.46, -0.19		-0.51, -0.77	-0.30, -0.64
			-0.36		-0.09	-0.21, -0.24
			-0.23	-0.35, -0.57		
Winter	-0.29, -0.36					

TABLE 9 Compensated Partial Own-Price Elasticities of Electricity Demand by Time of Day

	Connecticut		Arizona		Wisconsin	
	Narrow Peak 4 hours	Broad Peak	Narrow Peak 3 hours	Broad Peak (5-8 hrs)	Narrow Peak 6 hours	Broad Peak (9-12 hrs)
Peak Period						
Summer			-0.01		-0.01	-0.03, -0.04
Winter	-0.15, -0.32					
Mid-peak Period						
Summer			-0.1			
Winter	-0.18, -0.44					
Off-peak Period						
Summer			-0.01		-0.11	-0.00, -0.01
Winter	-0.19, -0.28					

TABLE 10 Total Price Elasticities, Peak and Off-Peak, July 1977 (Caves and Christensen 1980)

Peak/off-peak Ratio	Own-Peak Price Elasticity	Own-off-peak Price Elasticity	Cross Elasticity peak to off-peak price	Cross Elasticity off-peak to peak price	
8:1	-0.352	-0.316	0.148	0.184	6 hr peak
4:1	-0.305	-0.364	0.195	0.136	
2:1	-0.271	-0.410	0.229	0.090	
1:1	-0.257	-0.445	0.242	0.050	
8:1	-0.387	-0.232	0.113	0.268	9 hr peak
4:1	-0.329	-0.281	0.171	0.219	
2:1	-0.270	-0.340	0.229	0.159	
1:1	-0.224	-0.396	0.275	0.103	
8:1	-0.418	-0.197	0.082	0.303	12 hr peak
4:1	-0.371	-0.231	0.128	0.268	
2:1	-0.309	-0.287	0.190	0.212	
1:1	-0.249	-0.349	0.250	0.150	

for usage at the maximum of the peak. The thinking is that consumers may transfer to a different part of the peak period so that the maximum peak within the peak period is reduced.

Caves et al. found that the use of a DTOU rate induced a decline in maximum demand and a reduction in the ratio of peak to off-peak energy usage as people transferred within the peak period or reduced their consumption at the maximum peak within the designated peak period. The ETOU rate resulted in a decline in the ratio of peak to off-peak use and in a decrease in maximum demand as people transferred to the off-peak or reduced their peak-period consumption. The elasticity estimates indicated that maximum demand and peak demand usage were weak complements or at least nonsubstitutable, but that both maximum demand and peak-period demand were substitutes with off-peak energy use.

These results show that if a reduction in maximum demand is the objective of the pricing, a demand charge (DTOU) accomplishes this objective more directly. However, if the objective is a flattening of the load curve over a broader period of time, time-differentiated rates without a demand charge accomplish this directly [see paper by Sexton et al. (1989)].

Rate structure effects were examined by Patrick (1990), who employed pooled data from 11 different pricing experiments and focused on the length of time a rate is charged, the number of intermediate pricing periods, demand versus energy charges, and mandatory versus voluntary participation as important factors in assessing demand response. Among these factors he found that the length of the pricing period and energy charges were significant. In addition, he examined the intertemporal and interspatial stability of the parameter estimates across the 11 experiments and found that the parameter estimates are unstable across experiments but stable over time.

The general consensus from the large number of empirical studies is that TOU pricing reduces peak demand; therefore capacity needs and operating costs can be reduced. However, the question of welfare justification remains, since the empirical results are mixed. The length of the peak is important in the welfare calculation and therefore in determining cost-effectiveness. The reasoning is that if the peak period is too short, it may generate a secondary peak, whereas if it is too long, it may not reduce demand at the system peak and thus would not reduce the demand for capacity.

Patrick's results indicate that a reduction in peak demand is negatively related to the length of the peak. The choice of peak length can affect the

success of the pricing strategy. If the peak is too long, it inhibits substitution (as was the case in transit) since the transactions costs of transferring to the off-peak period rise. The load curve effects can be distinguished by separating the conservation effect, the reduction in aggregate demand, and the substitution to the off-peak.

Assessment

The residential electricity pricing experiments were essentially short-run experiments because the appliance stock is fixed. The long-run response to TOU prices may well be considerably different from the estimates that emerged from the experiments. Most analysts agree that these experiments were of limited usefulness. Only a few led to reliable elasticity estimates. A disturbing factor was the limit to which it may be possible to transfer results from one area to another. The experiments yielded a fairly wide range of elasticity estimates.

There are risks associated with attempting to implement TOU pricing on the basis of the experimental results. The elasticity estimates are subject to error, and they may not be transferable outside the target population or service area. Research on the transferability issue is important, and a comprehensive framework is needed to resolve such issues. The primary shortcoming of the experiments is that they did not provide robust quantitative evidence on TOU pricing. They did, however, provide qualitative evidence that TOU pricing works. Quantitatively, only a few experiments were sufficiently well designed that they provided a weak basis for decisions regarding implementation. It was not possible to determine which was superior: a phased or selective implementation focusing on larger customers and eventually extending to all customers or an overall implementation. These issues are precisely those that would be facing proponents of road pricing. A careful study of the electricity experiment experience would prove useful.

LESSONS FOR ROAD PRICING

The four utilities or utilitylike goods were selected because they provide a reasonably close parallel to roads. These goods are regarded as necessities by much of the population. They also all have the character of a social

contract in the sense that access is considered an economic right and plays an important part in pricing policy.

The telecommunications, transit, and electric utility experiments yield a number of general as well as specific lessons for students and advocates of road pricing. Among the specifics that these service markets had in common were nonzero demand elasticities and the impact of peak pricing. The characteristics of the structure of pricing were of particular importance. Issues included the number of pricing periods and the width of those periods, particularly the peak and the differential between peak and off-peak.[9] How normative issues are handled plays a significant role in attitudes to new pricing approaches and in public acceptance. All markets recognized that sophisticated pricing structures were not necessarily applicable to all and that targeting pricing strategies may be more successful and more likely to be implemented than a blanket approach. Two points are worth emphasizing. First, institutional changes led the move to efficient prices in all markets reviewed. It may be that the introduction of road pricing may have to be preceded by a corporatized roadway infrastructure or some institutional change that distances roadway managers (and price setters) from government and politicians. This affects both manageability objectives and the public attitude to road pricing as a tax grab. Second, technological change has played an important role in the evolving rate structures that better reflect economically efficient rates. The adoption of the evolving technologies may play a similar role in road pricing.

Perhaps the most important point to come out of this review is that road pricing is not without precedent. There are three additional analogues: a need to understand demand parameters and substitution possibilities; a need to understand the service package, such as which services to price, how to price them, and the optimal number of pricing periods; and the role of technological change in lowering the transactions cost of introducing efficient pricing schemes.

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NOTES

1. An economic good is one for which wants exceed availability. This means it is scarce. A free good is one that is not scarce.
2. This congestion or rationing of the available capacity by nonprice mechanisms results in a negative externality. There will be some welfare loss as call attempts by high-value users are not served in some cases.
3. Terms of service included access and whether usage would be included in a subsidy. Source of financing referred to the group that would provide the revenue that paid for the lifeline program.
4. Basing prices on costs is considered fair by some in the sense that higher cost responsibility should require a higher price.
5. The program is designed to avoid providing a windfall gain to inframarginal subscribers.
6. Also, there was a rejection of fully distributed cost pricing, as in telecommunications.
7. This was a major reason in some cases. There is no statistical evidence of cross-elasticities, but if one examines ridership, it is revealing. There is some evidence that the off-peak share of total ridership rose by almost 50 percent in those communities that introduced off-peak midday discounts. A peak surcharge program has an imperceptible impact on ridership distribution.
8. The increased ridership in the off-peak period can be considered an efficiency gain in a welfare theory sense.
9. Both telecommunications and electricity markets provided evidence that welfare diminishes with greater numbers of pricing bands.

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Cashing Out Employer-Paid Parking

A Precedent for Congestion Pricing?

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Almost all parking in the United States is provided free to the user. In the 1990 Nationwide Personal Transportation Survey (NPTS), motorists reported receiving free parking for 99 percent of all automobile trips. Because the average car is parked 95 percent of the time, it seems clear that, in most cases, congestion tolls would charge motorists for the use of roads during the brief time they are traveling between free parking spaces.

In considering the potential benefits of congestion pricing, previous research on parking pricing provides useful evidence that automobile use is surprisingly sensitive to parking price. The purpose of this study is to (*a*) present the evidence from parking studies on the price elasticity of demand for automobile travel, (*b*) explore how employer-paid parking subsidies contribute to the problems that congestion tolls are meant to solve, (*c*) propose a policy to "cash out" employer-paid parking subsidies, (*d*) explain California's new parking cash-out legislation, and (*e*) describe some early results of the California legislation and speculate on how it may serve as a precedent for implementing congestion pricing.

UBIQUITOUS FREE PARKING

What is the evidence that most parking is free? The 1990 NPTS provides information from telephone interviews of 48,400 persons in 22,300 households. For the NPTS "travel day file," each respondent was asked about all

automobile trips taken during the previous day. One of the questions asked about each automobile trip was, Did you pay for parking during any part of this trip? Table 1 shows the responses to this question. Nationwide, motorists reported receiving free parking for 99 percent of all automobile trips. In Southern California, a region with notoriously high land costs, motorists reported receiving free parking for 98 percent of all automobile trips. For work trips, 99 percent of the respondents reported paying nothing to park in both Southern California and the rest of the nation.

Another section of the NPTS, the "person file," provides responses from the same 48,400 persons to the question, Do you pay for parking at work? (not on the previous day, but in general). In response to this question only 95 percent (rather than 99 percent) of automobile commuters reported paying nothing to park. The explanation for this small discrepancy between the person file and the travel day file is not clear. Some respondents to the travel day question may have paid for a monthly parking pass at work and thus reported paying nothing to park during a work trip on the previous day. Nevertheless, even if some who do pay for monthly parking reported free parking for a particular day's work trip, this result indicates that almost all motorists perceive parking to be free when considering the day's trip. For nonwork trips there is no reason to suspect

TABLE 1 Share of All Automobile Trips with Free Parking

Trip Purpose	Percent of Trips with Free Parking	
	Southern California	Nationwide
To or From Work	99%	99%
Family/Personal Business	98%	99%
Shopping	100%	99%
Social/Recreational	97%	98%
Visit Friends/Relatives	99%	99%
School/Church	94%	97%
Work Related Business	90%	97%
Doctor/Dentist	100%	97%
Other	100%	100%
Pleasure Driving	100%	99%
Vacation	100%	93%
TOTAL	98%	99%

Source: 1990 Nationwide Personal Transportation Survey. All data are from the "travel day" file. Trip purposes are listed in descending order according to their share as a percentage of all automobile trips.

any overreporting of free parking related to a monthly rather than daily charge for parking, yet almost all travelers still reported paying nothing to park.

Given the ubiquity of free parking, it seems clear that, in most cases, congestion tolls would charge motorists for the use of roads during the brief time they are traveling between free parking spaces. This observation is not meant to suggest that motorists should not pay for the use of congested roads, but rather to suggest that charging for parking and charging for road use are complementary, not competing, policies. Both types of charge can be designed to prevent overuse of a scarce resource. Congestion tolls and parking charges would have a much stronger effect than congestion tolls with continued free parking. In addition, optimal congestion tolls would be lower and politically more acceptable in an environment of market-priced parking than in an environment of continued free parking.

Charging for congestion would require introducing new and technically complex forms of paying for road use, whereas in many cases charging for parking would require only the removal of an existing subsidy. Said another way, the failure to charge motorists for the congestion they cause is a "sin of omission," a failure to intervene in the transportation market to raise the price of driving to its social cost. In contrast, the failure to charge motorists for parking is often a "sin of commission," a deliberate intervention designed to lower the price of parking below both its market value and its social cost. It should also be noted that it is far easier to charge for parking than it is to charge for congestion; parking subsidies often require clumsy validation schemes designed to shield motorists from existing market prices for parking.[1] Therefore, is it sensible to introduce new and technically complex congestion tolls without first or simultaneously reducing existing parking subsidies?

EVIDENCE FROM EMPLOYER-PAID PARKING

Employer-paid parking may appear to be a generous and enlightened fringe benefit, but it greatly encourages solo driving to work. The 1990 NPTS found that 91 percent of commute trips to work were by automobile (up from 78 percent in 1983), and the average vehicle occupancy rate for work commute trips was 1.1 persons per vehicle (down from 1.3 in 1983). These figures imply that 83 vehicles were driven to work per 100

employees in the United States in 1990, an extraordinary automobile dependency that is strongly stimulated by employer-paid parking.

That employer-paid parking is a strong stimulus to drive to work alone can be illustrated in three ways. First, an employer's offer of free parking at work is often worth more than the offer of free gasoline for the trip to and from work. For commuters to downtown Los Angeles, Willson and Shoup (1990a) found that the average round trip for those who park free is 36 mi (58 km). If their gasoline mileage is 20 mpg (32 km/L), the round trip to work consumes 1.8 gal (6.8 L) of gasoline. At $1.50 a gallon, the cost of gasoline for the average round-trip commute trip is $2.70. The average employer-paid subsidy for commuter parking in downtown Los Angeles was $3.87/day or 43 percent more than the cost per trip for gasoline. An offer of free gasoline to all employees who drive to work alone would be recognized as an environmental outrage, but employer-paid parking is a much stronger financial incentive to drive to work alone. Pickrell (1991) points out that where the market price of parking is $5/day, employer-paid parking is a bigger subsidy for driving to work than an employer's offer to provide free gasoline and a free car for most commute trips.

Second, employer-paid parking subsidies dwarf the gasoline tax paid for the average work trip. The average parking subsidy of $3.87 for a trip that consumes 1.8 gal of gasoline is equivalent to a subsidy of $2.15/gal of gasoline used. Therefore, the federal gasoline tax would have to be raised from $0.14/gal to $2.29/gal (a 16-fold increase) merely to offset the parking subsidies now given to more than 50,000 solo drivers who park free at their employers' expense in downtown Los Angeles. Thus, even an improbably huge increase in the federal gasoline tax would discourage solo driving to work by much less than employer-paid parking already encourages it.

A third way to illustrate the powerful effect of employer-paid parking is to compare it with a hypothetical congestion toll. If the average round-trip drive to work is 36 mi and the average parking subsidy is $3.87/day, the parking subsidy would be equivalent to $0.11/mi traveled. Thus, imposing a congestion toll of $0.11/mi traveled would do no more to discourage commuters from driving to the Los Angeles central business district than employer-paid parking already encourages it.

Because employer-paid parking subsidizes such a large share of the total cost of driving to work, it substantially increases the amount of solo driving to work. The results from well-documented case studies of how employer-paid parking affects commuters' travel choices are summarized in Table 2. In these case studies either the commuting behavior of em-

TABLE 2 Effects of Employer-Paid Parking on Solo Driving to Work

Location, Date, and Type of Case Study	Solo Driver Mode Share			Cars Driven to Work per 100 Employees			
	Driver Pays for Parking	*Employer* Pays for Parking	Stimulated Increase in Solo Share	*Driver* Pays for Parking	*Employer* Pays for Parking	Stimulated Increase in Auto Trips	Price Elasticity of Demand
Civic Center, Los Angeles, 1969 (with/without)	40%	72%	+32%	50	78	+28	-0.22
Downtown Ottawa, Canada, 1978 (before/after)	28%	35%	+7%	32	39	+7	-0.10
Century City, Los Angeles, 1980 (with/without)	75%	92%	+17%	80	94	+14	-0.08
Mid-Wilshire, Los Angeles, 1984 (before/after)	8%	42%	+34%	30	48	+18	-0.23
Warner Center, Los Angeles, 1989 (before/after)	46%	90%	+44%	64	92	+28	-0.18
Washington, D.C., 1991 (with/without)	50%	72%	+22%	58	76	+18	-0.13
Downtown Los Angeles, 1991 (with/without)	48%	69%	+21%	56	75	+19	-0.15
AVERAGE OF CASE STUDIES	42%	67%	+25%	53	72	+19	-0.15

Source: Groninga and Francis (1969), Transport Canada (1978), Shoup and Pickrell (1980), Surber et al. (1984), Soper (1989), Miller (1991), Willson (1991).

ployees was compared before and after employer-paid parking was eliminated or the commuting behavior of matched samples of employees was compared with and without employer-paid parking.

Table 2 first shows the effect of employer-paid parking in terms of the solo driver mode share and reveals that between 7 and 44 percent of commuters shifted to solo driving from other modes and on average 25 percent of all commuters shifted to solo driving because of employer-paid parking.

Second, Table 2 shows the effect of employer-paid parking in terms of the number of cars driven to work per 100 employees.[2]

This measure reveals that employer-paid parking increased the number of cars driven to work by between 7 and 28 cars per 100 employees and on average increased the number of cars driven to work by 19 cars per 100 employees.

Finally, the last column of Table 2 standardizes the results in terms of the price elasticity of demand for the number of cars that commuters drive to (and park at) work, which ranges from −0.08 to −0.23 and averages −0.15. This result can be interpreted as meaning that a 10 percent decrease in the price of parking would increase the number of cars driven to work by 1.5 percent.[3] To some observers, an elasticity of −0.15 may imply that the demand for parking and automobile use is inelastic, and this in turn suggests that the demand for automobile use responds very little to price. But in this case the simple characterization of demand for automobile use as inelastic conceals more than it reveals.

One way to show that an inelastic demand does not imply an unresponsiveness to price is to examine the observed effect of parking prices on the share of commuters who drive to work alone. On average, charging for parking reduced commuters' solo driver share from 67 to 42 percent. Therefore, the number of solo drivers decreased by 37 percent (25/67). This is an enormous mode shift when compared with the results obtained by any other transportation demand management measure, such as free transit passes or guaranteed rides home for carpoolers. Although the estimated price elasticity of demand for parking is only −0.15, which may seem low to some observers, this does not imply that commuters do not respond strongly to the price of parking when that response is measured by the resulting changes in solo driver share.

Another way to show that an inelastic demand for parking does not imply an unresponsiveness to price is to examine the observed effect of parking prices on the number of cars driven to work. On average, charging for parking reduced the number of cars driven to work from 72 to 53

per 100 employees. Therefore, the number of cars driven to work declined by 26 percent (19/72). Again, this is an enormous reduction in automobile use when compared with what can be achieved by other policies, and it is achieved simply by eliminating an inappropriate subsidy.

The data in Table 2 show that automobile use responds strongly to parking prices and therefore suggest that automobile use would also respond strongly to congestion prices. However, there are several reasons to believe that automobile use would respond even more to congestion prices than to parking prices.

First, the studies in Table 2 refer to commuters' responses to the price of automobile trips to work, which are the most essential trips for most people. Commuters responded to the parking price increases only by choosing a different mode for their trips, not by changing the number of trips they made or the time at which they traveled. For other trip purposes, travelers have the option to respond to a congestion toll not only by choosing a different mode, but also by shifting their travel time or destination, or by not taking the trip. For example, in a British survey conducted by the Royal Automobile Club, motorists reported that 30 percent of their car mileage was "not at all" or "not very" important (Jones 1992, 104). For these less-essential trips, the demand for automobile travel should clearly be more elastic than for essential commute trips.

Second, the studies in Table 2 refer to responses to an increase in the price of commuter parking at one work site in an environment where almost all parking for all other purposes remained free (as shown in Table 1). The demand for parking at any one work site depends on the price of parking not only at that site, but also at other sites. If commuters have already arranged their lifestyles to accommodate to a world where almost all parking is free and the price of parking increases at the one location to which they must travel to earn their living, they will cut back on automobile use by much less than they would if all parking prices were raised to their market values. If all parking prices were increased to their market levels, families would make different choices regarding automobile ownership and perhaps also residential and work locations. These general equilibrium changes are not captured in commuters' responses to a change in the price of parking at one work site. Thus the price elasticity of demand with respect to an increase in the price of all parking (or of all automobile travel) should be greater than the figures presented in Table 2 for an increase in the price of parking at a single work site.[4]

Third, the studies in Table 2 refer to travelers' responses to an increase in only one component of a trip's price. A 10 percent change in the price of

the entire trip should lead to a larger response than a 10 percent change in the price of only one component of the trip. It is important to remember that the elasticity estimates in Table 2 refer to commuters' responses to changes in only the parking price of their trip and are therefore smaller than the elasticity of demand with respect to changes in the full price of automobile trips.

Three of the studies reported in Table 2 were "before and after" cases in which it was possible to observe commuters' responses to an increase in the price of parking; the other four were "with or without" case studies comparing the behavior of otherwise similar employees who differed only in regard to whether or not they paid for parking. But none of the three before and after cases involved a "pure" price increase of the sort that would reveal the "true" price elasticity of demand for parking as usually defined. In Ottawa the government stopped providing free parking to its employees but raised the price to only 70 percent of the market value, not to 100 percent. Moreover, some employees had not been offered free parking before the price increase, so their price of parking did not increase at all. Both of these factors would be expected to reduce the resulting observed change in mode split, and the Ottawa case does exhibit the smallest observed price elasticity. On the other hand, in the Warner Center and Mid-Wilshire cases, the price of parking increased only for solo drivers; carpoolers continued to park free. This form of parking price increase (for solo drivers only) produced the largest shifts from solo driving (44 and 34 percent). Removing these three "impure" cases of price change scarcely alters the average results, however, because the below-average response in Ottawa seems to have balanced the above-average responses in Los Angeles. The average price elasticity of demand for parking for the remaining four case studies is -0.14 (rather than -0.15 for all seven cases). The average change in solo share is 23 percent for the four remaining cases (rather than 25 percent for all seven cases), and the average change in the number of automobiles driven to work is 20 per 100 employees for the four remaining cases (rather than 19 for all seven cases).

One particularly notable result emerged from the Mid-Wilshire case study, in which parking was free to all drivers before the change. After the change, the price of parking rose to $57.50/month for solo drivers but remained free to carpoolers. The carpool share rose from 17 to 58 percent, but the transit share declined from 38 to 28 percent. Why did raising the price of parking for solo drivers reduce the transit mode share? The answer is that solo drivers began to seek carpool partners in order to park free and invited former transit riders to share their cars. This finding has important

implications for proposals to scale congestion prices for vehicle occupancy. If carpools are exempted from congestion tolls, the result may be to increase the carpool share and decrease the transit share. This is not an undesirable result, of course, because peak-hour transit service is often overcrowded and has a high marginal cost. Shifting some peak-hour transit standees into the empty seats of automobiles could spread transit demand more evenly over the day and reduce transit operating deficits.

The studies summarized in Table 2 all refer to one kind of automobile trip: the trip to work. This is the single most important trip purpose, although it is often noted that its relative importance has been declining. Data from the 1990 NPTS (Table 3) show that work trips represent 28 percent of all automobile trips and 64 percent of all automobile trips made during the morning peak hours. Work trips tend to be longer than non-work trips, so they account for a larger share of vehicle miles traveled than of trips. Work trips represent 33 percent of all vehicle miles traveled and 71 percent of vehicle miles traveled during the morning peak hours. Thus, employer-paid parking potentially influences about one-third of all automobile travel and about two-thirds of all automobile travel during the morning peak, when congestion is a great concern. Clearly, employer-paid parking heavily subsidizes many of the same automobile trips for which congestion pricing is being proposed.

EMPLOYER-PAID PARKING AS TAX-EXEMPT FRINGE BENEFIT

What explains the ubiquity of employer-paid parking? The chief explanation is the Internal Revenue Code's peculiar asymmetrical rule for

TABLE 3 Importance of Journey-to-Work Trips

	All Hours	Morning Peak
Work Trips as % of All Automobile Trips	28%	64%
Work Trip VMT as % of Total VMT	33%	71%

Source: 1990 Nationwide Personal Transportation Survey "travel day" file. The morning peak is 6AM to 9AM, Monday to Friday.

employer-paid parking. If the employee pays for parking at work, he or she cannot deduct the parking charge from taxable income as a work-related expense. But if the employer pays for the employee's parking at work, the code has classified the payment as a tax-exempt working condition fringe benefit. This special rule for employer-paid parking subsidies has had the unfortunate, unintended, and largely unnoticed effect of stimulating a huge increase in the number of commuters who drive alone to work.

It is particularly important to understand the asymmetry of the tax exemption for employer-paid (but not employee-paid) parking in order to understand the almost irresistible incentive it provides for employers to pay for their employees' parking. This tax exemption does not simply reduce the cost of commuter parking by the employee's marginal income tax rate in the same way that, for example, the tax deduction for contributions to charity reduces the cost of contributing to charity. To take advantage of the tax exemption for commuter parking, the employer has to pay for the employee's parking. Therefore, the tax exemption is of value only to the extent that the employer pays for the employee's parking. Although a conventional tax deduction reduces the price of the deductible item only by the taxpayer's marginal tax rate, the unique tax exemption for employer-paid parking has inadvertently shifted the responsibility for paying for almost all commuter parking entirely from the employee to the employer and has thus reduced the cost of almost every employee's cost of parking to zero. Further, the revenue loss created by this tax exemption must be made up by raising taxes elsewhere. Thus, all American taxpayers end up paying for a subsidy that congests traffic, pollutes air, and wastes energy.

The tax-induced 100 percent reduction in the price for parking at work would not be inappropriate if the goal of public policy were to encourage as many commuters as possible to drive to work alone. But of course the case is exactly the opposite. As a remedy for the serious problems caused by employer-paid parking, ridesharing and mass transit advocates have argued for years that the tax code should be revised to exempt employer-paid transit and ridesharing subsidies from taxation in the same way that employer-paid parking subsidies are exempted. The Comprehensive Energy Policy Act of 1992 took a short step in this direction by amending the special rule defining employer-paid parking as a "working condition fringe" and in its place creating a new category of tax-exempt fringe benefit called a "qualified transportation fringe." The new tax-exempt

transportation fringe benefit is defined as follows [Internal Revenue code, Section 132(f) (effective Jan. 1, 1993)]:

> QUALIFIED TRANSPORTATION FRINGE
> (1) IN GENERAL—For purposes of this section, "qualified transportation fringe" means any of the following provided by an employer to an employee:
>> (A) Transportation in a commuter highway vehicle [a van that seats at least six adults not including the driver] if such transportation is in connection with travel between the employee's residence and place of employment.
>> (B) Any transit pass.
>> (C) Qualified parking. [The term "qualified parking" means parking provided to an employee on or near the business premises of the employer or on or near a location from which the employee commutes to work by transportation described in subparagraph (A), in a commuter highway vehicle, or by carpool.]
>
> (2) LIMITATION ON EXCLUSION—The amount of the fringe benefits which are provided by an employer to any employee and which may be excluded from gross income . . . shall not exceed—
>> (A) $60 per month in the case of the aggregate of the benefits described in subparagraphs (A) and (B) of paragraph (1), and
>> (B) $155 per month in the case of qualified parking.

In effect, the new qualified transportation fringe exempts the first $155/month of employer-paid parking subsidies and the first $60/month of employer-paid vanpool or transit subsidies from income taxation. Both tax exemptions will be indexed to the cost of living. The rationale for the $155/month cap on tax-exempt parking subsidies is that taxes on employer-paid parking subsidies over $155/month would raise enough new tax revenue to replace the tax revenue lost by exempting the first $60/month of employer-paid vanpool and transit subsidies. Obviously, the estimate that a $155 cap will raise the right amount of revenue is little more than a guess, because there are no data on how many employees now receive employer-paid parking subsidies greater than $155/month or on the total value of such subsidies that might become subject to taxation. In addition, there is great uncertainty about how many employers would choose to offer tax-exempt vanpool and transit subsidies up to $60/month and how many employees would accept these offers.

This new cap on tax-exempt parking subsidies at $155/month and the increase in the cap on tax-exempt vanpool and transit subsidies to $60/month are clearly important changes. However, setting the cap on tax-exempt parking subsidies at 258 percent of the cap on tax-exempt vanpool and transit subsidies clearly continues the tax bias in favor of employer-paid parking (and thus in favor of driving to work alone). Further, there is no tax exemption whatever for employer-paid carpool subsidies or for employer-paid incentives to walk or bicycle to work.

Most significantly, the code's new category of qualified transportation fringe retains the strong asymmetrical incentive for employers to pay for their employees' parking. Moreover, the qualified transportation fringe tax exemption is automatically extended to social security taxes, state income taxes, unemployment insurance taxes, and all other payroll taxes. When all these additional tax rates are taken into account, the employer's offer to pay for the employee's parking can more than double the after-tax value of the employer-paid parking subsidy to the employee. Even after the recent reform, parking remains tax-exempt when paid by the employer but taxable when paid by the employee. This peculiar treatment of parking at work continues to make it extraordinarily tax-efficient for employers to continue paying for all their employees' parking at work.

Extending the tax exemption to transit passes and vanpool subsidies would help to counteract the continued tax exemption for parking subsidies, but this new tax exemption will probably not have much effect on commuter travel patterns. Employer-paid rideshare and transit subsidies were previously tax-exempt up to $21/month, but most employers did not offer their employees even this small amount, so it is not clear that increasing the allowable tax-exempt amount will induce many employers to offer a larger subsidy. Also, there is very convincing evidence from case studies to show that when parking is free, it is very difficult to lure commuters out of cars by subsidizing mass transit [see case study by Surber et al. (1984)]. Finally, the new qualified transportation fringe does not exempt from taxation any employer-paid subsidies for other alternatives to solo driving, such as carpooling, telecommuting, bicycling, or walking to work.

Despite the growing body of evidence (summarized in Table 2) that employer-paid parking seriously aggravates traffic congestion and air pollution and greatly stimulates gasoline consumption, the Internal Revenue Code still gives its most favored treatment to employer-paid parking

subsidies, and thus to driving to work, even after the important reform contained in the 1992 Comprehensive Energy Policy Act. This new legislation—designed specifically to save energy—has left the tax exemption for employer-paid parking more than two and a half times larger than the tax exemption for employer-paid transit subsidies, which proves how difficult it is to reduce the tax exemption for employer-paid parking. One reason for this political difficulty is that the tax exemption for employer-paid parking benefits so many workers at all income levels. Although the tax exemption provides the greatest benefits to those in higher income tax brackets, eliminating it would affect many low-wage employees as well.

CASHING OUT EMPLOYER-PAID PARKING

Given the extreme sensitivity of the issue, is there any possible public policy that can achieve the benefits of ending the tax exemption for employer-paid parking without provoking the inevitable fierce opposition to taxing the substantial parking subsidies now given to so many commuters? The popularity and success of a recent program in Los Angeles suggest that the answer to this question is yes. The city of Los Angeles took an imaginative step in the right direction in 1989 when it adopted its employee transit subsidy ordinance, which requires that

> Each employer in the City that offers free or subsidized parking to any employee . . . shall offer a $15 (fifteen) per month transit subsidy to each of its employees for their use in commuting to and from the employer's work-site. (Section 85.05, Los Angeles Municipal Code)

The political rationale for this ordinance was quite simple. If an employer offers a parking subsidy to an employee who drives to work, the employer should also allow an employee to use the subsidy to ride mass transit if the employee does not drive to work. The ordinance encountered no opposition when it was enacted and has encountered none since because it is very difficult for employers to argue that they should restrict their employees to using employer-paid travel subsidies only for parking (and thus for driving), but not for riding mass transit. The figure of $15/month was chosen for the Los Angeles ordinance because it was then the maximum transit subsidy that was exempt from federal income tax. This required transit alternative to the parking subsidy is a sensible, sensitive, and minimally intrusive public policy that is intended to expand the

commuter's options beyond the usual choice between a parking subsidy or nothing. The ordinance does not prohibit or discourage employer-paid parking; it simply says that an employer cannot confine its employees to the choice between a parking subsidy or nothing.

The precedent set by the Los Angeles transit subsidy ordinance suggests a logical next step to further expand the commuter's options beyond the usual choice between free parking or nothing by giving the employee the option to receive, in lieu of the parking subsidy, the fair market value of the parking subsidy, either as a mass transit or ridesharing subsidy or as a cash commuting allowance. Every local government should not have to enact its own parking cash-out requirement. Instead, the federal government could achieve the same result by amending the Internal Revenue Code's existing definition of tax-exempt "qualified parking" as follows [Internal Revenue Code, Section 132(f), Paragraph (5)]:

> QUALIFIED PARKING—The term "qualified parking" means parking provided to an employee on or near the business premises of the employer . . . *if the employer offers the employee the option to receive, in lieu of the parking, the fair market value of the parking, either as a taxable cash commute allowance or as a mass transit or ridesharing subsidy.*

The text in italics is the proposed change.

The proposed policy of requiring an employer to offer employees the option to choose cash in lieu of any offered parking subsidy has several important advantages, discussed in the following sections. (Because cash can be used to pay for any form of mass transit or ridesharing, the term "cash" is hereafter meant to include mass transit and ridesharing subsidies as well.)

OPPORTUNITY COST OF FREE PARKING

When commuters are offered the choice between free parking or nothing, parking has no opportunity cost. However, asking commuters to choose between a free parking space or its cash value makes it clear that parking has a cost, which is the cash not taken. The foregone cash would be a new "price" for taking the "free" parking, a price that would increase the perceived cost of driving to work. If a commuter forgoes the cash and continues to park free, he or she has in effect "spent" the cash on parking. Therefore, when the opportunity cost becomes explicit, some commuters who are now offered free parking and drive to work alone would begin to

take the cash and rideshare instead. The cash option would most strongly tempt commuters to rideshare to work sites where parking prices are highest. Because parking is usually most expensive in the most congested areas, the option to take cash instead of a parking subsidy would automatically target its strongest incentive to rideshare exactly where this incentive is most needed. Moreover, because an employee can always use cash to pay for nontransportation expenses, the offer of cash in lieu of parking rewards the most environmentally benign forms of commuting—walking, cycling, and mass transit—as alternatives to driving.

The proposal that employers cannot confine employees to taking a travel subsidy only in the form of parking would also encourage employers to take advantage of the newly enacted $60/month tax exemption for employer-paid vanpool and mass transit subsidies. Almost all employers now subsidize their employees' parking, but most employers have not taken advantage of the existing option to offer a $21/month transit subsidy.[5] If employers are not required to offer their employees the option to choose a tax-exempt transit subsidy in lieu of a tax-exempt parking subsidy, many will simply continue to offer the free parking to which their employees are accustomed. Thus, cashing out parking subsidies would increase the effectiveness of vanpool and mass transit subsidies.

Benefit to Employees

The proposal to cash out employer-paid parking subsidies avoids two seemingly intractable problems: voters do not like new taxes and motorists do not like to pay for something that they formerly got free. Most proposals for using parking pricing to reduce solo driving presume a need to cause discomfort for solo drivers [e.g., report by Koppelman et al. (1991, I-3)]. The option of cash in lieu of a parking subsidy should not cause discomfort for any commuter. Instead, commuters would receive a new option, the cash alternative. Employers could continue to offer tax-exempt parking subsidies so long as they broadened the offer to allow the employee the option to take the taxable cash value of the parking subsidy in lieu of the parking subsidy itself. Thus, employees who prefer cash or a ridesharing subsidy to a parking subsidy are clearly better off as a result of this policy, and those who continue to take the tax-exempt parking subsidy are unaffected (except that they will enjoy cleaner air and less congestion while driving to work). Nevertheless, although it sugarcoats the pill, the proposal to require cash as an option in lieu of free parking means that

commuters who drive to work will pay for their free parking, because those who forgo the cash in favor of the parking are in fact spending the cash to pay for the parking.

Transportation economists, and especially congestion pricing theorists, usually focus on sophisticated ways to make motorists pay for the social costs of their driving. In contrast, cashing out employer-paid parking does not charge commuters for using parking but rather pays them in-lieu cash for not using parking. Cashing out parking subsidies is like paying commuters to stop driving to work alone—a buy-back, not a take-away. Offering employees the option to cash out their parking subsidies would be a popular step in the right direction because, rather than punishing commuters for doing the wrong thing, it would reward them for doing the right thing.

Cost to Employers

The only cost to an employer when an employee chooses to cash out a tax-exempt parking subsidy is the payroll tax paid by the employer on the cash value of the parking subsidy. If the employee chose a tax-exempt vanpool or transit subsidy, however, there would be no payroll taxes. If the small burden of payroll taxes on cash were considered a serious objection to cashing out parking subsidies, it could be met by defining the cash-out value of a parking subsidy as the cash value that, when payroll taxes are added, equals the fair market value of the parking subsidy. For example, if the payroll tax rate is 12 percent, employers could offer $0.89 in cash per $1.00 of parking subsidy, and the payroll tax on the $0.89 would raise the employers' cash cost to $1.00. Alternatively, cashed-out parking subsidies could be exempted from payroll taxes. In either of these cases, an employer is no worse off when an employee chooses cash in lieu of a parking subsidy because the cash alternative is by definition no more costly than the parking subsidy.

Note that the proposal is for the employer to offer the cash alternative only to those employees who are offered a parking subsidy, not to all employees.[6] The size of each employee's cash alternative is equal to the parking subsidy offered to that employee, so if some employees are offered smaller parking subsidies than other employees, their required cash alternative would also be smaller. Nevertheless, there is a potential cost to employers because some employees who are now offered employer-paid

parking nevertheless do not drive to work. These currently ridesharing employees would become eligible to receive the cash alternative to the employer-paid parking that they are not taking, and the employer would not save anything on forgone parking with which to finance the new cash payment. However, such employees would constitute a tiny percentage. The 1990 NPTS found that 91 percent of the American work force commutes to work by car (Hu and Young 1992). One reason that many of the remaining 9 percent do not is probably that they are among the few employees who are not offered employer-paid parking (and who therefore would not have to be offered in-lieu cash). Of those very few who are now offered free parking but do not take it, some are certainly already offered an alternative ridesharing subsidy (such as a bus pass), and for these employees the employer's cost of the cash option would be only the difference (if any) between the cash option and the cost of the existing rideshare subsidy. For these reasons, any added cost to employers of offering the cash option to existing ridesharers would have to be very small.

Still, it must be admitted that the requirement to offer in-lieu cash may cause fear of increased costs for employers who (*a*) offer employer-paid parking, (*b*) do not offer equivalent ridesharing subsidies, and (*c*) nevertheless have a significant number of employees who turn down the offer of a parking subsidy and rideshare to work instead. In this unusual case, the added cost of offering cash to current ridesharers who are already offered but have turned down a parking subsidy must be considered the inevitable and wholly justified cost of moving to a commute subsidy policy that does not discriminate against ridesharers. Offering smaller subsidies to ridesharers than to otherwise identical solo drivers is discriminating against ridesharers in the same way that offering lower wages to women than to otherwise identical men is discriminating against women. At the very least, the tax code should be amended to discourage this discriminatory antiridesharing behavior, which it now encourages. Arguing against the required cash option on the grounds that it would increase the employer's cost is the same as arguing that employers should offer smaller subsidies to ridesharers than to otherwise identical solo drivers.

Some employers might choose to comply with the cash-option requirement by converting their existing parking subsidies for solo drivers into smaller but uniform travel allowances for all employees, with no increase in the employer's total travel subsidy. An advantage of the cash-option requirement is that these employers could blame the government for any

resulting redistribution of subsidies from solo drivers to ridesharers by claiming that it was the law.

A final reason to believe that the cash-option requirement would not burden employers is that it would treat all employers equally. By comparison, requirements for employer-based trip reduction plans, such as Regulation XV in Southern California, place onerous obligations on those who have more than 100 employees but no obligations on those with fewer than 100 employees. Employers might be much more willing to offer cash in lieu of a parking subsidy if they knew that the tax code required all employers to make the same offer; no employer would be put at any competitive disadvantage.

Intrusion on Employers' Decisions

Some might argue that even if it would not significantly increase employers' costs, the cash-option requirement would inappropriately intrude on employers' decisions about employee compensation, but the current tax exemption for employer-paid parking already does that. By subsidizing parking, employers are simply carrying out a public policy embedded in the Internal Revenue Code. Employers are not the cause of the problem; public policy is. The cash-option requirement is designed to remedy a flaw in the Internal Revenue Code, not to remedy any misbehavior by employers.

The definition of employer-paid parking as a tax-exempt transportation fringe in the code contains the following provision [Internal Revenue Code, Section 132(f), Paragraph (4)]:

> BENEFIT NOT IN LIEU OF COMPENSATION.—Subsection (a)(5) [which excludes qualified transportation fringe benefits from an employee's gross income] shall not apply to any qualified transportation fringe unless such benefit is provided in addition to (and not in lieu of) any compensation otherwise payable to the employee.

This provision means that if an employer does offer an employee cash in lieu of a parking subsidy, the parking subsidy itself does not qualify as a tax-exempt fringe benefit and becomes taxable. This perverse provision prohibits employers from offering taxable cash in lieu of a tax-exempt parking subsidy. In effect, the proposed cash-option requirement would turn Paragraph (4) on its head: if an employer *does not* offer cash in lieu of a

parking subsidy, the parking subsidy itself does not qualify as a tax-exempt fringe benefit and becomes taxable.

Compared with other solutions to the problem of employer-paid parking, the cash-option requirement intrudes least in employers' decisions about employee compensation. Employers who want to subsidize parking without offering an equivalent subsidy for ridesharing could continue to do so. The difference introduced by the cash-option requirement is only that the Internal Revenue Code would no longer reward this discriminatory behavior with a tax exemption for the parking subsidy.

The proposed change is simply that for the parking subsidy to be tax-exempt, an employer who offers to subsidize an employee's parking *if the employee drives to work* must also offer to pay the same amount *if the employee rideshares to work*. Few employers would argue that the Internal Revenue Code should encourage them to confine their commuting subsidies to parking (and thus to employees who drive to work). Also, most employers would find it difficult to argue publicly that employees should not be allowed to choose a ridesharing subsidy as an alternative to an offered parking subsidy.

Benefit to Low-Income and Disabled Employees

Another desirable feature of the cash-option requirement is that, because the lowest-paid workers are in the lowest tax brackets, they would gain the most after-tax cash from a taxable cash allowance in lieu of employer-paid parking. Also, the cash allowance would be larger in proportion to a lower income, so the cash option would clearly improve the relative well-being of the lowest-paid workers. Further, some employees are unable to benefit from the offer of employer-paid parking because they have a physical disability that prevents them from driving to work. Offering disabled employees the option to choose the cash value of any offered parking subsidy would enable them to benefit from parking subsidies to the same extent that employees who are not disabled can. These points directly respond to the conventional criticism that charging for parking is unfair because it harms either low-income workers or those who need to drive to work because of family or personal circumstances. Therefore, on equity grounds, offering employees the option to cash out their parking subsidies seems clearly superior to offering employees the customary choice between a parking subsidy or nothing.

Size and Distribution of Parking Subsidies

A simple way to implement and enforce the cash-option requirement would be to specify that employers report any tax-exempt parking subsidies on their employees' payroll forms in the same way they already report other tax-exempt fringe benefits (such as health care insurance contributions). This reporting requirement not only would tell employees the amount of the cash alternative available to them in lieu of their parking subsidy, but would also provide previously unobtainable data on the extent of total employer-paid parking subsidies, both locally and nationally. Further, the reporting requirement would make explicit—to employers, employees, and policy makers—what parking subsidies go to whom. This "daylight" feature might also focus serious attention on devising fairer and more efficient commuter travel subsidy policies that go beyond (but would not be required by) the obligation to offer cash in lieu of parking subsidies.

Strengthened Central Business Districts

Those who are particularly concerned about the competitive position of central business districts (CBDs) might question whether a seemingly impartial policy of requiring all employers to offer their employees the option to cash out employer-paid parking might somehow harm employers in CBDs where parking prices are highest. There are, however, several compelling reasons to believe that cashing out employer-paid parking would make central cities relatively more, not less, attractive places to work, shop, and conduct business.

Many downtown employers believe that they must offer their employees free parking because the higher cost of downtown parking would otherwise make it difficult to attract potential employees. But employer-paid parking simply equalizes the cost of parking in downtown and suburban work sites (by making it free to the commuter in both places) and does nothing to make a downtown location superior to a suburban location for workers. Because employers must pay more to provide employee parking in CBDs than in suburban locations, they could offer more cash in lieu of a parking space to downtown employees without any increase in cost to themselves. This higher cash option for downtown employees would make downtown work sites relatively more attractive than suburban work sites, at least for those who rideshare. Also, because

downtown work sites are more accessible by mass transit, downtown employees would be better placed to take advantage of the cash option by shifting to mass transit, especially with the new $60/month tax exemption for employer-paid mass transit subsidies. Similarly, downtown work sites are more accessible by carpools because a high density of employment implies a high density of potential fellow carpoolers. Employees who prefer to take the cash and cease driving to work would reduce congestion on routes to downtown, so downtown work sites would become more accessible to everyone, including those who continue to drive to work alone.

Single-occupant-vehicle commuting to work typically accounts for 65 to 85 percent of the total traffic volume to and from the CBD during peak hours (Beebe 1992). One of the current disadvantages of a central location is the traffic congestion on all the routes leading to the CBD, so when commuters voluntarily choose to rideshare if given the cash option, the resulting reduction in congestion can significantly improve the accessibility of downtown employment locations. In addition to the reduction in peak-hour traffic, parking spaces vacated by peak-hour commuters would become available to off-peak visitors, including shoppers, business clients, and tourists, who would find downtown relatively easier to visit. For all these reasons, any fears that cashing out employer-paid parking would weaken the CBD seem quite misplaced.

Tax Revenue Windfall

In making the choice between a parking subsidy or its cash equivalent, employees would have to consider that the cash is taxable whereas the parking subsidy is not. Nevertheless, many employees might prefer after-tax cash to a free parking space. For example, suppose the employer pays $100/month to provide the employee with a free parking space at work. If the employee is in the 30 percent marginal income tax bracket and his or her employer offers a taxable $100 payment in lieu of the tax-exempt $100/month parking space, the after-tax cash would be $70/month. Thus, the employee would "pay" $70/month to park at work. If he or she then chose cash in lieu of the parking space, this choice would prove that the employer's in-kind parking subsidy of $100/month was worth less to the employee than $70/month in cash.

When a commuter voluntarily chooses taxable cash rather than a tax-exempt parking subsidy, federal and state income tax revenues increase.

The tax revenue windfall is an additional benefit above and beyond any reductions in air pollution, traffic congestion, and energy consumption that also result when a commuter voluntarily chooses to cash out a parking subsidy. In the case of an employee choosing $70 in after-tax cash rather than a $100 tax-exempt parking space, the employee would pay $30 extra in taxes and still be better off. This increase in tax payments does not result from any increase in tax rates or from any taxation of previously tax-exempt parking subsidies. Rather it results from voluntary action: cashing out an inefficient in-kind parking subsidy that costs the employer $100 to provide but is worth less than $70 to the employee. Put most simply, cashing out inefficient parking subsidies would convert economic waste into increased tax revenue and enhanced employee welfare at little or no cost to the employer.

The size of the waste created by employer-paid parking is measured by the difference (if any) between what the employer pays to provide the space and the cash value the employee places on receiving the space. In the context of cashing out employer-paid parking, the value the employee places on a parking space is the lowest price at which he or she would "sell" the parking space back to the employer.[7] For example, suppose that $60/month is the lowest price at which an employee would sell a parking space back to the employer. In this case, the employee would choose the option of $100 in taxable cash, receive $70 in after-tax cash, and still be $10/month better off than with the $100/month in-kind parking subsidy. Thus, the option to cash out the parking subsidy would eliminate an economic waste of $40/month, of which the government would capture $30 as an increase in tax revenue, and the employee would keep $10 as a welfare increase.

The taxability of cash in lieu of a parking subsidy would reduce but by no means eliminate the effectiveness of offering the cash alternative as an incentive to rideshare. The taxability of cash is not an argument against offering cash in lieu of parking subsidies. If commuters freely choose taxable cash because they value the after-tax income more than a tax-exempt parking subsidy, how can anyone else argue that they are making the wrong choice? Indeed, choosing the taxable cash equivalent of a tax-exempt free parking space proves beyond any doubt that the parking space is worth considerably less to the employee than it costs the employer.

The research summarized in Table 2 clearly shows that the cost of parking, previously hidden from many commuters by parking subsidies, profoundly influences commuters' mode choices. Many commuters, rather than pay for parking, switch from solo driving to another mode

when asked to pay for parking spaces that they were formerly provided free. Thus, the option of cash in lieu of a parking subsidy would be a strong incentive to carpool, ride mass transit, bicycle, or walk to work. By allowing parking prices to influence commuting choices, requiring employers to offer the in-lieu cash option would reduce traffic congestion, air pollution, and gasoline consumption and would increase federal and state income tax revenue. It would do all this simply by allowing commuters to make travel choices in accord with their own preferences about how they wish to spend their own income.

It might be argued that some commuters would choose cash in lieu of an employer-subsidized parking space, pay taxes on it, and then use the after-tax income to park in a cheaper space without ceasing to drive to work alone. In that case, the employee would be better off (because the employee chose that option), the employer would be no worse off (because the in-lieu cash is no greater than the former parking subsidy), and federal and state income tax revenues would increase. Again, the option to cash out an inefficient parking subsidy (worth much less to the employee than it costs the employer) would convert economic waste into both increased employee welfare and increased government revenue.

How much would tax revenues increase? The following calculations, which are summarized in Table 4, suggest the considerable revenue potential of the required cash option. There were 110 million employees on civilian nonagricultural payrolls in the United States at the end of 1990 (*Economic Report of the President* 1991, 334). According to the 1990 NPTS, 91.4 percent of the American work force (or 100.5 million workers) commute to work by car, and the average vehicle occupancy for work trips is 1.1 persons per vehicle. Thus, 91.4 million cars were driven to work on every business day in 1990. If 90 percent of automobile commuters park free at work (as shown in the introduction to this paper), these data imply that approximately 82 million cars receive employer-paid parking. If the average cost of providing this employer-paid parking is assumed to be $30/month, the total value of all tax-exempt employer-paid parking subsidies would be $30 billion/year.[8] If 20 percent of existing automobile commuters who now get free parking chose the taxable cash alternative (or a mass transit or vanpooling subsidy greater than $60/month), taxable income would increase by $6 billion/year. At an effective marginal tax rate on this income of 20 percent, the increase in tax revenue would be $1.2 billion/year.

In this calculation, the assumed market parking price of $30/month is above the market price of many commuter parking spaces, but those who

TABLE 4 Effect on Income Tax Revenues of Option To Cash Out Employer-Paid Parking Subsidies

1.	Nonagricultural Work Force	110,000,000
2.	Share of Workforce Commuting by Car	91.4%
3.	Number of Workers Commuting by Car	100,540,000
4.	Persons per Car for Work Trips	1.1
5.	Number of Cars Driven to Work	91,400,000
6.	Share of Cars Parked Free at Work	90%
7.	Number of Cars Parked Free at Work	82,260,000
8.	Assumed Average Cost of Parking (per Month)	$30
9.	Total Annual Employer-Paid Parking Subsidy	$29,613,600,000
10.	Share of Drivers Who Will Cash Out Parking Subsidies	20%
11.	Taxable Value of Cashed Out Parking Subsidies	$5,922,720,000
12.	Assumed Marginal Income Tax Rate	20%
13.	INCREASE IN ANNUAL INCOME TAX REVENUE	$1,184,544,000

Sources:
1. Economic Report of the President, 1991, p. 334.
2. 1990 Nationwide Personal Transportation Survey (Hu & Young, 1992, p. 20)
3. (3)=(1)x(2)
4. 1990 Nationwide Personal Transportation Survey (Hu & Young, 1992, p. 22)
5. (5)=(3)/(4)
6. See Section I.
7. (7)=(5)x(6)
8. Assumption. See text.
9. (9)=(7)x(8)
10. Assumption. See Table 1 and text.
11. (11)=(9)x(10)
12. Assumption. See Table 2 and text.
13. (13)=(11)x(12)

now get the biggest parking subsidies would be the ones most tempted to take the cash alternative. Thus, the taxable cash alternative received by those who choose to cash out their parking subsidies should be significantly above the average parking subsidy for all workers. The assumption that 20 percent of those who now park free would choose the cash option is less than the average 37 percent reduction in automobile trips to work found in the case studies comparing automobile use between commuters

who do and who do not pay for parking at work (see Table 2). Finally, the assumed 20 percent combined federal and state income tax and social security tax rate is a conservative estimate of the marginal tax rate faced by those employees who would choose the taxable cash alternative to a parking subsidy. For all these reasons, the estimate of $1.2 billion/year is a deliberately conservative estimate of the income tax revenue that would result from cashing out employer-paid parking subsidies.[9]

CONSEQUENCES OF CASHING OUT EMPLOYER-PAID PARKING

Effects on Commuters' Travel Choices, Expenditures, and VMT

Before policy makers commit to the idea of requiring employers to offer the option of cash in lieu of parking subsidies, they would first want to know how much it would reduce traffic congestion, air pollution, and energy consumption. Previous research, summarized in Table 2, has focused on discovering how employer-paid parking increases solo driving but has not gone on to measure the resulting increases in vehicle miles traveled (VMT), gasoline consumption, and total spending on transportation. To go beyond the simple measure of mode choice to these other more fundamental measures of transportation system performance, it is first necessary to have data not only on how employer-paid parking influences the mode choice of each commuter, but also on the distance traveled to work by each commuter. Fortunately, these additional data are available in a transportation survey of commuters to downtown Los Angeles, which collected data from 5,060 employees working for 118 employers; the statistical sample was designed to represent accurately the entire population of office workers in downtown Los Angeles.[10]

Because the survey included data on both employers' parking subsidies and their employees' travel behavior and socioeconomic characteristics, these data can be used to estimate how employer-paid parking alters employees' travel choices. Because the survey provided information on the parking subsidy policy of each employee's employer, the data permit an accurate estimate of the price for parking faced by each employee, including the parking price that transit riders would have paid if they had driven to work. Few if any other statistical models of mode choice have been estimated with accurate information on parking prices that employees actually pay when they drive to work. Market parking prices are typically

used to represent what commuters pay for parking when mode-choice models are estimated; because of the prevalence of employer-paid parking subsidies, however, market prices clearly misrepresent the prices that commuters actually pay for parking or would have to pay for parking if they drove to work.

Willson (1991) used the employers' responses regarding their parking policy to select two subsamples of employees: the first was all those commuters whose employers do not subsidize any employee parking, and the second was all those commuters whose employers offer free parking to all employees. Willson then used these subsamples to estimate a logit model of commuter mode choice, with employer-paid parking as an independent variable and other more customary variables such as income, occupation, and travel time and travel cost to work by each mode. Willson's model is used here to predict how cashing out employer-paid parking would change commuters' travel choices.[11]

Because cash in lieu of a parking subsidy would be taxable, commuters would forgo the after-tax cash value of their parking subsidy if they chose to continue receiving the parking subsidy. Although commuters could continue to park free at work, they would thus "pay" the after-tax value of their parking subsidy for the "free" parking. Therefore, to estimate commuters' responses to the cash option, it is necessary to estimate how those now offered free parking would respond to an increase in the price of parking to a level equal to the after-tax cash value of the tax-exempt parking subsidy each commuter is offered.

Each commuter in the sample reported his or her annual income, so this reported income can be used to calculate the marginal income tax rate (federal, state, and social security combined) that each commuter would have to pay on any taxable cash received in lieu of a parking subsidy. It is assumed that commuters would react to an opportunity cost of $1.00 in the same manner as to an out-of-pocket cost of $1.00; that is, if a commuter forgoes the commute allowance in favor of free parking, that commuter has in effect "spent" the commute allowance on parking. Since the after-tax value of each commuter's parking subsidy is the "price" that commuter would "pay" for "free" parking, the after-tax value of each commuter's current parking subsidy (taking into account each commuter's marginal income tax rate) was used as the price of parking for that commuter to predict each commuter's probability of choosing each mode.[12]

The predicted commuter mode split resulting from parking prices varying between nothing and $5/day and the cash option reduces VMT by shifting commuters from solo driving to mass transit and carpools. Be-

cause there is very good transit access to downtown Los Angeles, many commuters choose mass transit if they must pay for their own parking at work, and the higher the parking price, the greater the transit share. There is also an increase in carpooling when parking prices rise. It is this mode-split information that has been used to predict commuters' reaction to the option of cash in lieu of employer-paid parking, with the after-tax value of the cash option used to represent the effective price of parking that each commuter would face if the cash option were made available.

Table 5 summarizes the effect on travel outcomes of offering employees the option to cash out their employer-paid parking. The share of commuters who drive to work alone would fall from 69 to 55 percent, and

TABLE 5 Effect on Travel Behavior and Expenditures of Option To Cash Out Employer-Paid Parking Subsidies: Los Angeles CBD Commuters

Travel Behavior or Travel Expenditure	Driver Pays for Parking	Employer Pays for Parking: *With* Cash Option	Employer Pays for Parking: *Without* Cash Option	Effect of Cash Option
1. Solo Driver Share	48%	55%	69%	-14%
2. Vehicle Trips to Work & Parking Spaces Occupied (per Employee)	0.56	0.62	0.75	-0.13
3. Parking Expenditure (per Employee per Year)	$563	$626	$750	($124)
4. Vehicle Miles Travelled (per Employee per Day)	18.1	20.2	24.1	-3.9
5. Vehicle Miles Travelled (per Employee per Year)	3,919	4,383	5,230	-847
6. Gasoline Consumed (Gallons per Employee per Year)	231	258	308	-50
7. Auto Use Expenditure (per Employee per Year)	$1,137	$1,271	$1,517	($246)
8. Parking + Auto Use Expenditure (per Employee per Year)	$1,700	$1,897	$2,266	($369)

Assumptions:

Days Worked per Year	217
Auto Fuel Efficiency (MPG)	17
Auto Use Cost ($/Mile)	$0.29
Cost of Parking ($/Month)	$83.82

1 mi = 1.6 km; 1 gal = 3.8 L.

VMT for trips to work would fall by 3.9 (6.3 VKT) per employee per day, or by 17 percent.[13] Gasoline consumption would fall by 50 gal (189 L) per employee per year, and total expenditure on parking and automobile use would fall by $369 per employee per year.

The data in Table 5 reveal the effects on the per-employee costs. To estimate how cashing out would reduce the total costs caused by employer-paid parking, these per-employee effects must be multiplied by the 69,503 employees who are offered free parking in downtown Los Angeles. Table 6 summarizes and compares the total costs of commuting to downtown Los Angeles under the same three scenarios as those in Table 5.

By shifting commuters from solo driving to ridesharing, offering commuters the option to cash out their employer-paid parking would eliminate 9,000 vehicle round trips per day to downtown Los Angeles. That is, the 69,503 employees who are offered conventional employer-paid parking commute to work in 52,100 automobiles. If offered the option to take their parking subsidies in taxable cash, they would travel to work in 43,100 automobiles. Ending employer-paid parking altogether would further reduce the number of automobiles to 38,900 but would of course also encounter fierce resistance from all those employees who would lose their subsidies. By contrast, employees should welcome the new option to cash out their parking subsidies.

The significance of the 9,000 fewer automobile commute trips can also be expressed in terms of reduced VMT and reduced gasoline consumption. Table 6 shows that cashing out parking subsidies would reduce automobile commuting travel to downtown Los Angeles by 285,000 VMT/day (458 565 VKT/day) or about 60 million VMT/year (97 million VKT/year) and would save 17,000 gal (64 345 L) of gasoline consumed for automobile commuting a day, or about 3.5 million gal (13.3 million L) of gasoline a year. This reduction in VMT would also reduce the external costs these commuters create. The last two rows of Table 6 show that offering these employees the cash option would reduce the total social cost of automobile commuting to downtown Los Angeles by $192,000/day, or about $40 million/year.

To summarize, for commuters to downtown Los Angeles, it is estimated that offering employees the option to cash out their current employer-paid parking subsidies would reduce

- Number of solo drivers to work by 20 percent,
- Number of vehicle trips to work by 9,000 a day,

TABLE 6 Effect on Total Costs of Commuting of Option To Cash Out Employer-Paid Parking Subsidies: Los Angeles CBD Commuters

Travel Behavior or Travel Expenditure (Total per Day)	Driver Pays for Parking	Employer Pays for Parking: *With* Cash Option	Employer Pays for Parking: *Without* Cash Option	Effect of Cash Option
1. Vehicle Trips to Work & Parking Spaces Occupied	38,900	43,100	52,100	(9,000)
2. Vehicle Miles Travelled	1,258,000	1,390,000	1,675,000	(285,000)
3. Gasoline Consumed	74,000	81,765	98,529	(16,765)
4. Congestion Cost Imposed	$252,000	$278,000	$335,000	($57,000)
5. Pollution Cost Imposed	$50,000	$56,000	$67,000	($11,000)
6. External Cost Imposed (Congestion + Pollution)	$302,000	$334,000	$402,000	($68,000)
7. Parking Expenditure	$180,000	$200,000	$241,000	($41,000)
8. Auto Use Expenditure	$365,000	$403,000	$486,000	($83,000)
9. Private Cost of Auto Use (Driving + Parking)	$545,000	$603,000	$727,000	($124,000)
10. Total Social Cost of Auto Use (Private + External)	$847,000	$937,000	$1,129,000	($192,000)
11. Relative Cost	75%	83%	100%	-17%

Assumptions:	
Days Worked per Year	217
Auto Fuel Efficiency (MPG)	17
Auto Use Cost ($/Mile)	$0.29
Cost of Parking ($/Month)	$83.82
Congestion Cost ($/Mile)	$0.20
Pollution Cost ($/Mile)	$0.04
Number Offered Free Parking	69,503

1 mi = 1.6 km; 1 gal = 3.8 L.

- Number of parking spaces demanded by 9,000,
- VMT for trips to work by 285,000/day,
- Gasoline consumption for automobile commuting by 3.5 million gal/year, and
- Total cost of automobile commuting to downtown Los Angeles by $40 million/year, or by 17 percent.

Effects Nationwide

The total number of people employed in downtown Los Angeles accounts for only 3 percent of total employment in Southern California. Therefore, offering *all* employees in Southern California the option to cash out their employer-paid parking subsidies would produce benefits that are far greater than these estimates for downtown Los Angeles alone. Although it is risky to extrapolate from one city to the rest of the country, it is at least instructive to explore the implications for the nation of what has been found for Los Angeles.

According to the estimates shown in Table 5, offering employees in downtown Los Angeles the option to cash out their parking subsidies would reduce average automobile travel per commuter by 3.9 VMT/day (6.3 VKT/day) or by 847 VMT/year (1363 VKT/year) and would reduce average gasoline consumption by 50 gal (189 L) per commuter per year. As estimated earlier, approximately 90 million commuters are offered some form of employer-paid parking. If all these commuters responded to the cash option as has been estimated for commuters in Los Angeles, offering all employees in the United States the option to cash out their parking subsidies could lead to a 76 billion VMT/year (122 billion VKT/year) reduction in automobile travel for commuting and could save 4.5 billion gal (17 billion L) of gasoline a year consumed for automobile commuting. This 76 billion VMT/year reduction in automobile travel is equivalent to 3.5 percent of the total 2.1 trillion VMT (3.4 trillion VKT) traveled by motor vehicles in the United States in 1991. The 4.5 billion gal of gasoline saved is equivalent to 3.5 percent of the total 130 billion gal (492 billion L) of gasoline and diesel fuel consumed by motor vehicles in the United States in 1991 (MVMA 1990).[14]

If cashing out parking subsidies annually reduced 76 billion VMT and 4.5 billion gal of gasoline consumption, the benefits would extend well beyond the transportation and energy sectors. If (as shown in Table 6), the external cost of automobile pollution emissions is $0.04/VMT, reducing automobile travel by 76 billion VMT/year could reduce pollution damage by $3 billion/year. Moreover, given the likelihood that the commuter's car and its fuel are both imported, cashing out employer-paid parking could improve the nation's trade balance.

Combustion of each gallon of gasoline produces 19.7 lb (8.9 kg) of carbon dioxide, so cashing out employer-paid parking subsidies could, by conserving 4.5 billion gal of gasoline annually, eliminate 88.7 million lb (40 million metric tons) of CO_2 emissions. This would make a significant

contribution toward the efforts of the United States to reduce the risk of global warming. For comparison, research done for the Environmental Protection Agency estimated that all the transportation investments funded by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) would eliminate 86 million lb (39 million metric tons) of CO_2 emissions annually (by the year 2000).[15]

Obviously, results generalized from one city to the nation must be viewed with some caution, but there are reasons to believe that cashing out employer-paid parking subsidies could be at least as effective in reducing solo driving elsewhere as has been found in Los Angeles. Table 1 showed that free parking is no more common in Southern California than in the rest of the country. Further, the clichés "Californians love their cars" and "Los Angeles doesn't have a good mass transit system" suggest that it is more difficult to get motorists out of their cars in Los Angeles than it would be elsewhere. Therefore, the annual reduction of 76 billion VMT and saving of 4.5 billion gal of gasoline may underestimate, rather than overestimate, the national benefit of the option to cash out employer-paid parking. In any case, the methods used to estimate the results of cashing out parking subsidies in Los Angeles have been clearly spelled out, so the reader can judge the methods and if necessary modify the estimates for the rest of the country. To achieve national benefits of even one-tenth of these estimates would be a major feat, however, so a marginally more precise estimate should not alter anyone's evaluation of whether offering employees the option to cash out employer-paid parking is a good idea.

Although voluntary conservation of 4.5 billion gal of gasoline a year would be a tremendous achievement, it would also reduce federal and state gasoline tax revenues. At the federal gasoline tax rate of $0.14/gal, the federal revenue loss would be $620 million/year. At the median state gasoline tax rate of $0.16/gal, the state revenue loss would be another $720 million/year. Therefore, total gasoline tax revenues would decline by $1.35 billion/year. This estimated gasoline tax revenue loss is roughly equal in size to the estimated income tax revenue gain of $1.2 billion/year caused by cashing out parking subsidies (see Table 4). Such a large reduction in gasoline tax revenue would be a major concern if the gasoline tax were not a user fee. But because the gasoline tax pays for road use costs, the gasoline tax revenue loss must be considered along with the 76 billion VMT decrease in road use. Cashing out employer-paid parking would reduce tax revenue only because it reduced road use, so the net fiscal effect on highway finance should not be adverse. Further, there are many reasons to believe that the gasoline tax seriously underprices road use, especially at

peak hours when cashing out would reduce VMT the most.[16] Indeed, if the gasoline tax did pay the full cost of road use, there would never be any problem in financing new roads or repairing old ones. Therefore, the net positive fiscal impact of reduced peak-hour VMT and reduced gasoline tax revenue should be a significant additional benefit of cashing out employer-paid parking.

This argument about the net fiscal impact of cashing out parking subsidies can be clarified by comparing it with the very different net fiscal impact of increasing automobile fuel efficiency standards. Increased fuel efficiency reduces gasoline tax revenue without reducing VMT. Indeed, increased fuel efficiency makes driving cheaper and thus would increase VMT. Therefore, increased fuel efficiency standards not only reduce gasoline tax revenue but also increase the demand for highway expenditure.

Another fiscal perspective is gained by comparing cashing out parking subsidies with charging congestion tolls for road use at peak hours. Charging congestion tolls and cashing out parking subsidies are complementary, and in some ways similar, policies. However, there is an important difference. The failure to charge motorists for the congestion they create is a sin of omission—a failure to intervene to raise the price of driving to match its full social cost. In contrast, employer-paid parking is a sin of commission—an intervention that reduces the price of parking below its fair market rate, let alone its full social cost. Ceasing an existing intervention that reduces price below social cost (i.e., cashing out employer-paid parking) is as much of a reform as is introducing a new intervention designed to raise price to equal social cost (i.e., charging congestion tolls). As a matter of priority, is it sensible to introduce new and technically complex congestion tolls to raise the price of automobile trips without first cashing out existing employer-paid parking subsidies that reduce the price of those same automobile trips?

Effects on the General Equilibrium

The predictions in Tables 5 and 6 are based on comparing the observed differences in commuting behavior between individual employees who differ only in that some park free at work whereas others pay for parking. But if the law is changed so that all employees are offered the option to cash out their employer-paid parking subsidies, all employees will suddenly pay for their parking, at least in the sense of forgoing cash or a rideshare subsidy if they take a "free" parking space. The aggregate behavioral

changes that will occur when everyone begins to pay for parking may well differ from the results predicted from behavioral changes observed when individuals begin to pay for parking. For example, if many employees decide to cash out their parking subsidies, what will happen to all the vacant parking spaces deserted by those who quit driving? How can so many more commuters cram onto already overcrowded mass transit? Won't driving become much faster and more pleasant with fewer cars on the road? In other words, is there a fallacy of composition in predicting the consequences of cashing out *all* employer-paid parking by observing the behavior of *individuals* who pay for parking?

Although it is not possible to answer all these questions regarding the general equilibrium results of cashing out all parking subsidies, it is possible to speculate on some of the more likely consequences. Cashing out parking subsidies would decrease the demand for parking among those who now park free, but their cutback on parking space use would increase the supply of parking for everyone else. Therefore, cashing out employer-paid parking may not immediately reduce the number of parked cars, but it would reshuffle cars and commuters in some surprising ways.

First, the option to cash out employer-paid parking would induce some who park free to carpool, especially because so many of those who currently park free would simultaneously be offered a cash incentive to seek out a carpool partner. It is easier to find a carpool partner when everyone else is also seeking one, so carpooling should benefit from economies of scale as a result of cashing out parking subsidies. Thus, more commuters should shift to carpools than would be predicted from either case studies or mode-split models that do not take this benefit of economies of scale for carpooling into account.

Second, with a parking supply that is fixed in the short run, a reduction in parking demand would reduce the market price of parking, and this price reduction would attract other cars to fill the spaces emptied by commuters who had cashed out their parking subsidies. Parking spaces vacated by peak-hour commuters would become available to off-peak visitors, including shoppers, business clients, and tourists, who would find downtown relatively cheaper and easier to visit. Because most work trips occur during peak hours, whereas other trips are spread more evenly through the day, cashing out employer-paid parking should reduce peak-hour congestion en route to and from work.

Third, if the shift to carpools increases the average number of occupants per car by more than it reduces the number of cars driven to work, cashing out could increase rather than decrease the number of commuters who

travel to work by car. That is, more people would commute to work in fewer but higher-occupancy cars; this phenomenon has been observed in case studies after employers began to charge for parking, because some former solo drivers formed carpools not only with other former solo drivers but also with former bus riders.[17] Peak-hour transit ridership could fall as a consequence. The marginal cost of peak-hour commuter transit service far exceeds its farebox revenue, however, so reducing peak-hour demand for mass transit and leveling out transit demand throughout the day should reduce transit deficits and improve transit service.

Fourth, cashing out might redistribute parking spaces in other ways. For example, when the Canadian government began charging its employees for parking in Ottawa, more women began to drive to work because they were more willing to pay for the parking spaces that were vacated by men who had taken a space when it was allocated free on the basis of seniority but were not willing to pay the market price for it. Two commuters began ice-skating to work.

All these effects would occur in the short run, when the supply of parking spaces was fixed. There are more substantial benefits from cashing out parking subsidies, such as reductions in off-street parking requirements and improvements in urban form, that would occur only in the long run, when the supply of parking spaces could be reduced in response to the reduced demand for parking.

CALIFORNIA'S PARKING CASH-OUT LEGISLATION: A FIRST STEP

The Internal Revenue Code creates a strong incentive for employers to pay for their employees' parking and thus a strong incentive for commuters to drive to work alone. States and localities then face the enormous problem of devising policies to deal with the resulting traffic congestion and air pollution. The state of California has recently enacted legislation that directly addresses the problems caused by employer-paid parking and that serves as a model of how the federal government could address the same problems.

California's Cash-Out Requirement

Briefly, the new California cash-out legislation requires that, in any air basin designated by the state Air Resources Board as a nonattainment area,

employers of 50 or more persons who provide a parking subsidy to employees must offer a "parking cash-out program."[18] As defined in the law, a parking cash-out program means

> an employer-funded program under which an employer offers to provide a cash allowance to an employee equivalent to the parking subsidy that the employer would otherwise pay to provide the employee with a parking space. "Parking subsidy" means the difference between the out-of-pocket amount paid by an employer on a regular basis in order to secure the availability of an employee parking space not owned by the employer and the price, if any, charged to an employee for the use of that space. (Section 43845, California Health and Safety Code)

The employer must offer an employee the option to take a cash allowance in lieu of a parking subsidy only if the employer makes an explicit cash payment to a third party to subsidize the employee's parking. Therefore, the employer clearly saves the cash paid for the parking subsidy if the employee takes the cash allowance. The employer's avoided parking subsidy directly funds, dollar for dollar, the employee's cash allowance, so there is no net cost increase for the employer when an employee forgoes the parking and takes the cash. The employer must offer the cash allowance only to each employee who is offered a parking subsidy, not to all other employees. Each employee's cash allowance is equal to the parking subsidy offered to *that* employee, so if some employees are offered smaller parking subsidies than other employees, their required cash allowance is also smaller. Thus, the law is written as tightly as possible to avoid increasing the employer's cost of subsidizing employees' commuting.

As discussed earlier, the cash option could increase costs for employers who (*a*) offer parking subsidies to solo drivers, (*b*) do not offer an equivalent subsidy to ridesharers, and (*c*) nevertheless have a significant number of employees who turn down the offer of a parking subsidy and rideshare to work instead. In this case, the added cost of offering cash to current ridesharers who are offered but have turned down a parking subsidy must be considered the inevitable and wholly justified cost of moving to a commute subsidy policy that removes inequities among employees. Arguing against the required cash option on the grounds that the employer must pay current ridesharers as much as solo drivers is the same as arguing that employers should continue to offer smaller subsidies to ridesharers than to otherwise identical solo drivers. What employer would be shameless enough to make this argument?

It is understandable that legislators would be cautious about imposing any unnecessary cost on employers in the first test of a cash-out requirement. As enacted, the law applies only in the clearest "win-win" situations in which employees will benefit, there is no obvious additional cost to the employer, and there are clear environmental benefits of reduced traffic congestion and air pollution. It seems entirely reasonable to require that an employer who offers to pay for an employee's parking if the employee drives to work must also offer to pay the same amount if the employee rideshares to work.

As proposed in the initial draft legislation, a parking subsidy was defined as the difference between (*a*) the market price of parking and (*b*) the price charged to the employee for parking, including cases in which the parking was owned by the employer or was provided free to the employer as part of the lease for office space. As a result of legislative negotiations, the cash-out requirement was subsequently restricted to situations in which the employer makes a separate, out-of-pocket cash payment to a third party to subsidize the employee's parking. Further, in cases in which an employer makes cash payments for parking under an existing (as of January 1, 1993) lease for the parking, the cash-out requirement does not apply until the lease expires or unless the lease permits the employer to reduce, without penalty, the number of parking spaces leased. Thus employers can continue to provide below-market parking to employees without having to offer the cash equivalent if they (*a*) own their own parking, (*b*) receive it bundled in an office space lease without separate payment, or (*c*) have preexisting long-term parking leases committing them to pay for the parking spaces. In creating these exceptions, the legislature made clear that it intended the cash-out requirement to apply only to employers who can reduce their payments for employee parking and use the cash saved thereby to fund the alternative cash allowance.

It seems only common sense to require that an employer subsidize a ridesharer as much as a solo driver. This is all that the new California legislation requires. As a first step it seems sensible to proceed cautiously, as the California legislature chose to do when it limited the cash-out requirement to cases in which the employer pays out-of-pocket cash to a third party to subsidize an employee's parking. But if the results of the first step prove successful, the way to obtain the full benefits of a market pricing policy for parking would be eventually to extend the cash-out requirement to all employer-paid parking subsidies.

If employers are given sufficient advance notice to plan for the market pricing of parking, and if they are able to learn from the experience of those

who are the first to cash out employer-paid parking subsidies, it does not seem a necessary feature of the California legislation to permanently exempt employers who own their own parking but who could put that parking on the market if their employees did not use it. When employers who own parking spaces can put them on the market, they can earn the market parking price if an employee does not take a free parking space. Therefore, it is a logical next step to say that when an employer could earn money if an employee did not take a free parking space owned by the employer but leasable to someone else, the employer should offer the employee the money that he enables the employer to earn. (If parking is so abundant at the work site that there is no market for parking, the employer would not have to offer any cash in lieu of the owned parking.)

The legislation also exempts employers from the cash-out requirement if they receive parking bundled with office space. But parking space leases can be "unbundled" from office space leases so that there are separate charges for parking and for office space.[19] Office rents are lower when parking is charged for separately rather than provided with the office space. Thus, in the long run, it would make sense to eliminate the cash-out exemption for bundled parking and to work toward a situation in which there is both a parking market and an office space market, without any conventional assumption that parking spaces and office space must come in fixed proportions at a single, all-inclusive price.

Finally, employers of fewer than 50 employees are exempt from the cash-out requirement, but this does not seem to be a necessary feature of the legislation. Why should any employee be denied the option to cash out a parking subsidy and begin ridesharing? Although it makes sense to exempt a variety of parking subsidies from the first trial of the parking cash-out requirement, moving to a genuine market policy for all commuter parking would, in the long run, serve both the employers' and the employees' interests and would further reduce traffic, save fuel, and improve the environment.

History of California Cash-Out Legislation

The first factor leading to passage of the California legislation was the research showing how strongly employer-paid parking has stimulated solo driving. Much of this research was supported by the Federal Transit Administration and the University of California Transportation Center. It was possible to estimate the effects of employer-paid parking by conduct-

ing case studies, either of "quasi-experiments" in which employers desubsidized parking or of side-by-side comparisons in which some employers subsidized parking and otherwise similar employers did not. The gradual accumulation of the evidence, summarized in Table 2, began to convince more and more people that employer-paid parking was an important issue. If there is a lesson here in regard to congestion pricing, the implication is that evidence from congestion pricing demonstration projects (if they turn out well) will certainly help to persuade nonbelievers that congestion pricing is an important issue.

A second factor was the productive relationship between the University of California faculty and the state government in Sacramento. In particular, a series of annual conferences at Lake Arrowhead, organized by Martin Wachs and LeRoy Graymer through UCLA Extension's Public Policy Program, gathered university researchers, legislators, and state officials to focus on the linked problems of transportation, land use, and air quality. The idea of cashing out parking subsidies was presented several times at these conferences, along with the accumulating evidence in favor of it. The cash-out bill that eventually passed (Assembly Bill 2109) was introduced by Assembly member Richard Katz, Chairman of the Transportation Committee, whose chief transportation aide, John Stevens, was on one of the panels where the cash-out proposal was debated.

A third factor leading to passage of the California legislation was the gradual refining of the idea from "charging for parking" toward "cashing out parking subsidies." In particular, there was the precedent of the city of Los Angeles Transit Subsidy Ordinance in 1989. This ordinance requires employers who subsidize parking for any employee to offer a $15/month transit subsidy to all employees. It seemed that if a city could require employers to offer a transit subsidy in lieu of a parking subsidy, why couldn't a city require employers to offer cash in lieu of a parking subsidy? The federal tax exemption causes the employer-paid parking problem, but cities and states do not have to wait for the federal government to change the tax code before requiring the cash option.

The legislation faced an unfortunate setback that is quite instructive for academics intent on influencing policy. In my writing I had focused on the tax exemption for employer-paid parking as the key problem, assuming that readers understood that the tax exemption is for *employees*, not for employers. Employers can deduct the cost of providing parking as a cost of doing business when calculating net business income, but employees do not pay a tax on the receipt of the parking. Those drafting the legislation assumed, however, that the problem was the employer's tax deduction,

not the employee's tax exemption. The reform proposed in the first draft of AB 2109 was to eliminate the *employer's* deduction for providing parking when calculating net business income for purposes of the state income tax. When this first draft of the legislation was circulated, it naturally drew a storm of protest from employers, who pointed out its many flaws. First, it was a tax increase for employers. Second, many employers would not be able to separate out the expenses they incurred to provide employee parking, especially if the employer already owned the parking spaces or if the parking was provided without separate charge in a lease for office space. Third, it did not apply to public or nonprofit employers who do not pay income taxes.

A further problem with the draft legislation was that it exempted from the employee's state taxable income any cash payments received in lieu of a parking subsidy. If an employer offered *only* a cash travel allowance and no parking subsidy, the cash travel allowance would presumably be taxable because it was not offered in lieu of a parking subsidy. But if the employer offered a parking subsidy *or* cash (so the cash in lieu of a parking subsidy would be tax-exempt for the employee), and the employee took the parking, the employer could not deduct the cost of the parking as a business expense.

I was dismayed to see that what I thought was such a simple proposal could have been so misinterpreted. The lesson for academics is that one shouldn't assume that legislators understand what one is proposing. I wrote to Assemblyman Katz to propose a rewording of the legislation to focus on the tax consequences for the employee, not the employer. Erik Lange, a lawyer and legislative aide to Assemblyman Katz, rewrote the bill extensively and added an inventive twist in response to employers' testimony at legislative hearings. Employers complained that it was unreasonable for local governments to require developers to provide parking for employees and the state government to require employers to offer employees cash for not using that parking. In response, the cash-out requirement was scaled back to apply only to employers who make regular cash payments to a third party to secure employee parking, so that whenever an employee takes cash, the employer clearly saves an equivalent amount on paying for parking. Also, the legislation requires local governments to reduce parking requirements when a developer implements a cash-out program.

With these amendments, AB 2109 easily passed in both the Assembly and Senate transportation committees and passed in the Senate with a large bipartisan majority. In the Assembly it passed on a strict partisan vote; the

only Republican who voted in favor of it is well known for his strong advocacy of splitting California into two separate states, North and South, so perhaps he hoped this bill would further that purpose. The almost unanimous Republican opposition puzzled me, because I had assumed that cashing out parking subsidies would be seen as a quintessentially market-oriented policy. I have since asked several Republican legislators why they voted against the bill, and their explanation is that the vote was late in the year and no one had time to study the bill. After I explained the bill to them, they said they liked it.

Finally, Republican Governor Pete Wilson signed the legislation in fall 1992. I am told that his aides in the Office of Policy Research were initially concerned that the bill intruded into collective bargaining and employers' decisions regarding employee compensation, but the bill was supported by the appropriate advisors in the administration (from the Department of Transportation and the Air Resources Board), many of whom had attended the conferences at Lake Arrowhead where the cash-out proposal had been discussed. Also, when employers and their lobbyists who had initially testified against earlier drafts of the bill were telephoned, all reported that the bill had been sufficiently amended to meet their objections.

Reasons for Success of California's Cash-Out Legislation

After the preceding political background, one may speculate on why cashing out parking subsidies became the law in California whereas congestion pricing, a much older idea, has had little political success. Four aspects of cashing out parking subsidies suggest possible criteria for choosing politically successful congestion pricing demonstration projects.

Incremental Nature of the Policy Change

Change, to be accepted, must usually be incremental. Problem-solving often means finding the next steps that can practically be taken toward ultimate goals. Cashing out parking subsidies, especially in the form that was legislated in California, requires very little change in the way most employers conduct their business. The required cash option is minimally intrusive on both the employers' and the employees' decisions because employers can continue to subsidize parking so long as they offer em-

ployees the option to choose cash instead. The political bargaining that led to the passage of California's cash-out legislation resulted in exempting employers who own their own parking or who have a long-term lease that does not allow them to reduce the number of spaces they rent. Thus, implementation will begin first with the clearest "win-win" case, in which the employer pays out-of-pocket cash to a third party to subsidize employee parking. In this case the employer's avoided parking subsidy directly funds, dollar for dollar, the employee's cash allowance, so there is no net cost increase for the employer when an employee forgoes the parking and takes the cash. Later, after employers have been given sufficient advance notice to adjust to the emergence of a market where parking spaces are allocated by price rather than by subsidy, another incremental step would be to extend the cash-out requirement to all employer-provided parking.

In regard to congestion pricing, one suggestion for a similarly incremental demonstration project would be to modify an existing flat toll on a congested bridge or tunnel rather than to introduce a new toll for a previously free facility.

Minimal Income Redistribution

One notable aspect of cashing out employer-paid parking is that it does not significantly redistribute any income. With minor exceptions, those who now receive a parking subsidy would continue to receive a subsidy, and those who do not receive a subsidy would continue to not receive a subsidy. Although the external benefits such as cleaner air and reduced congestion would accrue to everyone, the private benefits of cashing out parking subsidies would accrue to those who are already subsidized. In this sense, cashing out employer-paid parking appeals to the concept of equity defined as "everyone gets what they are accustomed to getting." If existing parking subsidies are unfairly distributed, cashing out would not require any change in this unfair distribution, although putting an explicit cash value on this unfairness might eventually lead to a redistribution of subsidies (such as an equal travel allowance for all employees) that is fairer when judged by the usual standards.

In regard to congestion pricing, a similarly nonredistributional demonstration project might be a revenue-neutral toll change on an existing facility. Any revenue gained from raising the toll at congested hours could be used to reduce the toll at off-peak hours. Any increase in tolls for solo drivers could be used to reduce tolls for higher-occupancy vehicles. In

general, the toll revenue should be redistributed to compensate those who will pay them, as proposed by Small (1992).

High Benefit/Cost Ratio

Another notable advantage of cashing out employer-paid parking is that it promises large benefits in relation to the cost. In cost/benefit analysis, there is a tradition of measuring only efficiency costs and benefits and of neglecting transfer costs and benefits. But for a political analysis, transfer costs and benefits seem as important as efficiency costs and benefits. Both the transfer and the efficiency costs of cashing out employer-paid parking are very low. The transfer benefits are also quite low and consist only of the cash payments that would accrue to those who are now offered a parking subsidy but have not taken it. What is left is a large efficiency benefit consisting of (*a*) increased welfare for employees who cash out their parking subsidies at no cost to their employers, (*b*) increased income tax revenue, and (*c*) the social benefits of reduced congestion, energy consumption, and air pollution.

In regard to congestion pricing, the implication is that proposals for demonstration projects should be judged on the basis not only of their expected efficiency benefits and costs, but also of their expected transfer benefits and costs. A high ratio of efficiency benefits to transfer costs would be a desirable feature, even if pure transfer costs (which are offset by transfer benefits) are disregarded in a conventional benefit/cost ratio. The most promising places to undertake demonstration projects might be in those locations where the inefficiency caused by the lack of congestion pricing is greatest and where the congestion tolls would redistribute income the least.

The Right Name

Another possible contributing factor in the legislative success of cashing out employer-paid parking was finding a more politically acceptable term than "paying for parking." Although the evidence clearly shows that employer-paid parking converts potential carpoolers and transit riders into confirmed solo drivers, no one will become popular by recommending that commuters pay for their parking. I know this from personal experience. The situation changed, however, when I began to recommend "cashing out parking subsidies." At one California Assembly hearing where I testified about the problems caused by employer-paid parking and

recommended the cashing-out solution, I was followed by a union official who began by saying that he knew of cases where a whole factory would go out on strike if an employer so much as removed a Coke machine from the shop floor. He told the Assembly members that free parking for employees was a nonnegotiable right. I sat there fearing what he would say next, and especially what he would say about me. I was very relieved, however, when he then said, "But I liked what the professor just said." He liked the idea that employees would continue to get free parking, and he liked the idea that they could cash it out. The option to take cash in lieu of free parking means, of course, that a commuter who takes the "free" parking in effect pays for it by forgoing the cash.

There are a number of other policies that the right name has helped to sell, and I suggest that advocates of congestion pricing search for a better name to market the idea. Some examples of euphemisms that have softened the path for some difficult policies are "traffic calming" for "traffic barrier," "green fee" for "pollution tax," and "pay at the pump" for "gas tax." Perhaps as a start it should be made clear that the goal of pricing is to promote the free flow of traffic, that it can be revenue neutral rather than a tax increase, and that there are discounts for off-peak use rather than surcharges for peak use.

SUBSIDIZING PEOPLE RATHER THAN PARKING

California's cash-out legislation requires employers who subsidize employee parking to offer employees the option to take their parking subsidies in cash. Other states could enact similar legislation, but it should be obvious that the Internal Revenue Code's special tax exemption for employer-paid parking is the root cause of the employer-paid parking problem. Employers are not responsible for the employer-paid parking problem. They are simply carrying out the public policy embedded in the Internal Revenue Code. It should not be left for every state to enact complicated legislation like California's that is designed solely to counteract a small, serious, but easily remedied flaw in the Internal Revenue Code.

The case has been argued here for amending the Internal Revenue Code's definition of tax-exempt "qualified parking" to require that an employer who offers an employee a parking subsidy must also offer that employee the option to take, in lieu of the parking subsidy, the fair market value of the parking subsidy, either as a taxable cash commute allowance or

as a mass transit or a ridesharing subsidy. Employers could continue with any existing parking subsidy arrangement so long as they broadened the offer to include the option of using the cash value of the parking subsidy for mass transit, ridesharing, or any other purpose the employee prefers.

The political bargaining that led to the passage of California's cash-out legislation suggests that at the federal level, it may be appropriate to implement the cash-out requirement in stages, beginning first with the clearest "win-win" case, in which the employer pays out-of-pocket cash to a third party to subsidize employee parking. In this case the employer's avoided parking subsidy directly funds, dollar for dollar, the employee's cash allowance, so there is no net cost increase for the employer when an employee forgoes the parking and takes the cash. Later, after employers have been given sufficient advance notice to adjust to the emergence of a market in which parking spaces are allocated by price rather than by subsidy, the cash-out requirement could be extended to all employer-provided parking. To repeat, however, the proposal is not to prohibit, tax, or even discourage employer-paid parking. Rather, the proposal is simply that an employer who offers to pay for an employee's parking *if the employee drives to work* must also offer to pay the same amount *if the employee rideshares to work.*

Because cash is taxable and a parking subsidy is tax-exempt, offering employees the option to cash out parking subsidies would reduce solo driving to work by less than would ending parking subsidies altogether. The research on commuters in Los Angeles, however, suggests that the taxable nature of cash does not seriously diminish commuters' response to cash. Requiring employers to offer employees the option to cash out their parking subsidies would reduce traffic congestion, improve air quality, conserve gasoline, enhance employees' welfare without increasing employers' costs, and increase tax revenue without increasing tax rates. All these benefits would derive simply from subsidizing people, not parking.

ACKNOWLEDGMENTS

Parts of this study are condensed from a report to the Federal Transit Administration, *Cashing Out Employer-Paid Parking* (FTA-CA-11-0035-92-1, Dec. 1992). The full 155-page report is available from Office of Technical Assistance and Safety, Federal Transit Administration, U.S. Department of Transportation, 400 Seventh Street, S.W., Washington,

D.C. 20590 or from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.

NOTES

1. Even in areas where the posted price of parking appears prohibitively high, the validation of parking charges means that parking is free to the driver, and thus is no disincentive to driving. High market prices for parking encourage ridesharing only if the driver personally pays for the parking. Most parking charges, where they exist, are validated for the driver. As one personal example, I served for several years on committees of a civic organization, Los Angeles 2000, which met at the Bank of America tower in downtown Los Angeles. After every meeting, all the dignitaries always lined up on the way out to have their parking tickets validated. After one agonizingly long meeting, a group of us were waiting in the basement garage for our cars to be delivered by the valet parking attendants (we had, as usual, all driven solo). Chancellor Young of the University of California, Los Angeles (UCLA), pointed out with horror that the posted price of parking was $2.50 for every 20 minutes (all of us had parked long and often in that underground garage, but no one had ever seemed to notice the posted parking prices). Although none of us had ever paid a penny to park, everyone instantly agreed how expensive it was to park downtown. Those high parking prices, however, never prevented any of us from driving alone.
2. This measure includes vehicles driven by carpoolers and vanpoolers as well as by solo drivers. Most of the case studies contained information on the number of employees who carpool but not on the average carpool size. The value of one vehicle per 2.62 carpool or vanpool commuters was used to estimate the number of cars driven to work by carpoolers; this value was found in the *1988 Commuter Survey* of Southern California commuters (Commuter Transportation Services, Inc. 1988). The resulting number of cars per 100 employees is quite insensitive to moderate variations in this assumption.
3. In general, when there is a large price change, the preferred measure of elasticity of demand is the logarithmic arc elasticity, but this measure is undefined when a price is raised from zero. Therefore, the elasticities in Table 2 are calculated as the linear arc elasticity, or "midpoint" elasticity, which approximates the average elasticity between two points along a demand curve. To calculate the midpoint elasticity, the percent change in price is defined as the absolute change in price divided by the average of the two prices between which elasticity is measured. Similarly, the percent change in quantity is defined as the absolute change in quantity divided by the average of the two quantities between which elasticity is measured. Because each case study examined the results of raising the price of parking from zero to a market price, the change in market price is equal to the market price, and the average of the two prices (zero and market) is always half of the market price. The percent change in price is thus 200 percent, and the midpoint elasticity is always half of the percent change in quantity.

4. It may seem unconventional to assert that the price elasticity of demand for parking at one site should be lower than the price elasticity of demand for parking at all sites. The conventional argument is that if only one firm in an industry raises its price, the observed elasticity will be greater than if all firms in the industry raise their prices. This is so because customers can purchase substitutes for any one firm's product from all other firms in the same industry, but cannot so easily purchase substitutes for a whole industry's product from other industries. But that firm-versus-industry argument applies when all firms in the industry produce similar and competing products or services, and parking at different locations may be seen as complements, not substitutes for one another. Therefore, the lower the price for parking elsewhere, the lower is the elasticity of demand for parking at a work site to which commuters must travel.
5. For example, UCLA spent $54 million to build its most recent campus parking structure (at a cost of $27,000 per additional parking space) but has never offered its employees the available option of a tax-exempt $21/month transit subsidy in lieu of a parking space.
6. By contrast, the Los Angeles transit subsidy ordinance requires an employer who offers a parking subsidy to *any* employee to offer a $15/month transit subsidy to *all* employees. This blanket requirement is far more intrusive than a requirement that only employees who are offered a parking subsidy be offered a transit subsidy, and still the Los Angeles transit subsidy requirement has aroused no opposition from employers.
7. This price at which employees would be willing to sell the space may be higher than the price they would be willing to pay for the parking space if their employer did not provide it "free."
8. An unpublished but well-circulated study (The Dimensions of Parking) done by Peat, Marwick for the U.S. Department of Transportation estimated that the total value of all employer-paid parking subsidies in the United States is $52 billion/year, or approximately 1 percent of the $5.5 trillion gross national product (GNP) in 1990. By comparison, the estimate here of $30 billion/year (still over 0.5 percent of the GNP) is very low.
9. Although the chain of data and assumptions necessary to make this revenue estimate is long, Table 4 shows each step and allows the reader to examine the consequences of varying any assumption. The employers' taxable income and tax payments would be unaffected if the new cash travel allowances were funded by replacing previous parking subsidies.
10. The Los Angeles CBD Employee-Employer Baseline Travel Survey was undertaken by the Community Redevelopment Agency of the city of Los Angeles in 1986; see paper by Willson and Shoup (1990b) for a full description of the survey.
11. See papers by Willson (1991) and Shoup and Willson (1992) for more detail on the estimation of this logit model. The model was initially estimated with data on both those who pay to park and those who park free. The model was then used to predict how varying the price of parking would affect the mode choices of all commuters in the subsample who park free. Thus, it predicts how those

who are now offered employer-paid parking would have behaved if they had not been offered employer-paid parking.

12. See paper by Shoup and Willson (1992) for the schedule of marginal income tax rates applied to commuters' incomes and by Willson (1991) for a description of the mode-choice model.
13. Note that allowing employees the option to cash out their parking subsidies would reduce average VMT by approximately two-thirds as much as would the politically unpopular although analytically superior policy of charging everyone the full market price for parking at work.
14. It is important to note, however, that the full benefits of cashing out parking subsidies would not materialize unless minimum parking requirements in municipal zoning ordinances were adjusted to the reduced demand for parking.
15. The 39 million metric ton reduction in CO_2 emissions is the "optimistic" estimate. The "conservative" estimate is 36.6 million lb, or 16.6 million metric tons (Apogee Research 1992, 1).
16. MacKenzie et al. (1992) estimate that gasoline taxes and user fees cover only about 60 percent of public spending on roads.
17. For example, see paper by Surber et al. (1984). In their evaluation of commuters' responses to Regulation XV, Giuliano et al. (in press) found that the average solo driver share fell by 6 percent and the carpool share rose by 33 percent, but the bus share did not change at all.
18. A nonattainment area is one that does not meet the state's ambient air quality standard. Because all major metropolitan areas in California are nonattainment areas, the cash-out requirement applies to almost all employers of 50 or more persons in the state.
19. Commuter Transportation Services (1992) conducted a survey regarding parking leasing practices of employers in high-density office centers in Southern California. The purpose of the survey was to assess how many employers would be affected by California's cash-out legislation. Fifty-eight percent of employers reported having separate, unbundled leases for parking in order to provide parking for their employees. Seventy-one percent of employers in downtown Los Angeles reported having separate leases for parking.

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The New York Region
First in Tolls, Last in Road Pricing?

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The existing tolls on roads, bridges, and tunnels in the United States constitute a logical first step in implementing the concept of road pricing. It stands to reason that where tolls are already in effect it will be easier to institute variable tolls, with higher tolls levied during more congested periods. Accordingly, experiences with tolls in the New York metropolitan area are reviewed. More toll revenue is collected in this region than in any other in the nation. Over 45 percent of the $3.7 billion in U.S. toll revenue is collected in New York and New Jersey. Half of that is collected by the Port Authority of New York and New Jersey (PANYNJ) and the Triborough Bridge and Tunnel Authority (TBTA) at facilities that are located in or connect to the five boroughs of New York City.

The Port Authority owns and operates six tolled bridge and tunnel crossings connecting the two states. Seven more toll bridges are operated by TBTA. Six connect boroughs of New York City. Elsewhere in the two states the New York Thruway Authority operates a toll road almost 500 mi (805 km) long from Buffalo to New York, which includes the Tappan Zee Bridge across the Hudson River, and a second road connecting New York City with Connecticut (Interstate 95). The New Jersey Turnpike is a highway network that runs the length of the state from the George Washington Bridge in the north to the Delaware Memorial Bridge in the south. The New Jersey Highway Authority operates the Garden State Parkway, a 170-mi (274-km) toll road from the northern border of the state to Cape May in the south. Tolled parkways in the Hudson Valley north of New York City complete the complement of tolled facilities in the region.

TRAFFIC INTO MANHATTAN

Vehicle traffic in the Manhattan central business district (CBD) has long been a problem of legendary proportions. Automobile travel speeds in midtown Manhattan now average only 7.5 mph (12 km/hr) on north-south streets and barely 5 mph (8 km/hr) on east-west streets (NYCDOT 1989). Since 1948 the number of people entering the CBD in automobiles and taxis has just about doubled from 388,000 to 761,000 daily. The increase from eastern entry points across the East River (from Long Island) has swelled by about 2.3 times from 135,000 to 310,000 and the increase from the west across the Hudson River (New Jersey) has grown by a similar rate from 43,000 to 101,000. Of the 3.3 million people entering the CBD daily, 34 percent now enter in automobiles and taxis, up from 18 percent in 1946.[1] Because Manhattan is an island, automobile traffic entering the CBD, with the exception of that originating in Manhattan north of the CBD, must cross a bridge or go through a tunnel.

The East River separating geographic Long Island from Manhattan is crossed by six facilities connecting Long Island directly with the CBD. Four, owned and operated by the city of New York, are free. They are, from south to north, the historic Brooklyn Bridge, the Manhattan Bridge, the Williamsburg Bridge, and the Queensboro Bridge (also known as the 59th Street Bridge). Two are owned and operated by TBTA—the Brooklyn Battery Tunnel and the Queens-Midtown Tunnel. The Triborough Bridge, a third TBTA crossing of the East River, connects a third borough, the Bronx, with Manhattan north of the CBD. It carries many vehicles that eventually cross into the CBD.

To the west, the Port Authority's crossings of the Hudson include two that connect directly with the Manhattan CBD—the Lincoln and Holland tunnels—and a third, the George Washington Bridge, that connects with Manhattan north of the CBD in much the same way that the Triborough Bridge does to the east. Three other Port Authority crossings connect New Jersey with Staten Island. There are no free crossings of the Hudson River in the metropolitan region.

PORT AUTHORITY AND BULK TOLL DISCOUNTS

The concept of bulk discounts at toll crossings serves many purposes. For the toll agency, the discounts convert to faster collection and lower labor costs. For the motorist, the queues at toll barriers decrease and the price is

lower. However, there are other impacts that are less positive. Bulk toll discounts tend to be available and useful for commuters, encouraging the use of vehicles during peak periods. This runs counter to the economic principle that the price of a scarce commodity should be higher. Road capacity in the peak period, especially in the New York metropolitan region, certainly qualifies as a scarce commodity. Lower tolls for peak users also encourage potential transit users to remain in their automobiles.

Discounts for bulk use have always been in effect on the Port Authority crossings. Upon their opening, each of the six PANYNJ crossings collected a $0.50 toll each way for passenger cars until 1970, when a $1.00 one-way toll was introduced. The toll was increased to $1.50 in 1975 and then in 1984 to $2.00. In 1987 the toll was raised to $3.00 and in 1991 to $4.00. When the round-trip toll was $1.00, a discount book costing $10.00 with 20 coupons that had to be used within a 35-day period was available. The coupons were valid for all six crossings. This amounted to a 50 percent discount. Since most of those who used the facilities often enough to benefit from the discount were traveling to and from work, and since most of them tended to travel in peak periods, the discount provided a lower toll in the peak, contrary to the principles of road pricing. The effect was to give the peak-period user a price break, undermining transit use and creating more peak-period congestion. When the tolls were increased in 1975 and 1984, the discount book was increased by the same rate, maintaining the same 50 percent discount.

In 1987 the Port Authority raised the base toll by another dollar to $3.00. This time the 20-coupon book was increased from $20.00 to $40.00, resulting in a lower bulk discount of only 33 percent while maintaining the same absolute difference in value for the bulk discount. For those who had argued for the elimination of the entire discount as a first step toward road pricing, this represented a modest move in the right direction.

In 1991 the Port Authority proposed to raise the base passenger car toll to $4.00 and to reduce the discount to only 10 percent by charging $72.00 for the 20-coupon book, or $3.60 per round trip. For those who had taken advantage of the bulk discount this represented an increase of over 140 percent in their tolls, even though the base toll was to increase by only 33 percent. Residents of Staten Island were particularly upset and lobbied the Governor of New York to reduce the price of the discount book.[2] They argued that they did not have a choice other than to drive, whereas users of the three other Port Authority crossings could use public transit, and that because of their island geography, they were at the mercy of the toll authorities. (Besides the three Port Authority crossings between Staten

Island and New Jersey, TBTA operates the only other bridge between Staten Island and the rest of the world, the Verrazano-Narrows Bridge.[3]) Governor Cuomo of New York affirmed the position of the Staten Island residents, rolling back the bulk toll for the three Staten Island bridges operated by the Port Authority to the existing $40.00 per book, deepening the discount to 50 percent from the previous 33 percent. Since parity by the governors of the two states is viewed as a political necessity when it comes to Port Authority matters, Governor Florio agreed to the reduction of Staten Island toll increases only if there was a partial rollback of the bulk toll for those using the George Washington Bridge. A constituency had also begun to build in northern New Jersey for a rollback and also for a rollback of the proposed fare increase on the Port Authority-operated Port Authority Trans-Hudson (PATH) rapid transit system, used mostly by New Jerseyans. Only those using the Lincoln and Holland tunnels were subject to the sharp increase in the cost of the bulk discount.

The Port Authority toll history described above is summarized in Table 1.

The concept of road pricing is to charge more for use of highway facilities when and where they are most congested, with the expectation that drivers will choose either a different time or a different route. The history of attempts to eliminate the bulk discounts for Port Authority tolls

TABLE 1 Port Authority Toll Bulk Discount History

Year	Base Toll Two-Dir.	20-trip Book	Price per Round trip	Percent Discount
To 1975	$1.00	$10.00	$0.50	50
1975-84	$1.50	$15.00	$0.75	50
1984-87	$2.00	$20.00	$1.00	50
1987-91	$3.00	$40.00	$2.00	33
1991 on	$4.00	$72.00	$3.60	10
		$60.00	$3.00	25
		$40.00	$2.00	50

Note: The $72 book established in 1991 could be used on all crossings, the $60 book on only the George Washington Bridge and the $40 book only for the three Staten Island crossings.

suggests the political difficulty that will likely arise when tolls already in place are raised for peak-period travel. Because toll increases often affect one geographic market disproportionately, the likelihood of organized political opposition is great. In the case of Staten Island, the residents have long believed that they were discriminated against because their borough is the least populated and the most removed in New York City. In fact, they are currently contemplating secession from New York City. These attitudes have resulted in a close-knit, politically aware, and active populace. When the toll increase was proposed, they argued as a voting block. Their arguments are not without foundation. As islanders they are dependent on the tolled facilities. Their transit options for trips other than to the Manhattan CBD are poor or nonexistent, and even their transit options to Manhattan are poor, often involving multiple transfers and slow service.

In 1979 the Port Authority published a study (PANYNJ 1979) of peak-period pricing concepts and examined the elimination of the commuter discount book. Peak-period pricing was rejected because it offered no reduction in delays at the three Hudson River crossings. The study projected that the gains in congestion reduction caused by the variable pricing ($3.00 in the peak and $1.00 in the off peak) would be offset by the losses from the elimination of the discounts. The combination was rejected because of concerns about sharp price increases for drivers who had no choice but to drive in the peak and about safety at toll price changeover time. At the time, using electronic toll collection to offset the increased delays that would be caused by the elimination of the discount books was not yet a serious consideration.

In the case of the New Jerseyans who argued for a rollback of the George Washington Bridge tolls, they too were geographically well defined. Fifty-six percent of George Washington Bridge automobile users in the morning peak period reside in Bergen County, New Jersey. Another 17 percent live in Rockland County, just to the north in New York State. Their arguments about the absence of transit alternatives to their automobile trips across the tolled bridges are somewhat weaker than the arguments of Staten Islanders, but still have merit. Those two counties have the lowest transit share for trips to the CBD than any counties west of the Hudson (see Figure 1), largely because of the relative unattractiveness of the transit options for travel to Manhattan. In contrast, users of the Lincoln and Holland tunnels are geographically dispersed, and no concerted opposition to the bulk discount resulted.

In the long run it seems that to break through the legitimate arguments against higher peak-period tolls, quality transit options need to be put in

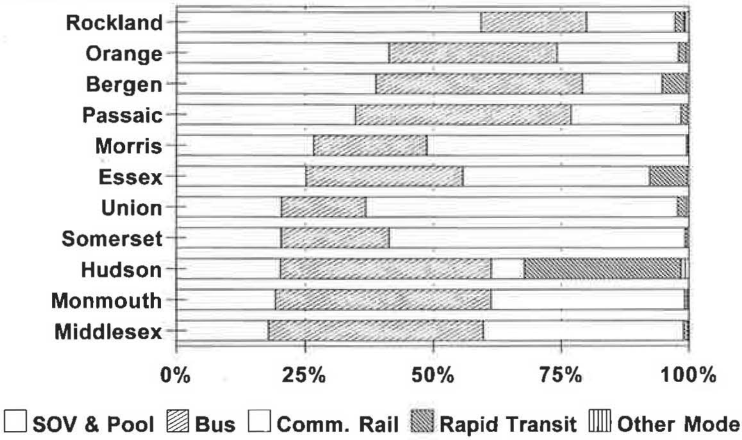

FIGURE 1 Modal shares to CBD: worktrips, 1980.

place. This could be done by using some (or all) of the added toll funds raised to improve the transit system. Elsewhere, voters have taxed themselves to raise funds for transit improvements.

Across Manhattan, the TBTA toll facilities have always had a mild bulk discount. The passenger car toll on the TBTA tolled crossings of the East River was recently (January 1993) raised from $2.50 to $3.00 one way and is collected in each direction. A bulk discount of 16.7 percent is available by purchasing of a roll of tokens. Given this method of distribution, there is no time limit on the use of the tokens. Throughout the 1980s the toll on the four crossings (and on other TBTA facilities) has been raised six times. Each time the discount was retained and increased slightly. In 1982 the bulk buying of tokens resulted in a 12 percent discount. Today it is up to 16.7 percent. Table 2 shows this toll history.

One might question the seeming ease of imposing toll increases on the TBTA facilities suggested by the toll history in Table 2. However, these increases have been most heavily opposed by bridges users who are geographically concentrated. The TBTA operates the Verrazano-Narrows Bridge, used most heavily by Staten Islanders. Residents of that borough have been successful in fighting off the increases at that crossing by the creation of deep discounts for residents, just as they have for the Port Authority crossings to Staten Island. Similarly, residents of the Rockaway area of Queens, a barrier beach peninsula with limited alternatives to two TBTA toll bridges, have lobbied successfully for discounts for their residents.

TABLE 2 TBTA Toll Bulk Discount History

Date	Base Toll One-Dir.	Discounted Token	Percent Discount
4/14/82	$1.25	$1.10	12.0
1/3/84	1.50	1.30	13.3
1/1/86	1.75	1.50	14.3
2/7/87	2.00	1.70	15.0
6/1/89	2.50	2.10	16.0
1/31/93	3.00	2.50	16.7

TOLLING THE FREE EAST AND HARLEM RIVER BRIDGES

Since the 1970s there has been discussion about introducing tolls on the four free crossings of the East River and on nine vehicle crossings of the Harlem River, which separates upper Manhattan from the Bronx. Figure 2 shows dramatically the high incidence of automobile use into the Manhattan CBD from the counties that feed these crossings. Approximately 130,000 commuters who reside in Queens, Brooklyn, Nassau, and Suffolk use automobiles each work day to cross the East River. In 1973, in response to the Clean Air Act of 1970, tolling these crossings was included in the New York State Transportation Control Plan. The intent was to improve air quality through the reduction of the amount of vehicle-miles of travel (VMT) by encouraging some drivers to shift to transit and causing others to reduce circuitous travel to avoid the existing tolls. The proposal led to an extended and vociferous battle in and out of the courts, which will not be fully recounted here.[4]

Those against the imposition of tolls argued that the tolls were regressive, affecting the lower- and middle-class residents of Brooklyn, Queens, and the Bronx, whereas higher-income residents of Manhattan, most of whom did not use the crossings, were unaffected. Cries of Manhattan elitism were heard, fueled by *New York Times* editorials in favor of the tolls. The issues of added congestion and carbon monoxide pollution in the vicinity of the toll barriers were also raised. Particularly galling to residents

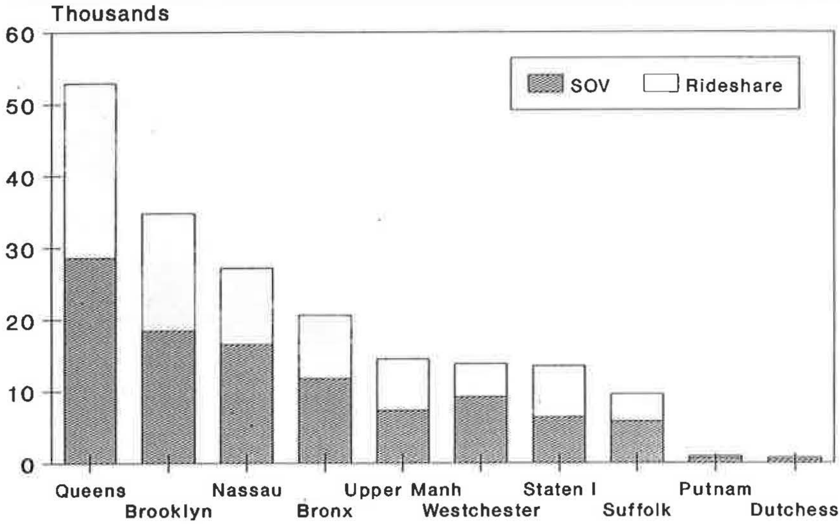

FIGURE 2 Work trips by automobile to CBD from east of Hudson River, 1980.

of Brooklyn and Queens was the fact that the toll barriers were to be placed at the east end of the crossings. Others argued that the tolls would be an economic burden to businesses and drive them from the city. Mayor Beame, in a fit of hyperbole, stated that the tolls would make a "ghost town" of New York.

One report during that period, *The Manhattan Auto Study* (Schwartz 1973), argued for variations in tolls by time of day, direction, and occupancy. The discussions all became moot when Senator Moynihan and Congresswoman Holtzman of Brooklyn sponsored a successful amendment to the Clean Air Act that allowed the tolls to drop if replaced by undefined public transportation improvements.

The issue resurfaced briefly in the mid-1980s when the new city transportation commissioner, Ross Sandler, a proponent of tolling the free crossings when he was Director of the Natural Resources Defense Council, suggested it as one of many options to reduce traffic congestion. The city administration saw little support for the tolls and the matter was dropped.

New York City fiscal difficulties have resulted in seriously deferred maintenance of the city's 800 bridges, including the four well-known ones crossing the East River. Frequent closings for emergencies, some for a year or more, have heightened the public's awareness of the problem. In that

light, the Mayor's Management Advisory Task Force reopened the toll issue by proposing that tolls be imposed to repair the bridges. It was argued that the tolls that would be raised by imposing toll levels equal to the TBTA tolls, estimated at $600,000,000 per year, would ensure that the bridges were maintained and made safe, that they would provide fiscal relief, and that they would relieve congestion and improve air quality. It was also argued that the diversion away from the previously free crossings to the TBTA facilities would raise revenues that could be put into the transit system, since TBTA already contributed excess revenue to keep the transit fares down.[5] An independent authority was proposed that could float bonds at a more favorable rate than the city could command.

The task force hit some of the anticipated objections head on. In addition to the focus on the revenue-raising potential of tolling the free bridges, it was argued that the congestion and pollution problems associated with new toll barriers could be overcome with electronic tolls. The argument that the technology was unproven was countered by pointing out that the major toll agencies in the region were all cooperating on choosing a common technology for toll collection (electronic toll collection will be discussed in greater detail later). The argument that only a small percentage of motorists would use the automatic tolling devices, leaving long queues at the toll barriers, was countered by the argument that the crossings are now largely used by regular and frequent customers who would support use of electronic toll collection. Nevertheless, as had been the case almost 20 years earlier, local officials in Brooklyn and Queens strongly objected, the mayor never supported the task force recommendations, and the idea died yet again.

In 1993 the requirements of the Clean Air Act Amendments of 1990 forced the city to again confront the need for transportation control measures that could reduce emissions from motor vehicles. Analyses by the city's consultants have concluded that the immediate requirements related to carbon monoxide can be met without such strong measures. It is likely that requirements still to come for reductions of nitrogen oxides and volatile organic compounds will cause the issue to be raised once more.

It is clear that it is exceedingly difficult to convince the body politic to pay for something that is now free. In contrast, during the 20 years of debate about imposing tolls on the free bridges, tolls on the TBTA facilities have been raised eight times from $0.50 to $3.00. Again, in the case of the East River toll issue, opposition was geographically concentrated, making it easier to organize opposition. These arguments have survived the shift away from air pollution reduction and toward needed revenues for bridge repairs. Nor has the promise of electronic toll collection, and the shorter lines and less pollution at toll barriers that it implies, swayed the result.

LATE NOTE ON POLITICAL OPPOSITION

As this paper was being drafted, a new drama was unfolding that reinforces the difficulty of decreasing bulk discounts as an early step in the direction of road pricing. The New York Thruway Authority has installed electronic toll collection technology for one barrier toll (50 cents) and for the Tappan Zee Bridge. The Tappan Zee Bridge toll is $2.50, but a discount of 60 percent is now provided through the purchase of a book of 20 tickets for $20, good for 35 days from date of purchase. The automated system is intended to do away with the book, but keeps the same deep discount. The Thruway Authority proposed that the period of use for the $20 worth of electronic cash be reduced to 30 days, since the rationale for the 35 days included 5 days to allow for the discount book to be mailed. The response was an outcry from motorists that reverberated into the fall election primaries, with every elected official in Rockland County (in which the majority of morning eastbound commuters reside) calling for the retention of the 35-day grace period. The citizenry had responded to the possibility that they would not be able to use all 20 of their 60 percent discount "tickets" if some months were shortened by holidays, vacations, sick days, or other changes in usual commuting behavior. They reacted vociferously to the possibility that they might lose one or two days, reducing their effective discount to 55 percent. With this type of opposition, it will not be surprising if higher peak-period tolls are a long time coming.

OTHER BARRIERS TO ROAD PRICING

Although the political arena continues to be a barrier to moving in the direction of road pricing, other considerations raise questions about the likelihood of putting an effective road pricing strategy in place, particularly in the New York region.

Tolls and Cost of Driving

Many drivers do not pay the full cost of driving. In 1984 the Port Authority surveyed trans-Hudson automobile drivers traveling to work and found that 64 percent bound for the CBD and 55 percent bound for other New York City destinations received some subsidy from their employers. Forty-seven percent of CBD employees received parking subsidies, 31

percent had tolls reimbursed, and 31 percent were provided with an automobile. This suggests that if these benefit policies stay in effect, the economic incentive to shift times or modes is nonexistent for a large portion of the driving population. On the other hand, for those who are not subsidized, particularly for trips to the CBD, the price of tolls is often but a fraction of the total cost of traveling by automobile. With daily parking charges averaging in the $10 to $15 range, with some locations as high as $20, a differential in tolls of, say, $2 or $3 would not likely cause a shift in either mode or time of travel.

Insufficient Price Elasticity To Shift Demand to Uncongested Periods

Drivers now traveling in the peak do not experience enough time savings and delay avoidance benefit to warrant a shift to less congested periods. Naturally, for drivers to shift from a peak toll time to another less congested period will require their perception that the differential toll is worth the inconvenience in their daily schedule. To illustrate the level of diversion that would have to occur, Table 3 is presented, which shows the hourly eastbound vehicle volumes for the three Port Authority crossings of the Hudson River. The volumes are based on the average of 21 weekdays in October 1992. The volumes are compared with the hourly capacity of each of the facilities, and the percentage of each hour's volumes that would need to move to a time when excess capacity was available is determined.

The analysis assumes that no drivers shift to transit or form carpools to avoid higher peak-period tolls and that all drivers who would need to move their drive times would move to the closest available hour with excess capacity. The analysis also assumes that drivers now driving in the hour closest to the hour with excess capacity get "first rights" to that capacity. Moreover, the analysis treats volumes on an hourly basis rather than in shorter time intervals. The analysis sets an arbitrary standard that cannot be exceeded, the rated capacity of the facility. In reality, some level of volume exceeding capacity is tolerated by motorists, leading to some delay. Thus, this standard strives to remove any delay at the crossings. Finally, the capacity used represents the capacity of the crossing and not that of the toll barriers. Despite the idealized nature of the assumptions necessary, the analysis is instructive. Obviously, a more refined analysis should be performed to confirm the nature of the conclusions reached here.

TABLE 3 Peak-Period Capacity and Use of Port Authority Crossings

Hour	Volume (vehicles/hr)	Volume Exceeding Capacity	% Shift Required Earlier 1 hr	Earlier 2 hr	Later 1 hr	Later 2 hr	Later 3 hr
George Washington Bridge Eastbound Hourly Capacity = 10,600 vehicles per hour							
6-7 am	9179	-1421	-	-	-	-	
7-8	11797	+1197	11.3	-	-	-	
8-9	10887	+87	-	-	0.8	-	
9-10	9372	-1228	-	-	-	-	
Lincoln Tunnel Eastbound Hourly Capacity = 4,200 vehicles per hour							
6-7 am	4003	-197	-	-	-	-	-
7-8	5055	+855	3.9	13.0	-	-	-
8-9	4869	+659	-	-	-	3.6	10.0*
9-10	4395	+195	-	-	4.4	-	-
10-11	3831	-369	-	-	-	-	-
Holland Tunnel Eastbound Hourly Capacity = 2,600 vehicles per hour							
5-6 am	1067	-1533	-	-	-	-	-
6-7	2711	+111	4.1	-	-	-	-
7-8	2963	+363	-	12.3	-	-	-
8-9	2772	+172	-	-	-	5.4	0.8*
9-10	2720	+120	-	-	4.4	-	-
10-11	2329	-271	-	-	-	-	-

*This group could move either 3 hours earlier or 3 hours later.

For the George Washington Bridge a large proportion of vehicles (11.3 percent) exceed capacity in the 7:00 to 8:00 a.m. period, and they can be accommodated in the previous hour. Only a small percentage of the 8:00 to 9:00 a.m. flow cannot be handled, and it can easily be accommodated in the following hour, if not later in the same hour.

The Lincoln Tunnel calculations in Table 3 suggest the need for somewhat greater shifts to flatten the peak period. About 4 percent of 7:00 to 8:00 a.m. drivers would need to travel an hour earlier. But since the 6:00 to 7:00 a.m. hour does not have much excess capacity, another 13 percent of the 7:00 to 8:00 a.m. vehicles would need to travel 2 hr earlier. The situation for the 8:00 to 9:00 a.m. drivers is worse; they could not be accommodated by moving just 1 hr. Almost 4 percent would need to travel

2 hr later and another 10 percent 3 hr later to find excess capacity. A significant share of 9:00 to 10:00 a.m. drivers (4 percent) would need to travel later too, although they might be accommodated in the later part of that hour.

The Holland Tunnel presents a situation almost as difficult as the Lincoln Tunnel if a volume/capacity ratio of 1.00 is to be achieved. Four percent of 6:00 to 7:00 a.m. drivers would have to travel an hour earlier, and 12 percent of 7:00 to 8:00 a.m. drivers would have to travel 2 hr earlier. Later in the peak period, 5 percent of 8:00 to 9:00 a.m. drivers would need to move by 2 hr to find enough capacity, and a few may need to shift their times still more. Over 4 percent of the 9:00 to 10:00 a.m. drivers would have to shift an hour later to avoid overloaded conditions.

Achievement of travel time shifts of the magnitude calculated above would undoubtedly require significant price differentials. To estimate (very crudely) the elasticity of demand required to achieve the time-of-day change needed, it is assumed that the average driver pays $15.00 per round trip, exclusive of tolls. If off-peak tolls are set at $3.00 and peak-period tolls at $6.00, the driver will realize a savings of 14.3 percent [3/(15 + 6)] by traveling later. If the fraction of drivers needing to shift in any particular time period is 5 percent, the elasticity of demand with respect to time shifts would need to be 5/14.3, or −0.35. If a shift of 10 percent is required, the elasticity needed would double to −0.70. To achieve such shifts may be very difficult. Price elasticities, particularly among automobile drivers, have been shown to be much lower. Increasing the toll differential could help some. If the peak toll was $10.00, a 10 percent drop would be achieved with an elasticity of −0.36. For drivers whose costs are paid by their employers, the elasticities might also be lower, but their likelihood of shifting to transit as a result of the higher tolls would be nil.

The above discussions ignore the fact that many, if not most, drivers traveling to work do not have the freedom of choosing their working hours. In that case and if transit is not a reasonable option, the imposition of higher peak road prices will be seen as "highway robbery." The promise of using the added funds for transit improvements may partially offset that complaint.

Safety Issues

Safety is another issue that has slowed the progress of road pricing. The issue was raised by the Port Authority in its 1979 pricing study. The

concern at that time was that drivers would either speed up or slow down at the time of day when the toll changed in order to pay lower tolls. Electronic toll collection can mitigate that problem considerably by varying tolls in small increments. However, this might also lower the rate at which drivers shift to less crowded periods as they become willing to pay for part, but not all, of the price differential needed.

Elsewhere in the metropolitan area, another safety concern led to the elimination of tolls. Until 1986 the Connecticut Turnpike (Interstate 95), running east-west across the southern edge of the state, collected tolls at a series of eight toll barriers. After a number of serious accidents involving trucks that were unable to stop at the barriers, public outcry resulted in the elimination of the tolls on this highway. Electronic toll collection may address that problem, too. Incidentally, the toll structure in Connecticut was highly favorable to commuters. The toll for passenger cars was $0.25, but a monthly commuter book brought that down to less than $0.09.

Electronic Toll Collection

All the toll authorities in the New York metropolitan area have coordinated their efforts to ensure uniform technology. This uniformity will make it possible for a drivers in the region to use one medium to pay for all tolls. Alternative technologies are undergoing final testing now, and full-scale demonstrations involving the general public are about to begin on the New York Thruway.

The authorities have indicated that their objective is to reduce transaction time, which causes the buildup of congestion. A second objective is to reduce collection costs through reductions in personnel. But no indication has been given that differential pricing by time of day is planned, although it is clearly possible with the technology being established. The authorities are understandably wary, given the public's reaction to any cost increases. The experiences recounted earlier in this paper make that clear.

To promote the use of electronic tolls in the interest of saving on labor costs, the toll operators may be prepared to offer discounts, running the risk of increasing peak-period congestion rather than lowering it and raising less revenue than originally anticipated. The environmental community, on the other hand, see road pricing in peak periods as a way to shift peak users to transit and to raise money for the support of transit systems. Reconciling these competing objectives will not be easy.

NOTE ON TRANSIT FARES

The issue has been raised whether the economic principles that argue for higher road fees in the peak also hold for transit fares. The argument is that the transit system is overcrowded in the peak; therefore a higher fare should be charged at that time. However, doing so raises the question whether it is in the best interest of society to drive commuters from transit to the roads at the very time of day when the roads are also crowded. Monthly transit vouchers for employees, as provided in recent federal energy legislation, come down on the side of encouraging peak-period transit use through pricing, as do the long-available deep discounts for commuters on the commuter railroads.

CONCLUSION

The likelihood of attaining a road pricing policy that rewards drivers for traveling at uncongested times on uncongested roads is uncertain because of the strong resistance to higher prices and the difficulty of achieving the desired results given the travel patterns and habits of the region's travelers (even if they supported road pricing).

Part of the difficulty in the past stemmed from the inability of proponents of change to adequately describe the benefits to be gained. For example, the Port Authority's attempts to reduce the commuter toll discount did not include a description of how the added funds to be raised might be used to improve the transit options for those drivers who would be hardest hit. With three-fourths of the users of the George Washington Bridge living in two counties and with a host of needed transit improvements identified for those two counties, elimination of the discounts could have been sold on the basis of using the added funds for needed local transit improvements. Similarly, imposing tolls on the free New York City bridges offered little in the way of specific transit improvements or bridge repairs. Citizens are not going to reach into their pockets willingly if they do not see what the extra funds will buy.

The toll authorities are to be congratulated on working together toward regional coordination of toll collection through electronic means. What remains to be done is careful operational and policy analysis to determine if the benefits on paper can be achieved in practice. Only then can the toughest hurdle, convincing the public, proceed.

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NOTES

1. These data are taken from *Hub-bound Travel*, an invaluable annual series of reports describing the numbers of people and vehicles entering and leaving the CBD on a typical business day. Started in 1924 by Regional Plan Association and repeated at 8-year intervals until 1956, the survey was later continued on an annual basis by Tri-State Regional Planning Commission and now by its successor, the New York Metropolitan Transportation Council.
2. The actions of the Port Authority as a bistate agency are subject to the approval of the two governors.
3. The toll history of this facility is fascinating too but does not directly bear on the issues in this paper.
4. For a full and excellent discussion of this battle see the master's thesis by Kleinerman (1984).
5. TBTA is an arm of the Metropolitan Transportation Authority, which includes the New York City Transit Authority, the Long Island Rail Road, the Metro-North Commuter Railroad, and the Metropolitan Suburban Bus Authority.

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ABBREVIATIONS

NYCDOT	New York City Department of Transportation
PANYNJ	Port Authority of New York and New Jersey

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Pricing Urban Roadways
Administrative and Institutional Issues

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Traffic congestion is a specter haunting residents of nearly all large metropolitan areas in the United States. Congestion has increased rapidly in urban areas, where motorists using the roadway have increased faster than growth in roadway capacity. Congestion imposes numerous costs on individuals, businesses, and the larger society: time is lost, fuel is wasted, air quality is degraded, and motorist frustrations increase. One proposed solution to traffic congestion is to adopt congestion pricing policies, in which motorists using the roadway would pay for the congestion costs they impose on other motorists.

The economic theory recommending congestion pricing arose 70 years ago in the debate between the welfare economists Pigou (1920) and Knight (1924). In order to manage demand for scarce roadway capacity, congestion economists argue, motorists who desire to drive during peak periods should be charged for the delays they impose on others. The use of peak-period pricing would allow those motorists willing and able to pay the price to save scarce time. Others unwilling or unable to pay the roadway charge would be forced to select alternative times or routes of travel, form carpools, or take public transit.

By reducing traffic congestion, this economic reasoning argues, the behavior of both the paying and nonpaying commuters will decrease the need for expanding roadway capacity, reduce fuel consumption, save scarce time, and result in more efficient use of the existing roadway. Applying the optimal price on the roadway reduces congestion to its most efficient level. If the simplifying assumptions are accepted, this form of

economic reasoning provides a powerful potential tool for addressing the specter of traffic congestion.

The need to monitor access to the roadway and to apply fees for its use constituted an early barrier to congestion pricing. The toll booth itself contributed to the congestion it sought to ease by interrupting the free flow of traffic and creating queues of approaching vehicles. Recent developments, however, including automated electronic toll collection techniques, negate this former barrier and demonstrate the technological feasibility of monitoring access and billing roadway users. With the technological barrier removed, the venerable economic argument advocating pricing mechanisms as tools for relieving traffic congestion is receiving renewed attention among academic researchers, transportation professionals, and some politicians.

A central issue now confronting advocates of congestion pricing is the political question about who should be responsible for creating and administering congestion pricing. The precision and orderliness of discussions about congestion pricing economics and technologies are more than matched by the seeming complexity and confusion when governance systems appropriate to congestion pricing are introduced. In part these differences derive from the former's reliance on market-based decision making (assuming perfect competition, no scale or scope economies, and a specified income distribution) and the latter's dependence on non-market-based decisions (involving voters, politicians, interest groups, preexisting governmental jurisdictions, bargaining, and compromise). This paper attempts to move beyond the economic and technical dialogue to address the implications for congestion pricing of institutional, administrative, and political issues.[1]

Traffic congestion occurs within and across entire metropolitan areas without regard to local political or jurisdictional boundaries. Congestion patterns vary markedly: congested corridors develop over bridges or through tunnels operated autonomously by local authorities; congestion traverses any number of suburban and city jurisdictions; and congestion occurs on county or state roads or on federally aided highways. It is the noncongruence of the problem—traffic congestion—with preexisting institutional arrangements—governmental jurisdictions—that gives such force and complexity to the institutional question. Moreover, the spread of congestion to suburbs and exurbs has meant that it increasingly has become a regional problem affecting entire metropolitan areas rather than being isolated to the downtown area or within a single political jurisdiction. The lack of regional institutions possessing sufficient power and

authority to address and manage congestion at the regional level poses a major barrier to implementing congestion pricing programs.

Compounding the lack of regionalism is the practice among U.S. cities of competing with each other within and beyond metropolitan regions for economic development (Peterson 1981). Imposing fees on traffic corridors would appear to raise the cost of production in the short term, making cities with congestion pricing less competitive than they otherwise might be. In the longer term, however, if the production costs imposed by congestion are removed, and if the resulting savings exceed the costs of a congestion pricing system, it becomes in the interest of businesses and cities to favor congestion pricing. Indeed, city officials have become interested in roadway pricing out of fear that congestion may become so severe that economic activity will leave their jurisdictions. Still, most political officials jealously guard the powers of their local jurisdictions and resist proposals to remove them to a larger regional jurisdiction or to a smaller rival jurisdiction.

METROPOLITAN FRAGMENTATION AND DECENTRALIZATION

A distinctive characteristic of governmental structures in the United States is the extent of jurisdictional fragmentation within and between subnational units. At least since de Tocqueville, this feature has drawn the attention of foreign observers.[2] A half-century ago, Charles Merriam wrote in his preface to Jones's classic study, *Metropolitan Government*, that "the adequate organization of modern metropolitan areas is one of the great unsolved problems of modern politics" (Jones 1942, ix). Merriam's assertion is at least equally valid today, as metropolitan governing structures continue to bedevil attempts to align problems of governing with their appropriate solutions.

For the present purposes, governmental fragmentation may be defined as the number of separately organized government units and their degree of overlap, with respect to both geographic territory and functional service provision. The number of government units in the United States from 1962 to 1987 is shown in Table 1. By 1987 there were 83,186 local government units, including counties, municipalities, townships, school districts, and special districts, each separately organized with its own set of officials, corporate powers, authority for service provision, and power to raise revenues through taxes and service charges. Among these local units

TABLE 1 Number of Government Units in the United States, 1962–1987

Type of Government	1962	1967	1972	1977	1982	1987
Total	91,237	81,299	78,269	80,171	82,688	82,237
U.S. government	1	1	1	1	1	1
State governments	50	50	50	50	50	50
Local governments	91,186	81,248	78,218	80,120	82,637	83,186
Counties	3,043	3,049	3,044	3,042	3,041	3,042
Municipalities	18,000	18,048	18,517	18,856	19,083	19,200
Townships	17,142	17,105	18,991	16,822	16,748	16,691
School districts	34,678	21,782	15,781	15,260	15,032	14,721
Special districts	18,323	21,264	23,885	26,140	28,733	29,532

SOURCE: Bureau of the Census.

of government, the most rapid increase occurred among municipalities and special districts.

The concern here is with the fragmentation of governmental units within metropolitan areas, where traffic congestion most frequently occurs and takes its most acute forms. The number of government units in metropolitan areas by type of government is as follows (Bureau of the Census 1988, xvi):

Type of Government	*Number of Units*
Counties	735
Municipalities	11,712
Towns and townships	5,036
School districts	5,975
Special districts	16,842
TOTAL	40,300

Nearly half of local governments in the United States have been created in metropolitan areas, and among the fastest-growing units of local government, more than half of the U.S. municipalities and special districts are found within metropolitan areas. The sheer number and design complexities of local governments provide the context of metropolitan fragmentation within which the search for institutional solutions to traffic congestion occurs.

There is nothing particularly new about governmental fragmentation in metropolitan areas. In the late 1950s, Wood (1961, 1) identified 1,467 governmental bodies in the New York region. Nor has the pattern of fragmentation eased in recent years as the creation of new municipalities

and especially special districts has increased. Today Chicago is not far behind New York, with more than 1,200 units of competing local governments (Rothblatt 1993, 11). Both the New York and Chicago metropolitan areas lack a formal centralized metropolitan government with any real authority, and they are not atypical of other metropolitan regions.

Explanations for the fragmentation of local governmental institutions are not difficult to find. First, historically the United States has always distrusted centralization of power and authority. To the extent that creation of separate and autonomous local units of government reinforces values of decentralization, it favored proliferation of governmental units. Second, as the suburbs became the locale after the mid-twentieth century for the largest growth in jobs, businesses, and population, they also incorporated as separate political entities. In doing so, they sought political autonomy from adjacent central cities in an attempt to recreate Jeffersonian democracy on the fringes of cities. The forced curtailment of annexation of newly settled suburbs by central cities suggests the importance to suburbanites of separate incorporation and political autonomy (Jackson 1972). It also suggests why autonomous suburban municipalities defend their local autonomy so fiercely from encroachment by both central city and metropolitan forms of government.

A third explanation for local government fragmentation deals with the rise and increasing use of special districts. These districts account for more than half of all the increases in local governments since 1977. Special districts have been created piecemeal, usually to perform a single function. Their appeal lies in their abilities to raise money while remaining off general government tax rolls, to be organized in ad hoc and geographically flexible fashion, to act as a conduit for federal government grant-in-aid programs, and to be generally of low political visibility. Special districts contribute to metropolitan fragmentation by overlaying general-purpose governments with units assigned a single functional purpose. Their advantages in financial flexibility, reliance on user fees, ease of creation, low political visibility, and adaptable boundaries are accompanied by their hidden character, crazy-quilt locational patterns, and barriers to popular control.

There are at least four respects in which metropolitan government fragmentation poses barriers to the adoption, implementation, and administration of peak-hour traffic pricing as a congestion management tool. The first is obvious: the geographic area experiencing traffic congestion is not likely to coincide with the jurisdictional lines of preexisting governmental units. In addition, it is often politically difficult, although not impossible, to create new governmental jurisdictions charged with the

mandate to adopt the congestion pricing tool. There are also other, perhaps less obvious, barriers that derive from metropolitan fragmentation. Thus, second, the decentralization of power and authority within the metropolis is quite difficult to reverse through any congestion pricing scheme that would concentrate power and authority. Third, preexisting municipalities and special service districts, some of the latter of which carry significant influence in metropolitan affairs, are likely reflexively to resist any congestion pricing proposals that threaten a reduction in their autonomy and status. Fourth, because most such municipalities and special districts are themselves highly competitive among each other, rivalry for control and influence is likely to occur whenever congestion pricing proposals are put forward. Combined, these barriers to adopting congestion pricing systems require that any proposals be drafted with significant attention to at least a half-dozen desirable institutional and administrative characteristics.

DESIRABLE CHARACTERISTICS FOR CONGESTION PRICING SYSTEMS

What would an idealized congestion pricing system look like institutionally and administratively? Questions of program design have attracted among the least scholarly and public policy attention, although in the end they may be among the most important in determining the political acceptance and effective operation of this innovative approach to managing traffic congestion. In the following sections six institutional and administrative characteristics of importance to this question are discussed: geographic scope, legal authority, financial capacity, degrees of autonomy, political accountability, and assignment of goals.

Geographic Scope

As the foregoing discussion of metropolitan fragmentation implies, a major barrier to effective congestion pricing systems is the disjuncture between the geographic scope of traffic congestion and the balkanization of governmental jurisdictions. Congested roadways tend not to honor political jurisdictional lines. In order to apply an effective remedy, the geographic scope of congestion pricing systems must correspond to the territorial boundaries experiencing traffic congestion.

In many cases, it is the entire metropolitan area that defines the geographic scope at which congestion pricing systems become effective. As

has been mentioned and will be discussed further, metropolitan-wide regional governments with sufficient power and authority to implement congestion pricing are often lacking. The problem is compounded in several metropolitan areas where the metropolis spills across state lines and in others where metropolitan areas adjacent to each other expand the geographic scope of traffic congestion to span two or more metropolitan areas, such as in Southern California and New York. Because of the metropolitan-wide occurrence of traffic congestion, Downs (1992, 60) has argued that "it would be impossible to plan and implement an effective peak-hour congestion pricing system except at a regional level."

Regionwide approaches to congestion pricing are called for where traffic congestion itself is regionwide. Still, there are identifiable areas in which traffic congestion is isolated to less than metropolitan-wide territories, and in these cases, what is called for is the design of congestion pricing entities whose reach is less than regionwide. The first, most obvious of such cases is that in which congestion is localized to specific bridges, tunnels, and roadways accessing ferry routes. When such infrastructure as these experience the brunt of traffic congestion, pricing specific facilities during peak hours offers the promise of relief at less than a regionwide application. So too does a second type of traffic congestion that is isolated to specific traffic corridors. In recent years travel from suburb to central city has been replaced as the predominant commuting pattern by commuting trips from suburb to suburb (Pisarski 1987, 43). In those suburb-to-suburb commuting areas in which heavily congested corridors are concentrated, a less-than-regionwide use of congestion pricing may be warranted. Pricing the roadway in specifically identified corridors is a policy option.

The territorial scope of traffic congestion helps to define the jurisdictional level most appropriate to creation of congestion pricing systems. When roadways spanning whole metropolitan regions are congested, peak-hour pricing remedies require a metropolitan-wide system. In cases of congestion localized to specific infrastructure or particular traffic corridors, facility-based or corridor-based entities organized at less than area-wide jurisdictions may be utilized.

Legal Authority

Any entity assigned responsibility for a congestion pricing program requires the legal powers to implement and enforce the program. Complicating the legality of congestion pricing proposals are a number of federal

and state statutes that limit how roads can be priced and how the revenues from such pricing can be used. Congestion pricing entities will also require the legal authority to impose heavy fines on deliberate violators in order to secure effective enforcement.

If the roadway in question is a federally assisted highway, federal statutes prohibit the application of tolls (Section 129, Title 23, U.S. Code). Thus federal legislation would need to be enacted specifically exempting identified federal facilities [as in the demonstration projects required by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA)]. State statutes and local government ordinances similarly contain restrictions on pricing the roadway and the permissible uses of revenues. Still, after reviewing issues of congestion pricing legality, Coit (1974) concluded that "in spite of a variety of federal regulations, substantial power to implement congestion pricing lies unused at the local level." Most counties and municipalities already possess the requisite legal authority, whether under the police or the tax powers granted by states to local general-purpose governments, to implement and enforce congestion pricing systems. Some special districts are similarly equipped.

If preexisting governmental jurisdictions lack sufficient legal powers, such powers will have to be assigned them, usually by state legislatures, or new jurisdictional entities will have to be created that possess such powers.

The basic legal issues that need to be considered before decisions are made about implementing congestion pricing are posed in the form of four questions by Bosley and Schaller (1978). The first asks whether congestion pricing is to be imposed as a regulatory measure under the police power in general or under specifically delegated authority. Either power is variable across the states and in need of careful review. Second, if the authority to price is there, is it a reasonable exercise of the police power? Third, does the pricing technique violate any constitutional principles? And last, is the pricing technique a valid exercise of the taxing authority? Some existing entities at subnational levels will meet all tests of the requisite legal authorizations, others will require amendment to existing powers, and in still other cases wholly new entities will have to be created.

Financial Capacity

By its nature, congestion pricing predictably will generate large volumes of revenue, yet its administrative costs will be significantly less than the revenue produced. In the greater Los Angeles area, for example, it is

estimated that congestion pricing would generate annually about $3 billion (Small 1992). Another estimate for the same region forecasts $2.5 billion in annual revenues and total costs for the congestion pricing system of about $80 million to $160 million, leaving a substantial balance for reinvestment or other distribution (Urban Institute and KT Analytics 1991). Given such large revenue volumes, administering a congestion pricing system will require an entity with substantial financial capacity (e.g., auditing, accounting, processing revenue, contracting, leasing, and purchasing).

Beyond simply the ability to handle large revenue streams, there are several additional requirements with regard to the financial capacity of a congestion pricing entity. First, a congestion pricing entity requires the capability of imposing and enforcing a peak-period pricing system. Second, peak-period pricing will have to remain for the entity the means toward the end of managing traffic rather than becoming an end in itself. One criticism of the Singapore congestion pricing scheme is that rather than being a traffic management tool, it quickly became a tool for generating revenue for the government (Toh 1977). Third, congestion pricing entities require the financial capacity to resist the raid of their treasuries from otherwise bankrupt municipal, county, or state governments. This practice has become commonplace in the 1990s among other transportation entities with large revenue streams (Olson 1992a, 1992b).

These last-mentioned financial requirements become more uncertain when placed in the context of the politics and administration of congestion pricing systems. The amount and sources of support for congestion pricing proposals will depend in part on how the revenues that it generates will be distributed. At least six alternatives can be envisioned:

- Dedicating revenues to trust funds for reinvestment in highway construction, maintenance, and administration, which is a familiar practice among the several states and their counties;
- Dedicating revenues to the just-mentioned purposes plus the development, maintenance, and administration of the congestion pricing system, which has the advantage of linking the source of roadway fees to the activity from which the fees are extracted;
- Before adopting the peak-hour pricing system, dedicating portions of the revenue yield to mitigating the adverse consequences of the system itself (e.g., relieving spillover traffic effects on nontolled arterials and city streets and providing support for users of other modes—public transit, vanpooling, carpools);

- Specifically recognizing adverse effects on central business district merchants through compensation and on low-income motorists by making provision for rebates, allowances, hardship waivers, and so forth;
- As the price to be paid for congestion pricing adoption, buying off the potential opposition (e.g., automobile clubs, working-class organizations, downtown merchants);
- Specifically dedicating portions of the revenue yield for use as they wish by revenue-starved officials of general-purpose governments, whose assent to congestion pricing is vital and who otherwise might oppose adoption of congestion pricing.

As is obvious, most of the latter revenue uses are less-than-efficient expenditures within the transportation system. Nevertheless, on questions of adoption and the political feasibility of congestion pricing, the primary distributional criterion may not be efficiency within the transportation system.

Whatever uses are made of revenues generated by congestion pricing, they will have important consequences for the political feasibility, organizational structure, and agency legitimacy of the congestion pricing system. Because most decisions about revenue uses will be made before congestion pricing is implemented, issues of financial capacity reviewed above will imprint the operating entity in important respects even before it becomes an operating reality.

Degrees of Autonomy

Congestion pricing entities generating substantial revenue streams are potentially vulnerable to capture by supervisory general-purpose governments that create them and assign them their operating powers. To operate effectively in the conduct of day-to-day activities (e.g., what hours are defined as "peak" for peak pricing, what price realizes optimal traffic flow), congestion pricing entities require a degree of autonomy in order to serve diverse political jurisdictions within metropolitan areas without being captured or made subservient to any one of them.

Any number of public entities are granted substantial autonomy and independence in American politics. From the Federal Reserve System at the federal level to utilities commissions among the states to seaports, airports, and any manner of public authorities at the local level, autonomy

has been granted where operating flexibilities and nonintervention by political officials are deemed essential.[3] Some public activities are defined as requiring operating, legal, and financial independence from direct supervision or intervention by political officials, shifting electoral demands, and special interest group claims. A congestion pricing entity is likely to resemble that type of public activity: it would be a single- or limited-purpose organization; when created, it would be assigned clear, statutorily mandated goals; its performance would be evaluated by criteria derived directly from the mandated objectives; and it would require technical competencies and experimental and innovative managerial behavior. The granting of a significant degree of autonomy and independence is premised on the perceived need for such an administrative arrangement in order to achieve economic efficiencies in operations and agency effectiveness in performance.

Political Accountability

The reverse side of the coin from autonomy is political accountability. Congestion pricing entities would not be unleashed to act however they desire, unconstrained by public adoption and approval procedures and without some form of political accountability. Even in the eventuality of privatized toll roads, some degree of public supervision, monitoring, and regulation is inevitable.

If some form of public supervision and control is inevitable, the question becomes the degree and kind of control structures appropriate to congestion pricing systems. As a minimum, sufficient control to ensure public direction in policy making and to extract an accounting for performance is necessary without at the same time compromising the desired degree of autonomy, as previously discussed.

Elected officials from jurisdictions within which congestion pricing entities operate will seek opportunities to provide direction in interpreting and guiding the entities' objectives and goals. Such public accounting will likely include the policy directions adopted, budgetary reporting requirements (including disposition of surplus revenues), and accessibility to policy decision boards by citizens. Because congestion pricing proposals are not likely to be adopted in the absence of some form of public approval, the degree and form of ongoing political accountability most usefully should be arranged before the adoption decision.

When public policy involves intense controversy or the extraction of large revenue sums, local government officials tend to engage in blame avoidance and masking behavior, creating decisional processes intended to disguise responsibility for unpopular policies. Not only are congestion pricing proposals highly controversial, they also extract large revenue sums. Given the controversy and the large streams of revenue, the ability of the public to trace responsibility for policy decisions of congestion pricing entities is a prime focus for political accountability measures.

These idealized characteristics—degree of autonomy and political accountability—are naturally at odds with each other. In a classic dilemma, the degree and kind of public control wrestles with the independence and autonomy that congestion pricing entities require. This dilemma represents an enduring paradox in public administration, for which perfect solutions are yet to be found. Yet it is enough to say now that what is necessary for effective attainment of the traffic management goal is a sufficient control structure to give public direction and to extract an accounting of performance without at the same time compromising equally important measures of flexibility and operating independence.

Goal Assignment

What is the objective of a congestion pricing program? Assigning unambiguous goals to agencies implementing new programs is often critical to program success. If performance goals assigned to agencies are broad rather than narrow, multiple rather than singular, and diffuse rather than specific, they frequently fail to accomplish their primary purpose.

That the question of goal assignment is problematic can be seen in the number and diversity of goals associated with the congestion pricing proposal. At the least, the following have been suggested as program objectives in congestion pricing proposals:

- Reduce traffic congestion to its most efficient level,
- Enhance air and water quality,
- Conserve energy,
- Generate or maximize revenue for general-purpose governments,
- Boost mass transit and high-occupancy-vehicle (HOV) utilization,
- Enhance social equity among the traveling public, and
- Assist in regional economic development.

These multiple goal structures are internally conflictual. If all are assigned to an agency, some will be accomplished at the expense of others.

Ideally, congestion pricing proposals will assign unambiguous, nonconflictual, and limited goals to agencies charged with their implementation, with the first goal listed above—reducing traffic congestion to its most efficient level—ranked at the top of the hierarchy of agency objectives. Still, it is perhaps inevitable that as a price for program adoption and continuing program support, more than one objective will be assigned to the implementing agency.

ALTERNATIVE INSTITUTIONAL ARRANGEMENTS

An Inventory

In considering implementation of congestion pricing proposals, what alternative institutional arrangements exist within metropolitan areas and what are their distinguishing characteristics? An initial task is simply to compile an inventory of existing institutional arrangements, after which their strengths and weaknesses as entities suitable for carrying out congestion pricing can be assessed.

The sheer number and diversity of institutions within metropolitan areas in the following inventory make it apparent why metropolitan areas are so balkanized among separately organized jurisdictions. Downs (1992, 130–37, 160–62) identifies and assesses six regional organizations that might be assigned the task of managing traffic congestion. These include

1. Autonomous local governments cooperating voluntarily;
2. State transportation or highway departments;
3. State and local planning agencies acting under state comprehensive planning systems;
4. Private coordination, planning, and policy promotion organizations;
5. Specialized regional government agencies; and
6. Federally rooted regional agencies.

Several different types of agencies are included within several of these arrangements. Walker (1987, 16) lists 17 regional approaches to service delivery and ranks them from easiest to hardest according to how politi-

cally difficult each is to achieve. (He is concerned with service delivery generally, not specifically with traffic congestion management.)

Easiest:
1. Informal cooperation,
2. Interlocal service contracts,
3. Joint powers agreements,
4. Extraterritorial powers,
5. Regional councils and councils of government,
6. Federally encouraged single-purpose regional bodies,
7. State planning and development districts, and
8. Contracting (private).

Middling:

9. Local special districts,
10. Transfer of functions,
11. Annexation,
12. Regional special districts and authorities,
13. Metropolitan multipurpose district, and
14. Reformed urban county.

Hardest:

15. One-tier consolidations,
16. Two-tier restructuring, and
17. Three-tier reforms.

In the following discussion suggestions from Downs and Walker and other studies of metropolitan organizational arrangements are used to create an inventory of the available institutional alternatives. The 15 institutional arrangements described are not exhaustive of all the possibilities. It might be claimed that such arrangements as joint powers agreements, extraterritorial powers, interlocal service contracts, and so forth should also be included. However, the 15 alternatives listed provide a broad range of alternative organizational forms for assessment. In the next section, each alternative is assessed with respect to its suitability to implement congestion pricing.

Annexation

Annexation involves the acquisition by a municipality of additional territory to enlarge the existing governmental jurisdiction. It is usually used

by central cities to expand their boundaries to outlying territories but can be used by suburban cities to achieve the same effect. In recent decades it has been utilized most frequently by cities in the South and the Southwest of the United States and much less often in the East and the Midwest.

Voluntary Cooperation

Widely practiced, voluntary cooperation among autonomous local governments consists of an agreement among officials from two or more jurisdictions to share information, technologies, and equipment or even to jointly adopt public policy measures. Officials from separate governments within metropolitan regions can also agree to act in concert on issues spanning the larger area. This approach allows for the possibility of cooperation in metropolitan areas that cross state borders or even international borders. The city councils of San Diego, California, and Tijuana, Mexico, have held joint sessions to discuss mutual interests. From such discussions a light-rail system has been built to connect the downtowns of the two cities and a transnational border authority has been proposed to promote infrastructure investment and shared economic development programs (Corso 1983, 342).

Privatization

One of the more popular reforms of the 1980s, privatization reduces but does not remove government involvement in the production and distribution of goods and services by turning these functions over to private firms instead of the traditional public agencies (Olson 1992b). Privatization can take a variety of forms: contracting out government service, letting franchises to private operators, or relying on market mechanisms to produce and deliver services. The state of California in 1990 authorized the construction of private toll roads, and private firms have been selected to build two of them. Both roads will connect state highways that are currently incomplete in Orange County. As discussed by Fielding in another paper in this Special Report, one will be an 11-mi (18-km) extension to State Route 57 and the second will be a 10-mi (16-km) stretch of State Route 91. The latter is scheduled to open in 1996. The promise of privatization is to introduce competition into road transportation and thereby to encourage economic efficiencies.

Private Coordination, Planning, and Policy Promotion Organizations

Private organizations composed of representatives from business, labor, universities, and the nonprofit sector are formed to study metropolitan issues and recommend policies aimed at solutions. When regional economies stagnate, such organizations can become particularly vigorous. As Dittmar et al. describe in another paper in this volume, the Bay Area Economic Forum, for example, has been very active in promoting pricing on congested bridges and roadways during peak commute periods. The forum justifies its concern out of fear that congestion is reducing the competitive position of the Bay Area economy. Such organizations provide an outlet for discussion, planning, and research, and they can influence the setting of regional agendas. Other examples of such private organizations include the San Francisco Bay Area Council, King County 2020, and Los Angeles 2000.

General-Purpose Local Governments

General-purpose governments within metropolitan areas are the most familiar. They consist of counties, cities, villages, urban towns, and townships. Created by state legislatures, they nearly uniformly possess both police and tax powers and are given general responsibilities for governing their territories within metropolitan areas.

Special-Purpose Local Governments

Perhaps less familiar, special-purpose local governments represent the fastest-growing form of government in the United States, and they outnumber the general-purpose types. Special districts may provide a related set of services, but most provide a single specific service. They are administratively and fiscally autonomous, setting their own budgets and raising their own revenues. As set-aside governments, they are involved in service provision for sewers, libraries, parks and recreation, housing, and fire protection and account for around 75 percent of the water supply, 25 percent of the electric power, and 80 percent of the local transit (Denning and Olson 1981). Special districts are particularly attractive because of their ease of creation, their flexibility, and their ability to circumvent taxing and borrowing ceilings and personnel lids.

Metropolitan Districts

Organizationally, metropolitan districts are the same as special-purpose local governments, except for their geographic scale. Metropolitan districts are organized across entire metropolitan areas. They may be single-purpose or multipurpose districts, and they otherwise resemble the special-purpose local governments in their independence and autonomy, financial capacities, legal authorizations, and flexibility and ease of creation. Examples of metropolitan districts include the Bay Area Rapid Transit District, the Southern California Metropolitan Water District, the Massachusetts Bay Transit Authority, and the San Diego Unified Port District.

Metropolitan Planning Agencies

Nearly every metropolitan area has an areawide planning agency. Federal funding and program review requirements played a large role in sparking the creation of metropolitan-wide planning bodies during the past three decades. Councils of government (COGs) and metropolitan councils represent variations on this type of areawide planning agency.

COGs bring together on a voluntary basis officials from municipalities in metropolitan areas. They meet regularly, share information, and prepare comprehensive plans for regional growth and development. Federal funding and voluntary contributions from members provide financing for professional staffing, administrative expenses, and regional planning studies. Beginning in the 1960s, the federal government assigned COGs the responsibility for commenting on the degree to which applicants for federal funds were complying with regional planning goals. Thus the COGs have an advisory role on federally assisted programs. The Southern California Association of Governments (SCAG) is representative of this type. It is the only structure in the highly fragmented seven-county region that reviews programs across both local jurisdictions and functional service areas to plan for the greater Los Angeles region.

A successor type of planning agency is the metropolitan council, which not only plays an advisory planning role but is also vested with some policy coordination responsibilities. Metropolitan councils possess the authority to draft development guides, review and comment on development plans of local governments within the region, and, most critically, to oversee and coordinate metropolitan commissions and special districts, including the power to appoint their policy boards, review their budgets,

and veto capital expenditures (Harrigan and Johnson 1978). Thus metropolitan councils have greater policy roles than do the COGs.

State-Mandated Metropolitan Planning

Mandated planning for metropolitan areas represents an increasingly popular arrangement whereby states require their local governments to develop plans to achieve state-defined goals. Growth management plans of this kind have received wide notice, although they have been limited to a dozen states at most. Still other state-mandated planning requirements deal with open space, the environment, housing, and transportation. Because all local jurisdictions in metropolitan areas are creatures of the state, this arrangement elicits strong compliance among local governments.

Regional Compacts

Regional compacts are institutional arrangements designed to address metropolitan-wide problems when the metropolis crosses state lines. Perhaps the most well-known regional compact is the Port Authority of New York and New Jersey. It was established in 1921 by an interstate compact between New York and New Jersey to develop commercial and transportation facilities for the region. Governed by a 12-member board of commissioners appointed by the governors of New York and New Jersey, the Port Authority has a significant degree of autonomy, a highly developed financial capacity, and broad legal authority. Port facilities include 6 interstate bridges and tunnels, 2 bus terminals, 6 airports, 10 truck terminals, the World Trade Center, facilities for international shipping and other commercial activities, and a railroad system. Creation of the Port Authority required congressional authorization because it spanned two state jurisdictions.

Highway Departments

All 50 states have highway departments or their equivalent. The transportation policies they pursue have significant impacts on metropolitan traffic congestion patterns. They also have the potential for direct involvement in relieving traffic congestion. By virtue of their organization at the state level, they have broad legal authority over state roadways, and because they are state agencies they tend to span whole metropolitan regions, except when the latter spill across state lines. Highway departments are also accustomed to handling large volumes of revenue through dedicated

highway trust funds and general appropriations. Among state agencies, highway departments are often granted significant autonomy through commissions and boards that buffer the agencies against direct political interference. They have developed levels of professional expertise on management of traffic that few agencies confined to the metropolitan level possess.

Federally Rooted Regional Agencies

Not unlike the rise of the COGs, federal policies implemented at the state and local levels have spawned a number of agencies with potential applications to congestion pricing implementation. The federal Clean Air Act, for example, authorizes the Environmental Protection Agency to take steps to ensure that state and local governments comply with federally set air-quality standards. This requirement has encouraged state and local governments to create regional agencies corresponding in jurisdiction to metropolitan areas where air pollution is most severe. Thus, the Southern California Air Quality Management District has the responsibility to propose and coordinate air-quality improvement measures, potentially including traffic management measures.

One-Tier Consolidations

An institutional arrangement that has a potential bearing on traffic management is the city-county consolidation, in which a county and the cities within it merge to form a single governmental unit. The county, in effect, becomes the government of the entire metropolitan region. Besides eliminating the balkanization of the metropolis, consolidation also significantly strengthens the power and authority of county government. Consolidation efforts that have succeeded include Nashville-Davidson County, Tennessee (1962); Jacksonville-DuVal County, Florida (1967); and Unigov in Indianapolis-Marion County, Indiana (1969).

Two-Tier Consolidations

The two-tier plan represents a federated approach to consolidation. Under this format, two levels of government are established within a metropolitan area. There is no merger or elimination of governmental units. Instead, those services that are areawide in their impacts are assigned to the superior, or metropolitan, tier, and activities whose effects are more localized at the community level remain with the preexisting local govern-

ments. Toronto and Miami are examples of the two-tier consolidation. Because roadway traffic has effects that are areawide, traffic management is assigned to the superior tier, thus overcoming balkanization, which nevertheless remains for more localized service delivery.

Three-Tier Consolidations

The three-tier plan attempts to deal with metropolitan issues across multiple counties. It retains existing county and municipal governments but superimposes on them a third tier. The multicounty tier is given responsibility for planning and coordinating services that affect the whole metropolitan area, including direct operating responsibilities in a number of service areas. The Greater Portland (Oregon) Metropolitan Service District is a prominent expression of the three-tier arrangement. Adopted by popular referendum in 1978, it has not only policy-making but also direct operating responsibilities.

Assessing the Alternatives

Some institutional arrangements are better suited to the accommodation of congestion pricing than others, and some are clearly ill-suited to the task. The strengths and weaknesses of the various alternatives are assessed next and in so doing the desired characteristics of congestion pricing systems developed earlier are applied to the institutional arrangements. Periodic reference is also made to political conditions that favor or disadvantage each arrangement both at the stage of its adoption and during its successful ongoing operation. No single institutional arrangement emerges as the perfect fit or even as the clearly preferred alternative. Still, a half-dozen of the arrangements appear more or less serviceable as administrative vehicles for introducing congestion pricing.

Annexation

Rearrangement of metropolitan institutions through annexation largely fails the test for administration of congestion pricing. It does expand the geographic scope for the annexing municipality to a larger territory within the metropolis, but it otherwise leaves the status quo. In addition, in all but the Sun Belt regions, annexation is a spent force. Elsewhere central cities rarely succeed in annexing their neighbors. Because most states now require dual referenda—voter approval of annexation by citizens in both

jurisdictions—central city predation on outlying territories is difficult to accomplish.

Voluntary Cooperation

Reliance on voluntary cooperation violates all six desired characteristics posited earlier for congestion pricing systems. It leaves the geographic scope unspecified, lacks both legal authority and financial capacity, is altogether too autonomous, fails the test of political accountability, and has no goal structure. The exit option under voluntary cooperation nullifies any good intentions that cooperating officials may have. Voluntary cooperation works best when noncontroversial issues are at stake, when program losers are difficult to identify, and when people's behavior or that of local governments is unaltered. None of these conditions apply to congestion pricing. This leads Downs (1992, 130) to conclude: "This is the least satisfactory type of arrangement with the fewest applications to fighting congestion, because it cannot compel local governments to coordinate their behavior closely or to monitor and adjust that behavior."

Privatization

The proposal to create privately operated roadways employing peak-hour pricing methods appears to have some application in selected traffic corridors, as the Orange County examples illustrate. But privatization is unlikely to provide a useful traffic management tool across whole metropolitan areas for several reasons. Part of the promise of privatization is the introduction of competition into road transportation systems. If privatization is applied across metropolitan areas, however, the problem of the monopoly supplier arises, nullifying the promise of privatization.

A more vexing issue involves legal authority. The state can, and does, devolve legal authority to general- and special-purpose governments and to private firms, but the privatization of roadway operations is not so simple. For example, in monitoring and enforcing peak-hour pricing, will the state patrol retain a policing role even on private facilities? Who administers and receives fines for violations? These and other complex legal issues require careful attention before the conversion of public freeways to private tollways.

Privatization holds the potential of infusing needed capital investment in new roadway capacities. It is unlikely, and unwise, to consider existing roadways for privatization (Poole 1992, 5). Cash-starved local govern-

ments and transportation authorities are likely to welcome such initiatives. But just because peak-hour-priced roadways are privatized does not mean that government financial responsibilities have ended. In letting franchises, the responsible government jurisdiction will have to specify the term of the franchise (35 years in Orange County), the permissible returns on investment, the conditions of pricing, hours, reinvestment for maintenance of the roadway, and so forth. There are questions within the terms of the franchise agreement about how much operating autonomy the private firm will have. Privatized roadways are likely to face recurrent issues over the political accountability of their operations. Finally, the question of what goal is to be realized through privatizing the roadway is not immediately apparent. Is it the supply of investment capital to complete roadway links otherwise left incomplete because of insufficient public investment capital? Is it the introduction of competition into roadway supply to achieve economic efficiencies in operations? Is it the generation of revenue for for-profit firms? Or is it to reduce traffic congestion to its most efficient level?

Thus, a mixed prospect emerges. The privatization alternative offers the infusion of capital into an otherwise unfinished roadway system, but it also raises a host of otherwise unresolved issues. Not to resolve them before letting private franchises is to invite program failure.

Private Coordination, Planning, and Policy Promotion Organizations

Two such organizations, the Bay Area Economic Forum and the Bay Area Council, the latter an employer-funded group, produced a report on market-based solutions to the transportation crisis that received wide public notice in the San Francisco area, favorable editorial comment, and endorsement from the metropolitan planning organization (MPO). In the end, the proposals for reducing traffic congestion were not adopted because the Bay Area Air Quality Management District lacked the necessary authority to impose them (McGill 1992, 22).

Private involvements in congestion pricing issues are several. These organizations can serve to educate the public broadly about the issues in question and inform key decision makers about the regional nature of traffic congestion. When elected officials may be averse to doing so, private organizations can speak forthrightly about controversial issues. They can act as catalysts in promoting programs to address congestion. But their primary limitation is the lack of public authority to accomplish

their ends. They also tend to draw from elite sources in the community, which is both a source of their strength and a limitation. In contrast to privatization proposals, private organizations lack the allocation of control over public resources. Private organizations have a role to play, and an important one, as promoters of congestion pricing alternatives, but as institutions responsible for implementing such schemes, they have a less important role.

General-Purpose Local Governments

General-purpose local governments, whether those of counties, cities, villages, urban towns, or townships, have the advantage of already being vested with substantial police power and taxing authority required for adopting and administering congestion pricing schemes. All but possibly counties, however, fail the test of geographic scope when congestion is areawide because their organization is less than metropolitan-wide. In large metropolitan areas, even the reach of counties falls short of metropolitan boundaries.

Counties have been reluctant players in traffic management, but the size of potential revenues from congestion pricing may change all that. Counties have a developed capacity for handling large revenue streams, but if their inducement for launching congestion pricing programs is the revenues that will be realized, the necessary degree of autonomy for the program as well as the goals assigned to the program will be compromised. Under these circumstances the objective of congestion pricing is likely to become the maximization of revenue rather than the reduction of traffic congestion to its most efficient level.

Special-Purpose Local Governments

Special districts are the fastest-growing type of government in the United States for several reasons. The first is simply the pragmatic. Under favorable state enabling legislation, special-purpose districts are easy to create. They are also quite flexible and can be applied to nearly any substantive problem area or designed to accommodate areas as small as a neighborhood and as large as a multicounty jurisdiction.

Political explanations for the popularity of special districts also help account for their rise. When popular demands for programs meet with resistance from general-purpose governments, which may not be able or willing to respond, a ready alternative is the creation of special districts. Special districts traditionally enjoy nonpartisan and autonomous status,

which is part of their appeal when partisan programs or departments of government are stalemated in providing programs or services. Their nonpartisan and autonomous status also appeals to business and other private interests. Public officials often embrace special districts because they serve their electoral needs. Politicians who desire to respond to popular demands but face legal constraints in doing so often turn to special districts. Where state constitutional or local statutory debt and tax limits tie politicians' hands, special districts provide an alternative because of the revenues they generate from user fees and their ability to borrow against future revenue yields. Personnel appointed to special district administrative ranks do not appear on general government employment roles, allowing politicians to claim to be doing more with fewer employees. Special districts are also a means for circumventing public unions or arcane civil service employment rules. Because of these significant advantages, it perhaps is not surprising that in the greater New York region, for example, of the 2,191 units of government, more than one-half are special districts (716) and school districts (661) (Danielson and Doig 1982, 4).

When evaluated in terms of the posited desirable characteristics for congestion pricing entities, special-purpose local governments have much to recommend them. Most special districts are granted broad legal authority to deliver goods and services within metropolitan areas. They have a long history of handling large and complex revenue streams and resisting raids by general-purpose governments on their substantial treasuries. The ability of special districts to retain internal control over the revenues they generate reflects the significant degree of autonomy granted to such entities in their enabling statutes. Special districts organizationally are guaranteed degrees of independence from partisan politics and insulated from general-purpose governments. Their goal structures also tend to be more limited, even singular at times, when compared with other metropolitan government units. Because of the degree of autonomy granted special districts, the problem becomes their political accountability. As set-aside agencies, special districts are not accountable in the same way as general-purpose governments, which frequently generates the criticism that they are politically less than fully accountable (Olson 1988a, 1988b). Still, whether through appointive or elected policy boards, special-purpose districts do have institutional structures allowing for accountability.

Special-purpose local governments tend to be organized on a geographic scale spanning less than whole metropolitan areas. Their scale of organization makes them suitable to assuming responsibility for conges-

tion pricing schemes applied to specific facilities, such as bridges and tunnels, and to specific traffic corridors. The utility of the special district is its ability to be designed specifically for less-than-metropolitan-wide applications.

Metropolitan Districts

All the advantages identified in special-purpose local governments are also found in metropolitan districts, plus one additional strength. What differentiates the latter from the former is that metropolitan districts are organized into jurisdictions spanning whole metropolitan areas. Instead of contributing to further balkanization of metropolitan areas, this type serves to reduce it.

Of the six desirable characteristics, only the question of political accountability is troublesome for metropolitan districts. But because these districts are usually charged with a single, or at most a limited, service function, politicians from other jurisdictions perceive them as less of a rival or threat to their sovereignty than general-purpose governments formed at the metropolitan level. This also makes creation of new metropolitan districts much easier. Some already exist in the transportation sector. They have been charged with planning and operating commuter rail lines, bus service, and fixed-rail mass transit systems. The Municipality of Metropolitan Seattle Transit Department (Metro) operates the bus system, the Tri-County Metropolitan Transportation District in Portland, Oregon, plans and operates mass transit, and the Golden Gate Bridge, Highway and Transportation District operates the Golden Gate Bridge leading into San Francisco. Because these districts are metropolitan-wide and already involved in transportation issues, they would appear to be prime candidates for congestion pricing responsibility. Downs (1992, 135) suggests that such agencies provide a strong model for new agencies: "If regional public agencies with the genuine power to affect traffic congestion are ever to be created, this is probably the form most will take."

Metropolitan Planning Agencies

There undoubtedly is a role to be played by metropolitan planning agencies, but it is likely to be a lesser role than that of the just-reviewed metropolitan districts and other special districts. Planning agencies organized at the metropolitan level simply lack the organizational capacity to act in anything other than an informational and advisory capacity.

The bill of particulars identifying weaknesses in COGs is extensive:

- They are only advisory, lacking substantial legislative power or authority;
- They are voluntary organizations whose members can withdraw at any time;
- They have few if any independent sources of revenue, relying instead on member contributions and shrinking federal grants;
- They are understaffed and lack technical expertise; and
- They give disproportionate influence to smaller jurisdictions because of the one-government, one-vote formula.

Even with this formidable set of organizational limitations, COGs can take the planning initiative on traffic management issues. SCAG has been particularly ambitious in this regard. In 1989, for example, it proposed, with the South Coast Air Quality Management District (SCAQMD), a drastic plan to curtail the region's escalating smog problem, including proposals to reduce automobile commuting (Brownstein 1989). The proposals drew support from residents concerned about the region's slow progress in combating air pollution and at least equal opposition from the cities of coastal Orange County, which feared loss of jobs and tax revenues. Duve, in another paper in this volume, discusses the San Diego Association of Governments (SANDAG), which similarly is aggressively pursuing a congestion pricing pilot program on portions of the I-15 HOV expressway.

Metropolitan councils, which succeeded the COGs, have an even greater potential role because of the greater policy areas assigned to them. The Metropolitan Service District in Portland, for example, has more policy involvements and operational authorizations than the Twin Cities (Minneapolis-St. Paul) Metropolitan Council.

Although both the COGs and the councils have potential roles to play in developing, planning for, and advocating congestion pricing, there are formidable constraints on the degree of their direct operation of congestion pricing systems. Their limited staff and expertise, voluntary membership, insecure funding base, and most critically their limited legal authority all place constraints on metropolitan planning agencies.

State-Mandated Metropolitan Planning

Growth management initiatives among the states in the 1980s created a high profile for this institutional arrangement. It has the advantages of (*a*)

forcing metropolitan areas to plan comprehensively across whole regions or risk losing state-shared revenues, (*b*) placing the full force of the state's legal authority behind the mandated goals, and (*c*) assigning singular or limited state goals to the metropolitan region. Traffic management conceivably could become the goal during the next decade just as growth management became the goal in rapidly growing regions during the last decade. Thus, this alternative represents a possible tool in the traffic management strategy.

There are a number of weaknesses in this alternative. First, it has been utilized in only about a dozen states. Second, when it has been used in the past, it has not involved the large revenue stream that congestion pricing is likely to generate, leaving uncertainties about its financial capacity. And last, state-mandated planning efforts can be heavy handed or perceived as such by metropolitan residents. This approach leaves little in the way of local (metropolitan) autonomy in deciding on the goals of the state mandate, let alone the initial choice to take this decisional route to congestion pricing. Political accountability is highly centralized with the state under this option, leaving little discretion at the metropolitan level.

Regional Compacts

The regional compact is rare because of the difficulty in securing its enactment. Not only do the two states in question have to assent to the compact, but congressional authorization is also required. The political barriers entailed in securing agreement between two states and the Congress reduce the likelihood that the regional compact will become a major institutional approach to congestion pricing.

Once created, regional compacts can become formidable agencies for pursuing their goals, as the Port Authority of New York and New Jersey has so convincingly demonstrated. In terms of the desirable characteristics, compacts span whole metropolitan regions, are legally secure, and have fully developed financial capacities, a significant degree of autonomy, and limited goal structure. As such, the few existing regional compacts might be thought of as vehicles to implement congestion pricing. But here the weaknesses in political accountability and responsiveness appear. For decades the Port Authority successfully resisted involvement in the region's mass transit programs, despite area residents' preferences and the strong urgings from the two state governors (Walsh 1978). Eventually the residents and governors prevailed. Given the substantial involvement that the Port Authority has in transportation issues in its region—including

operating six interstate bridges and tunnels, mass transit systems, two bus tunnels, and six airports—it might be thought of as an agency to be recruited to congestion pricing programs in its region.

Highway Departments

Highway departments in the 50 states are strategically situated to play crucial roles in adopting and particularly in administering congestion pricing programs. Traffic management has become much more important to highway departments in recent years. Some states have developed considerable expertise on the subject and have had experience with it.

Evaluated in terms of the posited desirable characteristics, state highway departments measure up well on all but one trait. They have jurisdiction over state roadways spanning metropolitan areas; they have broad legal authority in managing those routes; they are accustomed to handling large revenue volumes, including dedicated highway trust funds; they often enjoy grants of autonomy through highway commissions and boards that buffer them from direct political intervention; and their goal structures focus on the transportation function.

The question of political accountability is more difficult, particularly given the extreme degree of autonomy granted to them and their existence as state rather than metropolitan agencies. Not unlike the state-mandated metropolitan planning reviewed earlier, highway departments can be heavy handed, or perceived as such, when implementing road plans at the local level. Metropolitan residents have little readily available recourse in gaining access to or expressing their voice to highway departments. This is a critical issue in the decision whether to adopt a congestion pricing plan. Public approval of roadway pricing must be secured before its implementation, or the program will lack the required level of public support to ensure its effectiveness.

Federally Rooted Regional Agencies

The appearance of regional agencies as a consequence of federal programs and agency requirements provides opportunities for experimenting with congestion pricing programs. As with state highway departments, the most important challenge to such agencies is in generating broadly based public support for congestion pricing proposals from metropolitan residents and government officials.

The federally spawned agencies tend to have jurisdictions coincident with metropolitan areas, they often have significant grants of autonomy, and their involvement in traffic management derives secondarily from their primary goal (e.g., decreasing air pollution). Thus, there is some consistency between this type of agency and the posited desirable characteristics. Other agency traits make them less consistent.

These same agencies have more questionable legal authority to enter directly into congestion pricing, and they are not known for having developed the kind of revenue capacity desired for congestion pricing schemes. Yet the primary problem for such agencies involves their political accountability. If they simply attempt to impose congestion pricing, the reaction of commuters predictably will be to oppose the initiative strongly. Developing legitimacy for the initiative is a prerequisite to eventual program success. But the federally rooted regional agencies have less than fully developed ties to the community and are themselves not practiced in the skills of developing program support. As opposed to institutions lodged within local governments, these agencies also lack close ties with influential members of the local community and citizen groups. Thus the federally rooted regional agencies must take pains to involve citizens and public officials from the metropolitan area directly in a process toward decisions on congestion pricing. Not to do so will invite noncompliance and ongoing opposition.

One-Tier Consolidations

Strong counties have the same advantages in implementing congestion pricing as do the counties reviewed above, only more so. The one-tier movement, by removing subcounty jurisdictions through city-county consolidation, lessens fragmentation and potential jurisdictional rivalry. But because it has been adopted in so few places, and these were in the 1960s, the one-tier plan has very limited applications to congestion pricing. It is simply so difficult politically to effect this institutional reform that it is not now, nor is it likely to be, an important alternative.

Two-Tier Consolidations

The two-tier plan offers a promising resolution to the jurisdictional rivalry problem. It retains local jurisdictions but assigns the traffic management function to the superior tier (countywide) because of the areawide effects experienced in the transportation sector. Not unlike the one-tier reform,

two-tier institutional arrangements are politically very difficult to realize and are likely to remain so. With less than a half-dozen two-tier plans in place, this institutional alternative appears of limited utility to congestion pricing proposals.

Three-Tier Consolidations

The three-tier reform is even less frequently found than the one- or the two-tier plan, and for many of the same reasons. It appears not to be a viable institutional alternative simply because of the difficulty and infrequency of its adoption.

SUMMARY

On the basis of the foregoing review, at least five of the institutional arrangements available in metropolitan areas appear unsuited in one or more ways to the congestion pricing initiative. Annexation, voluntary cooperation, and the one-tier, two-tier, and three-tier consolidation reforms lack sufficient consistency with desired characteristics for congestion pricing implementation systems to merit continued consideration.

A half-dozen institutional arrangements display attributes closely aligned with characteristics desired in a congestion pricing approach to traffic management. County general-purpose governments, state-mandated metropolitan planning, federally rooted regional agencies, special-purpose local governments, metropolitan districts, and highway departments each contain sufficient strengths by the criteria utilized here to deserve careful consideration when congestion pricing implementation systems are proposed. None of these institutional arrangements is perfectly fitted to congestion pricing, but these closely approximate the preferred arrangements. The latter three—special-purpose local governments, metropolitan districts, and highway departments—appear to hold the greatest promise as potentially effective agencies in the implementation and ongoing operation of congestion pricing systems.

The remaining four alternatives—privatization, private organizations, metropolitan planning agencies, and regional compacts—fall in the gray area between clearly inappropriate and appropriate institutional options. Each appears to have some potential role in the process of adoption or administration of congestion pricing systems, but each falls short of the

half-dozen arrangements that appear best suited to congestion pricing programs.

CONCLUSION

The primary characteristic of the institutional arena within which traffic management programs are implemented in the United States is the extensive governmental fragmentation found in metropolitan areas, where traffic congestion is most severe. This paper has taken one proposed remedy for traffic congestion, congestion pricing, and has searched through a bewildering array of governmental institutions in metropolitan areas to assess whether agencies exist that might be suited to adopt and implement congestion pricing.

The approach has been to posit a half-dozen preferred characteristics that any entity ought to have if congestion pricing is to be implemented and administered effectively. Then existing institutional arrangements in metropolitan areas were inventoried, resulting in 15 alternative organizational arrangements. The preferred characteristics were then applied to the institutional arrangements to evaluate their suitability to congestion pricing programs.

From this analysis there appears not to be one single best way to organize congestion pricing across metropolitan areas. Instead there are at least a half-dozen workable alternatives, each demonstrating strengths and weaknesses, and other gray area institutions that can play some role in fostering, advocating, and implementing congestion pricing systems. This conclusion may be too unsettling for some, leaving adoption and administration of congestion pricing contingent on local preferences and idiosyncrasies. But because of significant variation in regional histories, cultures, politics, and institutional arrangements, this conclusion may be quite appropriate for the U.S. metropolitan context. What works effectively in one region of the country may not be most appropriate in other regions.

The absence of a pure institutional model is dictated in part by the ideal qualities suggested for congestion pricing systems. The geographic scope characteristic, for example, has opposite tendencies built into it. One can view geographic scope as requiring a systemwide orientation if the problem of traffic congestion appears generalized throughout the metropolitan region, as Bhatt has demonstrated for Washington, D.C., in another paper in this volume. Here application of congestion pricing systems across the

whole metropolitan region appears to be warranted. When traffic congestion is localized to specific infrastructure facilities such as bridges and tunnels or to particular roadway corridors such as a heavily traversed suburban highway link or an "hourglass" traffic configuration, less-than-metropolitan-wide and systemic agencies can be recommended. Here a facility-based or corridor-defined congestion pricing program appears to be more appropriate.

Existing metropolitan institutions may be capable of taking on congestion pricing proposals designed to meet the particular needs of a metropolitan area. Thus in the Bay Area, as discussed by Dittmar et al. in another paper in this volume, a metropolitan planning agency has taken the lead in coordinating a proposed congestion pricing demonstration project for the San Francisco-Oakland Bay Bridge, an entity owned, operated, and maintained by a state highway department. In other metropolitan areas, new agencies may need to be created where existing institutions with appropriate institutional and administrative characteristics are absent. Fielding in his paper in this volume shows that in Southern California, newly formed transportation corridor agencies under joint-powers agreements have begun to appear.

The incremental process of experimentation and innovation so characteristic of U.S. subnational government will result in diversity in the arrangements utilized to adopt and implement congestion pricing programs. The differing approaches taken in different metropolitan areas can serve as laboratories in which the many uncertainties involved in the administration of congestion pricing can be clarified.

Although this diversity in adopting congestion pricing institutions is predictable and can serve useful purposes, there exists an equally important need to select structures guided by the ideal characteristics suggested here for implementation of congestion pricing. The institutional arrangements and organizational formats selected as vehicles for introducing congestion pricing are not neutral or without their own set of influences. The types of structures selected will have important consequences for the ease or difficulty of adopting congestion pricing as well as eventual program success or failure. The very content of congestion pricing programs will also be strongly influenced by the structural, institutional, and organizational arrangements utilized in program administration. This paper has attempted to shed some light on how these structural influences are likely to vary across the alternative institutional arrangements available within metropolitan areas.

NOTES

1. The primary concern here is with congestion pricing systems utilizing peak-period pricing, although it is recognized that various alternative policies (tolls, cordons, parking, gasoline taxes, growth limitation) may also be advanced as antidotes to roadway congestion.
2. See his comment, "Beside the permanent associations which are established by law under the names of townships, cities, and counties, a vast number of others are formed and maintained by the agency of private individuals" (Tocqueville 1835, 204) For another foreign observer's similar views, see *The American Commonwealth* (Bryce 1901).
3. Part of this discussion draws from the author's previous work focusing on the economic and political performance of seaport authorities (Olson 1988a, 1988b).

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Equity and Fairness Considerations of Congestion Pricing

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Equity and fairness considerations are often central to transportation policy discussions. They have been part of the public debate regarding transit subsidies, automobile fleet fuel efficiency standards, toll roads, and a host of other policies. The purpose of this paper is to address equity and fairness issues associated with congestion pricing. Changing policy imperatives in the United States make congestion pricing an increasingly attractive policy alternative. However, serious barriers to implementation remain, and equity concerns have emerged as one of the most significant.

The paper begins with a discussion of equity and its many dimensions. The types of equity and fairness issues associated with congestion pricing are examined, and the difficulties of assessing equity impacts are discussed. Second, findings from previous research are summarized. Third, the equity of current policy with respect to the highway system is addressed, and fourth, the aspects of equity and fairness in the context of the travelers who would be subject to congestion tolls are discussed. Data primarily from Southern California are used to show that most travel on congested facilities is work related, and various commuter groups are examined to see how they might be affected by congestion tolls. Specific examples are used to illustrate how congestion tolls in Southern California might affect various commuter groups. The paper concludes with a discussion of the extent to which equity and fairness issues can be resolved and of the impact of these issues on the feasibility of implementing congestion pricing in the United States.

WHAT IS EQUITY?

Equity refers to the distribution of costs and benefits resulting from a policy decision. Traditionally, distribution has been considered with respect to household income. Equity assessment is most frequently applied to tax policy. Taxes are collected and then redistributed in the form of government programs or income transfers. Taxes are considered to be progressive if they constitute a greater proportion of income as income rises and regressive if the reverse is true. However, the net effects of tax policy are determined by how the benefits of government programs funded by the tax are distributed. For example, the federal income tax is progressive, but with the exception of the lowest income quintile, its net burden is only moderately so because government program benefits are more evenly distributed across all income categories (Musgrave and Musgrave 1989). It is also important to note that equity assessments are made relative to the existing distribution of income and therefore do not address the larger policy question of whether that distribution is socially optimal.

The equity of regulatory policies such as congestion pricing should also be considered in terms of net effects. Regulatory policies are generally aimed at correcting some type of market failure. Policies to reduce congestion fall into this category, because congestion is an externality problem. In considering the equity of such policies, the distribution of the benefits associated with the reduction of the congestion or pollution must be compared with the distribution of costs imposed to accomplish this reduction.

Other Aspects of Equity

In many policy debates equity takes on a much broader meaning and includes more generalized notions of fairness. First, equity may include geographic incidence. Regulatory policies may differentially affect regions or areas within regions. For example, proposals for parking restrictions are often hotly contested because they are viewed as detrimental to the competitive advantage of the affected location.

Second, equity may include incidence over time. Environmental policies are often justified on the basis of potential impacts on future generations (e.g., policies to reduce global warming). Impacts may also be assessed across existing generations or age cohorts. For example, air pollu-

tion poses a greater health danger for the very young and the elderly, and pollution controls may be advocated to protect these population groups.

Finally, equity may include fairness considerations within population subgroups or income categories. For example, policies that raise the price of traveling to work by private automobile may impose greater costs on workers with more schedule constraints. Working women are more likely to have significant schedule constraints than men and thus may be disproportionately affected by such policies (Hanson and Johnston 1985). Policies that require employers in certain locations to offer ridesharing incentives have a similar effect; some employees have the opportunity to take advantage of transit passes or carpool subsidies whereas others in otherwise similar circumstances do not.

Complexities Associated with Equity Assessment

Careful assessment of the equity impacts of congestion pricing is a complex and daunting task. First, the assessment is appropriate only if it can be compared with existing policy. Therefore the baseline needed is the net distributional effects of current transportation policy.[1] For example, if equity is a policy concern for congestion pricing, one must assume that it is also a concern for other aspects of transportation policy. In order to determine this baseline, the following information is required: (*a*) a complete accounting of all the various sources of transportation funding, both public and private; (*b*) an accounting of how these sources are distributed across income classes and other groups of interest; (*c*) a complete accounting of who benefits from using transportation resources, both directly and indirectly.

Given these extensive data requirements, it is perhaps not surprising that few attempts have been made to examine the equity of current transportation policy. Some studies have focused on specific aspects of transportation policy, such as the equity of public transit subsidies (Cervero 1981; Hodge 1986) or of highway funding sources (Rock 1982, 1990). No comprehensive studies of the distributional impacts of transportation policy are known to have been conducted within the past decade.[2]

Establishing the baseline is only the first challenge in evaluating the equity effects of congestion pricing. The second challenge is to be able to estimate the response to a specific pricing proposal. Since pricing strategies by definition affect demand, the nature and characteristics of demand must be known in order to predict the impacts of the proposal. Prior studies of

congestion pricing have used simplifying assumptions to avoid this difficulty [e.g., the paper by Small (1983)]. However, any serious effort to implement congestion pricing would require extensive study of potential responses.

Also to be considered is the final incidence of the toll charges and the revenues produced. For example, it is possible that employers would reimburse their employee's tolls. The toll cost would then be incorporated in general business expenses, which might be passed on in the form of higher product prices. Under these conditions, it would not be correct to assign the burden of the toll price to the highway user.

A final difficulty arises from the sensitivity of potential responses to the specific details of the policy itself. A freeway congestion pricing scheme, for example, might be configured with a system of rebates to low-income travelers or vouchers for express bus service. Alternatively, all the toll revenue might be used to replace local sales taxes or to fund mass transit construction. Each of these variants would have quite different equity consequences.

It is easy to see that a thorough assessment of the distributional effects of congestion pricing would require extensive research. The analysis presented in this paper is only a first step in conducting such an assessment.

PRIOR STUDIES

The distributional impact of congestion pricing has been a subject of concern from the time the concept was first proposed (Vickrey 1955, 1968; Sharp 1966). Since a congestion toll must result in the elimination of some peak trips and the primary direct benefit of the toll is time savings, it follows that the trips most likely to be eliminated (tolled off) would be those with the lowest value of time, and the trips most likely to benefit would be those with the highest value of time. Thus the distribution question is how these individual benefits and costs are spread across income classes.

Gomez-Ibañez identifies seven groups of winners and losers under congestion tolls (1992). Winners include those who continue to drive alone and whose value of time saved exceeds the toll (Group 1), those who previously used high-occupancy-vehicle (HOV) services and continue to do so (Group 2), and recipients of toll revenues (Group 3). Losers include those who continue to drive alone but whose value of time saved is less than the toll (Group 4), those who shift to a less-convenient untolled

facility (Group 5), and other (pre-existing) users of untolled facilities (Group 6). The impact on a seventh group, those who shift from driving alone to HOV modes, is unknown because it would depend on the benefits of avoiding the toll versus the inconvenience of using HOV modes.

Economists have shown that an individual's value of time savings is related to his wage rate (Small 1992a). High-income travelers will therefore benefit from the tolls, because the time they save will be worth more than the toll they pay (Group 1). To the extent that low-income travelers are already HOV users, they will benefit as well (from higher transit and HOV travel speeds). Middle-income travelers are likely to be in Groups 4, 5 and 7.[3]

Prior studies of the distribution effects of congestion pricing make three points. First, net effects depend on how toll revenues are spent. If revenues are not redistributed in any way, congestion tolls generally result in gains for higher-income groups and losses for lower-income groups (Else 1986; Cohen 1987). However, the revenue generation potential of tolls is large, and there are consequently many possibilities for offsetting toll impacts. In a recent analysis using a Los Angeles area congestion pricing proposal as a case study, Small (1992b) shows that it is possible to fully compensate losses due to the tolls for a wide spectrum of travelers with a revenue disbursement package that offsets some existing taxes, redistributes some revenue back to commuters and affected business centers, and provides funds to expand both highways and transit. In an earlier simulation study, Small (1983) showed that under three different revenue distribution schemes every income class benefits from congestion pricing except when the initial congestion level is low.

Second, under any but the most progressive redistribution schemes, higher-income groups would benefit more than lower-income groups. Thus, although it is possible to compensate losses through revenue redistribution and therefore generate net benefits to all income classes, the net effects would most likely be greater for higher-income groups.

Third, although it is possible to construct a revenue redistribution scheme that will compensate aggregate losses across income classes, it is not possible to compensate all losses to all individuals. Thus some travelers would be made worse off as a result of the tolls, no matter how revenues are redistributed. For example, in a study of peak tolls on the San Francisco-Oakland Bay Bridge, Harvey (1992) found that moderate-income, long-distance commuters working in south San Francisco would suffer substantial losses from the tolls, because as they would have no viable

alternative to driving to work. It is this aspect of congestion pricing that is the focus of fairness concerns.

Few studies have dealt with other aspects of fairness. Locational impacts have been considered in the context of downtown area tolls (Gomez-Ibañez and Fauth 1980; Urban Institute and KT Analytics 1991). Studies in Singapore suggest that the downtown has not suffered as a result of the tolls (Morrison 1986). No studies have directly addressed toll impacts across occupation, gender, or other categories.

EQUITY OF THE CURRENT SYSTEM

Any discussion of equity should begin with current conditions. As stated earlier, however, these conditions remain largely unknown. This section presents what is known of current conditions on the automobile and highway system.

Who Pays for Vehicles and Roads

Table 1 summarizes the initial assumptions for this paper regarding who pays for which parts of the system. It should be noted that costs are attributed to classes of the public, and differences that may exist regarding relative contributions within classes are not addressed. Highway users pay the capital and operating costs of the private vehicle. They pay for fixed facilities through fuel and other use taxes and for maintenance and operation of the highways through vehicle registration fees, fuel sales taxes, and other fees. The remainder of transportation system costs are paid by the general public in the form of federal and state income, property, and sales taxes. In 1990 total highway revenues were $73.9 billion. Fuel taxes and other use fees accounted for about 60 percent, other taxes and fees contributed 25 percent, and the remainder came from bond proceeds and investment income (DOT 1991).

Congestion costs are split between users and the general public. Users incur delay when they travel on congested roads; the economic costs of some of this delay are shifted to the general public. Little information is available on the costs of congestion. A Texas Transportation Institute study of 39 U.S. metropolitan areas estimated costs of time delay and excess fuel consumption to be $41 billion in 1987 dollars (Hanks and

TABLE 1 Who Pays for Using Vehicles and Roads

Item	Who Pays
Private Vehicle, Capital and Operation	User
Road System, Capital and Operation	User, via fuel and other use taxes General public, via federal and state income tax, local property tax, sales tax, and other
Congestion	User, via delay incurred General public, via added costs to business activities

Lomax 1990). Although this estimate may be very rough, it does suggest that congestion adds significant costs to transportation. There are no estimates of how these costs are distributed across classes of highway users.

Private Vehicle Use and Expenditures

More information is available on private vehicle use and expenditures. It is well known that use of private vehicles is related to income. Table 2 provides illustrative data from the 1990 Nationwide Personal Transportation Study (NPTS). The following travel characteristics are shown to increase with household income: vehicle ownership, number of person-trips, share of person-trips made by private vehicles, vehicle miles traveled (VMT), and trip distance. Table 2 also shows that work-trip frequency and distance increase with income.

Table 3 gives information on private vehicle expenditures by income category. The income and expenditure data are taken from the 1989–1990 Consumer Expenditure Survey (CES) (Bureau of Labor Statistics 1993). The income categories were selected on the basis of compatibility between the CES and NPTS data. The first two rows of Table 3 give the percentage distribution of households across income categories for the two data sets. Differences are due to different definitions of the household unit, as well as differences in sampling procedures, and so forth.[4] The comparisons presented here are thus only approximate and should be viewed with caution.

The second two rows in Table 3 give average gross income and expenditures (all items are defined at the bottom of the table). The next three rows give total private transportation expenditures, which include vehicle purchase, operation, insurance, fees, and so on, in dollars, as a percent of income and as a percent of all expenditures. Total dollar amounts increase with income but decrease with income when measured as a proportion of income. This reflects the more general pattern of consumer expenditures as a percent of income falling as income rises. Measured as a percent of all expenditures, private vehicle expenditures are fairly constant across income categories.

How do these expenditures relate to private vehicle use? The last two rows of Table 3 give transportation expenditures in cents/VMT. Table 2 shows that VMT rises steadily with income; the highest-income group averages four times as much VMT as the lowest-income group. Transpor-

TABLE 2 Private Vehicle Use by Income Category

ITEM	LT $10K	$10-19.9K	$20-29.9K	$30-39.9K	$40-49.9K	GT $50K
Vehicles/HH[a]	0.96	1.37	1.70	1.95	2.15	2.45
Vehicles/Adult[a,c]	0.64	0.80	0.92	1.00	1.04	1.11
Annual VMT/HH[a]	7,179	11,928	16,536	19,771	23,758	28,541
Daily Person-Trips/HH[b]	6.02	6.51	7.63	8.37	9.32	9.44
Average Person-Trip length[b] (miles)	6.37	7.97	8.31	9.06	9.53	10.46
Private Vehicle Trip Share[b] (of Daily Person-trips) (%)	72.2	84.0	87.4	88.9	91.5	90.2
Daily Work-Trips/HH[b] (%)	0.79	1.20	1.55	1.83	2.06	2.18
Average Work Trip Length[b] (miles)	9.34	8.68	9.65	10.93	10.98	13.59

SOURCE: 1990 Nationwide Personal Transportation Study data files
a NPTS Household file
b NPTS Travel day file
c Ratio is number of vehicles in household/number of adults in household

HH = household
VMT = vehicle miles traveled
1 mi = 1.6 km

TABLE 3 Private Vehicle Expenditures by Income Category

ITEM	LT $10K	$10-19.9K	$20-29.9K	$30-39.9K	$40-49.9K	GT $50K
Percent of Survey HH						
CES	20.6	21.0	17.7	12.4	9.4	18.8
NPTS	11.7	17.6	17.4	17.1	10.8	25.4
Income Before Taxes	5,751	14,641	24,676	34,422	44,648	78,711
Average Annual Expenditures	12,880	18,392	24,535	31,298	38,397	56,296
Total Private Transportation Expenditures						
Dollars	1,888	3,270	4,340	5,748	6,892	8,951
Percent of Income	32.8	22.4	17.6	16.7	15.4	11.4
Percent of Expenditures	14.7	17.8	17.7	18.4	18.0	15.9
Transportation Use						
VMT/HH (NPTS)	7,179	11,928	16,536	19,771	23,758	28,541
Expenditures / VMT						
TOTAL (cents / VMT)	26.3	27.4	26.2	29.1	29.0	31.4
Gas & Oil	7.3	6.4	6.5	6.2	6.0	5.7

SOURCE: 1990 Nationwide Personal Transportation Study data files; 1989-1990 Consumer Expenditure Survey data.

HH = household
VMT = vehicle miles traveled
1 mi = 1.6 km

tation expenditures per VMT also reflect the same pattern (Table 3), but the difference from lowest to highest is far less extreme (20 percent). Differences in expenditures per VMT reflect larger expenditures on new vehicles in higher-income categories, whereas gasoline and oil expenditures are greatest in the lowest-income category because of the use of older, less fuel-efficient vehicles.

What do these numbers suggest about equity? If VMT is considered as a measure of benefits, Table 3 shows that higher-income households consume more transportation benefits using a smaller proportion of available income. No data on tax contributions to transportation by income category are available. The incidence of the types of taxes used to fund highway services is given in Table 4. Since all but the federal income tax are regressive, it is likely that the net incidence of the direct costs and benefits of highway services is regressive. Research is greatly needed on this issue.

WHO TRAVELS ON CONGESTED FACILITIES?

The first step in determining the impact of congestion pricing is to determine the characteristics of those who would be subject to the toll. Unfortunately, data are very limited on this question. Most trip data (e.g., NPTS or census) are highly aggregate and not linked to specific routes. Even origin-destination data are not necessarily adequate; there must be sufficient detail to identify both the time and route of the trip. Such detailed information is best obtained from traveler surveys. In this section data culled from several different survey projects, most from the Los Angeles region, are presented. None of these projects were designed to determine who would be affected by congestion tolls. Thus the results presented are only suggestive.

TABLE 4 Incidence of Taxes Used To Support Highway Services (Musgrave and Musgrave 1989; Rock 1982)

TAX	INCIDENCE
Federal, state fuel gallonage tax	Regressive
State use fees	Regressive
State sales tax	Regressive
Local sales tax	Regressive
Federal, state income tax	Progressive
Property tax	Regressive

Trip Purpose

Data from three surveys of Southern California freeways provide some information on users of congested facilities and show that most trips are to work or work related. These surveys were conducted as part of the HOV lane planning effort within the region. Respondents were asked about the trip they made on the freeway that day. Table 5 gives the percentage of trips that are to work or work related, by hour, for the a.m. peak. This category of trips includes those from home to work or from work to home and those from home to work-related destinations. The majority of peak trips are included in this category; the range is from just under 70 to 98 percent. These percentages are biased upward by the way the survey was conducted;[5] nevertheless, they show that peak freeway travel (particularly at the peak hour) is overwhelmingly composed of work-related trips.

Additional data on traffic conditions show that the difference in the share of work travel on each freeway is also related to the level of congestion. The California Department of Transportation uses a level-of-service (LOS) index that extends the usual categories of A through F to levels of F based on the daily duration of congestion.[6] Both I-110 and Route 91 are rated LOS F-3 at the locations where the surveys were conducted, meaning that these freeways average more than 3 hr of travel speeds under 30 mph (48 km/hr) every weekday. In contrast, the I-405 location is rated F-0. The fact that work trips make up an increasingly large proportion of trips on

TABLE 5 Percent Share of Work and Work-Related Trips by Hour of Day, a.m. Peak, Various Freeway Locations

LOCATION / TIME	I-405 Orange County	SR-91 Orange County	I-110 Los Angeles Co.
6 - 7 AM	N/A	96.0%	97.9%
7 - 8 AM	85.9%	92.9	95.1
8 - 9 AM	78.4	87.9	92.6
9 - 10 AM	69.6	70.7	83.3
Survey date	10/87	10/88	5/89
N	1,903	3,662	1,145

SOURCES:
I-405: Orange County Transit District, 1988.
SR-91: Patti Post & Associates, 1989.
I-110: Caltrans Harbor Freeway Survey tape file.

congested facilities is entirely consistent with prior research on elasticities of various types of trips (Dix and Goodwin 1982; Levinson et al. 1980). The work trip is the most inelastic, particularly in the short run. As congestion increases, more flexible trips are diverted to other routes, times, or destinations. It may be concluded, then, that most travelers subject to congestion pricing will be commuters.[7]

Possibilities for Adjustment

Since most trips on congested facilities are work trips, it is appropriate to consider first what types of behavioral adjustments to the tolls are possible and second whether these opportunities are differentially distributed across income, occupation, or gender groups. In the longer term, it is clearly possible to change job or residence location; in the short term, it is unlikely. Thus forgoing the trip altogether or shifting the destination are not likely short-term responses for most commuters.[8] More likely short-term responses include switching to other modes, trip schedules, or routes or paying the toll. This discussion is restricted to these short-term responses.

From the point of view of the individual, responses to the toll depend on three different levels of opportunities and constraints. The first is that of household characteristics (income, availability of vehicles, responsibilities for other household members, etc.). These characteristics define the alternatives that are feasible for a given individual commuter. The second level is the workplace. If alternative work schedules (including a compressed work week and telecommuting) are available, for example, commuters have options for rescheduling the work trip or making fewer work trips per week. The third level is the supply of available transportation alternatives. High-quality transit service, alternative untolled routes, toll exemptions for carpools, and so on, define the array of transportation choices.

It is important to note that these levels are hierarchical. If household constraints are binding (e.g., children must be dropped off and picked up at a specific time), the individual will not be able to shift his or her work schedule or mode, whether or not such options are available. Similarly, a shift to transit is possible only when transit is available and when rearrangement of the daily schedule required to use it is feasible.

Household Characteristics

Prior studies of the distributional impact of congestion pricing have focused on household income, as summarized above. These studies assume

that preferences for travel are the same within income categories and therefore that the segmentation by income is sufficient to capture differences in incidence. What about differences within income categories? For example, there is extensive evidence that women have primary responsibility for child care and household tasks, whether or not they are employed (Hanson and Hanson 1980; Michelson 1985). Working women may therefore experience greater time pressure and have more constraints in organizing daily activity schedules than working men. This implies that travel demand characteristics differ by gender; that, all else being equal, women's demand for high-quality transport (e.g., driving alone) is less elastic than that of comparable men.

Women's greater reliance on the automobile has been documented in several studies (Kostynuik et al. 1989; Rosenbloom and Raux 1985). Recent work by Rosenbloom and Burns (1993) is illustrative. In a study of Tucson area workers subject to the region's trip reduction program, Rosenbloom and Burns found that women were more likely to drive alone to work than men in every household income category except that of $80,000 or higher. The study also found that, for comparable distances, women's trips to work took more time than those of men. The authors suggest that these slower speeds are the result of linking other tasks (such as picking up and dropping off children) with the work trip, another indicator of women's greater reliance on the speed and flexibility of driving alone.

If women are more likely than men to have more-rigid daily schedules, they will find it more difficult to make changes in their daily schedule. There is much evidence that this is the case. The Rosenbloom and Burns study showed that women were less likely to switch to other modes than men in response to trip reduction incentives offered at the workplace. An earlier study of a compressed-work-hour demonstration project in Denver showed that, when offered, men were more likely than women to choose the compressed schedule (Cambridge Systematics, Inc. 1980).

In an evaluation of a staggered-work-hours demonstration project in Honolulu, Giuliano and Golob (1989) found that nonparticipants were more likely to be women, have young children, be members of multiworker households, and ride with others to work. This demonstration project required public-sector workers to shift their daily work schedule 45 min later for a period of 4 weeks. Participation in the project was mandatory; nonparticipation required approval through a formal exemption process. Despite this requirement, nearly half of the subject employees declined to participate in the project. Reasons given for nonparticipation generally focused on child care or household-related schedule difficulties.

Project participants reported problems in several aspects of nonwork activities, including taking care of personal business (63 percent), scheduling social activities (56 percent), and doing things with household members (56 percent). Arranging for child care and children's school activities was also identified as a problem. Although these problems were at least in part the result of the temporary nature of the project, they do illustrate the extent to which one's work schedule is embedded in the larger pattern of the household activity schedule as well as the difficulties involved in making changes in the work schedule.

Finally, as part of an evaluation of an Orange County, California, HOV lane in 1987, Giuliano et al. (1990) conducted a survey of freeway commuters. Solo drivers were asked a series of questions about why they did not carpool. Women were more likely than men to rank the need for a car before or after work as very important, whereas men were more likely to rank the need for a car during work as very important, again suggesting that, for women, household-related constraints play a significant role in determining travel choices.[9] It is also worth noting that the need for a car during work can be addressed by the employer, but the need for a car before or after work is an individual matter.

Work Schedules and Trip Scheduling

Trip scheduling is a major response to congestion. As daily traffic volumes increase, peak periods extend in duration. This peak-spreading results because travelers shift their trips to less-preferred time intervals. Recent surveys and stated-preference studies of commuters show that changing departure time is the most-preferred strategy for avoiding congestion. Changing route is a second choice, but changing mode is often not considered an alternative at all (Mahmassani et al. 1991).

The cost to the individual of shifting a trip depends on whether the activity associated with that trip can also be shifted. If an employee can choose his or her own work schedule, the commute can be shifted to a less-congested (but perhaps less-preferred) time, with no other costs incurred. If the work schedule is fixed, the employee is faced with the choice of spending extra time commuting or waiting to start work.

Commuters traveling in congested corridors take advantage of flexible work schedules when such schedules are available. The Orange County freeway commuter survey described previously is illustrative. Figure 1 shows the distribution of work start times for commuters who use Route

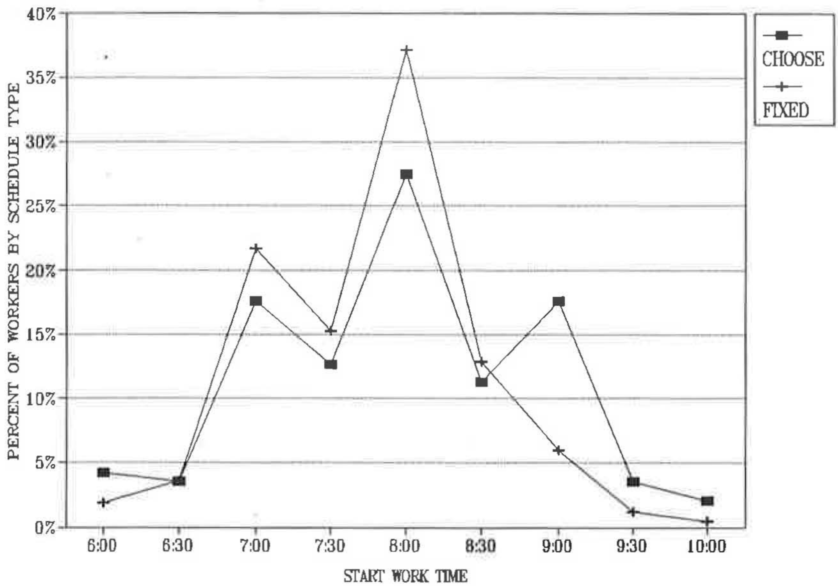

FIGURE 1 Work start times, Route 55, Orange County, California, by type of schedule.

55, a congested Orange County freeway. Commuters are segmented into two groups: those who are able to choose their own work schedule ("choose"), and those whose schedule is fixed by the employer ("fixed"). Work start times are more peaked for the fixed-schedule group, and there is a much higher share of later starting times among the choose-schedule group.

Similar patterns were also observed in the survey of downtown Honolulu employees (Giuliano and Golob 1989). When private-sector employees were offered the choice of flexible work hours as part of the staggered-work-hours demonstration project, work arrival times were shifted out of the 7:00 to 7:30 a.m. peak to both earlier and later arrivals.

It seems reasonable to expect that shifts in work schedules and work trip schedules would also be a primary response to congestion tolls. Thus the availability of flexible work schedules is of interest. The Route 55 survey also included freeway commuters from throughout Orange County and parts of Riverside and Los Angeles counties. Using the entire data set, schedule flexibility, defined as the ability to choose one's work schedule, is found to be associated with income, gender, and occupation. Figure 2 shows the relationship between household income and work schedule

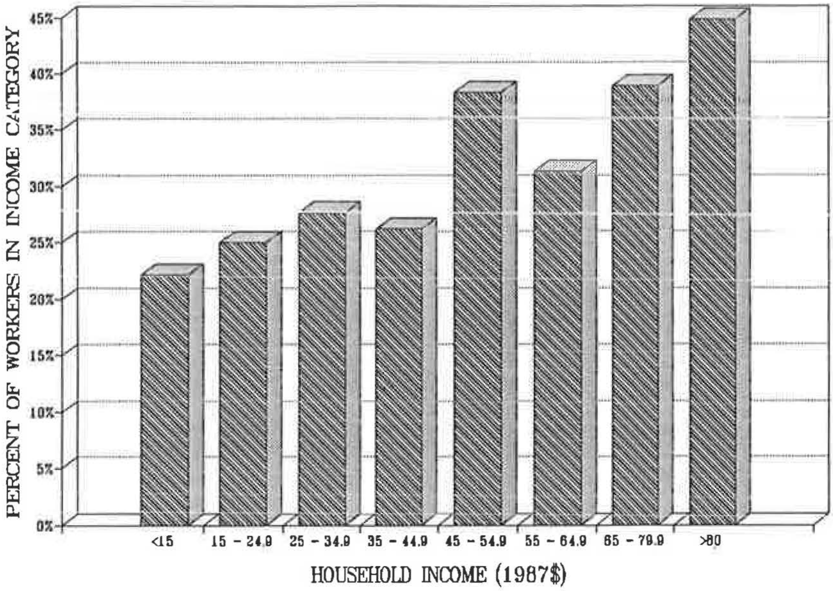

FIGURE 2 Relationship between work schedule flexibility and household by income.

flexibility. The freedom to choose one's own work schedule is clearly more available to workers from higher-income households.[10]

The Orange County survey data also show that men are more likely than women to have flexible work schedules. Nearly 40 percent of all male workers are able to choose their own work schedule, whereas only 28 percent of all female workers have this choice. Nor is this difference entirely attributable to differences in occupation across gender. Rather, in every occupational category except secretary/clerical, more men than women are able to choose their own work schedule, as shown in Figure 3.[11] Occupations are categorized into four groups: management/professional, secretary/clerical, sales, and all others (production, construction, service, self-employed). The most extreme difference is in sales: 73 percent of male sales workers versus 48 percent of female sales workers are able to choose their own work schedule. Thus, not only are women more likely to have occupations that are associated with fixed work schedules, but they are also more likely to have fixed schedules even in occupations where flexible schedules are more prevalent. Results from this survey suggest that work schedules are more flexible for higher-income male workers, and therefore these workers will have relatively more flexibility in responding to congestion tolls than their lower-income female counterparts.

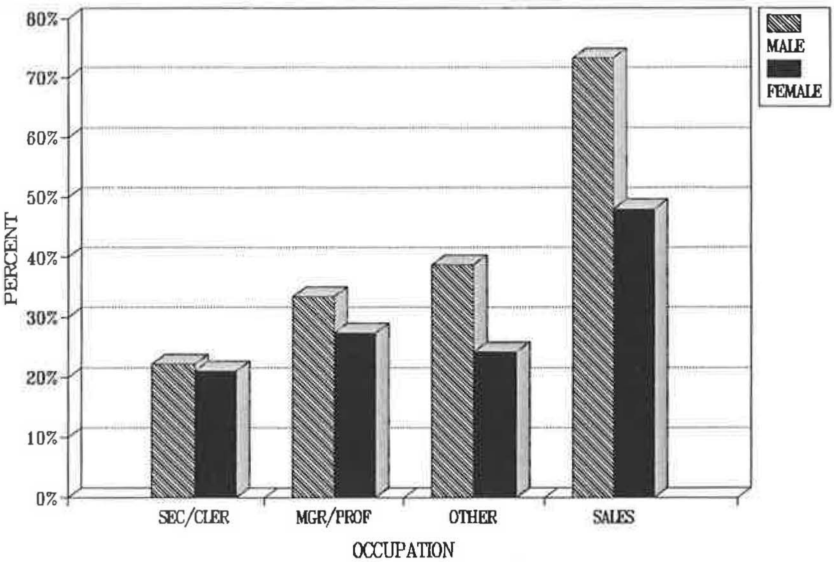

FIGURE 3 Relationship between choice of own work schedule and occupation and gender.

Supply of Transportation System Alternatives

Switching to other modes or routes is another possible response to tolls. The NPTS data show that the share of drive-alone work trips has continued to increase whereas shares of all collective modes have continued to decrease. As of 1990, public transit accounted for just 5.5 percent of all work trips. Public transit is obviously a poor substitute for the majority of commuters. To what extent, then, can mode switches be expected in response to congestion tolls?

Willingness to switch to public transit depends on its quality and availability. In Singapore, mode switching was the most-frequent response to the downtown congestion tolls. In Trondheim, Norway, a low-density city, a stated-preference survey indicated that switching to other travel times was generally a more-frequent response to the proposed downtown cordon charge. Stated-preference studies of proposed peak tolls on New York City bridges also revealed travel time shifts to be the preferred response. In addition, the New York City study suggests that the travel time shift is the preferred response even at relatively low peak charges; switches to other modes are related to the magnitude of the toll (Jones 1991).

Willingness to switch to public transit or carpool appears also to be related to gender. As noted earlier, Rosenbloom and Burns (1993) showed that women were less likely than men to take advantage of rideshare incentives offered by employers. Their data also show that mode choice is related to gender, marital status, and presence of children.

CONCLUSIONS REGARDING POTENTIAL RESPONSES TO TOLLS

The discussion in this section may be summarized with the following points. First, there are systematic differences in travel behavior that are not explained by income but by gender and household characteristics. Second, opportunities for responding to changes in travel costs or conditions differ by occupation and gender as well as by income. These two points suggest that peak-period demand is a mix of different markets, each with its own elasticity with respect to price and other alternatives. Analysis of any specific congestion pricing proposal would thus require estimating toll responses within each of these markets.

Third, predicting impacts of congestion tolls on the basis of income (incidence) does not provide an adequate description of the differential impacts such tolls would in fact have. And fourth, the traditional solution for addressing equity problems, redistribution of toll revenues, would not solve problems of differential impacts across gender, occupation, or other groups unless it were finely targeted by those dimensions.

COMMERCIAL TRAFFIC

Although the focus in this paper has been the commuter, any discussion of the fairness impacts of congestion pricing must include commercial traffic. Congestion adds to the cost of business for commercial traffic; the lost time must be paid directly in the form of additional wages and higher vehicle operating costs. Congestion pricing would give commercial carriers the flexibility to schedule trips more efficiently and thus could result in overall productivity increases. Commercial traffic is thus likely to be one of the greatest beneficiaries of the tolls.

Information on commercial traffic is almost nonexistent. However, a recent freeway truck study conducted in California provides evidence that trucks avoid congestion (Cambridge Systematics, Inc. 1988). In this study, counts of large-truck traffic were conducted during the a.m. peak (7:00 to

9:00 a.m.), midday (11:00 a.m. to 1:00 p.m.), and p.m. peak (4:00 to 6:00 p.m.) at several freeway locations in the Los Angeles, San Francisco, and San Diego metropolitan areas. Large trucks are defined as vehicles with three or more axles and a gross vehicle weight rating of 26,000 lb (11 778 kg) or more.

The study showed that the share of large trucks is lower in the peak periods than at midday and is lowest in the p.m. peak in all three metropolitan areas. Furthermore, large trucks apparently avoid the most congested areas. For example, Table 6 gives average large-truck percentages for all count stations and for count stations at which observed traffic volumes were greater than 1,700 vehicles/hr/lane for Los Angeles. Truck percentages on the high-volume (congested) locations are significantly lower in each time period. This study also included a cluster analysis of freeway segments based on large truck volumes, total daily traffic volume, injury accident rate, and ratio of daily traffic to roadway design capacity. The cluster analysis showed that the truck volume percentage is lowest on segments with the highest traffic volumes and accident rates.

POTENTIAL IMPACTS OF CONGESTION TOLLS: SOUTHERN CALIFORNIA EXAMPLES

Opportunities for responding to tolls differ by gender and occupation as well as income. In this section examples are presented to show how representative commuters from various population subgroups might be affected by congestion tolls. The Los Angeles area congestion pricing proposal as presented by Cameron (1991) and the associated revenue disposition proposal presented by Small (1992b) are used as the basis for these examples.

TABLE 6 Average Share of Large Trucks by Time Period, Los Angeles Area

	AM Peak	Mid-day	PM peak
Average % of large trucks, all stations[a]	4.43	6.34	2.88
Average % of large trucks, stations with VPHPL>1700[a]	2.67	3.12	2.15

[a] Average of the weighted percentage of large trucks as share of total freeway volume.

SOURCE: Computed by the author from Table 3, Technical Memorandum 1-2, Cambridge Systematics (1988).

The Los Angeles region pricing proposal calls for peak-period tolls averaging $0.15/vehicle-mi ($0.10/vehicle-km) to be charged on highways currently subject to heavy congestion. Tolls of this magnitude are estimated to reduce peak VMT by 26 percent and generate revenues of $3.12 billion in 1990 dollars (Cameron 1991; Small 1992b). Small (1992b, 365) proposes a revenue disposition package that is aimed at offsetting the negative impacts of the tolls, promoting social goals, and garnering political support. His package thus contains reimbursements to travelers, substitutions for taxes currently used to pay for transportation services, and funding for new transportation services. This package provides a useful context for considering toll impacts, because it represents a best case in terms of reducing negative effects. Other revenue disposition scenarios would likely result in making more commuters worse off.

In order to calculate impacts for specific commuters, Small's assumptions regarding incomes, value of time, fuel consumption, incidence of tax savings, and new investment programs were adopted. Small's use of a travel time penalty to express the inconvenience and added travel time cost of carpooling or using transit relative to driving alone were also adopted.[12] The example commuters presented here are based on Los Angeles region commuter survey data (Collier and Christiansen 1992). The survey data give a median commute distance of 10 mi (16 km) and a median speed of 20 mph (32 km/hr). The 75th-percentile commute distance is 24 mi (37 km), which is also the average distance of commutes made using a freeway. The average speed of freeway commutes in the survey is 30 mph (48 km/hr). For vehicle operating cost $0.15/vehicle-mi is used from the CES data cited earlier. It is assumed in all cases that mode switches would not affect automobile ownership. All impacts are calculated on an annual basis.

Case 1: Middle-Income Commuters

The first example is that of a middle-income solo driver with a 10-mi commute in a corridor where public transit is available (in Los Angeles, this might be the I-110 corridor leading downtown). At an average speed of 20 mph, his or her trip time would be 30 min. As in the paper by Small (1992b), congestion tolls are assumed to increase average speed to 30 mph. Table 7 gives the results in three parts: net trip benefits, net time and dollar benefits, and total net benefits. Trip benefits are the net effect of the tolls on the trip, including savings from switches to other modes. Net time and dollar benefits incorporate the benefits from using toll revenues to give all

TABLE 7 Impacts of Tolls on Middle-Income Commuters

Mode Before Mode After	Drive Alone Drive Alone	Drive Alone Transit	Drive Alone Drive Alone	Drive Alone Transit
Assumptions:				
Value of time savings (per hour)	$6.05	$6.05	$6.05	$6.05
Trip distance (1 way)	10	10	25	25
Before mph	20	20	30	30
After mph	30	30	40	40
Before fuel consumption	400	400	480	480
After fuel consumption	400	200	480	200
Results:				
Costs ($/yr)				
Congestion tolls ($.15/mi)	(750)	0	(1,875)	0
Transit fare[a]	0	(500)	0	(1,250)
Auto operating costs	0	750	0	1,875
Time Savings ($/yr)				
Amount (min/day)	20	20	24	24
Carpool/Transit penalty (min/day)[b]	0	20	0	30
Value ($/yr)	504	0	605	151
Net Trip benefits	(246)	250	(1,270)	474
Monetary Benefits($/yr)				
Travel allowance	120	120	120	120
Fuel tax	20	10	24	10
Sales tax	86	86	86	86
Property tax	57	57	57	57
Subtotal	283	273	287	273
Net time and money ben.	37	523	(983)	747
Other Benefits ($/yr)				
Improved hwys	64	0	64	0
Transit	32	127	32	127
Business centers	33	33	33	33
Subtotal	129	160	129	160
Total Net Benefits	166	683	(854)	907

[a] Transit fare assumed: $1/trip for 10 mile trip, $2.50/trip for 25 mile trip

[b] Carpool/transit penalty represents added time required to access/egress the linehaul mode plus inconvenience of mode relative to driving alone, in minutes/day.

1 mi = 1.6 km

employees a transportation allowance and to reduce existing fuel, sales, and property taxes. Total net benefits add the benefits from improved transportation facilities.

If this commuter continued to drive alone (first column in Table 7), he or she would pay tolls of $750/year, enjoy time savings valued at $504, and receive additional benefits from a transportation allowance and tax reductions totaling $283. The net time and dollar savings for this commuter would be $37. Benefits from improved transportation services would add $129, yielding total net benefits of $166. If the commuter shifted to transit, he or she would enjoy the same higher travel speed, but the time savings would be offset by the added time and inconvenience of taking transit (see second column of Table 7). The commuter would pay less in transit fare ($500) than in automobile operating cost ($750) and would also receive benefits from the transportation allowance, reduced taxes, and transportation system improvements. His or her total net benefits would amount to $683. Note that this commuter would not switch to transit without congestion pricing, because the inconvenience of transit (20 min/day, or $504/year) would be greater than the costs saved ($750 automobile operating costs less $500 transit fares, or $250/year).

The third and fourth columns of Table 7 give results for a middle-income solo driver with a 25-mi (40-km) commute. This case again assumes that without congestion pricing, driving alone would be the preferred mode. Congestion tolls are assumed to increase average speed from 30 to 40 mph (48 to 64 km/hr), thus reducing one-way trip time from 50 to 38 min. If this commuter shifted to transit, the total annual net benefits would be $907, mostly from automobile operating cost savings. If he or she continued to drive alone, the tolls would be far in excess of the value of time savings and other benefits, yielding a total loss of $854.

Most parts of the Los Angeles region are not well served by transit, however. Consequently, most commuters would find carpooling to be the only reasonable alternative to driving alone. Using the same commute distances and times to calculate the net impact of a switch to carpooling, for the 10-mi trip total net benefits would be $534 and for the 25-mi trip, $261 (not shown in Table 7).

These examples show that if middle-income commuters can take advantage of available transit or switch to carpooling, they would be likely to benefit from congestion tolls. Further, the longer the commute, the greater the impact would be. This happens because the revenue offsets are relatively fixed, whereas the toll increases with distance. Long-distance com-

muters who continue driving alone would be most adversely affected by the tolls.

Case 2: Low-Income Commuters

What about low-income commuters? Most low-income workers in Los Angeles drive alone; the second most frequent mode is carpooling. Small (1992b) calculated net benefits for a low-income solo commuter with a 10-mi trip. If this commuter continued to drive alone, he or she would suffer net time and money losses of $111, which would just be offset by benefits of improved transportation services (first column of Table 8). If there were a switch to carpooling, he or she would receive net benefits of $470 (second column of Table 8).

Low-income, long-distance commuters are quite likely to be carpoolers. Given the travel cost and time value used here, a low-income, long-distance commuter would choose carpooling rather than driving alone in the absence of congestion pricing. Therefore the impact of congestion fees calculated for a low-income carpooler is shown in the remaining columns of Table 8. If carpooling continued, the tolls would result in net losses of $87. If there were a switch to a three-person carpool, the added inconvenience of including one more person would be greater than the share of automobile operating cost and toll savings, leaving a greater net loss ($171). Finally, if this carpooler were able to switch from carpooling to transit, a net savings of $167 would be realized. These examples show that low-income, long-distance commuters would be quite likely to be adversely affected by congestion tolls, even when favorable revenue redistribution schemes were in place.

CONCLUSIONS

These simple examples demonstrate that the potential impacts of congestion pricing are significant. They depend greatly on the availability of transportation and other alternatives, as well as on the particular circumstances of individuals. Commuters who continued to drive alone, especially for long distances, would suffer the greatest losses, even under the most favorable revenue disposition assumptions. Commuters who avoided all or part of the toll by shifting to other modes, routes, or time periods would likely benefit.

TABLE 8 Impacts of Tolls on Low-Income Commuters

Mode Before Mode After	Drive Alone Drive Alone	Drive Alone Carpool	Carpool (2) Carpool (2)	Carpool (2) Carpool (3)	Carpool (2) Transit
Assumptions:					
Value of time savings (per hour)	$4.72	$4.72	$4.72	$4.72	$4.72
Trip distance (1 way)	10	10	25	25	25
Before mph	20	20	30	30	30
After mph	30	30	40	40	40
Before fuel consumption	320	320	400	400	400
After fuel consumption	320	256	400	320	200
Results:					
Costs ($/yr)					
Congestion tolls ($.15/mi)	(750)	(375)	(938)	(625)	0
Transit fare ($2.50/trip)	0	0	0	0	(1,250)
Auto operating costs	0	375	0	313	938
Time Savings ($/yr)					
Amount (min/day)	20	20	24	24	24
Carpool/Trans penalty (min/day)	0	15	0	20	20
Value ($/yr)	393	98	472	79	79
Net Trip benefits	(357)	98	(466)	(546)	(233)
Monetary Benefits($/yr)					
Travel allowance	120	120	120	120	120
Fuel tax	16	13	20	16	20
Sales tax	73	73	73	73	73
Property tax	37	37	37	37	37
Subtotal	246	243	250	246	250
Net time and money ben.	(111)	341	(216)	(300)	17
Other Benefits ($/yr)					
Improved hwys	64	64	64	64	64
Transit	32	32	32	32	32
Business centers	33	33	33	33	33
Subtotal	129	129	129	129	129
Total Net Benefits	55	470	(87)	(171)	167

1 mi = 1.6 km

Impacts of congestion pricing are not necessarily related to income. The evidence presented in this paper shows that male commuters in professional or managerial occupations or who had higher incomes would be more likely to have the flexibility to make changes in the work trip than female commuters in clerical occupations or who had lower incomes. Commuters with extensive household responsibilities would have few options but to continue to drive and pay the tolls. Commuters who were offered alternative work schedules would have the possibility of avoiding

tolls by making fewer peak trips; those who must work on a fixed, regular schedule would not have this choice. Finally, commuters traveling in corridors with reasonable alternatives to the private vehicle would have opportunities to benefit from the time savings resulting from congestion pricing without having to pay the toll. Since so many factors determine the impacts of congestion pricing, revenue redistribution cannot solve all equity and fairness concerns.

These observations lead to the obvious question of whether concerns about equity and fairness impacts could prevent congestion pricing from being implemented in any form. The answer is quite possibly affirmative for the following reasons. First, individuals most likely to be negatively affected would be from the broad spectrum of lower- and middle-income working households that constitutes a significant segment of the voting public. Second, impacts would be most negative for households with the least flexibility to make changes, such as multiple-worker households or households with young children. Third, these negative impacts would be determined by individual circumstances and thus easily perceived as arbitrary and therefore unfair. For example, a worker who traveled an uncongested route would not be subject to the toll but would receive the benefits of reduced taxes, and so forth, in the Los Angeles case study described above. A worker in similar circumstances who traveled a congested route would be subject to the toll. In the long run, these locational differences would decline as workers and employers shifted locations in response to the toll, but in the short run such differences would occur. Moreover, some differential effects would remain even in the long run, such as those related to the needs of specific occupations or household circumstances.

Although there are clearly many potential fairness problems associated with congestion pricing, there are also potential benefits. First, congestion pricing should reduce the day-to-day variability of travel time in addition to reducing congestion. Less congestion means fewer congestion-related incidents and accidents. Reduced travel time variability would be particularly beneficial for those with rigid time schedules, precisely those who have been suggested as least able to avoid paying the toll. Second, the magnitude of toll revenues would make it possible to offset existing regressive taxes and thus improve the equity of transportation funding policy. Third, the tolls would likely accelerate increased use of telecommuting, remote work facilities, and other alternative work arrangements that would increase work schedule flexibility. Finally, benefits to business

activities that rely on transport services would likely be large in heavily congested areas like Los Angeles.

Congestion pricing surely faces many challenges. Fairness concerns are legitimate and must be addressed. Ultimately, the fate of congestion pricing will be decided in the political arena. If pricing is to be introduced, voters will have to be convinced that its social benefits are worth the price each of them as an individual commuter is likely to pay.

ACKNOWLEDGMENT

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NOTES

1. It could be argued that determining the net effects of current policy is not necessary, since some set of circumstances must be considered as a given (if not the current policy, then something else). What really matters is the change resulting from the new policy. However, such an approach does not consider the larger issue of whether current policies fulfill stated equity goals.
2. The Environmental Defense Fund is conducting a study of distributional incidence in Southern California. The study is in progress, and results are not yet available.
3. Kain, in his paper in this volume, argues that much of the congestion pricing literature exaggerates potential negative impacts on low-income travelers by failing to consider (*a*) the improvements in transit supply that would likely result in response to a shift in demand, (*b*) the full array of options travelers have for avoiding the toll, and (*c*) the potential to offset losses from tolls by using the revenues to replace existing taxes. Regarding Kain's first point, it is certainly likely that transit services would be expanded under congestion pricing, and, all else being equal, these improvements would offset at least part of the toll burden for at least some people. The extent of these offsets, however, depends on the particular circumstances of the congestion pricing program implemented. Kain's second and third points are addressed in later sections of this paper.
4. NPTS uses the household unit, defined as a group of persons whose usual place of residence is a specific housing unit. CES uses the consumer unit,

defined as (*a*) a single person living alone or with others but who is financially independent, (*b*) persons living in the same residence who share responsibility for at least two major types of expenses, or (*c*) persons living in the same residence who are related in some way.

5. The surveys were conducted by videotaping license plates, identifying vehicle owners, and mailing surveys to the vehicle owners. Out-of-state vehicles and vehicles not registered to private individuals were thus eliminated from the sample population.
6. Categories are as follows: F-0, up to 1 hr of travel speeds of 30 mph (48 km/hr) or less; F-1, 1 to 2 hr at 30 mph or less; F-2, 2 to 3 hr at 30 mph or less; F-3, 3 hr or more at 30 mph or less.
7. More precisely, these data suggest that most freeway travelers subject to congestion pricing will be commuters. It could be argued that this may not be the case on arterials, since arterials carry fewer longer trips and hence fewer work trips. If indeed work trips are most inelastic, however, expectations should be the same about travelers in all congested facilities. That is, work and work-related trips should also account for the bulk of trips on congested arterials.
8. The number of trips made can be reduced by compressed work schedules, in which a regular full-time schedule of 40 hr is worked over fewer days.
9. For using a car before or after work, chi-square = 7.78, significant at $p < .05$; for using a car during work, chi-square = 14.36, significant at $p < .01$.
10. Chi-square = 22.65, significant at $p < .01$.
11. Chi-square for management/professional = 1.94, not significant, $n = 541$. Chi-square for sales = 6.96, significant at $p < .01$. Chi-square for other = 3.90, significant at $p < .05$.
12. In the paper by Small (1992b), see pp. 371–374 for a description of the revenue package and pp. 374–376 for a discussion of assumptions used in calculating net impacts.

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The Politics of Congestion Pricing

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Congestion pricing programs appear to be economically beneficial and technically feasible. Political issues must also be resolved, however, if congestion pricing programs are to be adopted in the United States. The key political issues involve ideas, interests, and institutions. The goals in this paper are to describe the political relevance of each issue, to outline the political aspects of various congestion pricing programs, and to offer suggestions for overcoming political obstacles.

IDEAS

Interests and institutions make policy change difficult because opponents usually have greater incentives and abilities to resist changes than proponents have to create them. Ideas will play a critical role if this resistance is to be overcome. Proposals that were "analytically sound and ideologically attractive" proved to be essential in cases where diffuse public interests have prevailed over concentrated private interests. [See, for example, *The Politics of Deregulation* (Derthick and Quirk 1989).] Sound and attractive proposals are those that politicians can simply and clearly explain as remedies to current public problems.

Most researchers have nonetheless focused primarily on the analytical soundness of congestion pricing proposals. Some ideas for making proposals ideologically attractive will be considered here. Some suggestions refer specifically to congestion pricing; others apply to policy innovation more generally. As beauty is inevitably in the eye of the beholder, these suggestions are necessarily speculative. Efficiency and, less often, equity

are the two politically relevant ideas usually mentioned by advocates of congestion pricing. The discussion begins with these terms.

Efficiency

The primary economic justification of congestion pricing is that it increases the efficiency of the transportation system: with congestion pricing, more people are able to go more places more quickly. Congestion pricing thus benefits society as a whole. But—and this is the "but" that is immediately raised in political settings—there will be both winners and losers in any congestion pricing scheme. Politicians and the public are quite sensitive to winners and losers (as will be discussed below). It is important to remember that they are also open to arguments about the public interest. Tocqueville noted this about the American people almost 200 years ago:

> Americans . . . are fond of explaining almost all the actions of their lives by the principle of self-interest rightly understood. . . . In this respect I think they frequently fail to do themselves justice; for in the United States as well as elsewhere people are sometimes seen to give way to those disinterested and spontaneous impulses that are natural to man; but the Americans seldom admit that they yield to emotions of this kind; they are more anxious to do honor to their philosophy than to themselves. (Wilson, 9)

Americans will support programs to benefit the public and will even sacrifice for them if they are convinced that the programs actually produce public benefits. The clearest examples of such public spirit are evident in wartime: millions of Americans have sacrificed life for country in the ultimate choice between public and private interests. Crises, real or perceived, bring additional examples. The public will support higher taxes to fund deficit reduction, educational reform, or universal health insurance whenever they become convinced that deficits, education, and health care are serious problems.[1] More mundane cases occur almost unnoticed. There is broad public support (i.e., willingness to pay) for such programs as Head Start, Medicaid, and unemployment compensation, even though most taxpayers never directly benefit from them.

To gain public support for this policy innovation, proponents must demonstrate that the social inefficiencies caused by road congestion and

social efficiencies created by congestion pricing are real and substantial. If they are, advocates must also be bold in advertising these facts.

Equity

Politicians and the public are not the only ones sensitive to the distribution of costs and benefits. Several analysts of congestion pricing have also examined the relationships between congestion pricing and equity.[2] Gomez-Ibañez (1992, 343–360) has outlined the potential winners and losers from congestion pricing programs. Several analysts have indicated that society as a whole would reap large benefits form congestion pricing and that, depending on program design, all income classes and most individual drivers could also receive net benefits (through some combination of time savings, monetary reimbursements, or both) (Small 1992). Giuliano, in a paper in this volume, suggests, however, that "so many factors determine the impacts of congestion pricing, [that] revenue redistribution cannot solve all equity and fairness concerns." Although some of these factors include gender, occupation, and family status, Giuliano says that "the negative impacts would be [also] determined by individual circumstances and thus easily perceived as arbitrary and unfair."

Analysts cannot for all practical purposes solve the equity issues that arise from congestion pricing if by solving them the goal is that not one person be disadvantaged. It is probably not a good idea for analysts to try too hard to solve them. In the first place, it is almost impossible to design a congestion pricing program that is both completely equitable and administratively feasible.[3] Fortunately, politicians have indicated that they and their constituents will be the ultimate judges of how much equity is necessary.[4]

Analysts can provide policy makers with two useful types of information regarding equity issues. First, they can compare the distribution of costs and benefits for various congestion pricing programs as well as for the existing transportation system. This information can help policy makers anticipate the sources of political support and opposition to the various programs. It can also demonstrate how inequitable the current distribution is. Second, analysts can estimate the total amount of revenue available from congestion pricing. This information can assist policy makers as they try to determine redistributions that are equitable enough to satisfy their constituents. Although analysts may be able to claim unequivocally that congestion pricing programs increase efficiency, they may have to be less

bold on equity issues. Still, they might be able to show that congestion pricing is not necessarily inequitable, at least not when compared with existing distributions.[5]

Congestion pricing programs are typically justified by appealing to such concepts as efficiency and equity. However compelling such terms are to analysts, these phrases may not by themselves be persuasive to politicians and voters. Yet efficiency in this case is synonymous with two characteristics highly valued by the American driver: speed and reliability. American drivers like to drive fast. American drivers hate delays. With congestion pricing, drivers will be able to drive faster and will be better able to predict travel times.

Speed

"Speed" may be a highly useful ideological selling point. It may seem odd at first glance that speed has ideological implications. Yet almost everything about the history of transportation in America demonstrates that the desire for speed has been a major motivating force. Americans unquestionably prefer fast transport to slow and believe that fast travel is virtually a right. This belief is not purely utilitarian. Driving faster (within legal limits) provides emotional as well as practical benefits: drivers save time (and hence money) and find the ride more enjoyable. Furthermore, the desire for speed unites individuals of differing economic backgrounds: virtually everyone wants to travel faster.[6] The pledge that congestion pricing will help citizens "Get Where You're Going, Faster" may thus hold significant promise as a political strategy. For congestion pricing to become politically attractive to the public, proponents might want to consider embracing the value of speed.

Reliability

Ask drivers how long it takes them to commute, and they will give you a single answer: the amount of time that it takes to arrive under good conditions. This is the answer that they want to be true, although they will admit that their actual travel times vary because of traffic congestion. This variation can be substantial: expected travel times can double or triple when traffic is heavy. Because drivers cannot always control their departure times, they face highly variable travel times. By relieving traffic

congestion, pricing would make travel times more reliable. Support for greater travel reliability is probably widespread.[7] This may be especially true for those with the least control over their travel schedules.[8] The promise that congestion pricing helps drivers "Get Where You're Going, On Time" may therefore also have potential as a political strategy.

Freedom of Choice

Congestion pricing advocates may want to define the advantages still more broadly. One way to do this is to link congestion pricing with increased freedom of choice. Opponents certainly will attempt to portray these programs as diametrically opposed to freedom. Their logic will be that roads are free, congestion pricing imposes fees, thus pricing reduces freedom. Advocates might respond that urban driving is not costless, because traffic congestion reduces the ability of drivers to move freely. Because congestion pricing increases mobility, it adds to driver freedom.[9] In addition to these specific ideas, three other more general ideas may be useful for enhancing the political attractiveness of congestion pricing.[10]

Simplicity

Citizens are understandably skeptical of complicated governmental programs. Congestion pricing programs that do not rely on complex strategies of implementation will be more politically attractive than those that do.[11]

Incremental Adoption

Emergencies may call for dramatic programs. Chronic problems, such as traffic congestion, do not. To increase their political acceptability, congestion pricing programs should be designed so that interests and institutions can gradually adjust to the changes and witness the benefits.

In particular, careful attention should be given to introducing congestion pricing programs on specific routes before implementing them over entire areas. There as several advantages to doing this. First, the public appears to be more supportive of pricing on new facilities rather than on existing ones. Second, these specific routes can help demonstrate the advantages, and resolve the problems, of the programs.

Effectiveness

Programs are more politically attractive when there is substantial evidence that they will work as advertised. Theoretical agreement is one form of evidence.[12] If analysts are unified on the effectiveness of congestion pricing, political acceptability is more likely to follow; if respected analysts question congestion pricing's value, acceptability is less likely. Practical validity is a better form of evidence. Unless congestion pricing programs produce quick and unambiguous benefits when they are first tested, it is unlikely that they will be tested again.

Ideas will play an important role if congestion pricing is to become politically feasible. The world is made of more than ideas, however; material interests also strongly influence political decisions. In the next section, the political role of interests will be examined.

INTERESTS

Individuals and groups are both potentially affected by congestion pricing programs. Individuals will be concerned about these programs because they are the ones who will bear the costs and receive the benefits. Interest groups will also have more general social reasons (e.g., concern for the environment, attitudes toward government) to support or oppose congestion pricing. In this section the role of individual interests in congestion pricing is examined first, followed by interest group involvement.

Individual Interests

Individuals will experience direct and immediate material costs and benefits from congestion pricing. For example, individuals assessed tolls pay costs that are immediate and direct, and individuals commuting faster feel immediate and direct benefits. Other costs and benefits will be indirect and in the future. Perhaps the most important indirect and future benefit concerns the redistribution of the (potentially massive) revenues generated through congestion pricing. In addition, as commuting and land use patterns gradually adjust to changed commuting patterns, certain neighborhoods and business districts will suffer, and others will prosper.

In their evaluations of congestion pricing programs, economists tend to focus on aggregate benefits and costs. Programs can then be ranked according to their economic attractiveness, with better programs accor-

dingly having larger net benefits or higher benefit-cost ratios. Although these aggregate measures can also be important politically (see previous section on ideas), politicians and their constituents typically are quite sensitive to the distribution, transparency, and timing of costs and benefits. These factors will in turn influence—but not determine—the political feasibility of the various congestion pricing proposals. Proposals cannot simply be ranked according to political feasibility, however, because feasibility shifts as the broader political environment changes.

Distribution

The distribution of benefits and costs is generally considered more important politically than the size of the net benefits. Benefits and costs may be either diffuse or concentrated.[13] It may be easiest in general to enact or maintain programs when benefits are concentrated and costs are diffuse. When this occurs, politicians can earn the gratitude of the winners, who stand to reap substantial benefits, and avoid the enmity of the losers, who will lose a trivial amount or even be unaware that they lost.[14] It seems generally more difficult to adopt policies when costs are concentrated narrowly and benefits are distributed widely. Here politicians will antagonize a minority (who see that they are being disadvantaged) without necessarily animating a majority (who may fail to notice that their lot has improved, or at any rate who believe that they are simply entitled to the benefits).[15]

When a proposal calls for both concentrated benefits and costs, politicians may still be reluctant to act. This is the case for several reasons. First, individuals are more likely to perceive new costs than new benefits.[16] Second, individuals are more likely to treat costs as certain and benefits as uncertain. Third, individuals are more likely to engage in political opposition to new costs than to support new benefits. As a result, even when the economic benefits and costs of a proposed program are equally concentrated, elected politicians may view the political costs from such proposals as higher than the political benefits.[17]

It is important to note that policy adoption is possible under any distribution of benefits and costs, depending on other features of the political situation. For example, an entrepreneurial leader might persuasively argue that some policy is essential, even though its benefits are diffuse and its costs concentrated.[18] Alternatively, political actors may emphasize the "virtue" of the diffuse beneficiaries and the "vice" of the concentrated losers in order to build coalitions and overcome opposition.[19]

On average, however, the more concentrated the benefits and the more diffuse the costs, the easier it is for politicians to adopt programs.

Congestion pricing programs can have varied distributions of benefits and costs.[20] Cashing out parking subsidies would concentrate monetary benefits in the hands of those who receive employer-paid parking and opt to accept this fringe benefit in cash; the monetary costs would be diffused widely across the tax-paying population who pay for this subsidy.[21] If parking subsidies were eliminated, in contrast, new monetary costs would be imposed directly on those with employer-paid parking, and diffuse (monetary and nonmonetary) benefits would accrue to the public in terms of less traffic congestion. In peak pricing programs, meanwhile, both benefits and costs are concentrated on those individuals who drive (or wish to drive) during the priced periods. Regarding the distribution of benefits and costs, therefore, it seems that cashing out parking subsidies would be the most attractive of these three programs politically, and eliminating parking subsidies would be the least appealing.

Transparency

The manner in which benefits and costs are distributed is also politically important. In short, the political attractiveness of any proposal increases as its benefits become clear and its cost opaque. Policy advocates thus usually have incentives to clarify the benefits of their proposals and to disguise their costs.[22]

The distribution and transparency of benefits and, more important, of costs are related. As costs become concentrated, it becomes harder to make them opaque; as benefits become diffuse, it becomes more difficult to make them clear. The costs of peak pricing are quite clear, for example, whereas the costs of cashing out are virtually invisible. In addition, the benefits of peak pricing and cashing out, but not eliminating subsidies, would be obvious to the recipients.

Timing

The timing of the benefits and costs is politically relevant. Proposals become more politically appealing when the benefits come early and the costs late. As congestion pricing advocates have learned, imposing costs first and providing benefits later is the road to political defeat.[23] Politicians again have motivations to design programs to "frontload" benefits and phase in costs.

Cashing out and peak pricing could each be designed to produce benefits up front. It may perhaps be somewhat easier to produce early benefits for cashing-out programs, however, because they would not increase government spending in the short term but would increase revenues instead.[24] Providing early benefits from peak pricing programs, in contrast, may initially require deficit spending or revenue bonding (to buy additional transportation facilities, for example), although these programs would yield substantial revenues once implemented.

Congestion Pricing and Individual Interests

Elected politicians are highly sensitive to the distribution, transparency, and timing of the benefits and costs of proposed policies because their constituents also are. In the politically easiest situation, programs would be designed so that benefits were concentrated, clear, and quick, whereas costs were diffuse, opaque, and delayed.

Congestion pricing program proposals vary considerably regarding the distribution, transparency, and timing of benefits and costs. The political feasibility of congestion pricing programs will increase to the extent that they are designed so that the distribution, transparency, and timing of their benefits and costs maximize political support and, more important, minimize political opposition. For these reasons, it appears that cashing-out programs are superior to peak pricing programs regarding the politics of individual interests.

Group Interests

The individuals who are likely to receive the benefits or bear the costs of congestion pricing may form groups to advocate or oppose the proposals. In the previous section the political factors affecting their support or opposition are discussed. In this section, the political implications of interest groups that have more general social reasons for supporting or opposing congestion pricing will be considered.

In the political world, congestion pricing programs are not merely traffic demand management tools. These programs will be seen by some groups as a way to accomplish their own social goals; other groups will oppose congestion pricing as detrimental to their organizational interests. For example, congestion pricing programs may be supported by environ-

mental groups (who see them as ways to reduce air pollution and gasoline consumption) or other liberal groups (who may view them as a source of revenue for funding their preferred programs). Alternatively, congestion pricing programs may be opposed by conservative groups (who believe them to be yet another government reach into citizen pockets or an invasion of their privacy) or automotive groups (who perceive them as being "anti-car").[25]

As with individual interests, it is reasonable to assume that the groups fearing congestion pricing will be more vocal in their opposition than groups that welcome these programs will be in their support. To overcome this asymmetry, three political strategies concerning interest group involvement might be worth considering if congestion pricing is to become politically more feasible.

Narrow Strategies

A narrow political strategy would be one in which social group opposition is minimized by minimizing the program's (politically) negative externalities. Such a program would be designed in such a way, for example, that there would be no net decrease in vehicle miles traveled (VMT), no net increase in governmental revenues, and no net increase in data collected on individual driving patterns.[26] This program, of course, would also lack politically positive externalities. If VMT is not reduced, air pollution and gasoline consumption will decline only slightly, if at all.[27] If there is no net increase in revenues, no other programs can be funded from them. Narrow strategies thus are based on neutralizing all social interest groups.

Broad Strategies

A broad political strategy would involve maximizing social group support by maximizing the politically positive externalities. In such a strategy, programs would be explicitly designed and, especially, marketed to gain support from groups that have no special interest in traffic congestion. The environmental benefits might be emphasized, or the funding potential might be promoted. By emphasizing the positive externalities, obviously, the politically negative externalities also become plain. The idea underlying this type of strategy is that although opposing groups might be more intense in their opposition, the number of supporting groups can be increased sufficiently to produce political success.[28] This strategy is therefore based on coalition building among competing social interest groups.

Transformational Strategies

A transformational strategy would not pit group against group. Instead, it would seek common ground among social groups, even those that are traditionally antagonistic toward each other. Transformational strategies often require some groups to change their views about what is best and other groups to modify their views about what is possible. Perhaps the best examples of transformational strategies are found in major diplomatic breakthroughs, such as the recent reconciliation between Israel and the Palestine Liberation Organization.[29]

One case of environmental-business group conflict can illustrate the possibilities of transformational strategies. Environmental groups characteristically supported regulation to reduce pollution, whereas business groups opposed regulation. The notion of "tradable pollution permits" transformed this dynamic.[30] Tradable pollution permits are now welcomed by at least some environmental groups because they reduce pollution and by at least some businesses because they are consistent with profit maximization. Before this could happen, environmental groups needed to realize that markets could be preferable to regulation for controlling pollution, and businesses had to accept that pollution controls of some sort were inevitable.[31] The idea behind transformational strategies is that programs can be designed so that common interests can be found among apparently hostile ones.

Congestion Pricing and Group Interests

Neither narrow, broad, nor transformational strategies are inherently superior regarding political feasibility. Once again, the specifics of the political environment and the skills of the political actors will suggest which strategy is most likely to be successful. Transformational strategies, because they unite opponents, nevertheless seem especially useful if major policy innovations are to be adopted.

Cashing-out or peak pricing programs could each be designed in ways that allow narrow, broad, or transformational political strategies to be used. Cashing out may have particular appeal as a transformational strategy in that it can unify potentially hostile groups—for example, those who will continue to drive to work and those who will not or those who seek environmental gains and those who oppose governmental expansion.

Peak pricing programs are a major policy innovation. As a result, advocates may want to think carefully about how to design peak pricing so

that transformational strategies could be used. Existing peak pricing proposals, in which government agencies directly charge drivers for road use, do not seem suitable. Because these programs would create clear divisions among individuals and between groups, narrow or broad strategies are dictated. One potential way to unite individuals and groups might be to issue "tradable peak period driving permits." Individuals (and groups) would be free to buy and sell these permits. Individuals then could decide whether they would rather drive during peak periods (and buy additional permits) or sell their permits and pocket the money. Environmental groups could benefit by purchasing permits and "retiring" them. Automobile groups could accept the greater options given drivers and the greater mobility of the commuting public, particularly if the alternative to congestion pricing is regulatory restrictions on automobile use. For political reasons, the concept of tradable driving permits deserves serious attention.

INSTITUTIONS

Congestion pricing programs will not run themselves. It takes governmental institutions to implement and manage these programs. Olson, in his paper in this volume, has suggested that, ideally, the institutions that administer congestion pricing should have several characteristics. According to Olson, the ideal institution would have

1. The legal powers to implement and to enforce programs across entire metropolitan areas;
2. The administrative capacity to manage the program (and especially its revenues) efficiently, effectively, and prudently;
3. The blend of autonomy and accountability necessary to serve diverse political jurisdictions responsibly without being either subservient or superior to them; and
4. Unambiguous, nonconflictual, and limited goals.

The political implications of each of these characteristics will be considered in turn.

Authority

The ideal institution would have the legal power to implement and enforce congestion pricing programs over an entire metropolitan area.[32] In prac-

tice, however, authority over urban transportation programs currently is fragmented in two important ways. In any given metropolitan area, numerous local governments will have jurisdiction over particular segments of the transportation system. All metropolitan governments, moreover, share authority over transportation programs with state and federal governments.

This institutional fragmentation poses several political problems for congestion pricing proposals. The existence of multiple governments makes it easier for hostile parties to veto proposals. It also makes it harder for sympathetic groups to ratify them.

The existing institutional situation not only makes it difficult to adopt and implement congestion pricing, it also makes institutional reform unlikely. In particular, governmental agencies with responsibilities for transportation may be reluctant to give up these duties (or, more especially, the powers that come with them) and are likely to resist political actors who want to wrest these powers away from them.

Because it would be such a challenge to create new organizations with metropolitan-wide responsibility for transportation, congestion pricing programs are likely to become politically more feasible if they can use governmental institutions that already have (at least partial) authority over metropolitan-wide transportation systems. Such agencies include "metropolitan districts" and state highway departments; federal offices, presumably, would also have metropolitan-wide jurisdiction.[33] The Bay Area Rapid Transit District (BART) is an example of a metropolitan district; only a handful of these districts have been created.[34] All states already have highway departments. Federal agencies with the potential for jurisdiction over metropolitan transportation include the U.S. Department of Transportation, the Internal Revenue Service, and the federal courts.

Administrative Capacity

Politicians do not always pay much attention to administrative capacity when considering policy and program proposals (Derthick 1990). The public, for its part, has little or no general political interest in program administration (although individuals have strong concerns if they believe themselves mistreated by administrators). When politicians are attentive, however, they may be just as interested in limiting administrative abilities as enhancing them (Moe 1988, 267–329).

These political aspects of administration pose both opportunities and challenges for congestion pricing advocates. On the bright side, the political feasibility of congestion pricing probably will be little affected by administrative capacities: a lack of administrative capacity will not hinder the prospects for program adoption. Yet the same lack of concern over administration that eases the chances for program adoption increases the probability of program failure. If policy makers do not try to ensure that a program will be managed well, it almost certainly will be managed poorly. As some of the Great Society experiments established, poor administration almost invariably reflects poorly on the reputation of the program itself (Moynihan 1969). Congestion pricing advocates therefore need not concern themselves about administration in order to get such program adopted, but they may be so concerned to prevent the programs from failing.

Analysts may want to consider the following points in designing congestion pricing programs to succeed administratively. First, administrative capacity is not easy to build. As noted earlier, simply creating *de novo* institutions is tough enough; establishing competent ones is even more difficult. To the extent possible, then, pricing programs should attempt to use institutions with demonstrated administrative skills. Second, administrative capacity is specific. Depending on its culture and mission, an agency can be effective at some tasks and incompetent at others (Wilson 1989, 90–110; Derthick 1990). Agencies are likely to be more effective at administering congestion pricing programs if these programs are consistent with existing competencies. Third, agency competency can be fragile. When a bureau is assigned a task that is contrary to its skills, the new task may be botched and the original competency damaged (Derthick 1990).

Autonomy and Accountability

Politicians may be relatively unconcerned about administrative capacity, but they are intensely interested in administrative autonomy and accountability. These factors affect both how much control they will have over the programs and how much credit or blame they will receive from them. In establishing an institution's autonomy and accountability, however, politicians face a tough balancing act. They may want an institution autonomous enough to provide them with political cover as it makes politically tough (but publicly beneficial) decisions. They may also want an institution accountable enough to respond to their political preferences. As Olson

points out, it is impossible to create an institution with maximum autonomy and accountability.

Goals

Agencies assigned unambiguous, conflictual, and limited goals may be more likely to achieve them than agencies with vague, divisive, and broad goals. Narrow political strategies (see previous section) may be more likely than broad strategies to produce achievable goals. From an institutional perspective, narrow strategies are thus preferable.

Congestion Pricing and Institutions

Ideally, the institutions administering congestion pricing programs would have sufficient authority, capacity, autonomy, and accountability, and clear goals. Either new institutions with these characteristics will have to be created, or existing organizations having such traits will need to be found. Given the difficulty in establishing competent institutions, the latter possibility may come more easily.

Peak pricing programs in particular appear to need competent institutions to manage them. Few metropolitan areas already have institutions with the authority and capacity to implement peak pricing.[35] State highway departments have the requisite traits and are strong candidates for running these programs, as Olson points out in his paper in this volume.

Cashing-out programs, in contrast, would place fewer demands on governmental organizations. The programs could be administered primarily through the revenue agencies. These agencies already have well-recognized authority and competence over matters of collecting and distributing revenues, and issues concerning their autonomy and accountability have largely been resolved. Cashing-out programs would not require these agencies to adopt new goals. All (institutional) things considered, cashing out appears in general to be politically superior to peak pricing, although peak pricing may be attractive in specific areas.

LIMITS OF ANALYSIS

Some of the key political issues concerning congestion pricing have been presented in this paper. An attempt has been made to show why ideas are

crucial and which ideas might be worth considering, how interests are affected and how these interests might be addressed, and what roles institutions play and how these roles are politically important. Throughout, the political feasibility of congestion pricing programs has been the prime consideration.

These comments are directed primarily at other analysts. It is hoped that scholars and practitioners will consider carefully the political implications of ideas, interests, and institutions as they attempt to design congestion pricing programs. These issues are as real and as important for program success as economic and technical factors, perhaps more so. The most economically efficient, and the most technically sophisticated, programs produce no benefit if they are not adopted. These political factors will to a large extent determine the success or failure of congestion pricing.

Paradoxically, this analysis of political feasibility will be of limited value to politicians. It should come as no surprise to close observers that elected politicians are more willing to trust the view from the trenches than the view from the (ivory) tower. It should also be clear that the public is understandably suspicious of policy experts who plan to "solve" social problems.

These facts bring on a final, critical insight. Congestion pricing becomes politically possible only through political action. Congestion pricing is likely to be rejected, or to fail if adopted, if it is designed, ratified, and implemented by experts. No analytical framework can replace a political system that allows participation, debate, and voting by the affected parties. No analytical cleverness can replace dedicated, persistent advocacy.

NOTES

1. For example, one recent national poll showed that over 60 percent of the public would support higher taxes to provide universal health care (*New York Times*/CBS poll, September 23, 1993).
2. These discussions implicitly assume that the status quo is equitable. They assess the equity of outcomes on the basis of changes from this status quo and not from any absolute standard.
3. Senator Daniel P. Moynihan (1973) describes a rather embarrassing episode in welfare policy when the Senate Finance Committee was considering President Nixon's Family Assistance Plan in 1970. Chairman Long was questioning administration analysts, who wanted to assure him that the proposed plan *always* made it more attractive to work than to receive welfare. Long shrewdly found rare cases in which this was not true. Rather than defending their claims as almost always correct, the analysts repeatedly modified their proposals to meet Long's objections. By doing so, they made the plan increasingly complex

and expensive; they also made themselves appear overpromising. These things helped doom the plan.

4. Several local politicians suggested this in their oral comments at the Congestion Pricing Symposium sponsored by the Transportation Research Board and the Commission on Behavioral and Social Sciences and Education of the National Research Council, Washington, D.C., June 23–24, 1993, at which this paper and others in this volume were presented.
5. Some analysts have suggested that equity concerns about congestion pricing are not real, but only serve as a "legitimate basis for opposition that is actually motivated by other reasons" (Giuliano 1992, 349). This conclusion is based on the obvious fact that many public policies are indeed highly inequitable, yet such an inference is neither analytically correct nor politically wise. As an analytical matter, policies may deviate from equity for several reasons. First, equity is only one of many competing values that may be in conflict; for example, equity may conflict with efficiency (Okun 1975). Whenever the other values are more important, less equitable policies may be acceptable. Second, equity itself has multiple dimensions: policies that are equitable by one criterion may be inequitable by another (Rae 1981). Third, individuals typically are more sensitive to the equity of *changes* in conditions than about the equity of *current* conditions. As a political matter, I believe that it would be a mistake to accuse those who defend equity as having more sinister motives. This allows the defenders to return the accusation that congestion pricing's proponents are insensitive to public concerns about fairness. It will be best for the proponents to avoid this charge. Concerns about equity should be taken seriously.
6. Not everyone, of course, will be able to travel faster than before *and* at the same times and frequencies; if they could, congestion pricing would have no impact on congestion. But individuals in virtually all economic groups will choose to pay the congestion prices at least from time to time. The secret of Grey Poupon mustard, after all, is that anyone can afford the very best at least occasionally.
7. Variable travel times do have one advantage. The excuse "I was stuck in traffic" may be more common, and usually more believable, than "the check is in the mail."
8. Note that these individuals are typically seen as bearing the brunt of congestion pricing's costs.
9. The concept that "freedom is not free" is itself hardly revolutionary. The public well understands that freedom is purchased.
10. For a similar discussion regarding health care reform, see the article by Norman Ornstein (Health Care Reform: Beware the Achilles Heel, *Washington Post*, March 30, 1993, p. A21).
11. Derthick and Quirk (1989, 246) contrast the federal government's procompetitive efforts to strengthen markets in transportation and health care. The government succeeded in the former through deregulation; this did not require new institutions and so was relatively easy to do. The government has been markedly less successful in reforming health care markets.
12. Derthick and Quirk (1989, 246) note that economists almost universally agreed that deregulating airlines and trucking would lower transportation costs.

13. In practice, of course, benefits and costs are usually "more or less" concentrated or diffuse, not either concentrated or diffuse. Actual policies, moreover, typically have some benefits and costs that are concentrated and others that are diffuse. For the sake of simplicity, it is assumed here that any policy proposal has one main type of benefits and costs and that each is either concentrated or diffuse.
14. Farm subsidies are a classic example of concentrated benefits and diffuse costs. The relatively few farmers are acutely aware that they receive checks from the government, whereas the costs of these programs are spread over the entire taxpaying public.
15. When the government imposes air pollution control regulations on specific firms, the firms immediately see their business costs increase. The public as a whole presumably benefits from cleaner air; they may not notice the improvement or they may believe that clean air is a right.
16. For evidence from the psychological literature on asymmetry in the perception of gains and losses, see the paper by Kahneman and Tversky (1984). For a discussion of the political implications of this asymmetry, see the papers by Lau (1985) and by Fiorina and Shepsle (1990).
17. The final logical possibility (diffuse benefits and costs) is not particularly relevant to congestion pricing and so is not discussed here.
18. Ralph Nader's successes in promoting automobile safety standards are an example of such "entrepreneurial" politics.
19. Imposing "sin" taxes on alcohol and tobacco to fund health care programs would be an example of such an approach.
20. Throughout this paper three types of pricing programs are distinguished: "cashing out" parking subsidies, eliminating parking subsidies, and "peak pricing." This approach differs somewhat from that of Bhatt and Higgins (1992), who also identify three basic types of programs: those that cover major facilities, areawide networks, and areawide parking. In this paper both major facilities and areawide networks are considered to be examples of peak pricing.
21. Shoup, in another paper in this volume, notes that the cashing out parking will increase tax revenues (if the cash is treated as ordinary income) and so will in fact reduce the overall taxpayer subsidy to parking. There would also be some elements of diffuse benefits and concentrated costs in the proposed cashing-out scheme. The broad driving public would benefit from less congestion, and the relatively few parking garage owners are likely to see revenues fall.
22. In contrast to most policy advocates, economists tend to favor policies in which both benefits and costs are explicit. If affected parties are completely informed, the logic goes, the policies will work more efficiently. Although the preference for complete disclosure may be morally commendable, it does not seem compatible with the economists' assumption that individuals are essentially self-interested in their political behavior. Policy advocates, to be sure, do not often find it to their advantage to fully reveal the costs of their proposals.

    To the extent that clarifying costs makes policy adoption more difficult, the analyst-as-advocate faces a dilemma. On the one hand, the analyst may feel the professional responsibility to divulge all relevant facts regarding policy proposals. On the other, the advocate may understand the political reality that

doing so will make it more difficult to enact desirable policies. One possible resolution is for the analyst to seek out policy options with potential costs that are inherently less visible.

23. As discussed by Dittmar in another paper in this volume, the public's initial response to a proposal by the San Francisco Bay Area's Metropolitan Transportation Commission "was overwhelmingly negative; . . . drivers were outraged that they would be heavily charged for using their cars (i.e., pay costs) without being given any other convenient choices (i.e., receive benefits). They argued . . . that mass transportation must be made more convenient before lawmakers make it more costly to drive."
24. For the potential effect of cashing out on tax revenues, see the discussion by Shoup in the section entitled "Tax Revenue Windfall" in his paper elsewhere in this volume.
25. It is not to be expected, of course, that all liberal groups will favor congestion pricing or all conservative groups will oppose it. Traditionally liberal groups might oppose congestion pricing out of concerns about its impact on lower-income groups; conservative groups might favor congestion pricing because of its promise of greater efficiency.
26. For example, Kain, in his paper elsewhere in this volume, in arguing that congestion pricing programs should be revenue neutral, is advocating a narrow strategy.
27. When traffic moves more efficiently, it does produce less of certain kinds of pollutants and higher fleet average miles per gallon.
28. Small (1992) describes some of the essentials of a broad strategy.
29. See, for example, the article by E. J. Dionne, Blessed Are the Realists (*Washington Post*, September 14, 1993, p. A23).
30. The idea of tradable pollution permits comes from Nobel Laureate Ronald Coase's work on determining the economic costs of social problems.
31. Transformational strategies do not, of course, produce unanimity among interests; some parts of the opposing factions will continue to oppose each other. For an example, see the article by Marla Cone, Anti-Smog Plan Praised, Jeered as Hearings Begin (*Los Angeles Times*, September 10, 1993, p. A3).
32. In this paper, it is assumed both that congestion pricing programs must operate over entire metropolitan areas to be effective and that no individual metropolitan jurisdiction would adopt such programs by itself.
33. Olson mentions metropolitan districts and state highway departments, but does not mention federal agencies.
34. For other examples, see the paper by Olson in this volume.
35. Metropolitan districts are the exceptions.

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Institutional and Political Challenges in Implementing Congestion Pricing

Case Study of the San Francisco Bay Area

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The passage of the Clean Air Act Amendments (CAAA) in 1990 and the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 has brought a new focus on measures to improve the performance of the transportation system and a renewed emphasis on the external impacts of measures to expand system capacity. Both acts also focus on market pricing of transportation as a potential way of influencing demand or altering modal choice. The requirement within ISTEA for the selection of demonstration projects in congestion pricing is an attempt to further this concept. Only one demonstration site has so far been selected nationwide: the Bay Bridge in the nine-county San Francisco Bay Area. In this paper the considerable efforts made in the Bay Area to introduce the concepts of market pricing are examined, the political and institutional barriers encountered to date are identified, and the manner in which these difficulties can be resolved as part of the ISTEA demonstration is suggested.

CASE STUDY APPROACH

This paper is not an attempt to provide a background or primer on the concept of congestion pricing. Rather, it is a case study of one metropolitan

area focusing on the political and institutional debate over the introduction of peak-period pricing as a new public policy. The recent history of this proposal is examined and various rhetorical themes are identified as having emerged from the public debate of this policy. An implementation strategy is then identified that attempts to respond to these themes. It should be noted that this case study is an analysis in process: peak-period pricing has been debated and adopted as policy but not yet implemented.

The case study will focus on two major public policy debates in the San Francisco Bay Area: the debate over the development of the Bay Area's plan in response to the California Clean Air Act and the legislative debate over attempts to enact a higher toll on the San Francisco-Oakland Bay Bridge. Both activities provide an important backdrop for the ISTEA demonstration project to introduce peak-period tolls on the Bay Bridge.

The San Francisco Bay Area is fertile ground for testing the concept of congestion pricing. As will be seen, there is active and open public debate of transportation issues, public concern over transportation and air quality is high, and there is a long tradition of taking direct local action to improve transportation. All five of the Bay Area's urban counties have voted a full 1-cent sales tax dedicated to transportation, and the voters have also chosen to devote bridge tolls to public transit. Moreover, there continues to be broad public support for measures to improve transportation and air quality: for 8 years, area residents have picked transportation as the most important problem facing the Bay Area in the annual poll conducted by the business-sponsored Bay Area Council. The Bay Area Council's 1990 poll focused on air pollution and specifically on the public's willingness to pay for clean air. According to the *San Francisco Examiner* (Gibbs 1991): "Sixty-five percent said they would go along with a $1 toll increase for solo drivers, and 53 percent said a $2 hike—to $3—on most Bay Area spans would be fine too." Given this broad public support for air quality and transportation, why has the concept of market pricing been so difficult to implement? This case study is an attempt to answer that question by charting the barriers encountered in introducing a new public policy concept to institutions and elected officials.

CENTRAL-AREA AUTOMOBILE RESTRAINT IN BOSTON

The 1970 Clean Air Act and subsequent attempts at implementation by the Environmental Protection Agency provide some well-documented case

studies of attempts to institute new and difficult public policies in a metropolitan setting. The attempt to put into action a package of transportation control measures was studied extensively at the state and city levels in the Boston area, and some measures were in fact used. Other "automobile restraint" policies proved more difficult to implement, particularly those dealing with area licensing and increased parking charges. Although these measures are not identical to the schemes in the proposed Bay Area congestion pricing program, they do bear enough similarity that an examination of some of the barriers encountered in Boston may provide a useful frame for reviewing the progress to date in San Francisco. Howitt's analysis of downtown automobile restraint policies suggests that this kind of complex proposal is fragile in that it faces opposition from the public, from decision makers, and from the large number of institutions involved in implementing the scheme. As far as the public is concerned, Howitt (1980, 156) found public response to be "more sensitive to the distribution and visibility of the impact of the policies than to the net benefit or cost. . . . What prevents the emergence of more active support for auto restraint policies is the almost total absence of individuals or firms that might receive immediate, direct selective benefits." Clearly any congestion pricing proposal must be able to demonstrate tangible benefits to the general public and to those who would be affected by the surcharge.

In Howitt's review of the response by decision makers and elected officials, he found three obstacles: the fear of electoral repercussions in the absence of an identified constituency, conflict with professional values or bureaucratic practice, and the inability of automobile restraint schemes to generate sufficient resources to induce cooperation by elected officials or agency staff (Howitt 1980, 160–161). Central to each of these is the need to identify supportive interest groups to counter expected opposition and the need for the proposal to generate sufficient revenue to offset bureaucratic obstacles or to demonstrate benefits derived from the program. Finally, Howitt notes that even if a program is adopted, implementation can prove challenging in terms of resources and the high degree of institutional coordination required. The resources provided by the ISTEA demonstration program can be used to offset some of these difficult start-up activities. As will be seen, however, each of the three types of obstacles has already been encountered in the discussion of market concepts. The form of resistance experienced has helped to shape the Bay Area congestion pricing demonstration.

CASE STUDY BACKGROUND

According to data collected in April 1991 by the Metropolitan Transportation Commission (MTC) and the California Department of Transportation (Caltrans), the San Francisco–Oakland Bay Bridge Corridor, connecting the East Bay with San Francisco, is one of the most heavily traveled in the nation. Automobiles, buses, trucks, ferries, and heavy rail operate in this area, providing more than 485,000 person trips daily. Of these trips, 135,000 are made during the morning peak period, 76 percent of which are in the westbound direction.

As part of the federal system of Interstate highways, the 8.4-mi San Francisco–Oakland Bay Bridge on I-80 is the primary facility in this corridor.[1] The eastern end is in Oakland, the western end in San Francisco. The bridge consists of an upper (westbound) deck of five mixed-flow lanes and a lower (eastbound) deck of five mixed-flow lanes. Together, both decks serve more than 250,000 vehicles per day.

Traffic Congestion on the Bridge

Traffic congestion is a consistent problem on the Bay Bridge. It occurs when traffic volumes exceed the capacity of the bridge during peak commute periods or when traffic is influenced by incidents or special events. Thus, congestion occurs because of the bridge's physical limitations, not because tolls are being collected. Westbound traffic congestion occurs at the metering lights inboard of the toll plaza during the morning and afternoon peak periods; eastbound traffic congestion occurs primarily during the afternoon peak period.

As peak-period travel volumes have steadily increased during the last decade, growing traffic congestion and delay have increased correspondingly. The problem is nowhere more apparent than on the Bay Bridge. The westbound approach to the Bay Bridge toll plaza from I-80 and I-580 is the most congested spot in the Bay Area.[2] As measured by daily vehicle hours of delay (DVHD), traffic congestion on this approach is growing:

Year	*DVHD*
1984	4,730
1987	9,120
1991	10,080

To the extent that the level of service (LOS) on the Bay Bridge can be tracked over time, the peak hour has spread, as shown by the distribution of hours at LOS D or worse:

Year	*Westbound Peak*	*Eastbound Peak*
1981	6:00 to 9:00 a.m.	3:00 to 6:00 p.m.
1991	6:00 to 10:00 a.m.	2:00 to 7:00 p.m.

Furthermore, traffic projections made for the San Francisco *Bay Crossing Study* (1990) show that the period in which westbound traffic volumes on the Bay Bridge exceed the measure of theoretical throughput capacity on the facility (10,000 vehicles/hr) will continue to grow unless demand or supply constraints change. Without a change in constraints (such as through congestion pricing), it is estimated that the period in which westbound morning traffic volumes equal or exceed 10,000 vehicles/hr will double from the current 1.5 hr to 3 hr.

Transit and Rideshare Alternatives

The Bay Bridge corridor has a multitude of rideshare alternatives that could support a congestion pricing program. These services include heavy rail [the Bay Area Rapid Transit (BART)], buses, ferries, carpools, vanpools, and a van shuttle service for bicycle users who travel over the bridge.

BART provides approximately 120,000 daily transbay trips in this corridor, AC Transit operates 31 bus routes providing approximately 18,000 daily trips, and the 10 daily ferry runs provide approximately 1,200 passenger trips each weekday. Most of the transit destinations in the morning peak are in downtown San Francisco. The BART system distributes riders throughout the downtown area. Riders arriving in San Francisco by bus or ferry generally walk or transfer to the San Francisco Muni bus or light-rail system for transport to their final destinations.

Furthermore, transbay transit services have some ability to expand. This was most clearly demonstrated when the Bay Bridge was closed for a month after the Loma Prieta earthquake. At that time peak-period transit ridership increased more than 100 percent in the corridor on a vastly expanded BART and ferry system.

Toll Structure and Collection

Tolls are currently collected manually only from westbound travelers. During the peak period (5:00 a.m. to 10:00 a.m. and 3:00 p.m. to 6:00 p.m.), 4 of the 20 lanes with toll booths revert to carpool lanes, allowing free passage for cars carrying three or more occupants. The existing toll is $1.00 for noncommercial vehicles and $3.00 to $10.50 for commercial vehicles, depending on the number of axles. To sustain the capacity on the bridge, westbound traffic is metered a short distance downstream from the toll plaza.

Caltrans recently released a Request for Proposal for an electronic toll collection (ETC) system utilizing automatic vehicle identification (AVI) technology on Bay Area bridges. The Bay Area Congestion Pricing Task Force—a diverse group of government, environmental, and business organizations—is currently working with Caltrans and the federal interagency congestion pricing group to determine the potential for coordinating the schedules of the Bay Area Congestion Pricing Demonstration Program and the Bay Bridge AVI implementation.

Lack of Spillover Impacts

A congestion pricing program would probably not result in shifting traffic congestion to new locations; in other words, no spillover impacts would occur. There are few reasonable highway alternatives to the Bay Bridge for automobile traffic traveling to San Francisco, and the parallel bridges that exist some distance to the north and south of the Bay Bridge do not directly link the East Bay with San Francisco. Thus, the existing transportation network lends itself to minimal spillover impacts from a congestion pricing program.

Security and Safety

Because the Bay Bridge is an existing toll facility, safety and security systems are already in place. Security for the toll and money-handling operations include television monitoring of toll collection activities, two toll officials situated in strategic locations to monitor toll booths and assist toll collectors in the event of an emergency, and a monitoring platform at

the Caltrans operations facility. Tow trucks constantly patrol the facility and can be instantly dispatched from the toll plaza to assist stranded motorists and clear traffic lanes.

Summary

The Bay Bridge is uniquely suited for a congestion pricing demonstration project because

- A number of reasonable transit alternatives exist for peak-period transbay travelers—experience after the Loma Prieta earthquake showed that transit can expand to serve transbay trips even when the Bay Bridge is completely shut down;
- Current congestion on the Bay Bridge is high and is a function of peak-period traffic volumes exceeding the physical capacity of the bridge, not toll collection activities;
- Toll collection and metering facilities are already in place and are adaptable to congestion pricing scenarios; and
- The lack of nearby parallel highways in the corridor minimizes the potential for traffic congestion spillover impacts.

BAY AREA CLEAN AIR PLAN

The passage of the California Clean Air Act in 1988 set the stage for the initial discussion of market-based approaches to transportation by setting a permissible ozone standard of 0.09 parts per million and by allowing no exceedances of this standard. (In comparison, the federal standard is set at 0.12 parts per million, and three exceedances of some duration are allowed.) Meeting the California standard in the relatively clean air of the San Francisco Bay Area (a moderate nonattainment area under federal law as of 1992) was estimated by the Bay Area Air Quality Management District to require reductions in hydrocarbon emissions of 35 percent and vehicle miles traveled (VMT) of nearly that much in a 7-year period. When it became clear that conventional transportation control measures (TCMs) were incapable of meeting this standard, MTC began to explore options through a TCM task force composed of businesses, environmental groups, and government. Much of the early discussion focused on the widely publicized Regulation XV program in Southern California, requiring employers to develop plans for their employees' commute patterns, which

was seen to exemplify the regulatory or "command and control" approach.

Bay Area Economic Forum's Market-Based Solution

Concerned with the possibility that the Bay Area might emulate Southern California by requiring all employers above a certain size to adopt trip reduction programs, the Bay Area Economic Forum, a consortium of business and local government, began to seek alternative approaches to improve mobility and air quality. Out of this analytical effort came their report, *Market Based Solutions to the Transportation/Air Quality Crisis* (1990), the thesis of which was that government should act to charge those who directly caused congestion and air pollution while generating revenue to improve transit and carpool alternatives for the single-occupant vehicle. The report, released on February 14, 1990, recommended a $3.00 peak-period toll on the state-owned bay bridges, an annual emission-based automobile registration fee, tolls on freeways, and the construction of carpool lanes and transit alternatives. The report made the front pages of local newspapers and garnered favorable press coverage and credibility. This was not surprising because it was introduced by a group led by the president of the Federal Reserve Bank of San Francisco and backed by numerous elected officials and business leaders (*The Tribune* 1990; *Mercury News* 1990).

MTC's Clean Air Plan

State law required MTC to submit a first draft TCM plan to the Bay Area Air Quality Management District in June 1990. The plan could be rejected or accepted by the District, which had the responsibility of adopting the entire plan and forwarding it to the state Air Resources Board. MTC was required to meet the target of reducing emissions and VMT 35 percent by adopting all "reasonably available TCMs," which it found impossible because "reasonably available" measures had been defined as measures that could be adopted within the existing authority. After concluding that such reasonably available measures would net only 5 to 7 percent reductions in hydrocarbons and being warned by the District to submit a plan that would meet the target, MTC proposed an array of contingency TCM options that would have to be implemented to meet the state standard. The

proposal included three options, all of which were labeled contingencies because MTC staff did not believe that an adequate case had yet been made for their implementation. The options included a bridge toll increase from $1.00 to $5.00, a $1.00 increase in gasoline taxes, emission-based vehicle registration fees, and parking charges proposed by the Bay Area Air Quality Management District at $3.00/day for employment sites and $0.60/hr at all other sites. At least three of these options were required in addition to conventional TCMs to meet the California air quality standard. All options except the parking charge required legislative ratification.

The response was overwhelmingly negative. As noted in the *Palo Alto Weekly* (Friedly 1991, 12), "Bay Area drivers were outraged that they would be heavily charged for using their cars without being given any other convenient choices. They argued, as do many politicians, that mass transportation must be made more convenient before lawmakers make it more costly to drive." The most vehement public opposition was focused on the parking charges proposed for shopping areas and employment sites. Bay Area legislators announced their unwillingness to support the proposal; some legislators even walked out of a meeting called by MTC to present its findings. The author of the California Clean Air Act told a reporter (Friedly 1991, 13), "I didn't create this beast. We didn't say, 'increase bridge tolls; increase [the] gas tax a dollar; indeed charge for parking $3 a day,' he says, being careful to distance himself from these proposals to clean the air."

Faced with public opposition and without a legislative sponsor, MTC adopted a phased plan in late 1990 calling for increased registration fees, higher bridge tolls and a $0.10 regional gasoline tax. Phase 2 involved $5.00 bridge tolls, $1.00 gasoline taxes, or emission-based registration fees of up to $100. Only if all else failed would the parking charges be imposed. The plan achieved a 21 percent reduction in emissions and represented the first public agency adoption of an approach embodying the market-based solutions advocated by the Bay Area Economic Forum.

Adoption of Plan with Market Components

The Bay Area Air Quality Management District evaluated and debated the MTC Clean Air Plan for a year before integrating it with stationary source programs and adopting the final plan in late October 1991. The District plan included market-pricing mechanisms but relegated them to a second stage, preferring to rely on the development of an employer-based trip

reduction program similar to that required by Regulation XV in Southern California. It was suggested that these employer plans would result in the equivalent of $3.00/day parking charges at work and take credit for the reduction in pollutants that would result from uniform application of these charges. The business community reacted strongly to this approach in a series of public workshops. Burke (1991), of Silicon Valley's Santa Clara County Manufacturing Group, said in an op-ed commentary urging the market approach: "Industry supports taking the tough, possibly unpopular steps. We hope public officials will, too." The suburban Contra Costa Council also advocated implementing market solutions first and using the revenues raised to provide a transit alternative (Hemmila and Cannon 1991). The District was criticized by environmentalists for not going far enough, but these groups generally supported both approaches. Although some modifications were made by the District to their plan in response to business concerns, they still believed that their support of market measures should be secondary to reliance on command-and-control techniques.

TOLL HISTORY OF THE BAY BRIDGE

An examination of toll surcharges on the Bay Bridge is useful as a backdrop to the more recent debate in the California legislature over proposals to increase the tolls. The use of toll revenues for purposes other than retiring bridge debt has long been established in the Bay Area. Bridge toll revenues have been used to pay for bridge maintenance and rehabilitation, for improvements to highway approaches to the bridge, and since the 1970s, for public transit improvements in bridge corridors. The transbay tube for the BART system was financed by a bond backed by toll bridge revenues, for example. The Golden Gate Bridge Highway and Transportation District, which owns and operates the Golden Gate Bridge, has used toll revenues to subsidize bus and ferry capital and operating expenses since the 1960s. As the *San Francisco Examiner* editorialized (1991): "Drivers have always heavily subsidized transit riders in the Golden Gate corridor. This is good social policy and it reduces the gridlock those who must use their cars, or simply choose to, would otherwise face."

Assembly Bill 664 in 1978 continued the tradition of utilizing toll revenues in the Bay Bridge corridor for congestion relief of the bridge by setting aside a portion of net toll revenues for mass transit in the corridor. Carpool bypasses of the toll plaza were constructed as a further incentive for commuters. In 1984, MTC, Caltrans, and the legislature began discus-

sions on a toll increase on all the state-owned bridges in the Bay Area. In 1988, after much debate, the legislature passed a measure calling for a regionwide vote to raise tolls on all bridges to $1.00 to finance a variety of bridge and approach improvements. Ninety percent of Bay Bridge revenues was to be set aside for transit improvements to be selected by MTC. The proposal, entitled Regional Measure One, passed overwhelmingly, with 73 percent of voters endorsing the toll increase. The huge majority vote effectively answered the question that had blocked toll increases in the legislature for years: once bridge construction bonds have been paid off, should the tolls be removed? Regional Measure One was thought to clearly reestablish a covenant with the legislature for the continuation of tolls and their use to relieve congestion.

PROPOSAL TO INCREASE BRIDGE TOLLS

With the adoption of the Bay Area Clean Air Plan, both MTC and the Bay Area Air Quality Management District, along with most Bay Area business advocacy groups and a number of environmental organizations, were now officially in support of the gradual introduction of market measures, including peak-period pricing into the Bay Area transportation system. During and immediately subsequent to this time, MTC was engaged in efforts to increase Bay Area bridge tolls for public transit. These efforts, although not all incorporating congestion pricing, served to shed light on the legislative implementation issues that may be encountered by the demonstration program.

Senate Bill 2100: Pricing Innovations

Just as the Bay Area Economic Forum unveiled its market-pricing proposals, California state Senator Quentin Kopp introduced Senate Bill 2100, which proposed raising tolls on the San Francisco–Oakland Bay Bridge from $1.00 to $2.00 and introducing transit pricing innovations. The bill included provisions for free rail-bus transfers, two-for-one BART tickets during off-peak hours, automatic toll collection, and ferry and bus feeder subsidies. Senator Kopp clearly intended the SB 2100 as a congestion pricing program, telling the press (Maybury 1990): "Drivers will enjoy a less congested ride because some drivers selected the other alternative [transit], and those who selected BART would enjoy a congestion free

ride on BART at less than half the previous price. As with all pricing policies, this will obviously cause a significant shift from auto to BART." Senator Kopp, Chair of the Senate Transportation Committee, further stated that toll increases were the responsibility of the legislature, because the overwhelming passage of Regional Measure One had clearly reestablished the covenant with the electorate.

Reaction to the bill was mixed. MTC, the entity that would be authorized to increase the toll, immediately took a position in support of the bill, as did the business-sponsored Bay Area Council. Legislators in suburban East Bay communities were less positive, preferring that the revenues generated be used to build new rail extensions rather than to subsidize increased transbay service. Senator Dan Boatright of Concord was forthright (Meibert 1990): "Senator Kopp doesn't represent our commuters. . . . If the people are going to pay an additional tax, they're going to want some capital outlay on BART. The way to get people off the roads is to extend BART." East Bay Senator Bill Lockyer sought guarantees "to make sure that the East Bay benefits at least in proportion to its contribution" (Maybury 1990).

When SB 2100 reached the Senate floor, Senators Lockyer and Boatright moved to amend it to require that it be put before the voters. The amendment passed the Senate 20 to 13, with Lockyer noting his opposition to the bill overall (McKenna 1990): "This is just another example of San Francisco taxing Eastbay residents and we're tired of it. . . . I think it's government coercion (to get people to use transit by raising the tolls). The practical result is rich people get to use the bridge while poor people take the bus." Senator Kopp responded by placing the bill in the inactive file, where it languished. In a later interview on the fate of the bill, the staff director of the State Transportation Committee suggested that the bill's failure was due in part to its lukewarm support by the region's transit operators. He noted that BART officials wanted all the revenues and wanted AC Transit to discontinue some of the service that it was providing.

Debate over SB 210

The state legislative session concluded in fall 1990 without the passage of the bridge toll legislation. During the interim, MTC staff began to explore the possibility of developing a bill to raise tolls on the three southern bridges that could meet the objectives of the Bay Area legislative delegation as well as the Bay Area transit operators. Senator Kopp indicated his willingness to carry the legislation if it were supported by the transit

operators, believing that their failure to do so in the last session had resulted in the substantial legislative opposition.

The bill eventually developed, SB 210, introduced March 19, 1991, was supported by each of the three major transit operators—BART, AC Transit, and the San Francisco Municipal Railway. It provided for free rail-bus transfers and a toll-free regional transit information number and allocated funds proportionally among the operators in relation to unfunded operating and rehabilitation needs and proportionally between East Bay and West Bay on the basis of the residences of bridge users. BART's share of the funding was allocated to its car rehabilitation program in recognition of management's stated preference. Although SB 210 embodied all the principles agreed on by the transit agencies, including the BART board, its focus on BART rehabilitation clearly did not sit well with individual BART board members and with East Bay senators, one of whom stated (Maybury 1991): "I think bridge toll increases may be necessary to finance extensions of BART. If I don't see some convincing evidence that that is in fact true, I'd be inclined to vote against doubling the bridge tolls."

At the first hearing of SB 210 in the Senate Transportation Committee, it was clear that in its form it would have trouble passing. Senator Kopp worked out a compromise with East Bay legislators in which most of the money would be devoted to BART extensions in outer East Bay suburbs. The final bill passed the Senate 6 to 3 and immediately ran into trouble with state Assembly members from the Bay Area, who passed the bill 41 to 27 after amending it to restore funding for transit operations, focusing on East Bay regions closer to the bridge. Assembly member Delaine Eastin stated the delegation's position in this way (Meibert 1991): "There ought to be some relation between the fees charged and the service provided." Senator Kopp responded by noting that he had agreed to the Senate compromise and could not support the Assembly's amendments. This set the stage for a rare joint conference committee, which met twice without coming to an agreement. At their second meeting, a provision for peak-period pricing of the tolls was discussed favorably by the committee and Senator Kopp.

POTENTIAL BARRIERS TO IMPLEMENTATION OF CONGESTION PRICING

The Bay Area's experience with development of the Clean Air Plan and MTC attempts to secure passage of bridge tolls have encountered some

obstacles along the way. Nevertheless, as noted by Howitt (Fauth et al. 1978, 194), policy debated and not adopted can be characterized as "skillful failure" if it helps to advance the understanding of an issue. Experience with the Clean Air Plan resulted in the adoption of policies in support of congestion pricing by both regional agencies, the business community, and environmental advocates. The bridge toll bills found strong support in the state assembly. Both the Clean Air Plan and the MTC toll proposals helped to develop an understanding of the concerns of the public and elected officials and exposed the obstacles that a congestion pricing proposal must overcome before passage. The following are the rhetorical themes raised during the debate over SB 210:

1. Roads should be free: there is an implied or specific covenant with the public to have freeways or to remove tolls once construction costs have been repaid;
2. Voters, not elected officials, should decide on fee or tax increases;
3. Pricing proposals disproportionately benefit the wealthy at the expense of the poor or the middle class;
4. Squabbles over revenues can block any proposal, especially if there is no clear link between the use of the proposal and those paying (e.g., BART rehabilitation programs);
5. There is a clear perception that adequate alternatives to single-occupant vehicles are not available; and
6. In the Bay Area there is tension among central city, inner suburbs, and outer suburbs that must be resolved.

Clearly any congestion pricing proposal must respond to each of the foregoing themes with tangible demonstrations either that the implied condition has been met or that the perception is false. Attempts at compromise throughout the legislative history of the bridge toll bills show some techniques that may be used. In the Boston case study discussed earlier the importance was stressed of agencies or individuals who act as "policy entrepreneurs" by advancing concepts and seeking support (Fauth et al. 1978, 186–188). In the case of the Bay Bridge tolls, both the Bay Area Economic Forum and MTC have played this role.

Patience and persistence are also required to advance new policies and get them before the public. The Regional Measure One bridge toll increase was sought unsuccessfully by MTC in the California legislature for 5 years before being approved by more than two-thirds of the electorate. Policy entrepreneurs must advance discussion of costs and benefits. The Bay Area

Economic Forum has been successful in getting recognition of market pricing as an alternative to regulation, but implementing agencies have been less successful in defining clear benefits with respect to bridge tolls. Attempting to sell the bill through the transit operators has failed; the operators did not agree on revenue distribution and legislators did not agree with the priorities stated by the operators.

The Boston case study also revealed that successful entrepreneurs can redesign policy to respond to objections and that revenues can be redirected to silence opposition through side payments (Fauth et al. 1978, 192). Both techniques were used with the bridge toll bill and they succeeded in moving the bill through the legislature: Senator Kopp developed a compromise on SB 210 to fund BART extensions to secure passage of the bill by the Assembly and MTC devoted funds in the bill to certain bridge construction projects in an attempt to secure the acquiescence of Caltrans. A final suggestion coming out of the Boston experience was to seek external allies; this technique has been central to the development of the Bay Area Congestion Pricing Demonstration Program.

BAY AREA CONGESTION PRICING DEMONSTRATION PROGRAM

Following the failure of SB 210 in the 1991–1992 legislative session, MTC began to develop a congestion pricing proposal for the Bay Bridge in response to the urging of the Bay Area Economic Forum and environmental groups including the Environmental Defense Fund. Working with these groups, MTC formed the Bay Area Congestion Pricing Task Force composed of the aforementioned groups and Caltrans, the Bay Area Air Quality Management District, the Bay Area Council, and the Santa Clara Manufacturing Group, the Sierra Club, the Union of Concerned Scientists, and the Natural Resources Defense Council. The task force developed a clear statement of objectives that guided the development of a proposal for a demonstration program imposing peak pricing on the Bay Bridge. The broad-based task force was intended to gain additional support for the project. Early on, the group decided to seek an ISTEA congestion pricing demonstration grant, partly for the additional funding but primarily for the recognition and federal support.

The proposal developed was calculated to build on past experience. The first-year demonstration funding would be used to study bridge use and develop a strategy that would clearly document the benefits across all segments of the user population. The demonstration proposal to the federal reviewers included the following four-step process:

1. Test the assumptions by collecting and analyzing data on bridge users through the use of an ongoing survey of 300 travelers and analyze the incidence of higher peak-period tolls on users by subregion of work and residence, by income group, and by factors such as trip type, time of day, and available travel alternatives. Identify market segments and likely responses.
2. Test the rhetorical themes and alternative mitigating strategies on the public, opinion leaders (the press, public interest groups, and decision makers), and identified market groups of corridor users through a progressive series of highly targeted focus groups (much the same as in a modern political campaign).
3. Develop a strategy that responds to public concern as identified through this progressive process and document the manner in which it is responsive; be willing to adjust to political realities. Include highly targeted service strategies that clearly respond to consumer desires and be able to demonstrate consumer satisfaction as a result of these strategies.
4. Present the resulting strategy, along with polling results and focus group results, to legislators and elected officials just before the proposal is introduced to the public and the legislature. Present the strategy as a broad consensus of business, environment, and government to counteract the divisive arguments generated by beneficiaries of the revenue. Demonstrate a clear connection between revenue and congestion relief or mitigation of social impacts in the bridge travel corridors.

The response to the proposal has been positive: the Bay Area proposal is the only one so far selected by FHWA for negotiation of a cooperative agreement. At the time of the writing of this paper, negotiations were under way and the public agency sponsors (MTC and Caltrans) were discussing project organization. The project schedule calls for survey and planning work in 1993, with design of transit and ridesharing services in response to demand from bridge users to involve the transit operators. An implementation campaign will be developed and presented to the public and the legislature in the 1994 session.

AN IDEA WHOSE TIME IS STILL TO COME

Implementing strategies such as congestion pricing on a local or statewide scale requires an understanding of regional values and a willingness to engage in a campaign to be responsive to these values. The Bay Area lesson indicates that a successful campaign requires both good data and careful

analysis and a sophisticated political approach. The approach suggested here, although developed in response to Bay Area concerns, may well be the necessary approach in other parts of the country. Certainly each region will have to be responsive to the same sets of pressures and barriers, although the way these issues manifest themselves will differ in each area. Evidence seems to indicate that this kind of individualized, user-responsive planning is one of the intended products of ISTEA and that the congestion pricing program is but one of the manifestations of this development. As former FHWA Administrator Tom Larson told the national conference on Moving Urban America in May 1992 (Transportation Research Board 1993, 143, 146):

> The transportation industry is beginning to get the message: the new paradigm is focused on consumers. A new focus is needed on how to address their specific needs. . . . The choice is clear. Using just the paradigm of a service-oriented infrastructure company, we can reach out to and understand the full range of customers. Then we must work to meet specific needs. Our customers, citizens of this great country, expect nothing less of us.

NOTES

1. The State of California owns the Bay Bridge and the State Department of Transportation (Caltrans) operates and maintains it.
2. Data are based on Caltrans floating car surveys. Floating cars are equipped with a computer program that records car speed and time as each car travels along the section of freeway under study.

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How Congestion Pricing Came To Be Proposed in the San Diego Region

A Case History

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In 1991 the San Diego Association of Governments (SANDAG) proposed an incremental freeway pricing scheme that would allow motorists to choose between a premium travel lane guaranteeing optimum travel speeds and the existing general-purpose lanes. Entry to the premium travel lane would require either the prescribed minimum vehicle occupancy of two persons or payment of a user fee or toll. Revenues generated by use of the premium travel lanes would go to enhance transit service and high-occupancy-vehicle (HOV) facilities in the freeway corridor.

The discussion in this paper covers how congestion pricing came to be proposed in the San Diego region and how and when political support developed and other evidence of how political leaders have publicly supported the concept of congestion pricing. An overview is provided of SANDAG's proposed Interstate 15 (I-15) congestion pricing pilot program and pending enabling legislation. To assist in understanding the choices available and the policy decisions made in the San Diego region, the discussion covers the intended benefits of the proposed program, how the concept of congestion pricing has been received by the public and the media, public comments received, and the thinking at SANDAG regarding the potential handling of equity issues.

BACKGROUND

Congestion Pricing Option

There is no single event, strategic plan, or organized professional advocacy that led San Diegans to the concept of congestion pricing. In fact, in looking back, it is difficult to identify even a hint of congestion pricing theory being discussed, let alone being sold, in the San Diego region.

Although no pivotal event led to the region's congestion pricing proposal, there is a historical explanation that illustrates how the concept of congestion pricing can evolve naturally through the public process. Viewed as a potential solution to the community's transportation needs, the concept of congestion pricing was advanced by citizens and elected officials as the region's preferred course of action.

Rapid Regional Growth

The San Diego region's dramatic growth provides the foundation for attitudes there regarding transportation and other quality-of-life issues. Much of the explanation of how congestion pricing came to be proposed in San Diego lies in the region's attempt to better manage its growth and to provide adequate transportation infrastructure.

The San Diego region consists of 18 cities and the county of San Diego, located at the southernmost part of California. Historically, the growth rate in the region has far exceeded those of the nation and California. In 1950 the regional population was approximately 500,000. Since then the region has grown by an average of 0.5 million persons per decade, with the current population in excess of 2.6 million.

The 1990 census ranked San Diego County as the fourth-largest in the nation (behind Los Angeles, California; Cook, Illinois; and Harris, Texas). The San Diego metropolitan area was one of 30 metropolitan areas (of 284) with 30 percent or greater growth during the 1980s. Although population growth in the early 1990s has slowed somewhat because of economic conditions, other components of the region's growth show no signs of abating.

Traffic Concerns

A by-product of growth and economic success has been the deterioration of personal mobility and air quality because of increasing traffic and traffic

congestion. In the early 1980s, population growth was the San Diego region's greatest concern. By the middle of the decade, public opinion polls indicated that increasing traffic congestion was the region's primary concern, surpassing overall concerns about growth, which ranked second.

During the 1980s the electorate passed several measures related to regional growth and transportation:

- The city of San Marcos, located in north San Diego County, adopted a peak-hour traffic reduction ordinance (June 1987).
- A $0.005 percent increase in the countywide sales tax was passed to provide $2.5 billion over 20 years for freeway, local road, and transit improvements (November 1987).
- Two transportation advisory measures were passed. One called for a regional growth management planning authority. The other required large employers to develop alternative work-hour programs to reduce traffic congestion during peak commute hours (November 1988).

Better Management of Transportation Facilities

In 1988, in response to the public's increasing discontent with the environmental, economic, and personal costs resulting from traffic congestion, SANDAG established a blue-ribbon advisory committee on transportation to advise the region on workable, efficient, and cost-effective solutions for reducing traffic congestion.

It soon became obvious to the advisory committee that the region could not afford to build its way out of congestion. Furthermore, and perhaps more sobering, it was apparent that sufficient right-of-way was not available to meet the projected demand for new transportation capacity, even if money were not the limiting factor.

Business leaders and elected officials concluded that the region's transportation and traffic congestion problems would have to be solved through better management and more efficient use of existing and programmed transportation facilities. To begin, the advisory committee recommended a comprehensive regional transportation demand management (TDM) program to SANDAG in November 1988.

Responsibility for Congestion Relief

SANDAG's acceptance of this comprehensive and far-reaching TDM program was made possible by the extensive participation of business and

community leaders. Overall, elected officials viewed approval of the TDM program as acceptance of the business community's recommended approach for better managing the region's transportation facilities and assignment of responsibility for reducing congestion.

The TDM program included programs to reduce traffic congestion and trips generated by three of the region's largest components of peak-period travel—employment, college and university students, and goods movement. The program, when fully implemented in 2000, will reduce peak-period congestion by 30 percent and automobile fuel consumption by 8 percent. Business leaders and policy makers involved in the development of the program agreed that it was important to ensure that each component of travel (e.g., employment, shopping, and recreation) bear its fair share of the responsibility for reducing the region's traffic congestion.

Policy makers also agreed that the cost of reducing the region's traffic congestion should be paid directly by those who cause it—persons who own and operate motor vehicles. Accordingly, SANDAG accepted the recommendation that the region pay for the TDM program by adding a surcharge to the annual motor vehicle registration fee.

Clean Air Act Impacts

The passage of the California Clean Air Act of 1988 has forced the San Diego region (classified as a severe nonattainment area for ozone) to revise its regional air quality strategy, including the already-approved TDM program, to help meet state-mandated air quality standards. The San Diego Air Pollution Control District (APCD), the lead agency responsible for revising the air quality strategy by June 1991, requested that SANDAG delay regionwide implementation of the TDM program until the APCD could verify that the TDM program would satisfy the transportation control measure (TCM) requirements of the California Clean Air Act.

Local elected officials, under increasing pressure from the public to solve the region's traffic congestion problem, were reluctant to hold up implementation of the TDM program. Accordingly, a modified version of the program was implemented by the city of San Diego (representing 70 percent of the region's employment) while an assessment of the ability of the program to meet the overall requirements of the TCM plan was made by SANDAG and APCD.

In 1990 the Federal Clean Air Act and California Congestion Management Act became law. Each will cause further modification of the TCM plan to meet the broader federal requirements.

Although performance goals of the region's TDM program were easily transferred to the TCM plan, APCD's criteria for development of TCMs placed added requirements on the TCM plan. The TCM plan will not only have to establish specific and enforceable performance goals but will also have to include incentives to induce solo drivers to use alternative travel modes and provide sufficient alternative mode capacity to meet the demand generated by the trip reduction program.

Increase in TCM Plan Costs

In April 1991 SANDAG adopted the TCM plan for air quality based on the requirements of the California and federal Clean Air Acts, the Congestion Management Act, and the criteria of the San Diego APCD. The total annualized government cost of implementing SANDAG's original TDM program was estimated at $8.2 million. The total annualized government cost of the newly recommended TCM plan was $91.7 million.

The TCM plan, combined with the planned actions of the California Air Resources Board to improve vehicle emissions and fuel technology, will result in a 35 percent reduction in the San Diego region's photochemical smog emissions by the turn of the century. When fully implemented in 2000, the TCM plan is expected to reduce peak-period congestion by 30 percent, automobile fuel consumption by 8 percent, and overall photochemical air emissions by just over 2 percent. Whereas the projected benefits of the TCM plan are the same as those of the original TDM program, the cost of implementing the TCM plan is nearly 10 times more than that of the TDM program.

Individual Measures

Table 1 gives the annualized government cost of each measure contained in the adopted TCM plan (costs apply to 2000). The cost of operating the programs for the noncommute, commute, college, and goods movement travel reduction programs totals $16.9 million per year. Operating subsidies for the transit and vanpool program and the college pass subsidy total $23 million per year. Capital improvements for traffic signals, bicycle

TABLE 1 Transportation Control Measure Costs by Revenue Category: Year 2000 (SANDAG 1992)

MEASURE	ANNUALIZED GOVERNMENT COSTS ($ millions)			
	PROGRAM	OPS	CAPITAL	TOTAL
1. PERSONAL TRIP REDUCTION PROGRAM (LEVEL 1)	5.0	-	-	5.0
2. GOODS MOVEMENT/TRUCKING PROGRAM (LEVEL 3)	0.6	-	-	0.6
3. TRAFFIC FLOW IMPROVEMENT (LEVEL 2)	-	-	3.3	3.3
4. TDM PROGRAM - EMPLOYMENT (LEVEL 2)	7.0	-	-	7.0
5. BICYCLE FACILITIES (LEVEL 2)	-	-	3.9	3.9
6. COLLEGE TDM/TRANSIT PROGRAM (LEVEL 1)	4.3	3.7	-	8.0
7. TRANSIT IMPROVEMENT PROGRAM (LEVEL 3)	-	12.8	11.1	23.9
8. VANPOOL PROGRAM (LEVEL 3)	-	6.5	10.0	16.5
9. PARK AND RIDE (LEVEL 3)	-	-	2.4	2.4
10. HOV LANES (LEVEL 3)	-	-	21.1	21.1
TOTAL ANNUALIZED COST BY REVENUE CATEGORY	$16.9	$23.0	$51.8	$91.7

facilities, transit vehicles and facilities, park-and-ride lots, and HOV lanes total $51.8 million per year.

Funding Strategy Shift

Policy makers were concerned about the potential shortfall of available revenue to support the TCM plan. Funding sources for the region's TDM program would provide only 20 percent of the $91.7 million in annualized government costs needed to implement the regional TCM plan.

No funding was available to support the total annualized cost to the private sector, estimated at $161.7 million ($1 per trip reduced). Policy makers feared that the shortfall of funding to cover government costs would lead to even higher costs for the private sector. SANDAG addressed these concerns by directing that a marketlike approach to establish user fees (for vehicle ownership, miles traveled, fuel, emissions, and occupancy) be used to pay for implementation of the plan. By unanimous action, SANDAG amended the region's TCM plan, resolving to pursue user fee programs. The board specifically included the following fee programs:

- A motor vehicle registration and emissions fee,
- A polluting fuels fee levied on fuel distributors,
- The development of legislation for implementing market-based TCMs, and
- A transit development and congestion pricing demonstration on I-15.

The SANDAG action indicated a fundamental shift in determining how transportation programs and projects needed to meet congestion and air quality requirements would be funded.

Before the initiative to develop new transportation programs for congestion and air quality, growth had been the region's primary concern. The preferred funding source to fix the problems stemming from growth had been those who caused the growth—developers. This led to the establishment of development impact fees in many areas.

Today, although many communities are not growing because of economic conditions, the symptoms and problems of prior growth, such as congestion and air pollution, remain. Now that the problem is defined as congestion and air quality, the preferred funding source for the TCM funding has become those who cause congestion and air pollution—motor vehicle owners and operators. This new funding approach will have a

broad impact because of the number and type of programs included in the TCM plan (e.g., trip reduction, goods movement, traffic signal coordination and optimization, bicycle facilities, transit conversion, transit service expansion, vanpool programs, park-and-ride facilities, and HOV lanes).

Furthermore, there is a rich history of important regional transportation programs and projects that have failed to receive the necessary funding and priority desired by local community interests. Many of these programs, especially the expansion of transit and the regional HOV network, have strong local constituencies that have influenced local elections. Accordingly, the issue of how to pay for the TCM plan opened up the opportunity for policy makers to advance local projects that were previously unfunded as part of the TCMs.

The proposed I-15 congestion pricing pilot program came about because the mayor of Poway and a newly elected council member representing the northern district of the city of San Diego teamed up to advance important transit and HOV facility needs in their communities. Through their efforts, the region's proposals for improved transit services and expansion of the HOV network were combined with congestion pricing and new intelligent vehicle-highway systems (IVHS) technologies to become the region's proposed congestion pricing pilot. The project will test the feasibility of establishing and pricing the use of a premium travel lane on the freeway with net revenues to be allocated to the enhancement of HOV facilities and increased transit in the I-15 corridor.

In June 1991 SANDAG staff began discussions with the California Department of Transportation (Caltrans), the Federal Highway Administration (FHWA), and the Urban Mass Transportation Administration [now the Federal Transit Administration (FTA)] regarding assistance for an I-15 transit development and congestion pricing demonstration. In November 1991 the SANDAG board of directors unanimously authorized SANDAG to apply for and execute a technical assistance grant with FTA. On October 22, 1992, FTA awarded SANDAG a grant to conduct the I-15 demonstration.

PROPOSED CONGESTION PRICING PILOT PROGRAM

FTA Project Description

The I-15 demonstration will include two phases. Phase 1 will demonstrate the implementation of low-technology congestion pricing mechanisms, such as a prepaid permit system for use of a premium travel lane by single-

occupant vehicles, initially established by using the available capacity on the I-15 HOV lanes. Phase 2 will demonstrate the implementation of high-technology congestion pricing mechanisms through the application of IVHS, automatic vehicle identification, and automated toll collection.

Each phase of the demonstration will study, monitor, and evaluate pricing and operating alternatives to determine the optimum strategy for increasing multioccupant vehicle travel, enhancing HOV access, and improving transit service along the I-15 corridor. Net revenue generated by the demonstration project will be used to support the development of a light-rail-equivalent transit system and to improve HOV development and access. The demonstration project will be managed in cooperation with Caltrans, the Metropolitan Transit Development Board, and the North County Transit District.

Expanded Proposal

On November 24, 1992, FHWA invited states and local governments to apply for participation in a congestion pricing pilot program established under the Intermodal Surface Transportation Efficiency Act (ISTEA). The SANDAG board of directors on January 22, 1993, voted unanimously to submit the proposal for the federal congestion pricing pilot program. SANDAG responded to the federal invitation by submitting an expanded proposal for a comprehensive multiphased congestion pricing pilot program demonstration in the San Diego region.

SANDAG's Approach to Congestion Pricing

SANDAG's approach to congestion pricing is guided by the following principles:

- Congestion pricing is not an end in itself, but a tool for achieving wider regional objectives to relieve traffic congestion, improve air quality, and enhance regional mobility. Hence, a congestion pricing project must demonstrate utility and benefits to the region and not be undertaken simply as a "proof of principle" initiative.
- Implementation of congestion pricing will most likely be achieved in stages. Each step must be preceded by adequate technical analysis and public involvement and education to ensure that the actions taken will be technically feasible, economically sound, and acceptable to the community.

• The project must strike a balance between what is theoretically desirable and what is feasible. Implementation of congestion pricing will generally be in the context of local or regional policy actions designed to address specific local transportation needs.

• The acceptance of congestion pricing by local communities will most likely depend on the allocation of revenues toward desired transportation programs and alternatives. These may vary greatly from one region to another.

• Congestion pricing programs should offer motorists the opportunity to choose a new, higher level of service or greater convenience in exchange for payment of a fee rather than cause motorists to pay a fee to keep what they have or avoid having to accept a lower level of service or convenience.

Project Design and Rationale

The objective of the congestion pricing pilot program is to promote the optimum utilization of premium travel lanes through a marketlike approach. Entry to the premium travel lanes will require either the prescribed minimum vehicle occupancy of two persons or payment of a premium user fee based on trip replacement costs and time savings. Access to the premium travel lanes will be controlled automatically to ensure that optimum travel speeds are maintained. Priority will be given to multioccupant vehicles, and user fees will be increased during periods of heavy demand. Revenues generated by use of the premium travel lanes will be allocated to enhance transit service and improve HOV facilities in the freeway corridor.

The initial phase of the program will price the use of available capacity on the I-15 HOV lanes. The I-15 HOV, a separated two-lane reversible facility, offers an excellent site for the initial testing of new IVHS technologies for automatic toll collection and access control. Entry to the premium travel lanes will be permitted either by meeting the required vehicle occupancy requirement or by payment of the appropriate user fee or toll. SANDAG will test market and price approaches designed to increase use of the premium travel lanes by multiple-occupant vehicles and will reinvest net revenues to support the development of commute alternatives and the mitigation of any adverse impacts or equity issues among travelers.

The congestion pricing pilot program will be staged geographically to provide an areawide multifacility and multicorridor application of congestion pricing. Subsequent phases will extend the premium travel lanes.

As additional segments come on line, the pricing scheme will be extended to cover the new facilities. The expansion of premium travel lanes in the region will likely parallel the planned development of the HOV network already approved by SANDAG and included as part of the regional transportation plan.

HOV facilities currently planned include a northerly extension of the existing HOV lanes on I-15 from State Route 56 to State Route 78, new HOV lanes on I-5 between I-805 (Sorrento Valley) and State Route 78 (Oceanside), and, eventually, their extensions southward, to I-8 (San Diego). The I-8 corridor, currently the region's most congested freeway, and freeways I-5 and State Route 94 are also forecast to have high HOV demand in the future and are potential candidates for HOV facilities.

In addition, with the nation's recent consideration of the North American Free Trade Agreement, the San Diego region may also be required to accelerate development of its planned HOV network in the portion of the region adjacent to the Mexican border.

Initial Test Site

Caltrans opened a two-lane reversible HOV expressway in the median of I-15 to buses, vanpools, and carpools of two or more persons in October 1988. The HOV facility extends from State Route 163 to State Route 56 [8 mi (13 km)] in the northeast part of the city of San Diego.

Currently, the two-lane reversible I-15 HOV segment carries approximately 1,600 vehicles in the peak direction (or 800 per lane) during the peak hour. Whereas more than 50 percent of the HOV lanes' capacity remains available, the HOV lanes carry about 31 percent of the southbound person trips (3,972) during the morning peak. The four general-purpose lanes carry about 69 percent of the morning peak person trips (8,800).

Although this represents fairly good utilization, the HOV lanes throughout the nation carry only about half the number of vehicles of the adjacent general-purpose lanes and therefore appear to HOV critics to be underutilized. The apparent available capacity has caused HOV lanes to be criticized by irate commuters who perceive the lanes as unfair and a wasteful use of taxpayers' money. Although not the primary intent, the proposed premium travel lanes will provide better utilization of the I-15 HOV and defuse any potential pressure to open HOVs up to general use.

KEY ISSUES

Pricing Principles

An important element of the congestion pricing pilot project will be the nature of the product for sale and the determination of the appropriate fee level.

Congestion pricing will work best when the product or service for sale is one that consumers want and one that will offer greater utility than the product or service currently being used. Congestion pricing programs will be more readily accepted if consumers are offered an opportunity to purchase a product or service that is more desirable or productive. This approach is preferable to one that requires consumers to pay a fee to keep a product or service they previously enjoyed for no charge or that would force them to accept a less desirable product or service because of added costs.

In reviewing the wants of the region's transportation system users, SANDAG found several products and services that travelers have historically supported: higher travel speeds and time savings, incentives to those who rideshare, and bus and light rail transit service in communities currently without such service. These interests led SANDAG to the congestion pricing scheme being proposed. Establishment of premium travel lanes on I-15 continues an incentive for multiple-occupant vehicle use. Single-occupant vehicle users could purchase available capacity on the premium travel lanes, thereby enjoying a higher level of service and time savings. If the net revenues were used to provide for the expansion of the HOV network and the development of transit services along the freeway corridor, these desired products could also be added.

Of course, to continue to have higher speeds and time savings to sell, the premium travel lanes program must be designed to maintain optimum travel speeds and to meet growing demand. New IVHS technologies will enable the premium travel lanes to be maintained at optimum travel speeds. The ability to allocate new revenues generated by the congestion pricing program to the development of alternative transportation programs and facilities will give the San Diego region a new opportunity to more fully manage the roadway to accommodate the projected increased demand. In its present form, enabling state legislation will allow SANDAG to price both the HOV and the freeway general-purpose lanes. Such authority would provide SANDAG with greater flexibility in sizing programs and facilities to meet demand.

Premium Travel Lane Fee

As mentioned earlier, an important element of the congestion pricing project is the determination of the appropriate fee level. SANDAG will consider the following factors in determining the level of the user fee:

- The cost of trip replacement on transit or other alternatives for the number of occupants that a single-occupant vehicle would need to fulfill the premium travel lane occupancy requirement (to encourage a shift in mode and trip patterns);
- The amount of available capacity on the facility—a higher fee would be charged as the volume of premium travel lane traffic increases (to test congestion and peak-period pricing);
- The time savings realized by single-occupant-vehicle users of HOV facilities (to test congestion pricing);
- The additional capital and operating costs attributable to pricing, such as costs of installing toll booths and collecting tolls or deploying an electronic toll collection system (to establish optimum application of IVHS);
- Additional facility maintenance costs associated with the pricing operation (to establish optimum facility design); and
- Level of fees needed to deter excessive single-occupant-vehicle demand and maintain free-flowing traffic in the HOV lanes.

Other pricing-related questions are as follows:

- Should pricing be higher during peak hours?
- Should pricing reflect trip length?
- Should regular users be treated differently from occasional users?

Equity Issues

SANDAG is aware of equity issues that may arise with respect to the implementation of the proposed I-15 congestion pricing pilot program. However, after more than 2 years of thorough media coverage in the region, equity issues have not been raised by the public. SANDAG is committed to addressing equity issues and has stated that project revenues will be used to mitigate adverse impacts and provide equity among travelers. SANDAG anticipates that such issues will involve low-income persons or equal access. However, it is impossible to resolve these issues until they actually develop.

The transportation system already favors those who can afford to own and operate a vehicle. Some persons who do not own automobiles may view the congestion pricing program as having no effect on their lives. Some may view the proposed transit service improvements as a welcome improvement in their personal mobility, providing access to jobs and services that is not currently available. Those who own automobiles may shift to transit or pay to use the premium travel lanes once in a while to save time. These represent new choices that are not currently available to anyone.

SANDAG will continue to monitor this aspect of the program closely as the program is implemented. A citizens' advisory committee will assist SANDAG in identifying adverse impacts and equity issues.

Interviews

The staff has interviewed more than 170 persons who have called to purchase a permit for the first phase of the project. Overall, the callers have indicated support for the better use of the I-15 HOV lanes, the intended use of the revenues for transit, or projects to improve access or flow on the proposed premium travel lanes.

In an attempt to determine the reason why a person would purchase a permit, staff found that callers were primarily interested in time savings. One request was from a physician whose office was at one end of the proposed project and whose hospital, where she provides on-call emergency services, was at the other. Another request came from a divorced father who has joint custody of his two sons and spends 3 hr a day on the freeway taking his children to and from school. The father lives at one end of the proposed project, and the boys' school is at the other end. Unfortunately, in the morning, when he takes the boys to school, the HOV lanes are open to traffic in the opposite direction. Returning to his place of work after dropping the boys at school, he travels in the direction of the HOV lanes, but he no longer has the proper vehicle occupancy. In the afternoon once again, the return trip offers HOV facilities when he is a single occupant and none when he has the boys in the car. The father reported that the proposed premium travel lanes would easily be worth $100 to $200 per month to him. The father realized during the call that the proposed transit improvement along I-15 would also solve his problem, providing transit service for his sons' trip to and from their school.

Media Coverage, Public Officials, and Public Response

The proposed congestion pricing pilot project has received substantial coverage by the media. During the past 2½ years, newspaper, radio, and television announcements, commentaries, and editorials covered the proposed demonstration project regionwide. Each offered a positive perspective regarding the project. Media coverage occurred when the SANDAG board first introduced congestion pricing as part of the TCM plan (May 1991), when SANDAG authorized submittal of a grant application to FTA (November 1991), when FTA approved the grant (October 1992), when SANDAG submitted the proposal to FHWA (January 1993), when transit fares had to be increased and services trimmed because of revenue shortfalls (1993), and when local companies reported their efforts to convert defense technology to transportation and IVHS applications (1993).

Many articles featured the elected officials instrumental in furthering the proposal. In addition, elected officials used their support for the proposed congestion pricing pilot and the benefits it would bring to constituents as part of their election campaigns. Each elected official who clearly supported the proposal and whose district would be affected by the congestion pricing project won reelection by a substantial margin. One local elected official, whose support was most visible and whose constituency would be directly affected by the proposal, won election to the state assembly.

News coverage has continued as enabling legislation [Assembly Bill (AB) 713)], which authorizes SANDAG and Caltrans to price the Interstate highway, was passed by the California legislature and was signed into law by Governor Wilson on October 10, 1993 (by a 78 to 0 vote in the Assembly and a 21 to 10 vote in the Senate).

SUMMARY

In the early 1980s, population growth was the San Diego region's greatest concern. A by-product of growth and economic success has been the deterioration of personal mobility and air quality because of increasing traffic and traffic congestion. The San Diego region's dramatic growth provides the foundation for the attitudes and politics there regarding transportation issues.

Although no pivotal event led to the region's congestion pricing proposal, there is a historical explanation that illustrates how the concept of

congestion pricing can evolve naturally through the public process. Viewed as a potential solution to the community's transportation needs, the concept of congestion pricing was advanced by citizens and elected officials as the region's preferred course of action.

Congestion pricing will work best when the product or service for sale is one that consumers want and one that will offer greater utility than the product or service currently being used. This principle led SANDAG to the congestion pricing scheme being proposed.

SANDAG proposed an incremental freeway pricing scheme, which would allow motorists to choose between the use of a premium travel lane guaranteeing optimum travel speeds and the existing general-purpose lanes. Entry to the premium travel lane would require either the prescribed minimum vehicle occupancy of two persons or payment of a user fee or toll. Revenues generated by the premium travel lanes would go to enhance transit service and HOV facilities in the freeway corridor. The use of new IVHS technologies would enable the premium travel lanes to be maintained at optimum travel speeds.

SANDAG is aware of equity issues that may arise with respect to the implementation of the proposed I-15 congestion pricing pilot program. However, after more than 2 years of thorough media coverage in the region, equity issues have not been raised by the public. SANDAG is committed to addressing equity issues and has stated that project revenues will be used to mitigate adverse impacts and provide equity among travelers.

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Enabling legislation (Assembly Bill 713), which would authorize Caltrans to price the Interstate highway, is moving through the California state legislature. The bill has passed the California Assembly Transportation Committee, the Ways and Means Committee, and the assembly by unanimous votes. The bill is scheduled to go to the Senate for approval in August 1993.

REFERENCE

SANDAG. 1992. *Transportation Control Measures Plan for Air Quality.*

Urban Transportation Congestion Pricing

Effects on Urban Form

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Two arguments have been made about the impact of transportation congestion pricing on urban form. Some argue that underpriced transportation has led to lower-intensity, lower-density land use patterns and a larger metropolitan area than would occur with efficient pricing and investment and that congestion pricing would correct this underpricing and thus would encourage more compact urban form. Others argue that congestion pricing on balance would have a further decentralizing effect by reducing the attractiveness of destinations served by the priced facilities and accelerating movement to locations within the region with lower costs (and often less congestion). Many in this latter group also believe that road pricing would create a negative image that could stymie business, developer, and consumer interest in the affected areas and that land regulations would largely block any higher-intensity center-oriented development that might be proposed.

The arguments matter for several reasons. First, to the extent that changes in land use, development, and urban form occur in response to congestion pricing, the impacts are likely to vary with the design of the pricing system and the use of the revenues. The developers of congestion pricing programs need information and insights into these potential effects in order to capture benefits and avoid unintended and undesired consequences. They also need some information about the size, scale, and time frame of the impacts in order to assess their overall importance.

Second, anticipated (or feared) impacts on businesses and residents, and their likely travel and locational responses, will be a significant political

issue in debates over transportation congestion pricing; potentially affected groups may be sources of support or of opposition depending on the impacts predicted. Both the affected interests and the decision makers to whom the interest groups will plead their cases need well-founded information on potential impacts and their likely magnitude and timing.

Third, in a number of metropolitan areas there is concern about growth patterns and economic development and their social and environmental consequences. In these areas the question of the impact of transportation congestion pricing on urban land uses and development will be debated directly. The assumptions underlying the contrasting arguments need to be clarified and made explicit.

The potential effects of congestion pricing on urban form are examined, drawing on both theoretical work and empirical evidence. The paper begins with a brief review of the literature on transportation and urban form, focusing primarily on the effects of changes in accessibility on land use and location. The many options available to travelers for responding to congestion prices are discussed next, some of which may considerably dampen or offset the potential for congestion prices to reshape urban form. Finally, the results are presented of interviews with a small sample of businesses and local government officials in which likely responses to congestion pricing were explored. The interviews, although preliminary, indicate that here too a number of strategies may be pursued, at least some of which could offset the potential impacts of congestion pricing on land use and development.

MODELS OF LOCATION AND LAND USE

Land use–transportation interactions have been the subject of a long tradition of inquiry, and a strong framework for the understanding of key relationships has emerged. Economic theories of location and land use are dominant, but sociological and historical theories also offer insights. A brief review of this work is presented here to serve as a framework for later discussions. Also presented are the results from recent models of location and transportation choice processes and case studies and statistical analyses.

Location Theory

More than a century and a half ago, von Thunen and Ricardo observed that land, labor, and capital are the primary inputs of production and that the

use of land is determined in part by its location. The location of transportation facilities and transportation technology determine the relative location, or accessibility, of places. Thus land values as well as land uses reflect the relative locational advantages that transportation systems confer. The theory postulates a clear causality: accessibility determines the worth of land for different uses at different locations.

In more recent times, Dunn (1954), among others, dealt with agricultural land uses; Isard (1956), Wingo (1961), and Alonso (1964), among others, dealt with the urban case. Kain (1975), Mills (1967), Anas (1985), and others have extended and elaborated on the basic approaches. All of this group of models are rooted in land economics and in the concepts of optimality and equilibrium in land allocation.

In simple form, consider a center at which production and distribution activities are concentrated. Transportation costs increase with distance from the center, and in determining the amount to bid for land at a particular location, the bidder takes the transportation costs into account. All else being equal, location at the center minimizes transportation costs; land values therefore are highest at the center, and other locations will command lower rents reflective of their greater costs of transport.

But not all land uses would gain equally from a central location. If transportation is ubiquitous, a central location maximizes access to suppliers and to markets. Specialization is best supported by such a location, which also offers greater opportunities for economies of agglomeration and economies of scale than do less centrally situated sites. Activities that are specialized, that can capture the economies that central places make possible, or that need regular face-to-face contact with other firms can minimize their costs by grouping close together in central locations. They thus outbid others for space there.

Ancillary firms that provide goods and services to these central offices also need good access to the center but require less face-to-face contact (and probably have a lower-salaried work force with lower values of time). Hence, they will locate near, but not at, the center. Other activities with less frequent need for central access bid less and locate farther out. Housing is one such activity, since access to the center is primarily needed for employment. A balance is reached, with particular uses characteristically found in central places and others in successive rings farther out.

If transportation costs are changed, the rent gradients change; since land uses and rents for land are tied to each other by market processes, land use potentials are changed. All else being equal, it would be expected that investments that lower the cost of transportation to an employment center

would simultaneously reduce the value of land at the center and increase the value at the periphery. Conversely, when transportation costs increase, the price of land close to the center increases.

These impacts play out in different ways for residential development than for commercial development. In the case of housing, reduced commuting costs (or times, since time has value) would make it possible for commuters to spend more on housing, travel farther, or both. If, as is usually the case, transportation is cheap relative to housing and one can buy more house per dollar farther from the center, households will have an incentive to live farther away from their workplaces. All else being equal, then, investments in transportation are likely to decrease residential density and increase the size of the urbanized area.

Business location choice will be affected somewhat differently. Although some businesses are tied to particular sites because of needs for special qualities available only there, others can choose where to locate within an urban area by considering the relative costs and benefits of doing business at any particular place. Transportation is one such cost; businesses need access to goods and markets, and their labor costs reflect commuting costs.

If transportation costs are reduced at a particular place, businesses there will be more profitable and better able to expand; other businesses also will find the location comparatively advantageous because of accessibility to metropolitan-wide labor and customer markets, and will seek to locate there. Thus, in theory, businesses will tend to congregate at points where transportation costs are low.

Population-serving businesses, which sell frequently purchased goods and services, are a special case because their competitive edge depends in large part on their convenience to residences. If residences decentralize, these businesses follow, decentralizing this portion of the work force as well. The specific location of these businesses, however, still depends on the relative costs of transportation to alternative locations. A general reduction in shopping-trip costs would permit population-serving firms to locate farther from residences and still be convenient to customers. Put another way, firms could attract customers from a wider area and still benefit from lower transport costs for inputs. In so doing, they might be able to lower costs, expand offerings, or both, and perhaps capture economies of scale and outcompete firms in less advantageous locations.

Overall, then, location theory holds that transportation improvements will tend simultaneously to increase employment at benefitted sites and to decentralize workers' housing. However, over time these very changes

will stimulate countervailing effects: increased employment will generate demand for housing near the worksites and suburban housing will create a pull for service-oriented employment, and so on.

Other Theories of Urban Growth

Although theories focusing on economic factors in explaining the spatial distribution of various land uses have been favored in transportation analyses, other theories of urban growth have emphasized historical and social factors and cycles of growth and decline. Burgess (1972), Hurd (1924), and Hoyt (1939) were among the early writers on the topic. As they saw it, industries located near the waterfront to utilize water transport and the water itself; their activities attracted workers' housing but repelled many other uses. The wealthier classes originally built houses near the center of the city, but as those houses grew obsolete, they chose to build new ones in outlying areas made accessible by new transportation systems. Their old houses filtered down to less affluent classes. Durability of buildings and infrastructure, along with patterns of blocks and ownership of parcels, retarded change in land uses by making land assembly, consolidation, and clearance difficult and expensive. Economies of scale in building made new construction cheaper on vacant land, and this, quite apart from land rents, further spurred suburbanization.

Harris and Ullman identified still additional factors affecting development, including the need for specialized facilities and services (transportation and other), agglomerations that support mutual profitability, forced clustering of nuisances, and constraints working against alternative housing location choices (e.g., lack of money, class segregation). In this conception of urban growth, different activities would locate in distinct nuclei, or subcenters, because of the interplay of these factors. Transportation would exert a different influence over location in the various nuclei because of different, specialized needs of the occupants. Berry (1967) emphasized specialization of places and the growth of hierarchies of places, with both historical factors and agglomeration economies playing a role.

Recent Models of Location and Transport Choice Processes

Both location theories and alternative theories on land use–transportation interactions provide useful concepts but are limited by restrictive assump-

tions and partial specifications of causal factors. Historical-sociological theories have been largely descriptive, with few attempts to extend them to formal prediction. Economic approaches, in contrast, have attempted to support forecasting; however, critics point to the limited number of factors explicitly considered and note the restrictive assumptions on which the basic analytic models are founded, particularly in their highly abstracted mathematical forms.

Adding realistic detail such as urban and suburban subcenters and multiworker households and accounting for other important factors such as land availability, building quality, and the effects of social class, race, and local government services requires simulation rather than analytic models. Models developed by Lowry (1964), Putman (1983), Herbert and Stevens (1960), Prastacos (1985), and others represent attempts to develop practical analysis and forecasting techniques for urban land use and transportation planning [see work by Hamburg et al. (1983), Berechman and Small (1987), and Bajpai (1990) for reviews of the state of practice].

In general terms, these models allocate jobs and housing within a region as functions of accessibility, land availability, population, and employment by category, income (for households), and other factors. Such models typically make several simplifying assumptions not wholly in accord with theory. Nevertheless, they can overcome some of the limitations of pure analytical approaches: for example, travel times and costs can vary in different parts of the region and other spatial and socioeconomic heterogeneities can be entered into the assessment. Although in many applications this class of models has only moderate predictive capability, model applications nevertheless indicate the importance to location decisions of transportation level of service.

Other modelers have attempted to develop a stronger behavioral justification for location decisions. Prime examples are logit models of household location and transportation choices [e.g., those by Lerman (1975) and Anas (1985), among others]. These models typically include, in addition to land use and transportation accessibility variables, detailed household socioeconomic and life-style descriptors (including the number of workers present, household income, age of household members, presence of children, race and ethnicity, etc.) The studies confirm that transportation decisions on the location of jobs and housing reflect concerns about transport costs. Other things being equal, congestion is associated with a preference for housing closer to work; long commutes are supported by better transport facilities.

For the most part, however, these models show that transport variables are no more critical to location decisions than such factors as housing type, size, and cost suitability; crime rates; and, for families with children, schools. Moreover life-style and life-cycle variations have been found to be as important as (in some cases, much more important than) transportation as determinants of location and land use choices.

Case Studies and Statistical Analyses

A fourth group of studies has used statistical or case approaches to investigate the effects of transportation investments on land use, location, and economic development. Regression analyses and input-output modeling have been used to examine national and regional effects; before-and-after assessments and survey research have been used to investigate the impacts of specific facilities and to understand transportation's effect on specific residential and industrial location choices.

Studies of the land development effects of both highway and transit investments have a long and detailed history [for example, see the highway cost-allocation studies of the 1950s and 1960s (U.S. Congress. House. 1957–1961) and the Spengler study (1930) of the land value impacts of the New York transit system]. Overall, however, the studies fail to provide a generalizable metric of the role of transportation in land development. Instead, they point out that the effects of transportation investments vary with the specifics of the case and must be considered in the broader implementation context.

Most of the highway studies have found that highway investments are but one factor in a larger growth and development equation [see a detailed review of this literature by Forkenbrock (1990)]. Some studies have failed to find an impact of any sort, especially in areas with weak markets for development; others have found that highway investments allow pent-up demand for new development to be released. Many of the studies that have attributed "growth" to a new highway have failed to account for the likelihood that the growth would have occurred elsewhere in the region had the highway not been developed, that a shift, not an increase, is what has occurred.

Environmentalists sometimes argue that it is precisely this shift that is of concern, particularly if development is induced by transportation improvements that make possible more trips, longer trips, or relocation from high-density areas in which many trips would be made by foot or transit to

low-density areas heavily dependent on the automobile. [See the work by Frank (1989), among others, for a review of the literature on the transportation, environmental, and other consequences of alternative development patterns.] Newman and Kenworthy (1989) claim that international data on transportation, land use, and energy consumption establish a strong basis for this concern, although others point out the limitations of their data and methods. Among metropolitan planning organizations, scenario testing exercises and a few modeling efforts using real data have explored this issue sufficiently to support the conclusion that shifts could occur sufficient to offset at least some initial travel and environmental benefits of transportation investments. [For a discussion of the modeling issues, see work by Harvey and Deakin (1991).]

But the magnitude of the effect remains unclear, and controversy continues over when and to what degree a highway improvement will induce trips, shift modes, and alter destination choices. Indeed, this is a topic for which focused research has been recommended (Suhrbier and Deakin 1988).

The results of transit studies are similar to those for highways. Most of these studies have focused on rail systems, though a few have looked at less place-specific investments such as trolleys on shared right-of-way and bus service [see, e.g., work by Spengler (1930), Warner (1962), Boyce et al. (1972), Cervero (1984), Gannon and Dear (1972), and Heenan (1968)]. In most of the transit studies the question of shifts is central, for many look to transit to help restructure development into more compact, efficient patterns. The studies found many localized land development benefits, but from a regional perspective the benefits have been quite modest. Shifts toward compact growth and increased density, when they occur, seem overwhelmed by stronger regional trends toward decentralization. Rail systems do seem to have supported additional downtown development, though several also apparently made once-remote suburban locations sufficiently accessible to spur development at the fringe (Warner 1962; Webber 1976). [See reviews by Knight and Trygg (1977), Libicki (1975), and Giuliano (1986).]

For both highways and transit, many of the studies suffer from methodological and other limitations (lack of explanatory power for observed correlations, difficulty in distinguishing cause and effect, failure to distinguish economic shifts within a region from investment-induced growth, double-counting of benefits). Few have been scoped broadly enough to identify possible shifts in production processes and changes in economic and social organization that might occur as a result of important new

transportation investments. Nevertheless, the studies offer useful insights. Overall, they find that transportation availability and quality are factors in location and development, but investments—at least the modest investments typical of today's transportation programs—will do relatively little absent other critical factors including appropriate land, labor, and capital. They also point to the difficulties in identifying and measuring the impact of transportation projects in real-world contexts.

Implications for Congestion Pricing

Location theory, other theories of urban development, empirically estimated models of land use–transportation interactions and location choice, and case studies and statistical analyses of transport impacts all provide useful insights about transportation and urban form but no clear, singular findings concerning likely impacts. This wide-ranging body of work suggests that, all other things being equal, transportation investments that lower the costs of travel should decentralize housing and centralize employment but at the same time stimulate countervailing pressures for housing near the employment center and for service employment near housing. Conversely, worsening transportation services will favor decentralization of jobs but support higher densities of housing in more central locations, although the relationships are not a simple mirror image because of precedent conditions in the developed areas.

Moreover, the empirical work points out that many other factors may be equally as important as transportation, or more so, in location and land use decisions. Overall, then, the impacts of transportation projects on land use and urban form must be considered in context with full recognition of the complexity and contingent nature of the phenomena being considered.

Congestion pricing adds a twist to the evaluation because it is not a straightforward matter to determine the change in costs resulting from its implementation. In most cases some travelers will face higher generalized costs—money plus travel time—whereas others will find their costs reduced. Use of the revenues from congestion pricing could substantially alter the magnitude and distribution of costs and benefits, and the specific choices could have widely different implications for urban form. For example, using revenues to expand a congested facility would have far different impacts than using the revenues to reduce other taxes currently paid by affected parties. Again, the implications are that the urban form

impacts are uncertain and contingent on the application and the details of implementation.

Finally, it is important to note that it is not always the case that congestion pricing on a particular facility will predominantly affect a specific place. Such a place impact would depend on whether the congestion-priced route is critical to a specific place (or strongly identified with it, to the extent that perceptions are driving decisions) or shared or even incidental to that place. As an example, congestion pricing of the San Francisco–Oakland Bay Bridge might have almost as much employment impact on south San Francisco, some miles away, as on downtown San Francisco, because the south San Francisco employees are highly automobile dependent, whereas downtown employees are not. Because of the complexity of the interactions involved, models will be needed to trace impacts through the transportation–land use system.

CONGESTION PRICING, TRAVEL BEHAVIOR, AND LAND USE IMPACTS

Models of transportation and urban form deal primarily with changes in accessibility and the effects of these changes on land use and development patterns. However, congestion pricing could stimulate a variety of changes in travel behavior, some of which could directly affect land use and some of which could offset impacts on land use. Moreover, the use of congestion pricing revenues for transportation investments may invoke another round of transportation–land use interactions. In this section, these potential impacts are reviewed.

Traveler Responses

The introduction of congestion pricing is likely to elicit a variety of traveler responses, only some of which are likely to have significant impacts on urban form. Moreover, the effect will be different depending on the traveler's income and the importance the traveler places on particular trips, as well as the degree of flexibility or constraint the traveler faces, including coordination requirements both at home and at work. Some travelers whose time is worth more to them than the congestion charges will find that the generalized cost of travel has dropped for them—they will be better off. This group includes both current travelers and those who are now deterred from making particular trips because the peak-period (con-

gested) time costs are too high. (This latter group would include certain high-income travelers and others of more modest income with regard to high-value trips such as airport access.) These travelers not only will be able to continue pre-congestion-pricing travel behavior, but also may make more or longer trips, or both, in response to the improved level of service.

Other travelers will find that it is not worth it to them to pay the price for a particular trip. They may find that they have no choice but to make the trip anyway if the travel choice is highly constrained or the alternatives are unacceptable. Or they may be able to continue their current level of trip making by finding a way to offset the charges, using a different (less congested or unpriced) route, switching modes, or making the trip at a less congested (less costly) time. Alternatively, they may change their trip frequency, their destination choice, or even their location choice to avoid the charges. These travel options are summarized in the accompanying text box.

Not all these options are likely to affect land use significantly. For example, a change in the time of travel, all else being equal, is unlikely to affect land use at all (one can imagine some instances in which congestion levels along an arterial make a difference in the attractiveness of a shopping destination, or where hours of operation could be affected by travel and traffic shifts, but in general the impacts surely would be minor). In contrast, changes in destination choice and trip frequency resulting from transportation congestion pricing could affect the relative competitiveness of different areas, which in turn may lead to changes in businesses' choices of whether or where to locate, expand, or move.

Impacts will also vary by trip purpose; that is, shopping trips are more price-elastic than work trips and so may be affected more (to the extent that they are affected at all, i.e., to the extent that they occur during the peak in congested areas).[1] Impacts and responses will further vary by level of congestion; for example, it is hard to shift trips out of the peak if that peak lasts several hours and easier if it lasts an hour or less.

Finally, impacts will also vary by whether congestion pricing is used only on one or a few facilities or is widespread (hence whether a route choice option is available), by whether the price varies across facilities (less shifting of locations should occur if the price variation is low), by whether there are competitive transportation alternatives, by whether there are competitive alternative destinations, and undoubtedly by many other factors.

OPTIONS AVAILABLE TO TRAVELERS FACED WITH CONGESTION CHARGES

No change in travel behavior or activities: pay charges; continue previous pattern

Increase trip making, level of activities, or both: pay charges; increase trip making to affected destinations because congestion charges make it easier to travel (possible without new infrastructure investments because of congestion relief; impact probably larger if revenues are invested in new infrastructure in affected corridors as some have proposed)

Reduce the overall costs of automobile use to offset the congestion charges without changing travel behavior or activities:

- Seek free parking or parking subsidy (if parking currently is priced)
- Use a more fuel-efficient vehicle
- Keep vehicles longer, replace vehicle with a more modest vehicle, and so forth

Change travel behavior without changing level of trip making or activities:

- Avoid charges by deferring trips to uncongested periods
- Avoid charges by using alternative routes with lower (or no) price
- Share costs (rideshare) (if carpools travel free, as they would in some proposals, this option would permit charges to be avoided)
- Switch to another mode with lower cost (e.g., use transit)

Reduce trip making, level of activities, or both: lower trip frequency, for example, work at home, shop less often but buy more per trip, shop by mail/phone/electronics, chain together trips

Change location of activities:

- Avoid charges by changes in trip destination (e.g., shop at a location accessible without driving on a priced, or high-priced, facility; change jobs)
- Avoid charges by changing trip origin, move household location

The important point is that both high-income and modest-income travelers can respond to congestion pricing in a variety of ways, some of which may reduce activity at particular destinations, others of which would have little or no effect, and still others of which could increase the activity level.

Use of the Revenues

As noted earlier, use of the revenues from congestion pricing strategies could have important implications for urban form, in some cases as large as or larger than those directly resulting from the price. For example, if revenues are used to build new infrastructure, the potential for land use–development impact from that new investment would have to be investigated. The specific type of infrastructure chosen would make a substantial difference in these land use impacts as well: widening a bottleneck on the priced facility would be far different from building a rail transit alternative or mitigating the traffic impact on a parallel arterial. Use of the revenues to compensate those most heavily affected (e.g., via a reduction of transportation taxes or a commute allowance) would have substantially less land use impact, as would using the revenues to fund air pollution reduction, noise reduction, safety improvements, and so forth, or simply placing the revenues in a general fund. Again, the impacts on urban form would be highly dependent on the specific expenditure plans.

It should be anticipated that numerous claims will be made on the revenues, some by people and in places that are perceived to be disadvantaged by congestion pricing. For example, owners of businesses in centers that might otherwise suffer (or perceive) increased costs of accessibility due to pricing may lay claim to revenues to otherwise improve their access: in this vein the Bay Area Economic Forum has proposed that revenues be spent in the corridor of origin. Similarly, arguing that the impact on their businesses could be disproportionately negative, trucking interests have indicated that they would seek a dispensation or substantial discount from congestion pricing, at least until enough experience has accumulated to support an evaluation of whether they can capture compensating travel time savings. The politics of implementation may make it necessary to accommodate such positions even if their economic justification as a general proposition is lacking. At the same time, economically justifiable investments that make it possible for vehicle miles traveled to increase may

be opposed by environmentalists or others. Hence the politics of revenue use is likely to be highly complex and not easily predictable.

Summary

Transportation congestion pricing may affect urban form via changes in travel behavior, particularly changes in trip generation rates and trip destination choices, as well as through longer-term location decisions. Moreover, the potential for affecting urban form will vary with the ways in which pricing revenues are used, in particular, whether and what kind of infrastructure investments are pursued.

POTENTIAL RESPONSES OF BUSINESS AND LOCAL GOVERNMENT TO CONGESTION PRICING

Just as travelers have a number of options in their response to congestion pricing, both business and local government could respond to congestion pricing strategies in a variety of ways, some of them including land use policies. To explore what responses might be forthcoming, interviews were conducted with a small sample of elected officials, senior planning staff, business representatives, and development interests in the San Francisco Bay Area. Because congestion pricing has been fairly widely discussed in the Bay Area, all those interviewed were familiar with the concept and its many formulations. Four scenarios were discussed involving congestion pricing on different types of facilities and with alternative routes:

1. Specific "gateway" facilities with no significant alternative routes (for example, the San Francisco–Oakland Bay Bridge),
2. Targeted limited-access facilities with comparable facilities not subject to congestion pricing (for example, Route 101 and I-280 on the San Francisco peninsula),
3. Targeted limited-access facilities with alternative routes via surface streets (arterials) (for example, I-80 and San Pablo Avenue along the East Bay shore),
4. All facilities as necessary (both limited-access facilities and surface streets may be priced).

In each case the respondent was asked what impacts might be anticipated and what his or her organization might do in response if such a congestion pricing strategy were implemented rather than whether he or she agreed that congestion pricing was necessary or desirable. Costs in the scenarios were approximately $0.08/mi to $0.10/mi ($0.05/km to $0.06/km) except for the Bay Bridge, for which a toll of $3 to $5 was assumed.[2]

Altogether, 18 interviews were completed.[3] Seven of those interviewed were representatives of businesses: two small business owners, one in downtown San Francisco and the other in Emeryville; a representative of a large business headquartered in downtown San Francisco; a representative of a manufacturing concern in South San Francisco; a representative of the trucking industry; and two representatives of retail businesses. Five more were with local elected officials, and five were local agency staff in planning and redevelopment departments. In addition, a representative of a union representing blue collar manufacturing employees in San Francisco and south San Francisco was interviewed. Although this sample obviously cannot support statistical analysis, the findings of the interviews, summarized below, are nevertheless revealing of some of the land use issues that may arise with congestion pricing proposals.

Potential Business Responses

A consistent reaction to the congestion pricing scenario involving only the Bay Bridge was that it would not affect a very large share of any one firm's employees (estimates of the share of employees coming from the East Bay ranged from 5 to 30 percent, some of whom cross the bay on another bridge or commute by transit; estimates of Bay Bridge users ranged from 2 to 10 percent[4]). Therefore, the respondents reasoned, few firms would find it necessary to do much to counter the effects of congestion pricing as an overall policy response. If congestion pricing were more widely implemented (i.e., on many facilities rather than on only one or two), respondents believed that it would be more likely to have an impact on location decisions and land uses, in particular on marginal uses in outmoded facilities.

It was recognized that for businesses most directly affected by congestion pricing, the size of the labor market could shrink unless higher wages were paid to offset the transportation cost premium. For those who hire numerous low- to moderate-income workers, this was seen as potentially making the businesses noncompetitive; employees of higher-income

workers saw this as much less of an issue. But many other factors were thought to make the impact on lower-wage workers a smaller reason for concern than it might have appeared at first glance; for example, low- to moderate-income workers generally are more likely to live nearby, commute by walking or transit, and so on.

Several respondents suggested that case-by-case adjustments for individuals who are adversely affected might be necessary or appropriate. For example, employees facing an expensive commute who either lack reasonable transportation alternatives or cannot make use of such alternatives for some reason (e.g., the need to transport children on the way to and from work) might be allowed to

- Change work start and end times to avoid the peak,
- Change to a different shift (manufacturing jobs), or
- Work at home some or even most of the time.

Two of the employers thought that to avoid their becoming excessively entangled in their employees' travel decisions, congestion pricing might lead them to implement a commute allowance to replace current parking and transit subsidies. One speculated that it might be necessary to raise the current parking subsidy in order to offset the added costs of tolls.

Respondents acknowledged that transportation is only one factor in business location decisions, and its importance varies with characteristics of the business; for many, taxes, crime rates, and the general business climate and image of a location are more important considerations. However, the respondents also noted that a number of businesses are located in places that are suboptimal under current conditions, in buildings that are outmoded, in labor markets that are costly, and so forth. Higher transportation prices due to congestion pricing could be the final straw for these businesses, forcing them to look for another location or even to close their businesses altogether. Most respondents believed that the impact would be greatest on industrial and retail uses rather than office employment, which they saw as already relatively footloose.

Companies that are adversely affected may not move initially because the costs of moving at that time may be too high. But the same firms may choose to expand elsewhere, relocate, or both, after the useful life of facilities is used up or a long-term lease expires. Hence some congestion pricing impacts may lag implementation by years.

One business representative with many highly paid workers believed that congestion pricing would be a major benefit, producing time savings

for travelers, less stress, greater scheduling flexibility, and higher productivity. He argued that congestion has deterred some firms from locating in places like downtown San Francisco and that congestion relief due to pricing should remove a barrier to these firms, stimulating growth. He also argued that the revenues from congestion pricing, if used to improve congested facilities or to provide good commute alternatives to those who are priced off, could result in an overall improvement in accessibility of the priced areas.[5] He saw the loss of certain marginal firms as inevitable and overall positive for the region, despite the likely hardship for some individuals.

The impact of congestion pricing on trucking was deemed a major concern. It was acknowledged that truckers are likely to find that congestion reduction more than offsets the congestion price, or they may be able to avoid peak-hour charges by careful scheduling. Nevertheless, most business representatives believed that they would see congestion prices passed on through trucking fees. Large businesses could avoid paying truckers' congestion charges by scheduling deliveries and pickups to avoid peak hours and peak prices; however, smaller businesses (and truckers) have less flexibility in scheduling, and truckers offering just-in-time services may find peak-period travel unavoidable. The "lack of options" argument appears to be a persuasive one; for this reason, the majority of the respondents believed that truckers would seek exemptions from pricing and would likely be granted such exemptions, regardless of the benefits they would also be capturing.

Potential Local Government Responses

Just as private actors may attempt to counteract real or perceived declines in accessibility (increases in general costs), shrinkage of markets, or both, by using a variety of strategies, local governments can be expected to take action to protect their tax bases and constituencies. Among the means to do so that are commonly available to local government (depending on individual state laws) are land use regulations, redevelopment powers, the ability to create special districts, and the authority to tax and spend.

For example, for a central business district perceived to be adversely affected by road pricing, local government or businesses might decide to provide free parking to offset the cost of the road price. Or, if it is assumed that many of those affected will switch to transit, a convenient circulator bus or transit shuttle might be provided. In a deregulated ground transportation environment this might stimulate van and jitney services, but in the

far more common restricted-entry situations, a shuttle probably would entail either government financing or funding through an assessment district or business association.

Attempts to offset perceived negative impacts of transportation congestion pricing are more likely in areas that have experienced difficulties in business retention and attraction (and among businesses that have experienced labor shortages or customer losses). City officials believe that in a strong real estate market very little organized public or private response might be generated, on the assumption that there will be plenty of takers for available space (or jobs, or goods and services) even if some are pushed out by the impact of congestion pricing. In a weak market, however, local business people would almost certainly seek help to offset pricing impacts, and local officials would be sympathetic to their concerns and likely would look for ways to be of assistance.

City officials also expressed concerns about pricing strategies that would lead to increased traffic on arterials under their control, for example, traffic diverted from a priced limited-access facility. They would expect to be compensated for the added costs of handling such traffic and, in some situations, for additional traffic mitigation, especially if residences or retail uses abutted the affected streets. Off-street parking to replace removed on-street spaces, improved transit services and stops, improved sidewalks, trees and other landscaping, and better signalization might be demanded by localities should traffic diversion occur. On the other hand, there were mixed reactions to the possibility that traffic levels might decline on parallel arterials. Some believed that this would be an improvement; others worried that reduced traffic could cut down business activity.

With regard to possibilities for increased development, local government officials were somewhat skeptical. They noted that current land use regulations often limit market responses to transportation system changes, in some cases for very long periods. They acknowledged that some increases in density or changes in use could occur under current zoning through increased occupancy rates, shifts to higher-intensity allowable uses, and so on, but cautioned that in many areas, higher density and change in use may be substantially limited by restrictions on height, bulk, or use; by other development regulations; or simply by delays encountered in areas where development proposals often arouse strong political opposition.

Several of the respondents noted that their responses to congestion pricing were unlikely to be justified from an economic perspective and indeed that in some cases their responses were internally inconsistent. They nevertheless argued that proponents of congestion pricing would

need to make the benefits visible and widespread in order to secure the allies they would need for implementation of pricing strategies.

Summary

Overall, both businesses and local officials indicate that they would pursue strategies that could compensate for the effects of congestion pricing. Some of these strategies appear likely to be beneficial; others could be counterproductive. Almost all would be designed to preserve jobs and amenities thought to be threatened by the pricing strategies.

CONCLUSIONS: WHAT WOULD EFFECTS ON URBAN FORM BE?

Currently, some travelers presumably would be willing to pay more to travel than they currently do; some presumably are being priced off the system by congestion (travel time) rather than dollar costs. Other travelers are using the roadways, making certain trips, and indeed living and working where they do in large part because travel costs as little as it does; at least some of these individuals would not be willing—or able—to pay more.

Given this heterogeneity in the travel markets and the evidence that there is considerable differentiation in traveler characteristics within particular travel corridors, it is difficult to say unambiguously and generally how pricing might affect urban form. Although in general, policies that increase the cost of transportation to an employment center would simultaneously raise land prices and concentrate development there, many other factors must be considered, including the presence of specialized subcenters, land use regulations that retard market-driven changes, and the slowness of response in land use changes even when government policy does not discourage them (e.g., obsolete uses persist at sites for decades, even when land use changes would be highly profitable).

Although increased economic and social differentiation of places could be one outcome of transportation congestion pricing, such changes could be greatly slowed by resistant government policies or, for that matter, resistance to change on the part of the private sector. Exploratory interviews conducted for this study, although limited in scope and extent, indicate that both government and business would be likely, at least in the short to medium run, to take action to offset perceived adverse impacts

resulting from higher transportation prices. Such actions might range from providing travel allowances to increasing the subsidy for parking, shifting work schedules to avoid the peak periods, and subsidizing certain land uses or businesses. Impacts on urban form would be moderated by such interventions.

ACKNOWLEDGMENTS

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NOTES

1. Note that regional averages of peak travel by trip purpose probably are not relevant since congestion varies by corridor; evidence from the Bay Area indicates that the share of discretionary travel during the peak is lower than average in highly congested corridors.
2. The Bay Bridge, 8 mi (13 km) long including approaches, currently is tolled westbound only.
3. Two other persons declined to be interviewed, even on a confidential basis, because they believe the topic is highly sensitive and the possibilities for misunderstandings are great. Eight of those interviewed asked that their comments not be for attribution. Because of such concerns, none of the respondents are identified except by general job title.
4. These estimates are roughly compatible with Bay Area travel data.
5. Most others discounted this possibility, seeing it as "theoretically possible, but not likely in practice."

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Congestion Pricing and Motor Vehicle Emissions

An Initial Review

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Traffic congestion is now widespread on freeways and arterials in most urban areas. The Federal Highway Administration estimates that more than 65 percent of urban freeways are congested during peak periods, creating more than 2 billion vehicle-hr of delay and user costs in excess of $15.9 billion per year (GAO 1991). Congestion levels are also rising, meaning that the delay, energy, and air quality impacts of congestion continue to worsen. Because there has recently been increased regulatory focus on implementing economic incentives in the environmental arena (EPA 1992a; Guensler 1992; Ketcham 1991; Regulatory Flexibility Group 1991; South Coast Air Quality Management District 1991; Hahn and Stavins 1990), it is natural that congestion pricing would be explored as a means to achieve transportation behavioral changes in the urban areas with the worst air quality.

Congestion pricing has the potential to fundamentally change trip-making behavior, yielding changes in the number of trips, types of trips, trip length, mode choice, and so forth. In theory, congestion pricing will increase the efficiency and capacity of the existing highway system by reducing the use of vehicles during peak periods. Emission reductions

would be associated with the actual reduction in vehicle activity as well as the change in vehicle operating conditions on the roadway. As traffic congestion is reduced and operating conditions move closer to free flow, traffic flows are smoothed and emission rates per mile of travel are expected to decrease.

Until a few years ago, analysts had sufficient confidence in existing emission models of the Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) to generate quantitative answers to congestion pricing impact questions. Indeed, given postulated changes in vehicle activity from congestion pricing scenarios, any number of consulting firms could use the existing emission modeling regime to prepare an analysis of congestion pricing emission impacts. However, the most recent literature in both the vehicle activity and emission rate modeling research indicates that many of the problems associated with using the existing modeling regime for impact analyses of this type are insuperable. These factors will be considered in the analyses and interpretation of empirical findings.

Accurate quantitative estimates of congestion pricing impacts on air quality are not possible at this time because a number of fundamental problems exist: (*a*) the changes in vehicle miles of travel (VMT) and trip making are difficult to predict accurately; (*b*) the effects that pricing will have on vehicle fleet composition and the vehicle operating environment are unclear; (*c*) the primary operating environment characteristic of concern in the existing modeling regime, average vehicle speed, is difficult to estimate reliably; and finally (*d*) the cause-effect relationships at work between the vehicle operating environment and emission rates are poorly modeled and highly uncertain, making emission impact assessments using average speed changes very unreliable.

The goal of this paper is to examine the air quality impacts likely to result from congestion pricing. A number of key questions must be answered: What effect will congestion pricing have on trip making and VMT? How will traffic volumes change on priced and unpriced routes? How will the change in traffic volume affect the operating environment of vehicles (examined as a change in average vehicle speed under the current modeling regime) and the resulting emission rates per unit of vehicle activity? What changes in vehicle emissions are expected to result from overall changes in vehicle activity and emission rates? In this paper, the focus is on the effects of postulated changes in average vehicle operating speeds on emission rates. The accompanying paper by Harvey in this volume on changes in travel behavior is used as input to the analysis.

Reductions in vehicle activity and trip making and VMT, assuming no changes in vehicle operating conditions, can be readily translated into percentage emission reductions, although many would argue that even these estimates could be questioned (Guensler 1993a). That area is not the focus of this paper. Instead, the existing emission modeling regime for average speed changes is examined, and a range of emission rate changes based on the projected changes in average vehicle operating speeds is provided. Using projected changes in average vehicle speeds provided by Harvey in the accompanying paper, percentage changes in emission rates associated with the implementation of four congestion pricing scenarios are examined.

The large ranges surrounding the projected percentage change in emission rates are based on the confidence intervals associated with the use of speed correction factors (SCFs) (Guensler 1993b). The actual range in emission rate impact is even greater than presented here, because there are additional sources of uncertainty for which statistical inferences of confidence have yet to be developed, such as the relationship between operating environment and changes in cold- and hot-start emission rates (Guensler 1993a).

SOURCES OF EMISSION MODELING UNCERTAINTY

Modeling results are highly uncertain because the models were only designed to roughly estimate a "bulk" emission inventory and were not designed to evaluate policy issues in the manner that they are often used. Discussions of specific emission modeling problems, such as off-cycle and modal emissions, characterization of the vehicle fleet, cold- and hot-start emissions, evaporative emissions, potential interaction between emission model correction factors, and specific quantification and spatial allocation of vehicle activity, can be found in many sources (Guensler 1993a; Harvey 1993; Bruckman and Dickson 1993; Pollack et al. 1992; Austin et al. 1992; Ashbaugh et al. 1992; TRB 1992; Bruckman and Dickson 1992; Purvis 1992; Benson 1992; Guensler and Geraghty 1991; Gertler and Pierson 1991; SAI 1991; Guensler et al. 1991; Ismart 1991; Lawson et al. 1990; FHWA 1990). It can be concluded that the current modeling methodologies, both for vehicle activity and emission rate estimates, are fraught with uncertainty.

Uncertainty is pervasive in all three emission modeling components: vehicle activity, activity-specific emission rates, and emission rate correction factors. Uncertainty is compounded in the methodologies used to develop the emission inventory. That is, vehicle activity uncertainty is combined with emission rate uncertainty that has already been combined with correction factor uncertainty. However, simple statistical formulas representing suspected ranges of uncertainty cannot be applied to the estimates to determine the net uncertainty. There are simply too many unanswered questions regarding the fundamental emission relationships and the basic applicability and usefulness of much of the data collected.

Without detailed reanalysis of the data used to develop the algorithms in existing emission rate models, practitioners cannot accurately identify the individual model components that yield the greatest uncertainty in emission estimates. Confidence interval analysis (based on reanalysis of the original data) can reveal how representative each of the model algorithms really is. Confidence interval analysis has been undertaken with the data originally used to develop the speed correction factors in existing emission rate models (Guensler 1993b), and these confidence intervals are used to examine how congestion pricing is likely to affect average vehicle operating speeds and the resulting vehicle emission rates.

CHANGES IN EMISSION-PRODUCING VEHICLE ACTIVITIES

The potential impacts of congestion pricing will be revealed through changes in vehicle activity, modeled as resulting from changes in land use configuration, trip generation, mode choice, trip distribution, and route selection, ideally in an iterative process (Harvey 1993). The implementation of congestion pricing may have the following effects on VMT, trip making, and trip characteristics, most of which are not accurately (or at all) addressed by travel demand models:

- Fewer trips due to increased costs;
- Elimination of some nonessential trips and shifting of others to off-peak periods;
- Shorter trips due to increased costs;
- Some increase in VMT if diversion to unpriced routes occurs;
- Longer trips if diversions around paid routes exist;

- Encouragement of peak spreading (shifting of trips to unpriced shoulders of the peak);
- An increase in trip chaining activity;
- Shifting of trips to carpools, transit, and paratransit due to increased travel costs;
- Changes in transit access mode;
- Changes in spatial resolution of vehicle route;
- Increases in average vehicle operating speeds on priced routes; and
- Smoother traffic flow, due to reduced acceleration/deceleration activity.

The number of trips undertaken is important from an emission modeling standpoint because the emission levels of all pollutants are elevated during the first few minutes of operation (Jacobs et al. 1990; CARB 1989; Heywood 1988; Joy 1992; Stone et al. 1990; Pozniak 1980) and hot- and cold-start emissions become important contributors to the on-road emissions inventory. In 1987 cold- and hot-start operations were estimated to contribute about 27 percent of hydrocarbon emissions, 35 percent of carbon monoxide emissions, and 19 percent of oxides of nitrogen emissions from the automobile fleet in the Los Angeles basin (CARB 1990). Because congestion pricing may change the number of vehicle trips made, emission reductions may result from reduced cold- and hot-engine starts. If congestion pricing results in an increase in trip chaining, some cold-start trips may be changed to hot-start trips, reducing emissions.

Figure 1 shows the cumulative hydrocarbon emissions for a typical modern catalyst-equipped vehicle making a 10-mi (16-km) trip at an average speed of 26 mph (42 km/hr) after a cold start. Approximately 55 percent of the hydrocarbon emissions are associated with the cold start, another 10 percent of the emissions with the engine hot soak (evaporation after shutting the engine off), and only 35 percent with the hot stabilized combustion on a per mile basis. Although the overall emission rates are much lower, modern, fuel-injected, catalyst-controlled vehicles emit a larger percentage of their emissions during cold start and hot soak than does the average in-use fleet. This indicates that trip-end emissions will become increasingly important as vehicle fleet turnover continues (but may be partially mitigated by new vehicle certification requirements, because manufacturers are expected to achieve much of their reduction in California through the control of cold-start emissions).

Harvey's study in the South Coast Air Basin indicates that congestion pricing will have only a modest effect on VMT and trip making. Region-

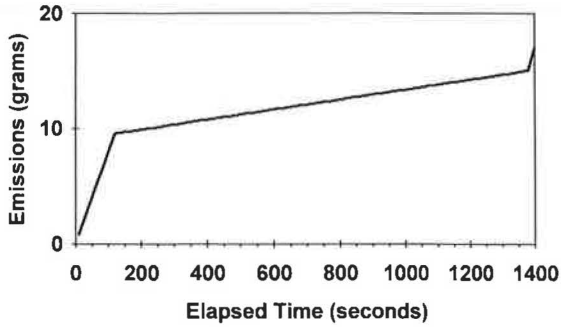

FIGURE 1 Cumulative emissions versus time, VOC emissions, 1987 average vehicle fleet (with catalyst), 10-mi trip at 26-mph average speed (16-km trip at 42-km/hr average speed).

wide congestion pricing of $0.15/mi ($0.09/km) (a market-clearing price designed to yield Level of Service D or E) may yield a VMT reduction of about 5.0 percent and trip reduction of 3.8 percent (Cameron 1991). In reality, this implies roughly a 4 percent decrease in engine start and hot soak emissions and a 5 percent decrease in VMT-related emissions—roughly a 4 percent decrease in automobile emissions overall, provided that vehicle operating conditions remain unchanged.

Yet, it is not likely that emission rates will remain stable as congestion pricing strategies are implemented. Changes in the composition of the vehicle fleet are likely to occur, and congestion reduction yields changes in the vehicle operating environment that in turn affect the emission rates. It is the expected change in vehicle operating conditions and subsequent emission rates that many analysts believe will yield the greatest emission benefit. But how sure is this?

POTENTIAL CONGESTION PRICING IMPACTS ON EMISSION RATES

Motor vehicle emission rates are functions of vehicle parameters, fuel parameters, vehicle operating conditions, and the vehicle operating environment. The accompanying text box lists some of the important variables that can be considered in developing emission rate estimates (Guensler 1993b). Congestion pricing can affect vehicle fleet parameters (such as model year, emission control technology, accrued vehicle mileage, etc.),

VEHICLE PARAMETERS, FUEL PARAMETERS, VEHICLE OPERATING CONDITIONS, AND ENVIRONMENTAL CONDITIONS KNOWN TO AFFECT MOTOR VEHICLE EMISSION RATES
(Guensler 1993b)

Vehicle Parameters
- Vehicle class* (weight, engine size, HP, etc.)
- Model year
- Accrued vehicle mileage
- Fuel delivery (e.g., carbureted or fuel injected)
- Emission control system
- On-board computer control system
- Control system tampering
- Inspection and maintenance history

Fuel Parameters
- Fuel type
- Oxygen content
- Fuel volatility
- Sulfur content (SO_x precursor)
- Benzene content
- Olefin and aromatic content
- Lead and metals content
- Trace sulfur effects on catalyst efficiency*

Vehicle Operating Conditions
- Cold- or hot-start mode (unless treated separately)
- Average vehicle speed
- Modal activities that cause enrichment*
- Load (e.g., A/C, heavy loads, or towing)
- Influence of driver behavior*

Vehicle Operating Environment
- Altitude
- Humidity
- Ambient temperature
- Diurnal temperature sweep
- Road grade*

*These components are not explicitly included in the EPA and CARB emission rate models.

fuel parameters (i.e., if modes that use clean fuels are encouraged), and vehicle operating conditions (such as average speed and acceleration).

Vehicle and fuel parameters that affect emission rates are functions of the composition of the vehicle fleet. If the composition of the fleet changes, fleet average emission rates also change. Recent studies indicate that older vehicles tend to fall into sociospatial patterns of ownership (Rajan 1993). That is, older vehicles are more likely to be owned by lower-income individuals or as supplemental vehicles in middle- and upper-income households (perhaps a vehicle for teenager use), and the patterns of ownership appear to exhibit a clustering effect. On the average, the emission rates for older vehicles are higher, although older vehicles are generally driven fewer miles per year. The vehicle activities undertaken by various socioeconomic groups also appear to differ (Micozzi and Bowen 1993). If VMT and trip-making reductions are significant in the lower-income quintiles and insignificant in the upper-income quintiles, or if the ownership and operation of higher-emitting vehicles are higher in the lower-income quintiles, the composition of the vehicle fleet with respect to emission production will change. Because a small fraction of the vehicle fleet is believed to be responsible for a large percentage of fleet emissions (Lawson et al. 1990; Pollack et al. 1992), further studies into the spatial and socioeconomic allocation of superemitting and malmaintained vehicles and vehicle activity seem warranted. These issues are tied to potential equity impacts that also must be addressed before the implementation of congestion pricing strategies.

Harvey's work (see the accompanying paper) indicates that pricing will have a varied impact on different income groups, noting that congestion pricing of $0.15/mi is likely to produce significant reduction in trip making and VMT within the first two income quintiles compared with the last two. Thus, fleet composition appears likely to change along the affected routes. The composition of the vehicle fleet is also important in estimating emission changes resulting from changes in operating conditions, because these factors are not independent. Emission behavior with respect to average vehicle speed differs between older and newer vehicle technology groups, complicating the emission impact analyses.

SPEED-RELATED MODELING REGIME

The existing baseline exhaust emission rates used in emission models were derived through the testing of thousands of new and in-use motor vehicles under the federal test procedure (FTP), a certification testing cycle for new

vehicles. The FTP consists of a defined set of modal patterns (start, stop, acceleration, deceleration, idling, and constant-speed cruise operations) and is composed of three subcycles, known as the Bag 1, Bag 2, and Bag 3 cycles (emissions are collected in separate sample bags for each subcycle). Bag 1 contains emissions from a cold engine start and running exhaust, Bag 2 contains only running exhaust emissions and is collected after the engine is hot and combustion is stabilized, and Bag 3 contains emissions from a hot-engine start and running exhaust. The bag samples are analyzed to determine the average emission rates for the vehicles operating under the test parameters. In California, the baseline exhaust emission rate for each vehicle class is the average emission result under Bag 2 of the FTP [the hot-stabilized subcycle with an average operating speed of 16 mph (26 km/hr)].

Because the certification cycle is used to test new vehicles for compliance with federal emissions requirements and in-use vehicles for evaluation of inspection and maintenance program effectiveness, numerous data are available for vehicles operating under the FTP Bag 2 cycle. However, emission rates noted under the Bag 2 testing conditions can differ significantly from the emission rates for the same vehicle when tested under other hot-stabilized testing cycles. Because thousands of vehicles have been tested under the FTP to develop the baseline exhaust emission rates, the desire on the part of regulatory agencies to define a relationship between baseline emission rates and emission rates at other average speeds seems logical. In this way, ongoing testing of vehicles can be conducted on the single certification cycle rather than on numerous cycles (saving substantial agency resources).

To model emission rates at speeds other than 16 mph, EPA and CARB developed SCFs, or statistically derived emission ratios (Guensler 1993b; Guensler et al. 1993; EPA 1992b; CARB 1992a; CARB 1992b; Caltrans 1992; EEA 1991; EPA 1988). These ratios can be thought of as the average emission rate for a vehicle group at the average speed in question divided by the average emission rate for the same vehicle group under Bag 2 of the FTP. To approximate vehicle emissions at speeds other than 16 mph, the baseline exhaust emission rate is multiplied by the statistically derived emission ratio. The SCFs were developed through the testing of more than 500 light-duty vehicles on laboratory dynamometers under a variety of chassis dynamometer cycles, including the certification cycle (Guensler 1993b).

The current emission inventory methodologies model SCFs and gram/mile vehicle emission rates as nonlinear functions of average operating

speed. Figures 2 through 4 present the relationships between speed and emissions for modern (1986 and later model year) fuel-injected automobiles. These figures present the multiplier that determines the emission rate for any operating speed compared with the average emissions for the vehicle class at 16 mph (Bag 2 of the FTP). Thus, in Figure 2, the carbon monoxide emission rate (grams/mile) at 5 mph (8 km/hr) is modeled to be roughly double that of the baseline exhaust emission rate for an average speed of 16 mph.

Research at the University of California at Davis indicates that speed-related emission factors currently used in emission modeling techniques are highly uncertain (Guensler 1993b). These emission correction factors, by the nature of their statistical derivation, yield uncertain results with high standard errors. The dashed lines in Figures 2 through 4 indicate the 95 percent confidence intervals that surround the SCF curves, based on statistical analysis of the original data used to develop the speed curves. Thus, in Figure 2, the carbon monoxide emission rate (grams/mile) at 5 mph is between 0.1 and 3.9 times that of the baseline exhaust emission rate for an average speed of 16 mph at a confidence level of 95 percent. This

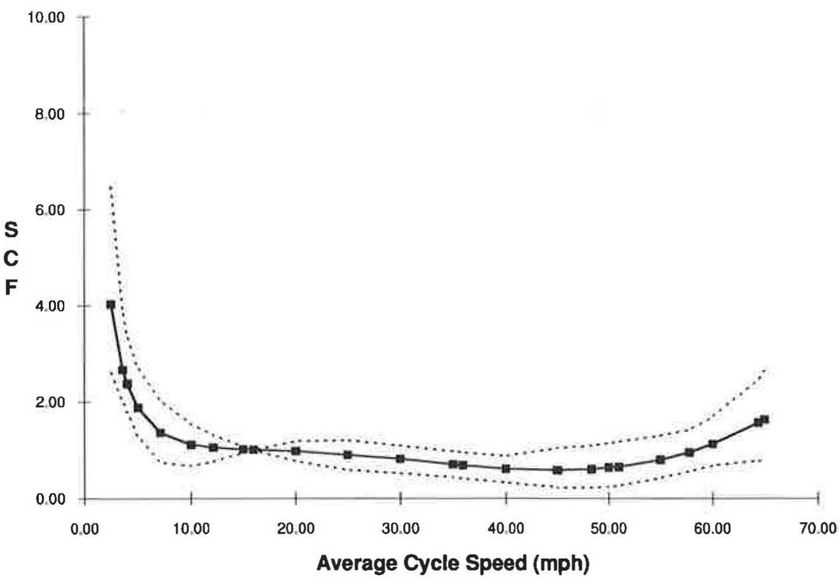

FIGURE 2 SCF (grams per mile) and 95 percent confidence interval, weighted disaggregate method, bootstrap approach, carbon monoxide, 1986 or later model year, fuel-injected vehicles. (Note: 1 mph = 1.6 km/hr and 1 gm/mi = 0.621 gm/km.)

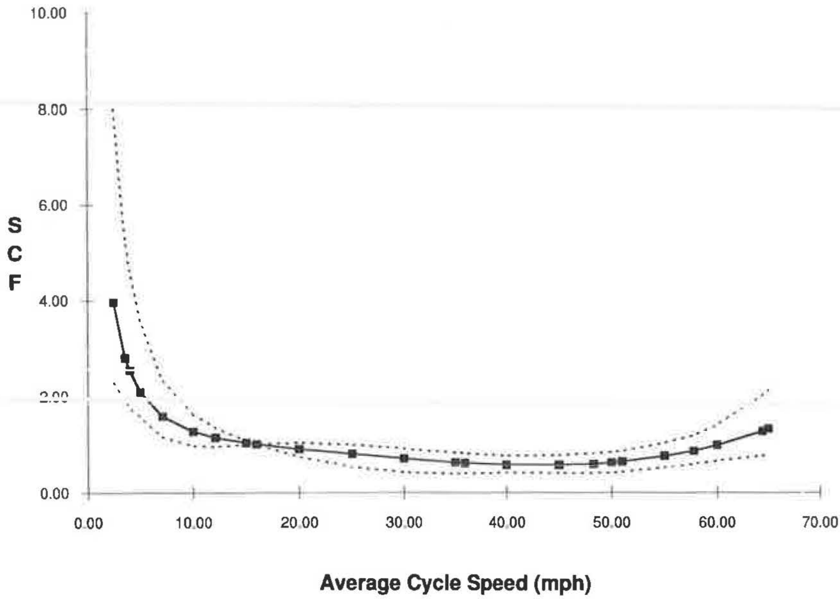

FIGURE 3 SCF (grams per mile) and 95 percent confidence interval, weighted disaggregate method, bootstrap approach, hydrocarbons, 1986 or later model year, fuel-injected vehicles. (Note: 1 mph = 1.6 km/hr and 1 gm/mi = 0.621 gm/km.)

is a huge range of uncertainty, yet there are additional sources of uncertainty unaccounted for in this analysis (e.g., intercorrelation of variables, representativeness of the test fleet, etc.) that make even these recently published uncertainty estimates conservative (Guensler et al. 1993).

AVERAGE SPEED ANALYSIS OF CONGESTION PRICING SCENARIOS

The four congestion pricing scenarios examined by Harvey include pricing on some freeways where no alternative routes are available (i.e., bridges), pricing on some freeways where alternative unpriced freeways are available for diversion, pricing on all freeways where alternative unpriced arterials are available for diversion, and pricing on all roads.

Table 1 summarizes the potential changes in average vehicle operating speed on the various affected facilities that are expected to result from the four congestion pricing scenarios postulated. For example, Harvey's analyses (see accompanying paper) indicate that targeted freeway pricing with

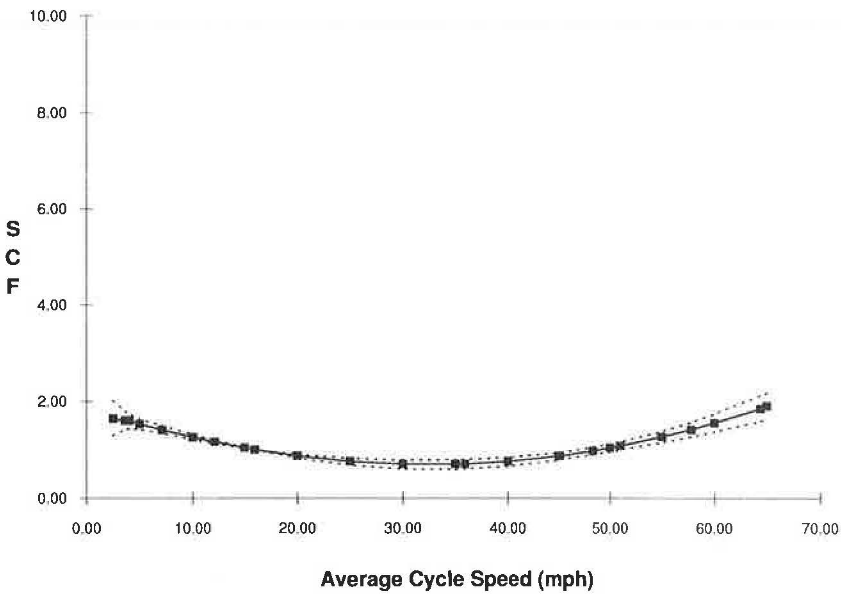

FIGURE 4 SCF (grams per mile) and 95 percent confidence interval, weighted disaggregate method, bootstrap approach, oxides of nitrogen, 1986 or later model year, fuel-injected vehicles. (Note: 1 mph = 1.6 km/hr and 1 gm/mi = 0.621 gm/km.)

no alternative unpriced routes (Scenario 1) may increase average freeway speeds from 30 to 50 mph (48 to 80 km/hr) during the peak periods and reduce average speeds on the priced freeways during the shoulder of the peak from 55 to 50 mph (89 to 80 km/hr) (because of peak spreading, caused by a price-induced delay in trip start times).

If the average speed of travel on a freeway were increased from 30 to 50 mph, emission models would predict a decrease in gram/mile emission rates for carbon monoxide and hydrocarbons and an increase in the emission rates for oxides of nitrogen along these routes. The estimated percentage changes in emission rates resulting from increased average operating speed were calculated for two significantly different groups of vehicles in the fleet: pre-1986 model year carbureted vehicles and 1986 and later model year fuel-injected vehicles.

Emissions models would predict that increasing average vehicle operating speeds from 30 to 50 mph would decrease carbon monoxide emission rates by 24 percent and hydrocarbon emission rates by 12 percent and increase oxides of nitrogen emissions by 50 percent for 1986 and later model year fuel-injected vehicles.

TABLE 1 Changes in Average Vehicle Speed Resulting from Four Postulated Pricing Scenarios

Pricing Scenario	Changes in Average Vehicle Speed by Facility
Targeted freeway pricing (no alternative unpriced routes)	Priced freeways (peak): 30 → 50 mph Priced freeways (peak shoulder): 55 → 50 mph Other facilities: no change
Partial freeway pricing (alternative unpriced freeways) (alternative unpriced arterials)	Priced freeways (peak): 30 → 45 mph Unpriced freeways (peak): 40 → 35 mph Freeways (peak shoulder): uncertain Other facilities: uncertain
Comprehensive freeway pricing (alternative unpriced arterials)	Priced freeways (peak): 30 → 45 mph Unpriced arterials (peak): 30 → 20 mph Peak shoulder: modest declines
Comprehensive pricing (no alternative unpriced routes)	Uncertain changes, higher speeds everywhere

NOTE: 1 mph = 1.6 km/hr.

Given the predicted changes in emission rates, one could easily surmise that the increases in average vehicle operating speeds are likely to yield significant reductions in carbon monoxide and hydrocarbon emission rates, concurrently increasing the emission rates of oxides of nitrogen. However, the point estimates do not tell the whole story. When the calculated emission rate changes include estimates of uncertainty, it becomes clear that the emission change estimates are questionable. For example, the 95 percent confidence interval for the estimated 24 percent reduction in carbon monoxide emissions associated with increasing average vehicle speeds from 30 to 50 mph for 1986 and later model year fuel-injected vehicles ranges from a 72 percent decrease to a 75 percent increase in emission rates. The range of uncertainty is huge.

Tables 2 through 4 contain estimates of carbon monoxide, hydrocarbon, and oxides of nitrogen emission rate changes for modern fuel-injected vehicles associated with the average vehicle speed changes postulated by Harvey (see Table 1). A bootstrap approach was used to calculate the upper and lower bound estimates in Tables 2 through 4 (Guensler 1993b). Because of multicollinearity of terms in the regression

TABLE 2 Predicted Changes in Carbon Monoxide Gram/Mile Emission Rates for 1986 and Later Model Year Fuel-Injected Vehicles Resulting from Postulated Changes in Average Vehicle Operating Speeds Estimated with Bootstrap Approach

Change in Avg Speed (mph)	Percent Change in Carbon Monoxide Gram/Mile Emission Rate		
	Low	Predicted	High
30 → 50	−72	−24	+75
30 → 65	+5	+105	+234
55 → 50	−51	−22	−2
30 → 45	−72	−25	+50
40 → 35	−14	+17	+58
30 → 20	0	+22	+58

NOTE: 95 percent upper and lower confidence limits used. 1 mph = 1.6 km/hr.

TABLE 3 Predicted Changes in Hydrocarbon Gram/Mile Emission Rates for 1986 and Later Model Year Fuel-Injected Vehicles Resulting from Postulated Changes in Average Vehicle Operating Speeds Estimated with Bootstrap Approach

Change in Avg Speed (mph)	Percent Change in Hydrocarbon Gram/Mile Emission Rate		
	Low	Predicted	High
30 → 50	−48	−8	+68
30 → 65	−1	+90	+220
55 → 50	−33	−17	−2
30 → 45	−47	−17	+41
40 → 35	−13	+9	+26
30 → 20	+11	+30	+76

NOTE: 95 percent upper and lower confidence limits used. 1 mph = 1.6 km/hr.

TABLE 4 Predicted Changes in Oxides of Nitrogen Gram/Mile Emission Rates for 1986 and Later Model Year Fuel-Injected Vehicles Resulting from Postulated Changes in Average Vehicle Operating Speeds Estimated with Bootstrap Approach

Change in Avg Speed (mph)	Percent Change in Oxides of Nitrogen Gram/Mile Emission Rate		
	Low	Predicted	High
30 → 50	+32	+50	+71
30 → 65	+110	+175	+251
55 → 50	−22	−18	−14
30 → 45	+16	+25	+36
40 → 35	−11	−8	−5
30 → 20	+15	+25	+39

NOTE: 95 percent upper and lower confidence limits used. 1 mph = 1.6 km/hr.

model, the results are highly sample dependent, raising questions about whether test samples were representative of the fleet.

On the basis of more detailed analysis of percentage emission rate change for combinations of initial and final average speed (in 5-mph increments), the following conclusions can be drawn (Guensler 1993b):

1. Changes in average vehicle speed yield greater percentage changes in carbon monoxide and hydrocarbon emission rates for older carbureted vehicles than for newer fuel-injected vehicles (except at speeds exceeding 50 mph, where the emission change estimates for older carbureted vehicles are highly uncertain).

2. Changes in average vehicle speed appear to provide greater percentage changes in oxides of nitrogen emission rates for newer fuel-injected vehicles than for older carbureted vehicles.

3. Percentage changes in emission rates are more stable (i.e., the confidence band is narrower) for older carbureted vehicles than for newer fuel-injected vehicles, making the percentage change estimates more certain for older carbureted vehicles than for newer fuel-injected vehicles (except at speeds exceeding 50 mph, where the emission change estimates for older carbureted vehicles are highly uncertain).

4. Predicted increases in emission rates are fairly certain for all pollutants when moving toward extremely low speeds (i.e., 5 mph), and predicted decreases are fairly certain for all pollutants when moving from extremely low speeds.

5. Increasing average vehicle speeds from low [0 to 30 mph (0 to 48 km/hr)] to moderate [30 to 45 mph (48 to 72 km/hr)] should provide carbon monoxide emission benefits for older vehicles and hydrocarbon emission benefits for all vehicles. However, the carbon monoxide benefits for modern fuel-injected vehicles associated with these speed changes are highly uncertain.

6. Increasing average vehicle speeds from very low [below 15 mph (24 km/hr)] to low to moderate [perhaps between 15 and 40 mph (24 and 64 km/hr)] should provide an emission benefit for oxides of nitrogen.

7. Model-predicted emission changes for carbon monoxide and hydrocarbons are extremely variable for increases from moderate to very high average travel speeds. The confidence bands are wide and encompass both positive and negative predictions. However, on the basis of the presumed cause-effect relationship between engine load and vehicle enrichment, moving toward very high free-flow travel speeds from moderate speeds is likely to significantly increase emission rates and prove detrimental to air quality. It is probably reasonable to expect increases in both hydrocarbon and carbon monoxide emission rates at high speeds even though the confidence bands are wide.

8. Changes in carbon monoxide and hydrocarbon emission rates associated with small relative average speed changes at high speeds (e.g., increasing average speed from 50 to 55 mph) are too uncertain to assess accurately. Given the highly variable response of vehicles to the changes in average test cycle speed, the limited number of vehicles tested, and the nature of the high speed cycles themselves (high initial acceleration rates), the high degree of uncertainty is to be expected for carbon monoxide and hydrocarbon emissions (Guensler et al. 1993).

9. Decreasing average vehicle speeds from above 60 to below 55 mph [but remaining above 35 mph (56 km/hr)] is likely to provide large emission benefits for oxides of nitrogen and moderate emission benefits for hydrocarbons, and may also provide carbon monoxide benefits (as indicated by the bootstrap analysis).

10. The average speed modeling regime for oxides of nitrogen is probably not unreasonable. The range of confidence for changes in oxides of nitrogen emissions is narrow even for high-speed operations, indicating that the oxides of nitrogen increases are likely to be significant and fairly

certain at high speeds. Because emissions of oxides of nitrogen are more important in ozone formation than was previously realized by air quality management planning agencies (NRC 1991), evaluation of oxides of nitrogen emissions changes is paramount in congestion pricing impact assessments for many areas.

EFFECTS OF MODAL ACTIVITY

Average speed does not cause emissions. Two trips with the same average speed can be made by a vehicle, but the emissions from each trip may differ significantly because emissions are a function of combustion parameters and emission control systems. The modal characteristics of the trip (acceleration, deceleration, and cruise and idle patterns) appear to be much more likely to cause changes in combustion parameters and control system efficiency than does the average speed.

Second-by-second laboratory tests indicate that changes in operating mode (acceleration and deceleration) are capable of producing significant emissions but are not currently modeled (Darlington et al. 1992; CARB 1991; Benson 1989; Calspan 1973a, 1973b; Kunselman et al. 1974; P. J. Groblicki, presentation at CARB meeting, Nov. 5, 1990). Recent laboratory testing indicates that high acceleration rates are significant contributors to instantaneous emission rates and that one sharp acceleration may cause as much carbon monoxide pollution as the entire remaining trip (CARB 1991; Carlock 1992). Pollutant "emission puffs" occur, typically when the vehicle goes into enrichment and not enough air is available to facilitate complete combustion, and these events may be associated with high rates of acceleration or deceleration. Surprisingly, even vehicle operations at a relatively stable high-speed flow appear to show some variability in emission rates that may be associated with accelerations and decelerations, even though the rates of acceleration and deceleration at these speeds are low (Guensler 1993a). Modal effects are not directly addressed in "average speed" emissions analysis.

Congestion pricing is likely to smooth vehicle flows and reduce the number of significant acceleration and deceleration events that cause elevated emission rates. But the impact of flow smoothing is not well represented in an average speed modeling regime that is based on a limited number and variety of test cycles used in developing the relationships (Guensler 1993b). Better tools are needed to assess both the actual changes

in modal operations and the changes in emission rates associated with the changes in modal operations.

It can be postulated, however, that when congestion pricing smooths vehicle flows on freeways, emission reductions will result—the change in emission rate should be toward the optimistic end of the confidence interval. Similarly, if congestion pricing causes increased congestion on arterials, emission increases will result—the change in emission rate should be toward the pessimistic end of the confidence interval.

CONCLUSIONS

The emissions impacts of congestion pricing on trip making and VMT are relatively straightforward if the operating environment of the vehicle remains unchanged. A percentage reduction in trip ends (starts and engine shutdowns) can be translated into percentage changes in trip-end emissions. Similarly, reductions in VMT can be translated into reductions in running emissions. However, recent research (Cameron 1991; accompanying paper by Harvey) indicates that pricing-induced changes in trip making and VMT are expected to be small (less than 5 percent). Rather, analysts have been advocating congestion pricing primarily for the benefits in reducing traffic congestion, expecting that the changes in the vehicle operating environment (i.e., average speed) will produce significant emission reductions.

The analyses described here indicate, however, that changes in average vehicle operating speed yield highly uncertain emission impact estimates. Even so, a number of conclusions can be drawn from the analyses. If congestion pricing policies are implemented, it is fairly certain that they should be designed to (*a*) increase average vehicle speeds from below 15 to above 15 mph (but below 40 mph) for emission benefits in all pollutants, (*b*) increase average vehicle speeds from below 30 to above 30 mph (but below 40 mph) in areas where reductions in carbon monoxide and hydrocarbon emissions are desired, (*c*) avoid allowing previously congested routes to exceed 40 mph average speed as a result of the pricing policy, and (*d*) avoid creating congestion on arterial unpriced routes. Thus, from an air quality perspective, congestion pricing is recommended only in areas where average speeds are currently below 35 mph (demand exceeds capacity). Market-clearing prices should be set so that average speeds do not increase beyond 40 mph. Pricing strategies should also ensure that significant reductions in average vehicle speeds do not result on arterials.

Because the travel demand and emission rate models do not well represent the actual cause-effect relationships at work (especially for modal activities), it is impossible to determine the overall emission impacts of congestion pricing policies. However, many of the changes noted in vehicle activity and the factors that affect emission rates are positive from the perspective of cleaning the air. The likely impacts of congestion pricing on vehicle activity and the variables that affect vehicle emission rates are summarized in Table 5.

Because changes in average vehicle speed yield significantly different percentage changes in emission rates for older carbureted vehicles and newer fuel-injected vehicles (as well as relative certainty associated with these percentage changes), the fleet composition under congestion pricing scenarios is important. If the bottom two income quintiles own a greater percentage of carbureted vehicles and are also affected more by congestion pricing (i.e., trips and VMT are reduced to a greater extent) than those in the upper-income quintiles, fewer of the older vehicles will be present in the postpricing fleet. Thus, the composition of the vehicle fleet resulting from congestion pricing (i.e., the vehicle and fuel parameters affecting fleet emission rates) may play a significant role in net emissions estimates and should be examined in detail. This factor will probably create equity considerations that will need to be addressed.

Congestion reductions (or increases on arterials) that arise from congestion pricing will yield changes in vehicles' modal operating environment. When average speed increases and flows are smoothed, the change in emission rate should be toward the optimistic end of confidence intervals. When average speeds decrease and flows become less smooth, projected emission rate changes should be toward the pessimistic end of the confidence intervals.

FURTHER STUDIES

Over the short term, EPA is evaluating the FTP and will likely make changes to the test method (Guensler 1993a). However, because the FTP improvement effort only directly addresses adequacy of baseline exhaust emission rate estimates, it is unlikely that estimation of the emission inventory and analysis of scenarios such as congestion pricing will be significantly improved. Further research into modal modeling being undertaken by the Georgia Institute of Technology, the University of California at Los Angeles, and the University of California at Davis should

TABLE 5 Potential Impacts of Congestion Pricing on Emission-Producing Vehicle Activities and on Variables Expected To Affect Vehicle Emission Rates

	Impact
Emission-producing activities	
Vehicle miles traveled	↓
Engine starts and hot soaks	↓
Diurnal evaporation	NC
Vehicle refueling[a]	↓
Modal behavior (and idling)[b]	↓ ↑
Vehicle and fuel parameters	
Vehicle age[c]	↓
Accrued vehicle mileage	↓
Tampering and inspection and maintenance[c]	↓
Vehicle operating conditions	
Average vehicle speed[d]	↓ ↑
Vehicle load	↓

NOTE: NC = not likely to significantly change activity or emission rates. ↓ = likely to decrease activity or emission rates. ↑ ↓ = likely to partially increase and partially decrease activity or emission rates.

[a] Changes in emissions associated with vehicle refueling will also be a function of changes in trip making as well as changes in fuel efficiency associated with retained trips (DeLuchi et al. 1992).

[b] Pricing will reduce congestion and pollutant emission rates from modal activities on routes where flows are smoothed. However, reductions cannot be reliably quantified at this time. Not also that emissions may increase along those routes that become more congested as a result of traffic diversion.

[c] Congestion pricing may result in a change in vehicle fleet composition. The demand elasticity for operators of older vehicles will likely yield a smaller percentage of older vehicles in the peak-period fleet. In general, older vehicles have higher emission rates and are more likely to be tampered with (although this assertion is currently being debated). Because the emissions behavior of older and newer vehicles is significantly different, the potential emissions impact of fleet composition is important. Note that potential impact on fleet composition may also have serious equity implications.

[d] The emission rate decreases are for CO and HC, and increases will result for NO_x. Note also that emission rates for all pollutants may be substantially increased if high-speed operations result.

help shed light on the significance of the modal emissions component in the evaluation of congestion pricing scenarios. Disaggregate data are now becoming available for instrumented vehicles, and modeling work in this area continues. But the development of significantly improved emission inventory modeling methodologies will require the collection and analysis of huge amounts of new data on new testing cycles and new testing equipment, probably with second-by-second emission resolution (Guensler 1993a).

It took more than 1 year to assess the uncertainty associated with the use of speed correction algorithms in the models, so modelers are a long way from deriving uncertainty estimates for other modeling components. Nevertheless, the reanalysis of SCFs demonstrates how other modeling components could be examined if sufficient resources were allocated and how uncertainty analysis for each modeling component could be incorporated into the analytical framework. In addition, this paper did not include sensitivity analysis of the models, that is, how sensitive the models are to errors in estimation of the independent variable, average speed (Bruckman and Dickson 1992).

This paper only examined estimates of uncertainty in percentage change in emission rates, and a detailed empirical study of net emissions change should follow. The new analysis should use predicted changes in number of trips, predicted changes in VMT along each route, predicted changes in average speeds along each route, and SCF uncertainty estimates (Guensler 1993b) to predict the total emission impacts of the proposed congestion pricing policies and the confidence intervals around the predictions.

Decisions in the air quality and transportation arenas are made in the face of tremendous uncertainty. Most decisions, unfortunately, are made by policy makers who do not know the magnitude of uncertainties involved. This problem arises partly because not enough research on emission rate and activity uncertainty has been conducted and partly because institutional policy-oriented learning is a slow process hindered by the structure and nature of the policy arena. It is hoped that this paper will help apprise policy makers of the uncertainty involved in assessing the emissions impacts of policies designed to change average vehicle speeds and will communicate the need to gather, disseminate, and analyze new and better emissions data.

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ABBREVIATIONS

CARB	California Air Resources Board
Caltrans	California Department of Transportation
EEA	Energy and Environmental Analysis

EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GAO	General Accounting Office
NRC	National Research Council
SAI	Systems Applications International
TRB	Transportation Research Board

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Private Toll Roads
Acceptability of Congestion Pricing in Southern California

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Private toll roads in Southern California demonstrate attempts to price highways realistically and to use high-occupancy-vehicle (HOV) lanes efficiently. Such routes are located in areas in which population and employment grew impressively during the 1970s and 1980s, peak-hour congestion is severe, air pollution exceeds health standards for ozone 180 days per year, and earlier attempts at congestion relief have had limited success. The objective in describing one of these toll roads is to suggest how obstacles to congestion pricing might be overcome by combining congestion pricing with expansion of HOV lanes and successful ride-sharing programs. The heavy hand of politics rests on all congestion pricing projects, and this case study is no different. It does illustrate, however, that congestion pricing can be made politically acceptable. If the private toll lanes are successful, a new opportunity for congestion relief will be available using regional HOV facilities.

INCREASING CONGESTION

Traffic congestion in Southern California is bad and becoming worse. Hanks and Lomax (1990) constructed an index of congestion by comparing daily vehicle miles traveled per lane-mile with optimal capacity in 39 metropolitan areas (Figure 1). By their index, the Los Angeles Urbanized Area, which includes Orange County, is the most congested metropolitan area in the nation, and the adjoining San Bernardino-Riverside Urbanized

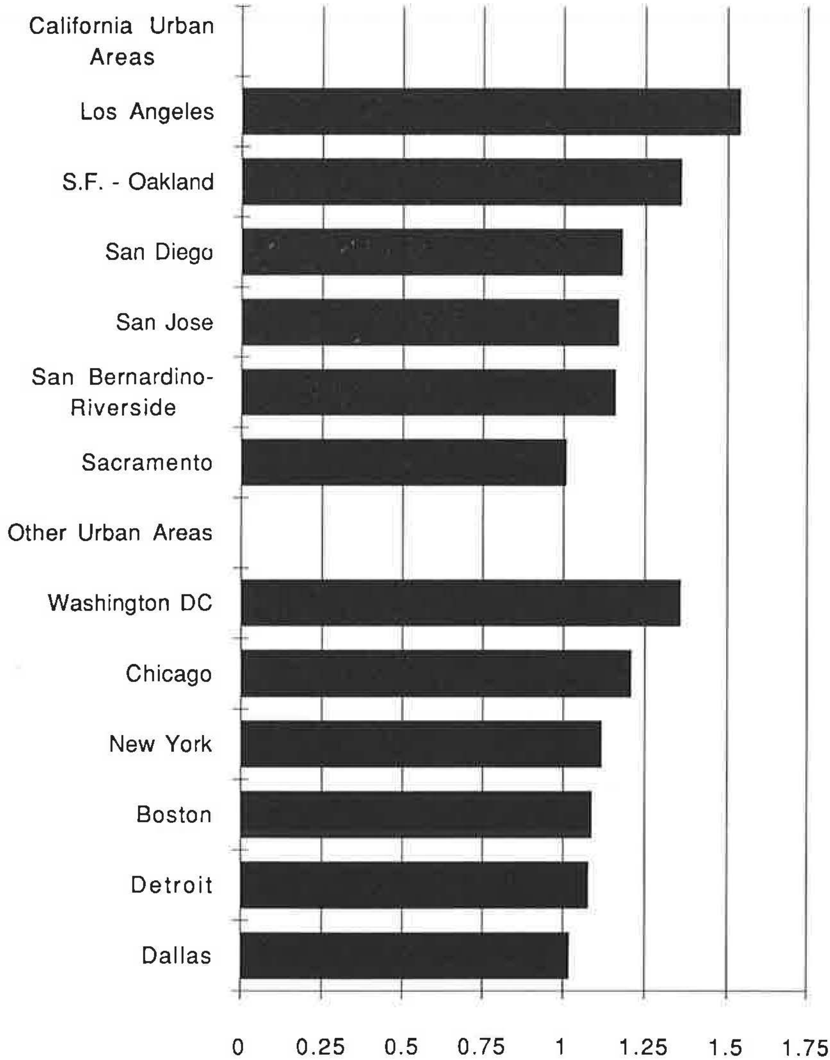


FIGURE 1 Roadway congestion index on freeways and principal arterial streets, 1989 (Hanks and Lomax 1990, Table 9).

Area is almost as congested as Chicago. A superb highway network has been constructed, but it is fouled by heavy travel demand (Figure 2). Hanks and Lomax estimated that travel delays cost residents and business in Los Angeles and Orange counties $6.8 billion in 1988. The loss to individuals is annoying, but the loss to business relying on truck freight is more serious because it impairs productivity growth.

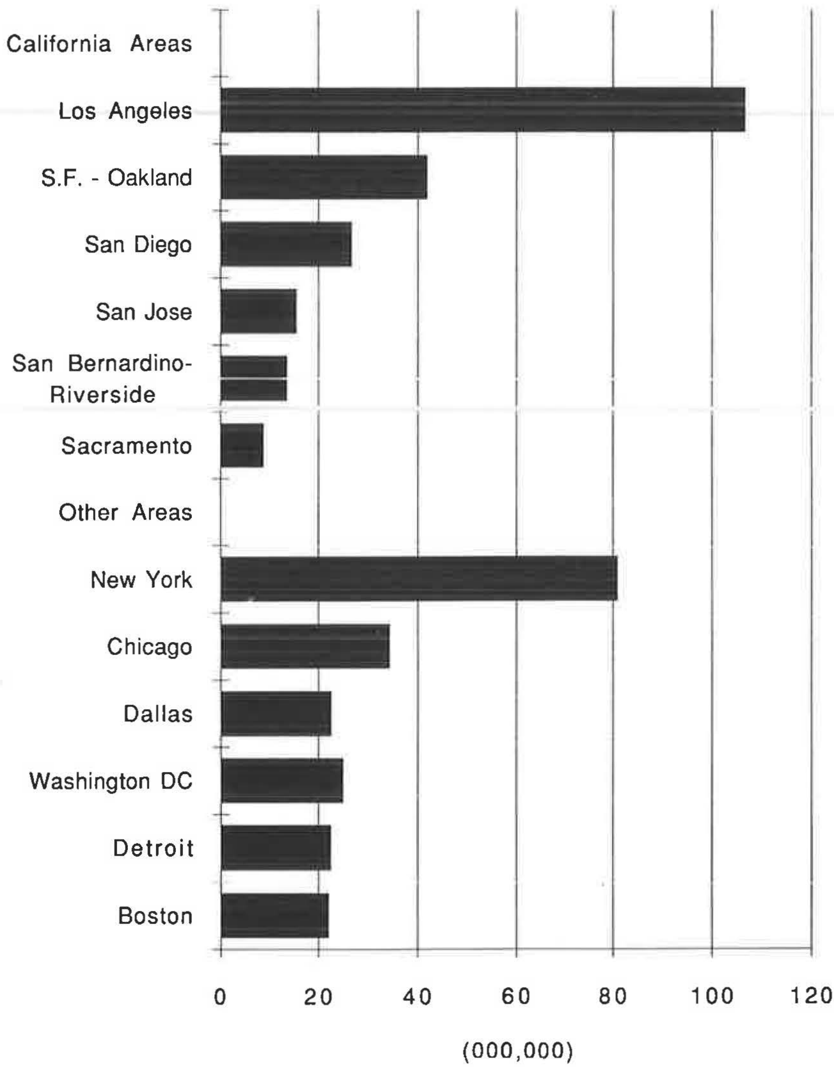
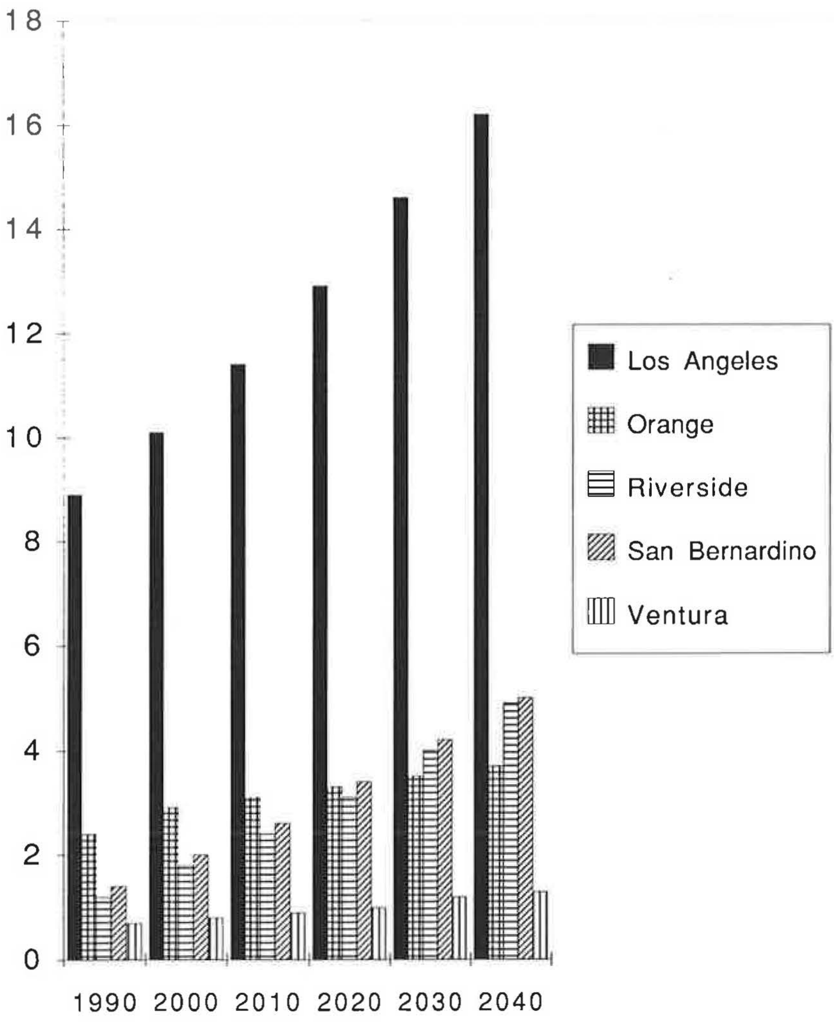


FIGURE 2 Daily vehicle miles of freeway travel by urbanized area, 1989 (Hanks and Lomax 1990, Table 2). (1 mi = 1.6 km.)

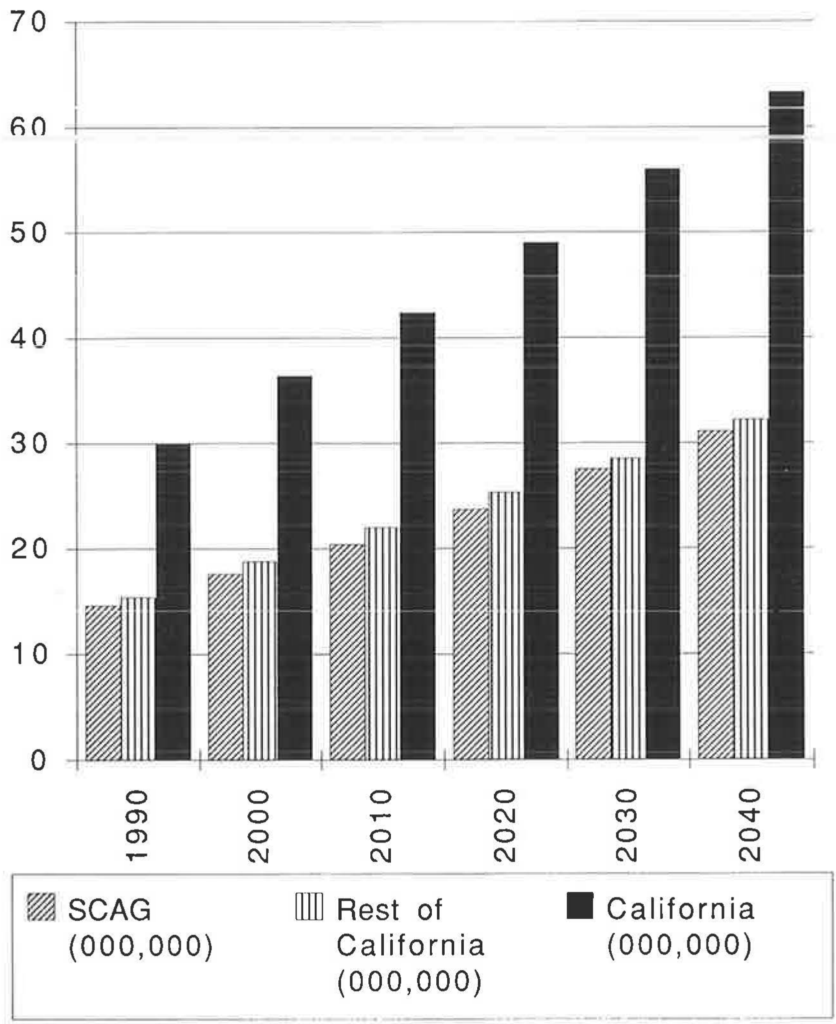
High rates of population and household income growth together with the unwillingness of elected officials to increase taxes and the opposition to new urban highways have exacerbated congestion. The population increase in California has continued to exceed the national average and, despite the current downturn in the economy, is likely to continue (Figure 3). Within the counties that compose the Southern California Association



SOURCE: California State Department of Finance 1993

FIGURE 3 Future population growth by county in Southern California.

of Governments (SCAG), population is projected to increase from 14.6 million in 1990 to 20.4 million by 2010 (Figure 4). Meanwhile, increasing household incomes, primarily achieved through growth of multiple-income households, have enabled Southern Californians to increase vehicle ownership at a rate slightly faster than population growth. By 1990 there were almost 10 million drivers, driving more frequently and further,



SOURCE: California State Department of Finance 1993

FIGURE 4 Future population growth in Southern California.

and although the ratio of automobiles to licensed drivers is approaching saturation, projected population increases through natural growth will add a new cohort of eligible drivers each year.

Nevertheless, road capacity has not increased with demand (Figure 5). Congestion has resulted because elected officials have been unwilling to increase fuel taxes and urban residents have opposed having more highways built near them. Vehicle miles of travel (VMT) doubled in California between 1973 and 1990, whereas lane-miles of state highway increased from 45,600 to only 48,700 (73,430 to 78,422 lane-km)—a mere 6.8 percent increase.

Increased travel and congestion have had many undesirable consequences. Although hydrocarbon and particulate emissions have been reduced, the increased number of vehicles continues to degrade air quality.

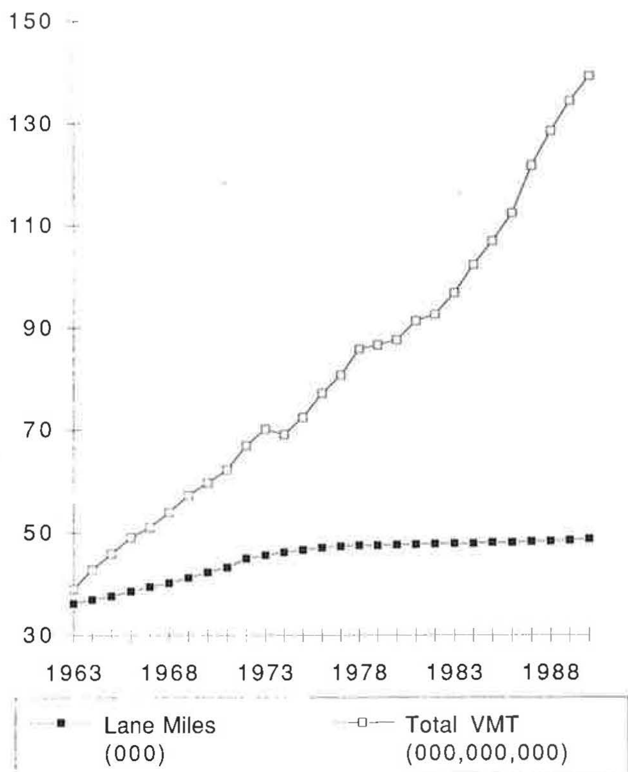


FIGURE 5 Increasing highway congestion in California, 1963–1990 (California Department of Transportation 1992, Table 3–1-2).

Ozone is the most hazardous pollutant, and the concentrations at monitoring stations in Los Angeles and Orange counties continue to exceed the state's maximum 1-hr standard of 9 parts per million on half of the days each year (Figure 6).

An even more damaging effect of traffic congestion is its influence on business decisions. Uncertainty over delivery time compels manufacturing and commerce to hold larger inventories and pay higher transshipment costs. It also discourages agglomeration of warehouse and distribution facilities into larger and potentially more efficient centers. The Southern California economy developed in association with the superb highway system built during the 1950s and 1960s. Subregional specialization occurred in aerospace, entertainment, and manufacturing (Scott 1988). As

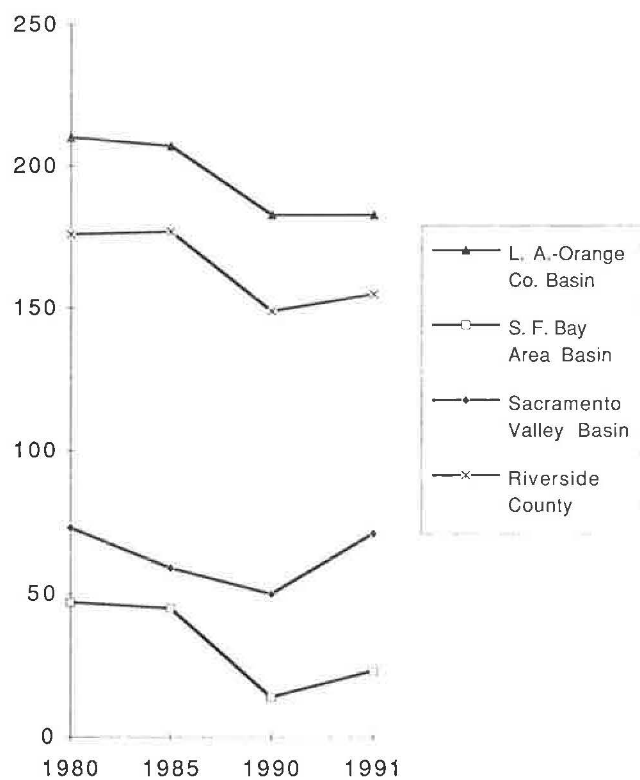


FIGURE 6 Air pollution: days with ozone concentrations exceeding the California standard, 1980–1991 (California Air Resources Board 1992, Table D).

congestion increased, firms sought to relocate, and those who were not tied to the local market have expanded in less-congested metropolitan areas.

Although there have been several attempts to plan for increasing travel demand, there have been few successes. Most of the effort has been devoted to managing traffic without expanding road capacity. Increasing taxes to pay for additional roads has been unpopular; from 1967 to 1982 there was no increase in the fuel tax although VMT increased from 51 million to 93 million (82 million to 150 million VKT). Recent increases in fuel and sales taxes have financed reconstruction and expansion of existing facilities but have been insufficient to accommodate demand.

MANAGEMENT SOLUTIONS

The Transportation Development Act (TDA) of 1971 was intended to expand transit service in major metropolitan areas as a substitute for home-to-work travel by automobile (Lamare 1981). The state sales tax was increased and one-fourth of the 1-cent tax increase was allocated exclusively for transit in metropolitan counties. Transit was struggling to survive in California cities before the TDA. Only three Bay Area counties had a guaranteed source of funding and this was dedicated to the Bay Area Rapid Transit (BART). Southern California Rapid Transit District (SCRTD), the regional bus system in Southern California, had not purchased a new bus since 1960. TDA changed this: new buses and maintenance facilities now prevail even in rural counties. Local sales taxes have augmented state funding and enabled development of new rail systems in five metropolitan areas and a 114-mi (184-km) commuter rail system in Southern California.

Transit ridership has increased, but despite generous state and federal assistance, only 5 percent of commuters in Southern California used public transit in 1992 as the primary mode of travel. Commuting by rail and bus is important in central cities and along high-density corridors, but it remains a minor contributor to regional solutions.

Innovations in state planning were proposed by the State Transportation Board in 1978 (Elliot 1986). Eight principles for transportation planning were outlined, but one suggesting that "users should be required to pay a fair share of the costs that occur from their use [of transportation facilities]" created such an outcry from interest groups that the entire plan

was rejected by the governor. The intention was to introduce congestion pricing, but the board failed to develop a constituency of support for their imaginative plan and it collapsed like the Hindenburg.

In their attempt to reduce travel, the South Coast Air Quality Management District (SCAQMD) adopted Regulation XV in 1988 requiring employers with more than 100 employees to take responsibility for changing their employees' commuting patterns. Initial results are promising; single-occupant vehicle (SOV) commuters decreased by 5.8 percent in the first year for covered firms, and carpooling increased (Giuliano et al. 1993). Because carpooling and vanpooling account for 15 percent of commuter trips in Southern California, Regulation XV has created optimism. To increase ridesharing, however, will require real incentives involving time savings rather than plans; 77 percent of commute trips are still made in SOVs.

Expanding HOV facilities provides an incentive for ridesharing because it allows long-distance freeway commuters to save time when passing through congested bottlenecks. Since they have recovered from the disastrous experience on the Santa Monica Freeway (Billheimer 1978), the California Department of Transportation (Caltrans) has aggressively expanded HOV facilities throughout California whenever they have added lanes (Figure 7). With 173 lane-mi (279 lane-km) of HOV available and another 392 lane-mi (631 lane-km) committed, Los Angeles and Orange counties have the largest HOV system in the United States. In 1992, 12.7 percent of the freeway miles in Los Angeles and Orange counties provided HOV lanes, and proposed projects will increase availability to 28.7 percent (Turnbull 1992).

Impressive additions are under construction. The Century Freeway (Route 105) was completed in 1993 with space for HOV lanes as well as transit. HOV lanes are being added to the San Diego Freeway (I-405) from Century Boulevard (adjacent to the Los Angeles airport) to Carson, and these will eventually connect to the existing lanes through Orange County; a 10-mi (16-km) transitway is under construction on the Harbor Freeway from the Route 91 freeway to downtown Los Angeles. These lanes will be reserved for carpools and buses, thereby linking the Harbor transitway with Route 91 HOV lanes to provide access between the "job belt" of central Los Angeles and the residential areas of Riverside and San Bernardino counties.

Despite their proximity to major traffic generators, the potential travel advantage of the HOV lanes has not been realized. Of the respondents to

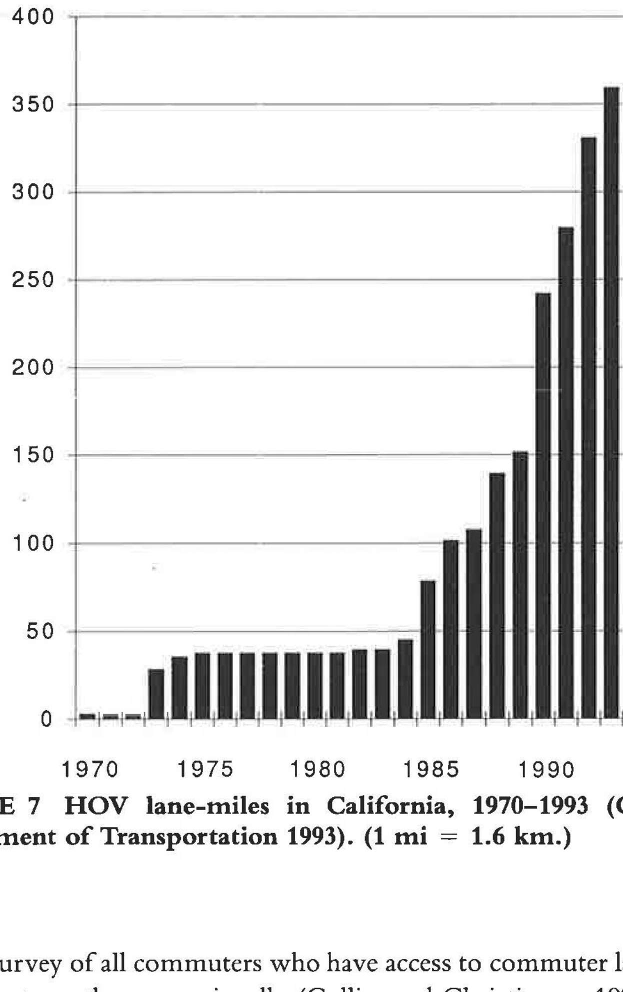


FIGURE 7 HOV lane-miles in California, 1970–1993 (California Department of Transportation 1993). (1 mi = 1.6 km.)

a 1992 survey of all commuters who have access to commuter lanes, only 28 percent use them occasionally (Collier and Christiansen 1993). Ridesharing has increased slightly, but not nearly to the extent anticipated. The mean travel time savings of 14 min one way has not been sufficient to persuade a higher proportion of drivers of SOVs to forgo the convenience, flexibility, and comfort of driving alone.

During the peak-of-the-peak travel period, HOV lanes are fully utilized. But in the shoulders of the peak when other lanes are congested, many HOV facilities are underutilized. This encourages illegal use by SOVs, criticism of HOV facilities, and the lowering of eligibility from vehicles with three occupants to those with two (HOV3 to HOV2). Because 43 percent of HOV2 users are family members commuting to

work, school, or daycare facilities, effectiveness in trip reduction tends to be exaggerated.

Nevertheless, the combination of increasing ridesharing and the availability of HOV facilities offers a marvelous regional opportunity to minimize congestion. As HOV2 vehicles begin to crowd out higher-occupancy vehicles from commuter lanes, access will need to be restricted to HOV3 vehicles. This is already the practice in Northern California and on the San Bernardino Busway. And if introduced gradually with sufficient time given to build a constituency for the change, the HOV3 restriction combined with an opportunity for SOV and HOV2 to purchase access to the lane could increase efficiency and expand congestion pricing.

Paying for access together with free access for HOV3 would be a win-win solution because it would make most people better off:

- HOV3 and buses would encounter less congestion and attract more riders;
- HOV2 users could share the cost between them;
- SOV users who value time savings more than the toll would be better off;
- Regular lanes would operate more effectively, at least for a short time, because more space would be available;
- Air pollution and congestion would be reduced because there would be an incentive for HOV3;
- Users would be paying for the additional capacity; and
- Libertarians would cheer because travelers would have a choice: when they need to save time, they could use the toll lanes; when arrival time is not critical, they could save money by using the uncontrolled lanes.

The losers would be the HOV2s who travel with family members or those who are unwilling to share the toll. Opposition should be expected from other highway interests such as trucking associations, automobile clubs, and local agencies whose residents may be adversely affected. However, the opposition might be persuaded if the policy were introduced gradually as a carefully designed regional policy to improve mobility and reduce air pollution as well as to fund additional facilities.

Congestion pricing is essential; only by controlling access through charging tolls can the commuter lane operate efficiently. Prices must be varied in response to demand so as to encourage some SOV and HOV2 commuters to change their travel behavior and avoid peak-of-the-peak periods. Fortunately, the technology is now available to price facilities in

response to demand, as well as HOV facilities on which to evaluate public acceptance of congestion pricing.

CONGESTION PRICING IN CALIFORNIA

Private firms have proposed two toll roads using public rights-of-way to expand state highways: Route 57, an 11-mi (18-km) extension of an existing freeway that will be constructed as an elevated highway (on a viaduct) down the middle of the seasonal Santa Ana River at an estimated cost of $625 million, and Route 91 [10-mi (16-km)] utilizing the median of the existing Riverside Freeway along the congested Santa Ana Canyon at an estimated cost of $110 million, the initial segment of which is shown as a solid line in Figure 8. An option to expand the project on Route 91 in the future is shown by the hatched line in Figure 8.

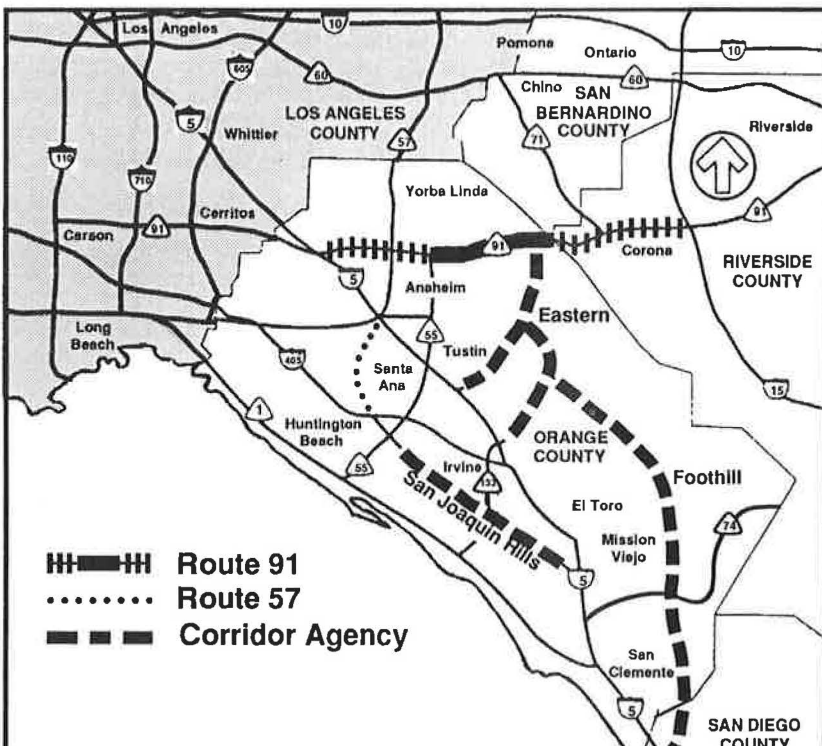


FIGURE 8 Orange County toll roads.

Both toll roads will use automatic vehicle identification (AVI) technology, automatic toll collection (ATC), and changeable message signs to guide traffic. These toll roads offer students of transportation an unparalleled opportunity to investigate how travelers respond to congestion pricing because both roads will be built as HOV lanes and use congestion pricing to allow access for SOVs and HOV2s. Tolls will be varied to reduce peak-period demand, to increase revenue, and to provide a competitive return on investment for private firms.

Because the Route 91 toll lanes have received all environmental clearances and are scheduled to open in 1996, more information is available on their operation and expected use. Less information is available on the Route 57 toll road. The franchise is owned by the Perot Group, and they have vexing environmental and community issues to mitigate before they can obtain environmental clearance. The viaduct is proposed as a four-lane HOV facility that will link with HOV facilities to the north and south, but operating and travel forecasts are not in the public record. For this reason, operating features of Route 91 only will be detailed.

In the median of Route 91, the primary link between Orange and Riverside counties, the California Private Transportation Corporation (CPTC) has been granted the right to plan, construct, and operate four tolled lanes for 35 years. These lanes will operate like an HOV facility, but unlike the usual HOV facility, vehicles with one or two occupants will be permitted to enter only by paying a toll. Vehicles with three or more occupants (HOV3) will travel free at first, and at a discount later should the use of free travel jeopardize the economic viability of the project.

Congestion on Route 91 is already severe for 5 hr each day and this period is expanding as travelers shift to the shoulder of the peak to avoid congestion. Caltrans had planned HOV lanes for the median. They had cleared the project environmentally but had insufficient money for construction. By using private funds, lanes can be constructed sooner and state funds can be shifted to higher-priority construction along the I-5 corridor.

By making excess HOV lane capacity available to toll-paying vehicles, CPTC estimates that they will receive sufficient tolls to cover operating and maintenance cost as well as to provide a 17 percent rate of return on investment (which is capped under the franchise agreement). An additional 6 percent can be earned by increasing vehicle occupancy through promotion of ridesharing and transit. Excess income will be shared with the state.

Preliminary estimates indicate that travelers would be willing to pay a toll of $2.50 per trip during peak hours for the time saved to travel 10 mi. Trips on the facility when the highway is uncongested will be discounted.

Tolls will vary in response to demand; prices will be increased during peak periods to avoid congestion in the restricted lanes, with roadway signs designed to flash numbers as high as $9.99. The aim is to maintain speed on the restricted lanes so that patrons save time compared with users of the unrestricted lanes. Toll charges are based on a value of time saved, estimated at $0.22/min, for peak-period commuters in SOVs. During the shoulder of the peak and the off-peak periods, tolls will be lowered automatically to encourage use of the tolled lanes.

Fortune Magazine summarized operations as follows:

> The new road's most appealing feature is its ability to operate without toll plazas, which often cause backups. To enter the fast lane, a car must have an automatic vehicle identification (AVI) tag clipped to its rearview mirror. The tag, which is being developed by MFS (Omaha, Nebraska) and Texas Instruments, could cost drivers around $30. About the size of a credit card but twice as thick, it incorporates a microchip, an antenna, and a lithium battery. As a car approaches the toll road, the card exchanges radio signals with the highway's computers, which charge the toll against the driver's prepaid account, typically $80 a month. If a car has no AVI tag, the system will alert a waiting highway patrolman to nab the interloper or will videotape the car's license place for ticketing by mail. (Ratan 1993)

Routes 91 and 57 were chosen as privately funded toll roads in response to California legislation (AB 680), enacted in 1989 (Gomez-Ibanez and Meyer 1991; Poole 1992). A competition in 1990 produced eight proposals. Four were selected and franchise agreements signed in 1991. Two proposals were for Orange County, a third for San Diego, and a fourth for rural Northern California between San Jose and Sacramento (Fielding and Klein 1993). All three of the Southern California proposals will use congestion pricing because it is the only way by which private firms can recover their investment. Varying tolls by time of day increases revenue and enables peak capacity to be accommodated by a smaller facility.

A unique coalition of interests enabled passage of AB 680. Its author was Assemblyman Baker, but the push needed for passage came from the Office of Privatization within Caltrans, from the private engineering and construction firms who desired a larger share of the state's business, and from a conservative governor who sought to expand highways without increasing taxes. A highway bond issue had been defeated in June 1988. This led to a reconsideration of ways to finance highways, and private tollways were proposed (R. W. Poole, Jr., personal correspondence).

However, a majority of legislators as well as state employees were opposed to tollways. A compromise was reached in 1989 when the legislature desired the governor's support to place transportation bond issues on the ballot (to be paid for by an increase in fuel taxes). Governor Deukmejian agreed to let the electorate decide on the tax increase, but only if the legislature agreed to pass AB 680.

As Carl Williams, Assistant Director of Caltrans, remarked about the origins of AB 680: "Sometimes when you are moving around, trying different things, you get lucky. And this was pure luck" (Gomez-Ibañez and Meyer 1991, 67). Attempts to introduce road pricing in 1978 had been unsuccessful; in 1989 politics and substance coalesced.

Representatives for the professional engineers in California government have continued their opposition, but their appeal to the State Supreme Court over the legality of the process was rejected in 1993. Opposition continues to be expressed by members of the legislature: a constitutional amendment to limit the duration of private contracts was placed before the electorate but defeated in 1992, and legislation has been introduced to prevent local governments from assisting private toll road enterprises. It is unlikely that there will be additional private toll roads unless one of the current projects demonstrates financial success, which is why the Route 91 toll lanes in Orange County are critically important for the future of congestion pricing.

Insufficient highway capacity and favorable attitudes to privatization contributed to the acceptance of private financing and toll roads in Orange County, where increasing jobs and travel had created severe peak-hour congestion. Although population had increased by 25 percent to 2.2 million between 1975 and 1985 and VMT by 50 percent, only 4 mi (6 km) of additional state highway had been constructed. Routes had been designated, but there was insufficient state or local money for construction. All this created a perceived need for additional roads as well as the availability of expansion opportunities like completing Route 57 and constructing the planned but unfunded HOV lanes on Route 91.

Orange County Transportation Authority (OCTA) has been an innovator in privatization. In the 1970s, an extensive system of dial-a-ride modules was established using private contractors. In 1992, 125 small buses were operated by private companies with coordination provided by OCTA. Staff experience in contracting out for service has encouraged the authority to expand opportunities for private firms in commuter rail and highway services.

Research from the University of California at Irvine has popularized privatization. From the early work on taxis and privatization of transit to

articles and national conferences on HOV lanes, ridesharing, and road pricing, the university has diffused information that has influenced decision makers. University extension activities gave credibility to toll roads as a way to expand highway capacity (Austin et al. 1986). Orange County was designated for a federal pilot project in 1987 and this led to the creation of the Transportation Corridor Agency (TCA) to be responsible for planning and constructing three public toll roads.

The TCA legislation allowed local governments to form joint-powers agencies for the purpose of planning and constructing toll roads. Orange County and 20 cities have created three agencies administered as one unit. These public agencies control development of three toll roads: San Joaquin Hills Corridor, a 17.5-mi (28.2-km) road slicing through rugged hills from Route 73 in Irvine to I-5 in San Juan Capistrano and estimated to cost $1 billion; Foothill Corridor, a 30-mi (48-km) freeway running from I-5 in San Clemente to Tustin and estimated to cost $746 million; and Eastern Corridor, a 23-mi (37-km) road linking Route 133 with Route 91 in the Santa Ana Canyon and estimated to cost $630 million (Figure 8). TCA plans to charge uniform, distance-based tolls and not vary charges according to congestion.

Although TCA has rejected congestion pricing, the agencies have popularized toll roads with elected officials. Without this initial understanding, congestion pricing may not have been acceptable. As public agencies, TCAs can fall back on federal and state assistance if tolls are insufficient to service their debt; they are designing their toll roads as very expensive, general purpose freeways. The private toll road companies cannot do this; they will lose their investment if the roads revert to the state. Therefore, they seek to limit their investment and maximize revenue.

The TCA toll roads could be built as smaller expressways rather than as eight-lane freeways if congestion pricing were used (Austin et al. 1986). However, their purpose is to open up areas for urban development rather than to operate as cost-effective roadways. Route 91, by comparison, is in a heavily congested corridor. The HOV lanes cannot operate effectively as a toll road unless prices are varied to provide travelers with a financial incentive to move their travel times to the shoulder of the peak.

OPPOSITION TO CONGESTION PRICING

Primary opposition to congestion pricing has come from the Riverside County Transportation Commission (RCTC). Route 91 is the major link between the dormitory suburbs in Riverside County and the employment

centers in Orange and Los Angeles counties. Commuters using the eight-lane freeway already battle severe congestion, and the peak hour is expanding as travelers shift to both sides of the peak to avoid congestion (Figure 9).

Using local funds, RCTC assisted Caltrans in constructing two HOV lanes up to the county line and expected Orange County to continue the project. OCTA gave priority to the I-5 corridor and welcomed the private toll lanes. Riverside County officials believe that they were misled; they used local sales tax revenue for their section of Route 91, yet their residents will be expected to pay tolls to use the segment through Orange County.

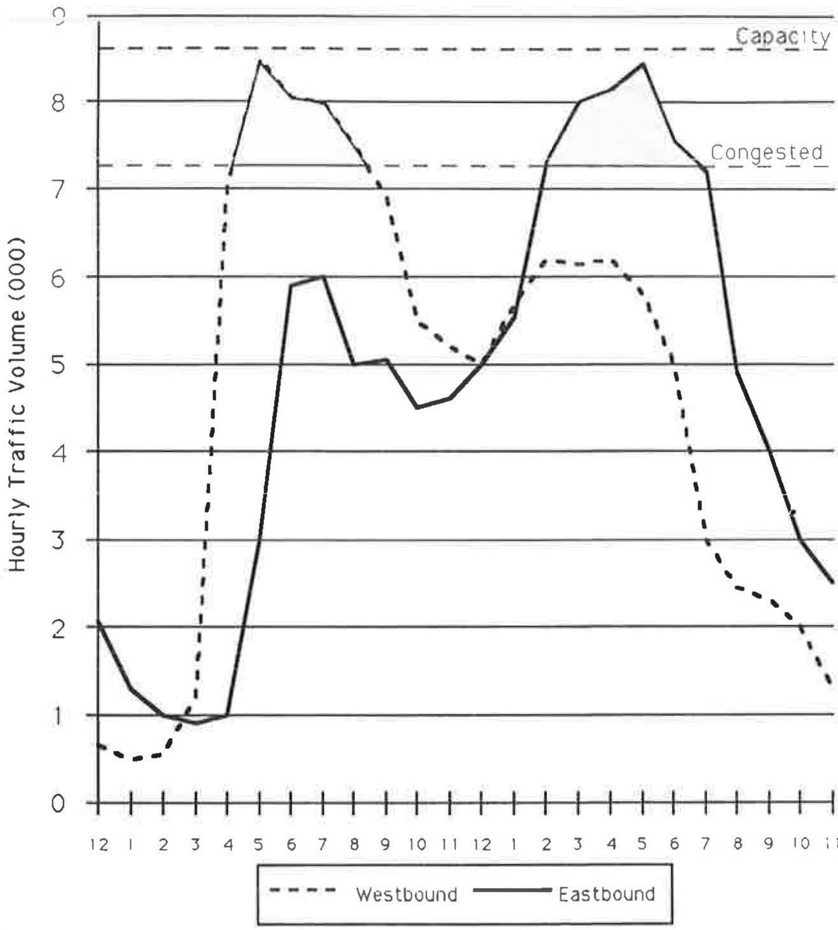


FIGURE 9 Hourly traffic variation on Route 91 at the Orange-Riverside County boundary (Wilbur Smith Associates 1992, Table 3).

Riverside claims that this action violates regional transportation policies. OCTA and the toll road company, CPTC, have attempted to accommodate Riverside by proposing free access for HOV3 vehicles with the provision that HOV3s will be charged discounted tolls should HOV3 demand jeopardize the financial viability of CPTC's investment.

Although they have accepted the compromise, RCTC representatives continue to criticize the tollway. Among issues mentioned are safety, because vehicles with two persons weave out of the Riverside HOV lanes to avoid the toll lanes in Orange County, and the deterrence of ridesharing. Objectors claiming that the toll lanes will discourage ridesharing are the most ominous; they cite inconsistency with regional policy adopted by SCAG and SCAQMD, and this challenges the constituency for congestion pricing. If operating and safety problems arise when the toll lanes open, Riverside commuters angered by the change probably have sufficient political power to overwhelm a divided regional constituency (Lave 1993). They could compel Caltrans to buy out the private company and allow lanes to revert to free HOV operation.

Both Caltrans and FHWA are troubled by possible adverse effects on ridesharing of having to pay for access. FWHA has announced that proposals allowing SOVs to buy into HOV lanes would be excluded from congestion pricing demonstration projects because "HOV buy-in projects would not promote the congestion relief and related air quality and energy conservation objectives of the ISTEA" (*Federal Register*, June 16, 1993).

Concerns expressed by state and federal agencies together with the objections cited by RCTC raise important questions that deserve to be answered. Although analyses of travel demand in the corridor are dated, an estimate of daily demand is possible. Using available survey data and a simple multinomial logit model, it is possible to generate a preliminary estimate of travel demand under congestion pricing by vehicle occupancy type.

Tables 1 and 2 were calculated using projected daily travel demand from the SCAG regional model modified by Wilbur Smith Associates (1992) for the Route 91 corridor. A screen line at the county boundary was chosen to best represent commuter travel. Calculations estimated by the author are based on the afternoon peak-period (2:00 to 6:00 p.m.) demand eastbound. A constant 14.5 percent of projected daily demand is allocated to the afternoon peak. Eastbound maximum travel demand occurs on Monday through Thursday in the afternoon. Potential demand is higher on Fridays when commuters are joined by recreational travelers, but Friday has been excluded from this exercise.

TABLE 1 Projected Daily Vehicle Trip Demand in Five Lanes: Four Uncontrolled and One HOV (Without Tolls) After 2000

DAILY VEHICLE TRIPS: SR-91			PEAK EASTBOUND TRIPS 2 - 6 p. m. (3)			
Year	Total (1)	p.m. Peak (2)	Total	SOV	HOV2	HOV3+
1991	222,000	56388	32190	24947.25	6148.29	1094.46
1996	262,000	66548	37990	29176.32	7446.04	1367.64
2000	290,000	73660	42050	30612.4	9713.55	1724.05
2005	337,000	85598	48865	34889.61	11825.33	2150.06
2010	370,000	93980	53650	37555.01	13573.45	2521.55

NOTE:
1. SCAG regional model adjusted for capacity constraints by WS Assoc. 1992, Fig. 13
2. Caltrans traffic counts; 25.4% daily trips 2-6 p.m.
3. Caltrans traffic counts assuming constant 14.5% of daily trips. Vehicle occupancy from Caltrans surveys Route 55 peak hours, Northbound, 1991. HOV lane not available until 2000.

Tables 1 and 2 demonstrate the potential demand by various types of passenger vehicles under different assumptions. The purpose of these simulations is to estimate the effect of the HOV buy-in plan on ride-sharing. Figures 10 and 11 show how potential demand relates to highway capacity.

Table 1 assumes that only a single uncontrolled lane will be added eastbound. Afternoon demand is allocated to vehicle type using 1991 vehicle occupancy data recorded by Caltrans for Route 55. Proportional allocation remains constant through all time periods as trips increase.

Caltrans had scheduled adding one untolled HOV lane in each direction to Route 91 by the year 2000. This would have increased eastbound afternoon capacity during the 4 hr from 32,000 to 39,000 vehicles. Projected demand by HOV2 and HOV3 vehicles is estimated to increase from 7,243 in 1991 to 16,095 in 2010. The single HOV lane would have been congested when it opened, and all eastbound lanes would have continued to operate beyond design capacity. Addition of a single HOV lane would not have promoted congestion relief for afternoon commuters.

If Caltrans had had sufficient funds to construct two HOV lanes, afternoon capacity (46,200 vehicles) would have exceeded potential demand until the year 2004. Funding was not available; this is why the private toll lanes were approved as an alternative that would provide additional capacity sooner.

A simple multinomial logit model was used to calculate the effect of two controlled (tolled) lanes on projected afternoon demand eastbound on Route 91. The results are reported in Table 2 and Figure 11. Calculation of the logit model was simplified by the following assumptions:

TABLE 2 Projected Daily Vehicle Trip Demand in Six Lanes: Four Uncontrolled and Two Controlled HOV (with Tolls) After 1996

DAILY VEHICLE TRIPS: SR 91			DAILY PEAK PERIOD VEHICLE TRIPS EASTBOUND 2 - 6 p.m. (3)						
			Total	Four Uncontrolled Lanes			Two Controlled Toll Lanes		
Year	Total (1)	p.m. Peak	2 - 6 p.m.	SOV	HOV2	HOV3+	SOV	HOV2	HOV3+
		(2)							
1991	222,000	56388	32190	24947.25	6148.29	1094.46			
1996	262,000	66548	37990	22869.98	6382.32	265.93	4368.85	1595.58	2507.34
2000	290,000	73660	42050	25314.1	7064.4	294.35	4835.75	1766.1	2775.3
2005	337,000	85598	48865	29416.73	8209.32	342.055	5619.475	2052.33	3225.09
2010	370,000	93980	53650	32297.3	9013.2	375.55	6169.75	2253.3	3540.9

NOTE:
1. SCAG regional model adjusted for capacity constraints by WS Assoc. 1992, Fig. 13
2. Caltrans traffic counts; 25.4% daily trips 2-6 p.m.
3. Small (1983) estimated the lane capacity of a 10 mile nonuniform stretch of freeway with a single bottleneck at 1770. Route 91 will have 2 lanes operating over 4 peak afternoon hours for a free flow capacity of 14,160.

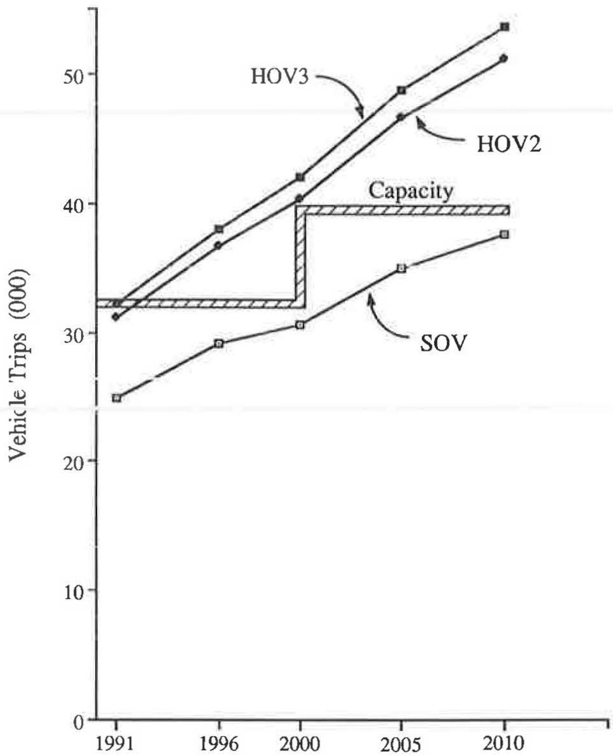


FIGURE 10 Projected peak eastbound vehicle trips in five lanes (four uncontrolled and one HOV without tolls), on weekday afternoons (2:00 to 6:00 p.m., Monday–Thursday), by vehicle occupancy at county boundary. Capacity would increase in 2000 from approximately 32,000 vehicles to 39,000 vehicles with the addition of one HOV lane.

• Projected eastbound afternoon trips were calculated at a constant 14.5 percent of daily trips with no capacity constraint;

• Trips were allocated to one of six mode and facility choices;

• Coefficients for individual utility were based on a survey conducted by the Resource Systems Group (1992); travel time and toll charge were assumed to be the parameters influencing choice, with modal bias constants that account for the unmeasured perception of the two ridesharing modes on each facility;

• All trips were 60 min;

• The potential time savings by using the toll lanes was 10 min;

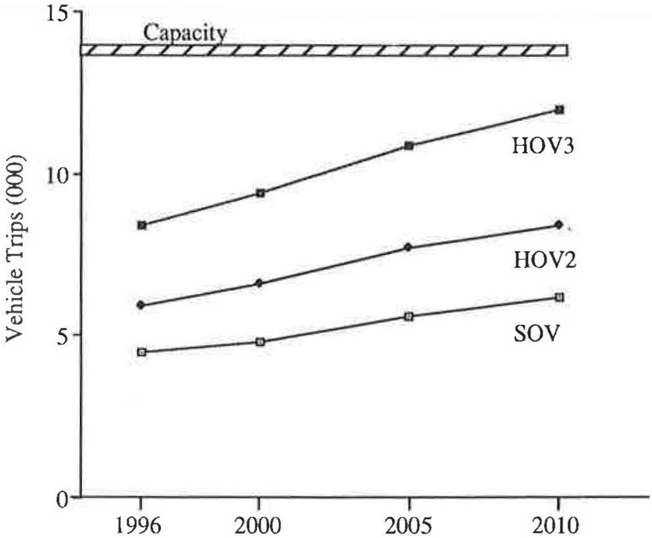


FIGURE 11 Projected peak eastbound vehicle trips in two toll lanes, on weekday afternoons (2:00 to 6:00 p.m., Monday–Thursday), by vehicle occupancy at county boundary. Approximate capacity would be 14,200 vehicles.

- Tolls were constant at $2.00 for SOV and HOV2; and
- Transponders were purchased by 90 percent of HOV3 vehicles to travel free in the tolled lanes.

Comparison of Table 1 with Table 2 illustrates how HOV buy-in can encourage ridesharing. Without tolls, the two eastbound HOV lanes would not be constructed; with the toll lanes, the following benefits would be achieved:

- Congestion in the uncontrolled lanes would be reduced; the potential demand of 29,518 vehicles in 1996 is below the 32,000-vehicle capacity and free flow should continue until 1999.
- The two controlled toll lanes would be uncongested.
- Although total HOV2 and HOV3 vehicles on the uncontrolled facility would exceed those on the controlled facility after 2005, the controlled lanes would encourage HOV3 vehicles. With an average occupancy of 3.6 persons per HOV3 vehicle, the number of people involved in ridesharing would increase.

The number of people involved in ridesharing would increase as the result of constructing toll lanes with free access for HOV3+ vehicles. This estimate is probably conservative: first, the private operator has a financial incentive to increase vanpooling and buspooling, and second, projected travel demand will probably be constrained by capacity limits on the uncontrolled facility (Figure 10).

Preliminary results from the simple logit exercise are satisfactory. They suggest that HOV buy-in projects promote congestion relief. However, more detailed studies are required before the hypothesis can be accepted or rejected. Better data on travel demand utility under different situations are required as well as knowledge about the willingness of travelers to change to higher-occupancy vehicles. The assumptions of the current model are coarse. In addition, the coefficients of demand utility are based on a selected sample that was not fully representative.

Users of both the controlled and uncontrolled lanes appear to be better off than they would have been had a single HOV lane been constructed. Both groups have a wider range of travel choice, more of them will rideshare, and in addition, the cost of constructing the toll lanes is borne by the beneficiaries rather than taxpayers.

CONCLUSION

Toll lanes on Route 91 provide a fascinating case study of how congestion pricing became acceptable. Traffic congestion in the Santa Ana Canyon is already severe and will expand in duration. The highest weekday demand occurs in the morning, but the afternoon peak is longer-lasting and frequently affected by traffic incidents.

Sufficient additional capacity to accommodate potential travel is unlikely to be constructed, and previous attempts to manage transportation demand have had limited success. The two most promising developments are ridesharing and construction of HOV lanes. If these were combined with congestion pricing, access could be expanded and the lanes could be used more efficiently.

Blending congestion pricing with ridesharing, HOV lanes, and highway privatization facilitates development of a constituency for congestion pricing. Venture capitalists recognize that this is the only way in which they can earn a competitive return from highway investment, highway advocates see a way to expand capacity, private engineering companies

view it as an opportunity to obtain additional work, and clean air supporters and groups connected with conservation of resources recognize that incentives for ridesharing may reduce adverse environmental impacts. Regrettably, the publicly sponsored toll roads in Orange County are not organized along these lines—the agencies operating them are content to rely on flat tolls and may have to be bailed out by state and federal assistance.

Toll roads and congestion pricing remain controversial throughout California. The lesson from Route 91 is that a constituency can be developed and significant opposition overcome when toll roads and congestion pricing are introduced as part of a regional program to reduce congestion and air pollution. Political acceptance is also assisted when the beneficiaries are seen to be paying for the HOV expansion rather than the general public.

ACKNOWLEDGMENT

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Potential of Next-Generation Technology

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The purpose of this paper is to review the capability of technology to provide for the kinds of pricing (of urban congestion) that economists assume in the best case—the ability to vary prices with changes in conditions and to communicate this information to drivers so that they have genuine price signals in advance of making their decision about route or trip timing. On the assumption that technologies likely to be developed in the short term will fall short of the foregoing ideal, guidance is needed on the range of price signals and price variation likely to be available, the potential of these price signals to influence behavior and to achieve greater efficiency, and the performance of the technologies in terms of high-speed transactions, automated enforcement, and avoidance of fraud. The scope of the paper, although originally limited to point and cordon pricing and pricing based on time and distance, was broadened to cover parking pricing as well.

The discussion is based on current work on road pricing in the United Kingdom and on work elsewhere, as reviewed recently (May 1992). In particular the discussion draws on recent integrated transport studies in London and Edinburgh in which road pricing has been shown to play a pivotal role (May 1991); the current U.K. Department of Transport London Congestion Charging Project, for which the author is a technical adviser; a recent inception report for a proposed study of road pricing in Edinburgh; proposals for congestion charging in Cambridge; a series of public attitude surveys conducted in the United Kingdom and elsewhere; and current research into road pricing at the University of Leeds.

The discussion begins with potential criteria for the assessment of new technologies, starting with the definition of the concept of economically

optimal pricing, broadening to the consideration of other potential objectives of urban congestion pricing, and then outlining the criteria for the design of effective congestion pricing technologies. This set of criteria is derived from the seminal work by Smeed in his review of road pricing conducted almost 30 years ago (Ministry of Transport 1964).

The range of next-generation technologies is reviewed next—first the types of charging mechanisms envisaged, those available for parking pricing, and those that impinge on other aspects of vehicle ownership and use, and second current developments in the technology for in-vehicle units (IVUs), vehicle-to-roadside communication, vehicle detection and classification, and vehicle identification and enforcement. This review is based on a recently completed study for the London Congestion Charging Project (Department of Transport 1993). The section ends with an assessment of the likelihood that each of the technologies will become available, operate reliably, and deliver each of the charging mechanisms envisaged.

In the next section the performance of the alternative charging structures is considered versus the objectives and criteria established in the first section of the paper. This third section draws on evidence from other studies for the London Congestion Charging Project, research currently under way at the University of Leeds, and a recent study in Edinburgh.

Last, a series of conclusions is drawn on the potential for approaching optimality in pricing with the technologies likely to be available in the near future.

CRITERIA FOR ASSESSMENT OF NEW TECHNOLOGIES

The technologies for road pricing need to be assessed at two levels: whether they provide a methodology capable of achieving the objectives of congestion pricing and whether they satisfy the criteria for efficient and effective operation. Reviewed first are the potential objectives for congestion pricing and second, the operational criteria.

Objectives

Congestion Relief

The initial case for congestion pricing was an economic one, related to the efficiency with which congested road networks are used. As demand to

use the road network increases, speeds fall and the costs to the individual user rise. This process achieves an equilibrium in which travelers use the road only if the cost to them is less than the benefit gained from traveling. This can be thought of as control of demand through congestion. However, as speeds fall, each additional user reduces the speed further and hence imposes costs on other drivers, who are slowed down by his presence. Because the individual driver does not perceive these costs, he may decide to travel even though the total costs imposed by the journey exceed the benefits. Were the driver to be exposed to these additional costs through congestion pricing, he would no longer travel in these conditions. Road pricing, by charging the difference between the marginal social cost and the marginal private cost of the journey, would thus ensure that the only people who traveled were those whose benefit from traveling exceeded the cost that they imposed on themselves and others.

This analysis lay behind the estimates of one of the most extensive studies of road pricing, the Smeed Report (Ministry of Transport 1964). In it, and later, Smeed estimated that each additional driver was likely to impose time losses for other vehicles equal to his own travel time at a speed of 21 km/hr (13 mph) and twice his own time at 16 km/hr (10 mph). Smeed, however, used simple supply-and-demand models to derive these estimates, and others have demonstrated weaknesses in his approach (Button and Pearman 1983).

A particular problem concerns the definition of marginal social costs and the way in which they arise. It is common practice to limit the marginal social costs to those imposed upon, and directly experienced by, other road users. These include travel time, operating costs, and, potentially, accidents. Environmental and land use impacts are typically considered separately, not least because of the difficulty of assigning monetary values to them. Even with this limited definition, problems arise.

As congestion increases, drivers do not simply experience increased travel times; they also suffer increased variability in travel time and may incur time costs in allowing for the uncertainty in their journey times. Recent work for the London Congestion Charging Project has provided bases both for estimating the variability associated with different journey times (albeit with low levels of statistical reliability) (Steer, Davies and Gleave 1993) and for valuing that variability (Cranfield Institute of Technology 1992).

Moreover, the way in which an additional driver generates additional time and operating costs for others is itself poorly understood. Most theoretical analyses of the problem have used simple single-link models, in

which traffic conditions are represented in a static, time-independent form and the complexities of network interactions are ignored (Evans 1992). The reality is much more difficult to analyze (Hills 1993). The generation of congestion is a time-dependent process in which, as demand begins to exceed capacity at critical junctions, queues form that in due course can block upstream junctions and lead to reductions in capacity. This process in turn encourages changes in demand, with drivers rerouting to avoid congestion, retiming their journeys, or possibly changing their destinations. All these processes lead to the gradual extension of congestion both in space and in time. Given this complexity, it is very difficult to identify the marginal social cost imposed by any individual vehicle. As others have noted (Smith and Ghali 1991), drivers who arrive early in the peak but after demand has begun to exceed capacity impose far greater costs on others than those who arrive at the end of the peak, since they delay everyone who follows them in the congested period by the time that it takes them to pass each bottleneck. Equally, the drivers whose presence leads to the blocking of an upstream junction impose greater costs than those who precede them, because their action has led to a reduction in capacity for those who follow. In addition, of course, those who pass through more bottlenecks, whether these are the critical junctions whose capacity is first exceeded or those whose capacity is later reduced, impose greater costs than those who make shorter or more peripheral journeys.

Thus a situation exists in which

- The economic optimum is identified as that in which the price, or congestion charge, equals the difference between the marginal social cost and the marginal private cost;
- Those costs are normally defined to include time and operating costs and, potentially, accident costs but to exclude costs associated with environmental and land use implications;
- The additional costs associated with variability and uncertainty in journey time are normally excluded, although they should, and potentially could, be included;
- The supply models usually used by economists to estimate the optimum charge are simplistic time-independent models in which the optimum charge can be determined uniquely from specified supply-and-demand curves; and
- The reality is much more complex and indicates that the charge should vary with time of travel, distance traveled, and passage of specific

bottlenecks and that the relationship between optimum charge and each of these is itself complex.

The transport planner's response to this situation has been to avoid the challenge of defining the optimum charging regime and instead to assess a range of more simply defined charging regimes in terms of their contribution to net present value (NPV) of benefits measured in conventional social cost-benefit terms, in which reductions in travel time, operating and accident costs, and increases in consumer surplus are offset against the costs of operating the scheme (Bates et al. 1992). Some examples of this form of analysis are presented in the section on assessment of performance against objectives.

Environmental Protection

As noted earlier, it has been conventional practice not to include environmental externalities within the marginal social costs of car use. More recently, however, it has been suggested that the analysis could be extended to include the objective of reducing environmental impacts. Such impacts can be considered as local, in the form of noise, primary pollutants, visual intrusion, danger, and accidents; regional, in the form of secondary pollutants such as ozone and acid rain; or global, through the contribution of traffic to the generation of carbon dioxide. To an extent, all of these can be reduced by improved design of vehicles, but it is generally accepted that the effects of such improvements will be seriously undermined by the continued growth of travel demand (Department of Energy 1990). At a local level, the most common response has been to restrict traffic in particularly sensitive areas, thus reducing the capacity of the overall network, which in turn strengthens the efficiency case for road pricing. Such an approach does nothing, however, to reduce the regional and global pollutants, and more recent analysis of these has led to advocacy of a "carbon tax," which would confront the driver with the environmental costs of his journey (Pearce et al. 1989). Determining the level of such a tax is not easy, but research is under way into methods of environmental valuation (Pearce and Markandya 1989). It seems probable that two types of charge will be identified—a fuel tax to represent the environmental costs of burning fuel, which would internalize the costs of generation of carbon dioxide and oxides of nitrogen and ozone, and a congestion charge to represent the additional environmental costs, such as carbon monoxide and noise, that arise at low speeds. By adding the latter into the marginal

social cost calculation, it should be possible to incorporate it within the economic analysis outlined earlier (Button 1991). It is important to note that the economic optimum achieved without environmental costs will almost certainly differ from that obtained when they are included. The resulting congestion charge will be higher and the optimum traffic flow lower, generating a loss of consumer surplus that will be offset by the gain in environmental value.

Accessibility and Urban Revitalization

In addition to these two primary objectives of congestion pricing, it has been argued that it can also contribute to the improvement of accessibility and to the revitalization of urban areas. Accessibility, or ease of reaching activities, is perceived partly in terms of cost and partly in terms of time spent traveling (Jones 1981). If pricing reduces congestion, it should reduce travel time, but it will also increase the cost of travel, at least for certain classes of vehicle.

Land use activity in urban areas will be influenced partly by accessibility, partly by the quality of the environment, and partly by the overall image of the area's transport policy. Congestion pricing will have a mixed effect on accessibility and a positive one on the environment, but its overall image may well be seen as negative.

It is difficult to see that accessibility and regeneration benefits can be included within a conventional social cost-benefit analysis unless the impacts on incomes, profits, and, perhaps, the environment can be quantified. Accessibility benefits arise whether people travel or not and are therefore not adequately represented by changes in consumer surplus. There is no appropriate means of valuing changes in land use patterns yet, and the ability to predict them is equally limited. It is probable, therefore, that accessibility and land use issues will be treated either as an overriding reason for rejecting congestion charging, for fear of the resulting economic decline, or as a basis for fine-tuning congestion charging regimes that have been justified and optimized on the basis of efficiency and environmental arguments.

Equity

Much the same can be said of the treatment of equity as an objective. Equity concerns in transport usually relate to the imbalance between private car users on the one hand and bus passengers, pedestrians, and

cyclists on the other; more generally they may consider the conflicting requirements of those with differing needs to use the road system as reflected in higher or lower values of time; a wider definition would also include concerns for the residents through whose area travel takes place. These are all predominantly horizontal inequities and ones that congestion pricing should help to reduce by reallocating road space and by reducing environmental impact. However, there are other equity concerns that are seen as disbenefits of congestion pricing. Some of these too are horizontal equity issues, affecting groups such as disabled drivers, service vehicles, and those whose personal security may be at risk. These groups are usually treated, if at all, by exemptions from the specified charge. The major argument has, however, revolved around vertical equity issues and suggestions that congestion pricing would be regressive (Richardson 1974).

Once again, these issues cannot be adequately reflected in a conventional social cost-benefit analysis, although it is possible to disaggregate such analyses to indicate the distribution of benefit among income groups. An example of a recent analysis for London is presented in the section in which performance is assessed against objectives. As with accessibility and urban revitalization, it seems probable that equity issues will be used as a reason either for not countenancing congesting pricing in the first instance or for improving on an initial specification either through exemptions or through provision of complementary transport policies to accommodate those most adversely affected.

Revenue Generation

Until recently the generation of revenue from congestion pricing has been seen as a side effect, albeit an attractive one, rather than as an objective in its own right. Much of the debate has centered on ways of using that revenue to good effect, particularly through the financing of complementary transport policies that enhance the performance of road pricing as part of an integrated transport strategy (May 1991). However, there are some notable examples in which pricing was introduced primarily to raise revenue, particularly in Norway, where the toll rings in Bergen, Oslo, and Trondheim are designed specifically to raise revenue for new transport infrastructure.

Again, it is difficult to include the benefits of revenue generation within conventional cost-benefit analysis, since the revenue is treated solely as a transfer payment. However, recent U.K. analyses of integrated transport strategies have introduced the concept of the present value of the financial

outlay (PVF) in which the stream of financial costs and revenues is discounted in the same way as resource costs and benefits to provide parallel indicators of both socioeconomic and financial performance (Bates et al. 1992). It is then possible to combine NPV and PVF by assigning the latter a shadow cost greater than unity to reflect the opportunity cost of other uses of the revenue. As will be seen in the discussion of performance against objectives, recent analyses have indicated clearly that the optimum charge for any charging regime is much lower if one is attempting to maximize NPV than if one is aiming to minimize PVF. Moreover, the design of the charging regime will be different. The Norwegian schemes have demonstrated the importance for revenue maximization of designing a toll ring that offers few alternatives and thus achieves very low elasticities. In contrast, schemes such as area licensing in Singapore, designed to reduce congestion, have offered a wide range of alternative modes, routes, and times of travel and achieved much greater responsiveness to price (May 1992).

Summary

The principal objective of congestion pricing is clearly the greater efficiency gained by congestion relief, and this is appropriately achieved by equating the charge to the difference between marginal social cost and marginal private cost. However, the determination of the marginal social cost is complex, and optimal charges in these terms are thus difficult to specify.

The other primary objective of congestion pricing is environmental protection, and this can potentially be incorporated within the efficiency analysis by valuing the environmental impacts. The optimum charge will inevitably be higher once environmental costs are internalized in this way.

The secondary objectives of accessibility, urban revitalization, and equity cannot be incorporated by valuing the impacts. It is possible that these objectives will be used as a basis for the outright rejection of congestion pricing. If not, they are best accommodated by fine-tuning a congestion pricing regime that has been optimized in efficiency terms by means of exemptions, variations in charge, or provision of complementary transport policies.

Revenue generation, if it is to be considered as an objective, must be treated separately and will lead to very different definitions of optimum charging regime and level of charge.

Because it is conceptually difficult to define an optimum charge, most transport planning studies of congestion pricing have not attempted to do so but have instead sought to identify an optimum NPV (or, potentially, an optimum PVF) among a predefined set of charging regimes and charging levels. Such an approach will indicate which of those regimes and levels performs best and whether its benefits exceed those of not introducing congestion pricing. They will not, however, indicate that the optimum charging system has been identified nor will they identify the benefits foregone by not identifying the optimum. Current research at Leeds is attempting to develop procedures by which more optimal strategy specifications can be identified (May and Bonsall 1991).

Operational Criteria

Whatever the objective or objectives against which congestion pricing regimes are designed and optimized, there will be a set of criteria that help determine whether the regime is likely to perform effectively. One of the most all-embracing sets of such criteria was that defined in the Smeed Report (Ministry of Transport 1964), which specified that

1. Charges should be closely related to the amount of use made of the roads;
2. It should be possible to vary prices for different areas, times of day, week, or year, and class of vehicle;
3. Prices should be stable and readily ascertainable by road users before they embark upon a journey;
4. Payment in advance should be possible, although credit facilities may also be permissible;
5. The incidence of the system upon individual road users should be accepted as fair;
6. The method should be simple for road users to understand;
7. Any equipment should possess a high degree of reliability;
8. The system should be reasonably free from the possibility of fraud and evasion, both deliberate and unintentional; and
9. The system should be capable of being applied, if necessary, to the whole country and to a vehicle population expected to rise to more than 30 million in the United Kingdom.

Some of these criteria relate to the objectives outlined above. Criteria 1 and 2 are concerned with the ability to levy an optimal charge which, as

noted above, is likely to vary with distance traveled, type of road and location used, and time of travel. Criterion 5 relates to the equity issues discussed earlier. However, the other criteria relate to ease of use and ease of operation.

Criteria 3, 4, 6, and 7 concern the ability of drivers to respond in an optimal way to the charges levied. If they do not understand the charging structure, do not know the charge in advance, or cannot readily make the payment, they may well make suboptimal decisions. Of particular importance to the design of charging regimes is Criterion 3, which raises the concern that in any regime whose charges vary with conditions, drivers may become aware of the true cost of their journey only when it is too late to make the choice of mode, timing, or route that may for them have been optimal.

Criteria 8 and 9 and to an extent 7 concern the efficient operation of the charging regime in terms of implementation costs (9), operation (7), and enforcement (8).

All these criteria remain valid some 30 years after they were proposed, although Criterion 9 would now be specified in terms of a potential Europe-wide system and a vehicle population approaching 200 million.

Other criteria that have emerged since those outlined by Smeed include requirements that (Thompson 1990; Hau 1992):

10. The system allow occasional users and visitors to be equipped rapidly and at low cost;
11. The charge recording system be designed both to protect individual users' privacy and to enable them to check the balance in their account and the validity of the charges levied; and
12. The system facilitate integration with other technologies, particularly those associated with driver information systems.

Of these, Criteria 10 and 11 affect efficiency of operation, but 11 has also been identified as important to public acceptability and efficient use, particularly in light of the experience with the Hong Kong experiment (Dawson and Brown 1985). Criterion 12 is relevant both to efficiency of operation, since it may reduce the costs of implementation, and to efficiency of use, since real-time information and short-term prediction may enable drivers to respond more effectively to regimes whose charges vary with traffic conditions.

In the assessment of performance against objectives, the range of charging regimes potentially available is assessed against all 12 of these criteria.

NATURE OF NEXT-GENERATION TECHNOLOGY

Type of Charging Mechanism

Charges for Vehicle Ownership and Use

The simplest forms of congestion charge have solely extended existing charging and taxation arrangements. In Hong Kong a substantial increase in car ownership taxation in 1982 was used as a means of reducing congestion. The tax for purchase of new cars was doubled and the annual license tax trebled. The effect on car ownership was marked, with a 25 percent reduction in the first year and continuing reductions thereafter (Dawson and Brown 1985). However, the impact on car use was much more varied, with a 19 percent reduction in the New Territories, where incomes were lower but congestion less serious, and little or no reduction in those areas where congestion was worst. It was immediately clear that, even in as compact an area as Hong Kong, charges on ownership were unlikely to have a sufficiently direct impact on congestion. A more complex system has since been introduced in Singapore in which a quota for new car purchases is specified each month and the purchase tax is determined by a bidding process for that quota; cars licensed only for use during weekends incur a substantially lower tax (LPAC 1991). It is too early to judge the effect of this system, but it is generally accepted that other, more location-specific charges will be needed in addition to ensure that congestion is relieved.

Another approach based on existing taxes is an increase in fuel taxation. As noted above, this has been proposed as one means of achieving reductions in carbon dioxide emissions (Pearce et al. 1989). Evidence indicates that there is an elasticity of demand with respect to fuel prices in the range -0.1 to -0.5 (Goodwin 1988); thus such a tax could be expected to reduce traffic levels. Unfortunately, this same evidence indicates that it is off-peak and leisure journeys that are forgone first (Atkinson and Lewis 1975) and once again such taxes are seen to be too indirect in their impact to be effective as a means of congestion relief.

It is clear that charges for ownership and use are not sufficiently closely related to the congestion imposed to meet the requirements for optimality, and they are not considered further here.

Charges Related to Patterns of Vehicle Use

As noted in the previous section, theoretical analysis of optimal charging suggests a system in which the charge levied for every link in the road network is determined by its supply-and-demand curves. In practice this point pricing system would be difficult to achieve and even more difficult for the driver to comprehend. Not surprisingly, practical developments have focused on simpler systems.

The most commonly proposed direct charging structure involves cordon charges, in which a charge is levied to cross [or in the case of the London supplementary licensing proposal (GLC 1974), to be within] a specified cordon. The charge can vary by time of day, direction of movement, or type of vehicle, and the cordon can be a single boundary or can encompass a series of cells. The complexity of the system is to a large extent determined by the technology envisaged. The first operational system, introduced in 1975 in Singapore primarily for congestion relief, involved purchase of daily or monthly licenses, which were placed on the vehicle's windshield and allowed entry to the center of Singapore in the morning peak period. Charges varied by vehicle type, with the added provision that cars with more than three occupants could travel free. This latter provision was made feasible only by a manual enforcement system; enforcement agents were stationed at every entry point to record the registration numbers of vehicles that were in violation (Holland and Watson 1978). The system is still in operation and has been extended to the evening peak, with charges still levied on inbound travel, although the exemption for shared cars has been withdrawn, partly because it was being abused (LPAC 1991). However, the Singapore government has recently invited three consortia to stage competing technology trials for a replacement electronic system that would permit the extension of charging to a series of cordons covering the entire road network of the country.

Other operational systems also use a single cordon but have been introduced primarily to raise revenue for new infrastructure rather than to reduce congestion. A cordon of toll booths was introduced around the city center of Bergen, Norway, in 1986, with charges levied at toll booths and a fixed price from 6:00 a.m. to 10:00 p.m. on weekdays (Larsen 1988). A similar cordon was introduced around the majority of the city of Oslo in 1990 in such a way that virtually all through traffic was intercepted, and with charges operational for 24 hr per day. Since December 1990, this system has offered the choice of either manual or electronic toll collection. The latter involves electronic identification of tags, which can be trans-

ferred between vehicles and permit both prepayment and postpayment of tolls levied. A more recent installation in Trondheim provides a similar choice to drivers.

By far the most extensive cordon charging system envisaged to date was that designed for Hong Kong. In this case, all vehicles were to have been fitted with electronic number plates, which were to be identified as they passed a set of loops buried in the highway. A charge was then to be added to the vehicle's account, depending on the vehicle type, location, and time of day. The owner was to receive a bill at the end of each month specifying his use of the road network. The technology was intensively tested using a fleet of 2,000 equipped vehicles and 20 detector locations in Hong Kong Central, and it performed to a very high level of accuracy (Catling and Harbord 1985). At the same time, desk studies were conducted to specify the most appropriate charging structure for the congested road network of Kowloon and Hong Kong Island. The most complex of these envisaged some 185 charging points, creating 13 cells, with charge levels changing eight times a day and differing by direction of travel (Harrison et al. 1986). The proposals were, however, rejected, partly on the grounds that the requirement to identify each vehicle uniquely would be an invasion of privacy.

Even these more complex charging structures have been criticized as being too inflexible. In particular, it is argued that they will levy charges even on occasions when congestion does not occur and will fail to levy higher charges when congestion is unusually severe (Oldridge 1990). Some critics have also suggested that they could give rise to inequities at, and additional congestion immediately outside, the cordons and that they would be inflexible (Thorpe and Hills 1991). On this basis, it is suggested that they fail to satisfy Criteria 1 and 5 discussed in the preceding section.

Two variable-charge systems have been proposed to overcome these problems. The first levies a charge based on the time spent in a defined area, with the potential to specify several different charging areas and with charging rates in each area varying by time of day. One proprietary system for achieving this has also been advocated by its proponents as a means of levying parking charges in the same areas (EASAMS 1991).

The second variable-charge system, proposed for Cambridge, envisages an in-vehicle unit (IVU) that records the time taken for a rolling 0.5 km (0.3 mi) of travel. Once the time exceeds a predefined threshold, a charge is levied and the odometer record is reset to zero (Oldridge 1990). The current proposals envisage one fixed travel time threshold and one

charging rate throughout the city and at all times of day on the basis that charges would be levied only when congestion is experienced. However, it would clearly be possible to vary the threshold and the charging rate by both area and time of day.

It will be important with both systems to assess the response of drivers carefully, since in neither case will the charge incurred be known in advance, hence contravening Criterion 3 and potentially Criteria 5 and 6. Moreover, both systems are potentially capable of encouraging drivers to drive more aggressively in order to reduce the charge incurred. It is interesting to note that in early attitudinal research on alternative charging regimes in London, respondents have been critical of time-based charging, both because they see travel time as unpredictable and outside their control and because they suspect that it will encourage hazardous driving (Accent 1992).

An interesting variant of these proposals is a system that would charge simply on the basis of distance traveled. As with time-based charging, the charging rate could be varied by area and time of day. This would overcome most objections to cordon-based and time-dependent charges but would still not relate dynamically to the level of congestion experienced.

Beyond these charging regimes there has been a proposal for a system in which charges would be determined by the costs imposed on subsequent vehicles (Smith and Ghali 1991). It is clear that such charges could not be determined directly on the basis of current conditions but would instead require developments in the short-term prediction of traffic conditions. They would therefore be even more in contravention of Criteria 3, 5, and 6. It seems unlikely that an operational version of such a charging structure will be available in the near future. Once such a system is available, it too is likely to have quite complex effects on driver behavior, since it will generate substantial peaks in the road pricing charge at the onset of each peak period.

In summary, and discounting for the moment the last of these proposals as impractical, the charging regimes that are available or envisaged are

- Point or cordon charges, in which vehicles are charged each time they pass a defined point and for which the charging rate can vary by
  - –Location,
  - –Direction,
  - –Time of day, and
  - –Vehicle type;

• Time-based charges, in which vehicles are charged a rate per minute spent traveling (and potentially also when parked) within a defined area and for which the charging rate can vary by

- –Area,
- –Time of day,
- –Vehicle type, and
- –Vehicle activity (primarily whether moving, idling, or stationary);

• Distance-based charges, in which vehicles are charged a rate per kilometer while they are within a defined area and for which the charging rate can vary by

- –Area,
- –Time of day, and
- –Vehicle type;

• Congestion-specific charges, in which vehicles are charged each time they take more than a specified time to travel a specified distance and for which the charging rate (and potentially the time and distance thresholds) can vary by

- –Area,
- –Time of day, and
- –Vehicle type.

Charges for Parking

Charges for parking inevitably follow very different principles from those for moving vehicles. The main elements in the determination of a charging regime are the type of space, the time of arrival or departure, the duration, and the type of vehicle and user.

The main types of space usually distinguished in the development of parking-charge policies are on street, public off street, and private nonresidential off street. Private residential space is not usually considered. Government agencies usually have the authority to impose charges on all on-street space and may also be able to do so with public off-street space. In the United Kingdom the latter spaces fall into two categories: those spaces owned and managed by local government and over which they have direct control and those spaces managed by the private sector. The authority to license privately operated public car parks is available but has been little used because of the compensation costs involved (May 1986). Private nonresidential off-street space presents the major barrier to the imposition of areawide parking charges, since in most countries governments have no jurisdiction over the way in which such spaces are used. In the United

Kingdom, where such spaces represent between 40 and 60 percent of all city center parking, attempts were made in the 1970s to develop legislation for charging and taxing them, but the proposals were abandoned in the light of the opposition that they generated (May 1986).

Charges can be varied by time of arrival, time of departure, and duration, although the last of these is by far the most common. Most duration-dependent charging scales involve a coarse or a fine linear relationship between charge and duration, although charging rates that fall with duration are also common. Escalating charges are less frequently used, since they may encourage drivers to remove and repark their vehicles.

Charges can be varied by vehicle type, provided that the charging method permits ready vehicle identification. Permit systems that allow certain categories of user such as residents, drivers with disabilities, and local businesses to pay lower charges are in widespread use.

The most appropriate basis for levying congestion charges through parking fees is not immediately clear. Parking is potentially associated with congestion, mainly through

1. The use of road capacity for parking rather than movement (in the case of on-street parking only),
2. Travel to and from the parking space, and
3. Travel during the search for a parking space.

The first of these elements will depend on the precise location of the parking and the time at which it takes place. However, in practice, parking is usually prohibited in those locations where and at times when it would seriously reduce capacity.

The second is the key element and will depend in part on arrival and departure times. However, it also depends on distance traveled, and there is no means by which this can be related to the parking charge. It is interesting to note that, although it is conventional practice to charge more for longer parking times, since these are more commonly associated with peak-period travel, there is a strong case for charging more for shorter durations, since parking spaces used in this way generate more travel.

The third element is often thought to represent a significant part of the total congestion in city centers, although there is little documented evidence on the scale of the problem of traffic caused by drivers searching for parking. It is a frequently stated element of parking policy to charge at a sufficiently high level to ensure that spaces are available to those who need them. In part this can be thought of as a congestion avoidance charge.

However, higher charges may well generate noncompliance, which may exacerbate other congestion problems.

In addition to these three efficiency-related aspects of parking charging policy, it is worth noting that charges may be levied to achieve accessibility, land use, and possibly environmental objectives; will often be varied on grounds of equity; and are usually treated as a significant revenue resource. As with other forms of congestion pricing, the requirements of these different objectives may well be in conflict.

In summary, the relationship between parking charges and congestion is less than straightforward, and the potential for imposing charges is severely constrained by the inability to charge for private nonresidential space. Within this context, the main forms of parking-charge regime are

- Arrival charges, in which vehicles are charged each time they park and for which the charging rate can vary by
  - –Location,
  - –Type of parking space,
  - –Time of day, and
  - –Vehicle (and user) type;
- Departure charges, in which vehicles are charged each time they leave a parking space and for which the charging rate can vary by
  - –Location,
  - –Type of parking space,
  - –Time of day, and
  - –Vehicle (and user) type; and
- Duration charges, in which vehicles are charged at a rate related to the period during which they have parked and for which the charging rate can vary by
  - –Location,
  - –Type of parking space,
  - –Time of day, and
  - –Vehicle (and user) type.

Current Developments in Technology

Nature of the Technological Requirements

The requirements for congestion charging related to vehicle use are considered first. The requirements for parking charges are different and are treated separately at the end of this section.

A number of elements are required for the operation and enforcement of any system that charges directly for the use of roads (Department of Transport 1993):

1. An IVU that stores either fixed or variable data, can communicate with the roadside to carry out transactions, and may also include display material for the use of either the driver or enforcement staff;
2. A payment and accounting system that enables charges to be levied and audited by both operator and driver;
3. A roadside communications beacon that can either interrogate (two-way) or communicate with (one-way) the IVU;
4. A means of detecting the presence of a vehicle and (if required) of classifying it as it passes at speed; and
5. An enforcement system to identify uniquely all noncompliant vehicles.

In addition there may be a need for networking among roadside communications beacons and with a control center for administration, financial control, enforcement, and auditing purposes. The last set of requirements is not considered further in this paper, since it is less directly relevant to the feasibility of alternative charging regimes.

For a shortlist of the most practical options, the review for the London study (Department of Transport 1993) assessed the remaining four requirements given above against the following criteria:

- Functional and technical performance,
- Operational performance,
- Standardization and compatibility,
- Administrative requirements, and
- Potential for evolution and technical development.

The findings are summarized in the following sections; as in the full report, little is said about costs, which, given the status of development, are very difficult to assess reliably.

It is of interest to note the scale of the requirements under these criteria as estimated for the most extensive scenario for congestion charging in London (Department of Transport, 1993):

- Vehicles equipped with IVUs: 4 million,
- Roadside beacons: 4,000,
- Transactions per day: 40 million, and

• Enforcement checks per day per beacon at which compliance is assessed: 1,850.

IVUs

Seven classes of IVU-based system are available or under development:

- Paper stickers,
- Read-only tags,
- Read-and-write tags,
- Automatic debiting transponders,
- Cellular-radio-based systems,
- Autonomous in-vehicle meters, and
- Semiautonomous in-vehicle meters.

Of these, the review for the London study discounted cellular radio because that communications medium will not permit a large number of simultaneous transactions and because detection of offending vehicles is infeasible. Autonomous meters were discounted also, because with no roadside communications, they rely on the driver to switch them on and off.

Stickers, which are the form of IVU employed in Singapore, simply convey information to an observer or camera. The information is limited by the number of different types of sticker that can readily be distinguished by the operator or camera. This restricts the system to cordon-based charging and to a small number of separate areas and times of day. The London supplementary licensing proposals (GLC 1974) included outline designs for stickers that would have separately identified two areas, two times of day, and two vehicle types. This is probably approaching the limits of the system's capability, particularly since the day for which the sticker is valid must also be indicated.

Stickers are relatively easy to forge and virtually impossible to read in multilane and high-flow conditions and in poor weather and light. They cannot be readily standardized. They are complex to administer, although they do provide the most obvious means of equipping and charging occasional visitors. This approach has been proposed for the Cambridge system. Stickers offer little opportunity for evolution or integration with other technologies.

Read-only tags are already in widespread use for automatic toll collection. They contain a fixed identification code that, when interrogated, is relayed

to the roadside system. The code may identify the user, or (as in Hong Kong) the vehicle, or, as in most current applications, the user's account. Data transfer is limited, and most processing is conducted at the roadside. These tags permit the identification of vehicles by type as they pass predefined points, by time of day, and by direction. They thus facilitate point or cordon charging, the structure for which may be complex, since it is determined by the roadside system.

Although read-only tags are a proven technology, which is independent of the vehicle and highly reliable, they do have the serious limitation that their one-way communications link precludes multilane or high-flow operation, in which several vehicles have to be processed at once. This limitation can potentially be overcome by using lane-specific roadside units, but this adds to the complexity. Because read-only tags are simple, they are open to fraud, although there is little evidence of this to date. Standardization (of operating frequency) is feasible. Administration is relatively straightforward, and special read-only tags for occasional users and visitors could easily be provided. There appears to be little opportunity for further evolution of the technology or for integration with other information systems.

Read-and-write tags extend the principles of the read-only tag to allow some information to be received from the roadside and stored either on the tag or on a separate card, which may be removed and read at special service points. The main application of this additional facility would be to provide the user with an independent record of recent transactions. However, it also has the potential, unproven as yet, to permit time-based charging.

The two-way communications facility may also make multilane operation and simultaneous processing of several vehicles more feasible. However, all read-and-write tags require an internal battery, and some with smart cards require a link to the car's battery, which makes them more vulnerable to failure and tampering. Their greater complexity makes them less open to forgery but also less appropriate for occasional users. Standardization is straightforward, and there is some opportunity for further evolution and cost reduction. However, the opportunities for integration with other information systems are limited by the low level of communication with the vehicle.

Automatic debiting transponders incorporate a higher speed and a more reliable two-way communications link with the roadside and allow some of the processing to be conducted in the vehicle rather than at the roadside. Interfaces with smart cards and with display facilities and keyboards are also possible. The system thus provides more information to the driver

and in particular permits time-based charging to be implemented by use of an internal clock.

The higher level of two-way communications permits multilane and high-flow operation, achieves greater security, and facilitates certain types of accounting system, as discussed later. The technology has been proven in single-lane operation, but at present all systems require a link to the car's battery, which makes them vulnerable. Standardization is occurring as the systems develop, and administration presents few problems, although the devices are less appropriate for occasional users. The technology is evolving rapidly, with the potential for installations independent of the vehicle and for substantial cost reductions. The higher quality of two-way communications makes integration with real-time route guidance and information systems perfectly feasible.

Semiautonomous in-vehicle meters provide, in addition to the transponder, a meter, which can be time-based, and a link with sensors in the vehicle, such as the odometer. It is these additional links that permit distance-based and congestion-related charging. The communications link, which may be of lower performance than that for a transponder, permits the roadside unit to advise the IVU that the meter should be switched on or off and the rate at which charges should be levied.

In-vehicle meters are in the early stages of development and are not yet a proven technology. All would require a link to the car's battery, at least for the foreseeable future, and some require links to vehicle sensors, which render them vulnerable to tampering. Some developments envisage erasure of the stored value in the smart card if such tampering occurs. The emphasis on transactions within the vehicle requires a different level of enforcement, since the audit trail is otherwise incomplete. Proposals have been made for separate enforcement beacons to overcome this problem. Because the technology is in the early stages of development, standardization is only beginning to be considered. These systems will inevitably cost more and be more complex to fit, particularly if there are links to the odometer, and this will limit applications, particularly for occasional users. The potential for development and integration with other information systems is, however, considerable.

Payment and Accounting Options

The review for the London study identified the following forms of accounting:

- Prepayment:
  –Drawing right accounts, in which the user sets up an account with the operating authority and undertakes to maintain a positive balance;
  –User-held credit, in which the user purchases credit, which is stored in a smart card that interacts with the IVU to deduct charges specified either by the roadside device (in the case of a transponder) or by the IVU itself (in the case of an in-vehicle meter); or
  –Subscription, in which the user purchases a subscription that permits a fixed number of charges or unlimited use for a specified period.
- Postpayment:
  –Direct debit, in which the user permits the operator to debit the user's bank account either instantaneously or periodically;
  –Billing, in which the operator bills the user periodically for charges incurred over the period.

These forms of accounting in turn are achieved by five different methods of automatic charging:

1. *Automatic account identification (AAI) with postpayment* uses the roadside unit to record the user's unique account identity and time of passage, which are then used subsequently for debiting or billing. This system raises possible problems of invasion of privacy and requires records to be kept until billing and auditing are complete. From the operator's point of view it also has the disadvantage of later generation of revenue.
2. *AAI with prepayment* collects the same information as in AAI with postpayment but deducts the charge immediately through the roadside unit. This requires immediate validation, high data security, and, potentially, real-time transactions. The latter may pose considerable problems for a large-scale system. Once the transaction is complete, the information can be destroyed. This overcomes privacy issues but makes auditing by the user more difficult. Ideally, difficulty with auditing can be remedied with read-and-write tags or transponders by recording information for the user.
3. *Subscription accounts based on identification* use the same information as AAI together with a roadside record of the number of journeys left in the user's account.
4. *Anonymous subscription accounts* permit unlimited use during a specified period, subject possibly to limits on time of day or area. The accounting system simply checks that the user has a valid subscription for the area and time period during which travel occurs.

5. *Anonymous automatic debiting* is achieved by the use of smart cards or in some cases the transponder itself to store credit in the IVU. All transactions then take place within the vehicle itself. This avoids the need to identify the user but requires more complex IVU software and a more detailed enforcement check to ensure that charges are being appropriately levied.

All these forms of payment and accounting are available as proven technology, with the exception of user-held credit accounts operating with anonymous automatic debiting. As with the in-vehicle meters to which these systems apply, they are currently under active development.

It is important to note that the different accounting systems will have differing impacts on user response and hence on the optimality of charging. In particular, subscription accounts with unlimited use totally fail to impose a charge related to marginal use, since marginal use is free once the "season ticket" has been purchased. The subscription account in which a specified number of journeys are purchased and the delayed postpayment accounts will almost certainly not have the immediacy that reminds users of the marginal costs of their journeys, although this is an issue on which further behavioral research is needed.

Vehicle-to-Roadside Communications

The review for the London study shortlisted five technologies for vehicle-to-roadside communications, noting that the technology for vehicle detection and classification (see following section) will be markedly different for each of them.

1. *Inductive loops* were used in the Hong Kong experiment and shown to be highly reliable (Catling and Harbord 1985). They are, however, expensive to install, transmit at a low data rate, and operate over a short range that requires the tag to be on the underside of the vehicle. Although they can clearly operate in multilane sites, there is little evidence of their accuracy under high-speed operation. As a mature technology they do not offer much potential for evolution.

2. *Radio frequency systems* are being used in the GEC Timezone application (EASAMS 1991) and appear likely to be developed further in intelligent vehicle-highway systems (IVHS). They offer performance similar to that of microwave systems, which are more fully developed, and appear to have the potential to operate from overhead gantries in multilane sites.

There is considerable potential for their evolution and integration with other information technology applications. Their main drawback is a limitation on available frequencies.

3. *Surface acoustic wave systems* are a modulation technique for use in radio frequency and microwave transponders that is already in use in the Oslo toll ring. The technology is limited to read-only tags because the code cannot be altered after manufacture. It has been used successfully in high-speed, single-lane operations and has been shown to work in multilane sites, although there is doubt as to whether it can uniquely identify different vehicles. There appears to be considerable potential for further development of the system as a low-cost communications method.

4. *Microwave systems* are a proven technology for single-lane sites, transmitting information at a higher rate than would be required for congestion pricing over ranges of up to 30 m (98 ft). The PAMELA transponder has also been tested on multilane sites with promising results (Blythe and Hills 1991). The technology itself is mature, but its applications for in-vehicle meters offer considerable opportunity for further development.

5. *Infrared systems* have been used effectively in route guidance technology. They have the advantage of being able to support a very high data transmission rate, but they are adversely affected in certain climatic conditions. They have been proven for one-way communication in both single- and multilane sites but appear not to be effective for two-way communications at multilane sites. The technology is still being developed but has yet to be proposed for congestion pricing.

European researchers consider microwave systems to be the most promising of these technologies, although it is clear that radio frequency applications also have potential.

Vehicle Detection and Classification

An effective automated enforcement system requires the detection and classification of all vehicles at selected enforcement sites and the unique identification of noncompliant vehicles, which is discussed in the following section. For a current DRIVE II project, CASH, the following demanding criteria have been specified for detection and classification:

- The system should not affect the speed or interrupt the flow of free-flowing multilane traffic;

• Up to six lanes of mixed traffic, all traveling in the same direction, must be processed, and the system should have sufficient spatial resolution to be able to resolve vehicles when there is a minimum separation between them of 1.0 m (3.3 ft) along the highway and 0.25 m (0.82 ft) across the highway;

• The system should be able to resolve the interference that may occur when many vehicles fitted with transponders attempt to communicate with the roadside system concurrently;

• The enforcement system must check the class of each vehicle and locate those vehicles that do not possess a working transponder or do not have a transponder at all and those vehicles that execute an invalid transaction; and

• The enforcement system should attempt to record the identity of all noncompliant vehicles.

The requirements for true multilane operation, in which lane changing and lane straddling are possible, are very demanding, and it has been suggested that vehicles at enforcement sites might be required to stay in lane as a means of simplifying the detection requirements.

The review for the London study identified the following combined detection and classification systems:

1. *Hybrid inductive loop and axle-sensor systems* do not quite achieve the specified detection dimensions but should perform well in single-lane sites and those where lane changing is prohibited. They are, however, inaccurate in detection and classification at low speeds. They are also vulnerable to damage during road work.

2. *Pulse-mode microwave systems* can meet the dimensional requirements for detection and can classify accurately by pattern recognition from a single sensor. Pairs of sensors can provide speed and direction of movement. Their main potential weaknesses are that they require a gantry installation and that smaller vehicles can be obscured by larger ones and not detected.

3. *Infrared light-beam systems* can also achieve the dimensional requirements for detection but provide a coarser classification, based on vehicle length, which is measured by a pair of sensors. These systems also require gantries for multilane sites.

4. *Video image-processing systems* can potentially detect and classify individual vehicles from one camera to cover six lanes. However, accuracy is

not yet sufficiently high and can be affected by lighting conditions and by shadows and other disruptions.

It is generally accepted that any of the current detection and classification systems will need to be improved in performance by an order of magnitude to meet the demands of urban congestion pricing enforcement. As an interim measure, these requirements could be reduced by enforcement only at single-lane sites or ones at which lane changing is prohibited. However, such reduced enforcement must not be done in such a way that loopholes in the coverage are provided. Among the technologies, microwave, infrared, and video imaging all appear to offer potential for further development.

Unique Vehicle Identification

The only way in which vehicles can currently be identified uniquely is by their license plate. Although some thought has been given to using uniquely identified tags, or electronic number plates (as in the Hong Kong field trial), this would require all vehicles to be so equipped, and the tags would be more vulnerable to tampering, since they would not be as obvious as the license plate.

The two main approaches for license plate identification are photographic cameras and video cameras. Either can be read off line manually or automatically using image recognition techniques, but only video pictures can be analyzed automatically in real time.

1. *Photo logging* uses an automatic camera with a 1/1,000-sec shutter speed and an automatic electronic flash, usually aimed at the rear license plate. Such installations are already in widespread use for automatic recording of vehicles that speed or violate red traffic lights. Photo logging provides much higher resolution images than video, but can be degraded in poor climatic conditions. It is only used to record vehicles that have been identified as violating and therefore provides a limited record of overall conditions.

2. *Video logging* uses a video camera, usually aimed at the front license plate, with automatic blocking out of the image of the vehicle occupants to protect privacy. An image processing facility is included to digitize and store the images. Image compression can also be used to increase storage capacity. In this way, details of all vehicles can be stored until the validity of

the transaction has been checked. Alternatively, details may be recorded only for noncompliant vehicles.

Both of the foregoing systems suffer from the inability to record all license plates, largely because of constraints in the field of view. Dutch research has found that about 16 percent of images are invisible, primarily obscured by adjacent vehicles (Ministerie van Verkeer en Waterstaat 1988). This problem becomes more acute when drivers attempt to evade detection by obscuring the license plate, falsifying it, or removing it altogether. Most such actions can be observed, but this may not be sufficient to deal with an outbreak of such actions on a large scale. Steps have already been taken to declare reflective number plates, which are one of the most effective means of obscuration, illegal.

Automatic license plate reading has now been developed to the level where it is about 60 to 95 percent successful, depending on the image and the software employed. This is an area in which research developments are rapid, and it is anticipated that success rates of 90 to 95 percent will be achieved in the near future. Automatic license plate reading could be combined with enhanced video cameras to provide real-time recording of the number plates of vehicles identified as noncompliant. The main barrier to complete effectiveness will continue to be obscuration of license plates by other vehicles and by drivers evading detection.

Automated Charging for Parking

To a limited extent, the IVUs developed for congestion charging can also be used to levy parking charges automatically. Read-only tags, read-and-write tags, and transponders can be used to levy fixed charges for arrival or departure but are only suitable for off-street parking when roadside systems can be mounted at a limited number of entrances and exits. In-vehicle meters can be used, together with the time clock, to levy charges related to duration. These could also be triggered by roadside devices at car park entrances and exits, in which case a different time-based charging rate could be applied for different car parks or to differentiate between time spent parked and time spent on the road. It is conceivable that a sensor linked to the ignition could enable different charging rates when the engine is running and when it is off, thus allowing a different time-band charging rate for on-street parking and for time spent moving. It is also possible that an in-vehicle meter could accommodate a charging scale that was not linearly related to duration.

In addition to these approaches, to which relatively little consideration has been given, there has been considerable growth in cashless parking systems (May 1987). Most of these are designed to enable cash to be used also. The main developments are in cashless meters, which are operated by a smart card or credit card; pay-and-display machines, which issue a paper ticket but are operated by a smart card or credit card; and in-car electronic parking meters. The last of these is a device similar in size to an electronic calculator that can be charged with a specified credit value and is set by the driver at the rate applicable at the time of parking. The charge is then decremented at the specified rate, and a flag indicates when the device has zero credit. All of these systems except the cashless meter will permit variable charging scales, and all will permit changes in tariff by location and time of day. It would be possible to use the same smart card for both congestion charges and parking charges. The main limitation with any of these systems is that they require manual enforcement, which, though easier for stationary than moving vehicles, is demanding of resources.

Potential for Implementation of Charging Structures

For each of the charging structures identified earlier as available or envisaged, the potential for current and developing technologies to provide them is assessed in the following discussion.

Point or Cordon Charges

Point and cordon charging still remains the most readily achievable of the various regimes envisaged. These charges could be provided through read-only tags, read-and-write tags, transponders, or in-vehicle meters, although the last of these is an unnecessarily complex technology for such a simple charging regime. IVU technology is already available to operate point charging and is in use in the Norwegian toll rings and in several toll road operations. The one limitation is that the read-only tags now in use permit only single-lane operation. This limitation will be overcome with the development of read-and-write tags and transponders.

Any of the payment and accounting options could be used, although user-held credit and automatic debiting would be inappropriate, since they are designed for use with in-vehicle meters. As argued earlier, subscription accounts and postpayment by billing would also be inappropriate gener-

ally, since they do not send the necessary immediate signals of marginal cost and may not induce the desired response from drivers. AAI with prepayment appears to be the most suitable accounting procedure, but it ideally requires the provision of auditing information for the user. Once again, it should be possible to provide this information through read-and-write tags or transponders.

All the communications systems are potentially applicable, although inductive loops are clearly of limited use. None has yet been fully proven for use on multilane sites, but it appears that microwave and radio frequency communications should be able to achieve this.

Further development will be required in vehicle detection, classification, and recording systems. Microwave, infrared, and video imaging systems are all potentially capable of the first two but will require an order-of-magnitude improvement in accuracy before they can achieve enforcement at multilane sites. Video logging and automatic license plate reading are the preferred technology for unique recording of noncompliant vehicles, but again these systems require further development to improve their accuracy. They are unlikely, even so, to solve the problem of the one in six vehicles whose license plates are obscured by following or preceding vehicles.

Time-Based Charges

Time-based charging can be achieved by use of automatic debiting transponders, in-vehicle meters, and, potentially, read-and-write tags. In-vehicle meters are in the early stages of development and will not become a proven technology for at least another 2 years. They will require a link to the vehicle's battery, which will make them vulnerable to tampering. However, for time-based charging they will not require an additional, and potentially vulnerable, link to vehicle sensors. Other potential disadvantages include higher cost and greater difficulty in equipping visitors' vehicles; conversely, they offer much greater potential for integration with other information technology applications.

The payment and accounting system would be limited to user-held credit, either at the roadside with prepayment AAI or through smart cards and automatic debiting in the vehicle. The technology for the latter is still being developed and is unlikely to be proven for a further 2 years.

The requirements for communications and enforcement would be met in the same way as for point pricing. However, the enforcement task is

somewhat greater, since it needs a check that the automatic debiting facility is operating as required and that the smart card is still in credit. These additional facilities are also under development.

Distance-Based and Congestion-Specific Charges

The position on provision of distance-based and congestion-specific charges is identical to that for time-based charges, with the exception that a link is required from the in-vehicle meter to the odometer, thus further increasing the difficulty of equipping occasional users, the cost of the unit, the potential for tampering, and the need for more detailed enforcement.

Arrival- and Departure-Based Parking Charges

For off-street parking, arrival- and departure-based charges could operate in exactly the same way as point charges, with the added simplifications that multilane sites are rarely if ever required and that enforcement is easier and can be reinforced by automatic entrance or exit barriers.

For on-street parking, however, such charges can only be achieved by electronic meters, pay-and-display machines, and in-car electronic parking meters. All of these are more appropriate for duration-based charging and require manual enforcement, which is particularly demanding when enforcement of payment related to arrival or departure time is required.

Duration-Based Parking Charges

For off-street parking, duration-based charges could operate in the same way as time-based charges, with beacons at entry and exit to trigger the charging rate. It is possible that a varying charging scale could be implemented.

For on-street parking, these could simply be charged at the same rate as time spent traveling in the defined area. Alternatively, it is conceivable that a different rate of charge could be levied for vehicles whose engines were stopped. Again, a varying charging scale is potentially feasible. However, it is not clear in either case how the time-based charging systems would differentiate between vehicles parked on street and those parked off-street, perhaps in free residential parking, within the charged area.

Both on- and off-street charges could also be levied through electronic meters, pay-and-display machines, or in-vehicle parking meters, although, as noted above, manual enforcement would be required.

ASSESSMENT OF PERFORMANCE AGAINST OBJECTIVES

Each of the congestion pricing and parking pricing regimes is now considered against the objectives and criteria outlined in the first section. Of the objectives, only efficiency through congestion relief and revenue generation are considered in detail. It is assumed that environmental protection could be represented by an additional charge to represent marginal environmental impact and that issues of accessibility, economic development, and equity are to be considered once optimization has been achieved against other objectives. Some recent findings are reported on the distribution of benefits for different income groups from a recent study of congestion pricing in London. A number of other general issues arise that are pursued as part of the consideration of point-based charging, since this is the most widely studied charging method.

Point or Cordon Charges

Congestion Relief

As noted earlier, definition of the true marginal cost of travel in complex networks is difficult, and none of the recent studies of practical congestion charging systems has attempted to do so or to relate charges to marginal cost. Instead, the most common approach has been to specify one or more charging regimes, vary the level of charge for each, and produce a series of estimates of the NPV of the regime relative to the same transport system without congestion pricing (i.e., with zero charges).

An early example of this approach is found in the study of supplementary licensing in London (GLC 1974; May 1975). This study used a combination of sketch planning and detailed network modeling to estimate the impact on travel time, vehicle operating cost, consumer surplus, and system capital and operating costs. The regimes studied included a cordon around central London, both throughout the working day and only during the peak hours, and an all-day central area cordon combined with a cordon around inner London operating either all day or during the peak hours. In the latter cases the inner London cordon was charged at either 25 or 50 percent of the central London charge. The charge was modeled as a charge for cars to enter the area, and the options of charging more for commercial vehicles and less for residents were also tested. The

latter was possible because a low-technology sticker was to be used. The main results are summarized in Table 1 and Figure 1.

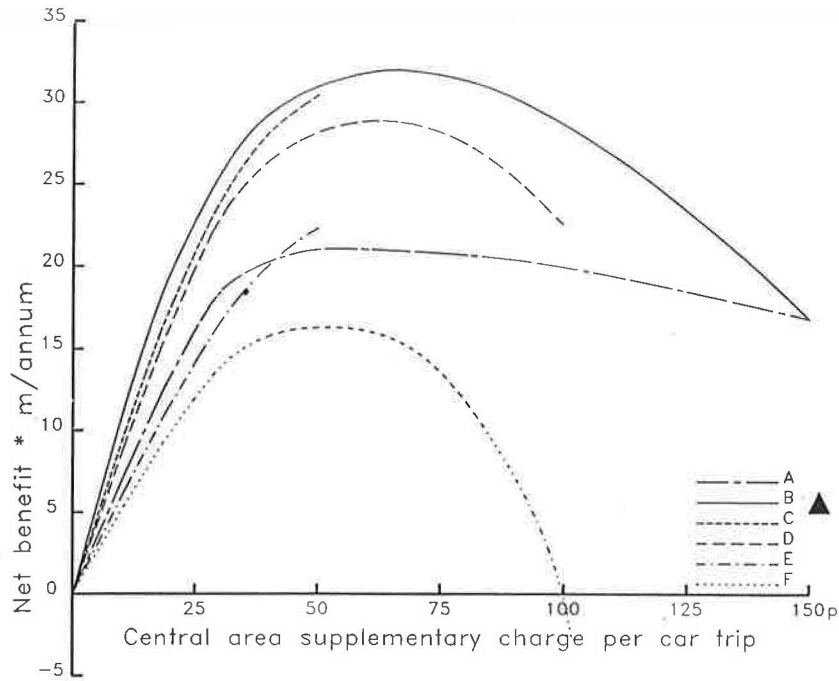
It can be seen that clear optima were obtained in each of those tests that assessed a wide enough range of charges. Below this optimum value, increases in charge are gradually encouraging more drivers whose marginal costs exceed their benefits to transfer to other destinations, modes, times of day, or routes. Above the optimum charge, drivers are being diverted even though their benefits exceed their marginal costs. In practice, of course, as the optimum is reached, some journeys, particularly short-distance, cross-boundary ones, will be diverted even though it is efficient to make them, whereas even above the optimum charge some inefficient journeys, which either are long-distance, cross-boundary ones or do not cross cordons, will continue to be made. These inequities are an inevitable by-product of a coarse charging system that fails to reflect the optimal charge on each link.

Despite this suboptimality, it is clear from Figure 1 that considerable benefits are obtainable and that the maximum benefit is higher for certain charging regimes than for others. In particular, all-day charging in central London produces significantly higher benefits than peak-period charging (which has an uncharacteristically flat optimum), presumably because there is considerable off-peak congestion, which is aggravated under peak-period charging by transfer from the peak. The inner-area peak charging regimes produce optima close to that for all-day central area charging, but

TABLE 1 Supplementary Licensing in London: Main Alternatives Considered

Alternative	Area Controlled	Time of Control	Charge Ranges Tested[a]
A	Central	08.00–10.00	20p–£1.20
B	Central	08.00–18.00	20p–£1.20
C	Central	08.00–18.00	20p–£1.20
	Inner	08.00–10.00	5p–30p
D	Central	08.00–18.00	20p–£1.20
	Inner	08.00–10.00	10p–60p
E	Central	08.00–18.00	20p–£1.20
	Inner	08.00–18.00	5p–30p
F	Central	08.00–18.00	20p–£1.20
	Inner	08.00–18.00	10p–60p

[a] Charges per car per day at 1973 prices; higher charges for commercial vehicles, lower for residents.



* at 1980 values, 1973 prices

▲ for scheme details see Table 1

FIGURE 1 Supplementary licensing proposals for London, 1974.

with lower NPVs. These three regimes provide a spectrum of levels of inner-area charge from zero to half that for the central area. It may well be that there is an optimum in this spectrum at around 10 to 15 percent of the central area charge at which inner area charging produces higher benefits than central area charging alone. However, it is clear that extension of charges throughout the day at the inner cordon is disbeneficial; this is the only test that has generated a negative NPV.

Much more recently, a similar set of tests was conducted for Edinburgh as part of a follow-up to an integrated transport study completed in 1991, which demonstrated the pivotal position of congestion pricing as part of an integrated transport strategy for the city (May et al. 1992). The results are summarized in Table 2 and Figure 2.

In this case, the modeling was carried out using a strategic model of the city, START (Bates et al. 1991), which represents the full hierarchy of choices available to travelers and the complex demand-supply interactions

TABLE 2 Cordon Charging Tests for Edinburgh: NPV and PVF

	Charging Level					Base Charge (pence per cordon crossing)				
	Central Cordon		Outer Cordon							
Option	Peak	Off-Peak	Peak	Off-Peak		50	80	100	150	300
A	1.0	1.0	0.0	0.0	NPV (£millions)	62	71	69	49	−84
					PVF (£millions)	172	249	291	386	566
B	1.0	0.5	0.0	0.0	NPV (£millions)	43		56	54	
					PVF (£millions)	116		199	271	
C	1.0	1.0	0.5	0.5	NPV (£millions)	81		100	87	
					PVF (£millions)	255		442	602	
D	1.0	1.0	1.0	1.0	NPV (£millions)	97		121	104	
					PVF (£millions)	328		575	781	

NOTE: NPV = net present value; PVF = present value of financial outlay.

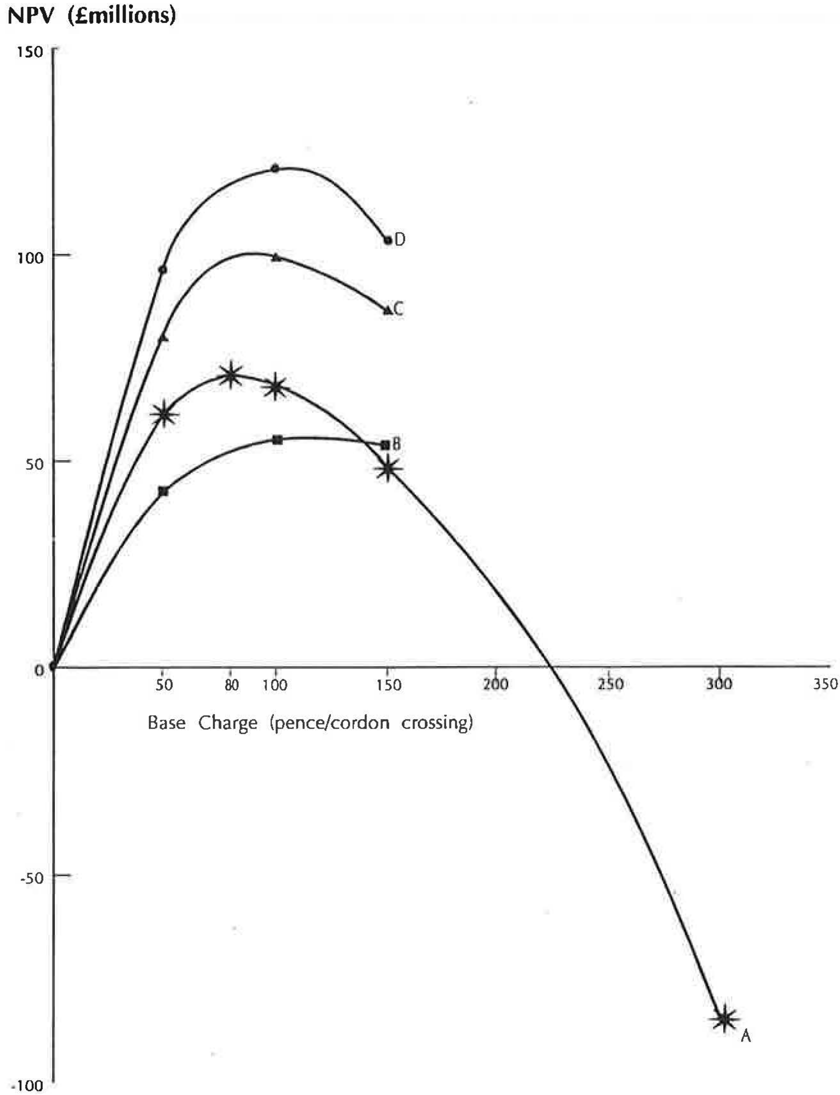


FIGURE 2 NPV for cordon charging options (see Table 2).

that result. Four options were tested: an all-day charge to cross a cordon around the city center in either direction (Option A), a similar regime but with charges at half the level in the off peak (Option B), and two regimes that combined all-day central-area charging with all-day charges to cross a cordon just inside the outer ring road, with charges at half the level of those for the central cordon (Option C) and at the same level (Option D). No

attempt was made to consider different levels of charge for different types of vehicle or any more complex temporal or spatial boundaries.

Here the same overall patterns appear, with pronounced optima for each charging regime (except possibly Option B). However, in this case higher NPVs are achieved by adding the outer-area cordon. Results of a further analysis (Figure 3) suggest that there may be an optimum charge for the outer-area cordon at around 150p, although it should be noted that there will be an interaction between the levels of central and outer charge that needs to be tested to identify this optimum. This example serves to indicate that even with a relatively simple congestion charging regime, identifying the optimum set of charges is a complex problem.

As an aside, it is interesting to observe that all of the initial strategy tests included a simple form of congestion charging, with an all-day charge of 150p per crossing for a central area cordon. It is clear from Figure 2 that the optimum benefits are at least 150 percent greater than those obtained from that specification. The issue of generating optimal strategies from a limited set of prespecified strategy elements is one currently under study at Leeds (May and Bonsall 1991).

Revenue Generation

The tests for the provincial city also investigated the potential of maximizing revenue expressed as the PVF. The results are included in Table 2. No maximum is apparent in any of the tests, although extrapolation suggests that a maximum may be achieved with Option A at around 500p per crossing. Once again, the values of PVF are much higher for regimes that include outer area charging. However, the most important conclusion is that, not surprisingly, maximization of PVF occurs at much higher charges than maximization of NPV and, crucially, at levels for which NPV is markedly negative. This implies that the pursuit of revenue maximization is likely to produce significant disbenefits. However, it is possible to argue that a charge at somewhat above the economic optimum is worth pursuing given the additional revenue generated, particularly if that extra revenue can be dedicated to transportation purposes. In particular, the loss of £2 million in NPV in increasing the charge in Option A from 80p to 100p is certainly worth incurring as a means of generating an additional £42 million in PVF.

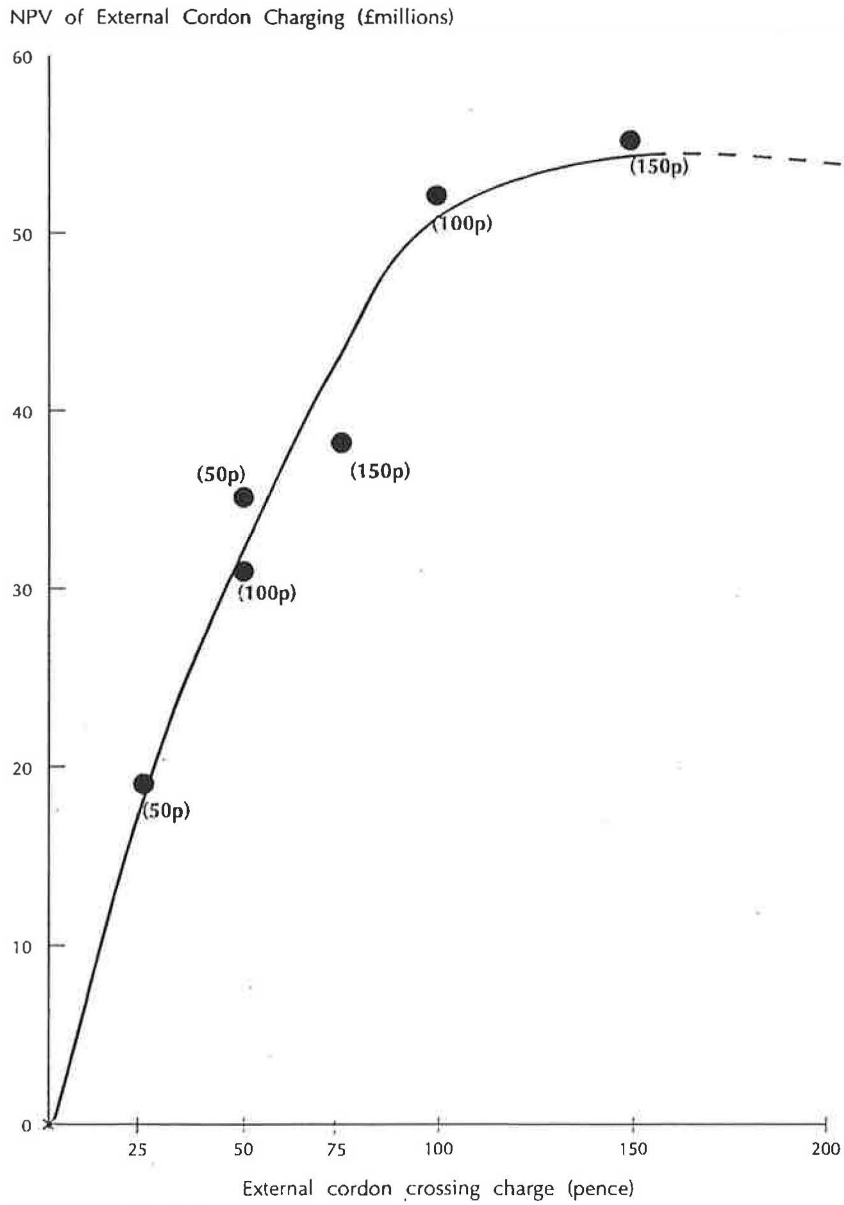


FIGURE 3 NPV for external cordon charging (see Table 2). (Figures in parentheses are central-area cordon crossing charges.)

Equity

A recent study at Leeds, funded by the U.K. Economic and Social Research Council (ESRC) (May and Nash 1990), indicated the way in which the benefits of congestion pricing are distributed among income groups. The study was based on a START model of London constructed for the London Planning Advisory Committee, which demonstrated the benefits of a strategy that included congestion pricing. The pricing regime originally tested involved a charge of 50p in each direction to cross each of three concentric cordons, one around central London and the others within and around inner London, as well as a series of screen lines within central London (LPAC 1992). Although the inner London cordons operated only during the peaks, the central London cordon and screen lines imposed charges throughout the working day.

For the ESRC study, the model matrices were split into six, representing three household income groups for households with and without cars. Each group was assigned behavioral values of time based on research elsewhere (Fowkes, Sherwood et al. 1993), but benefits were calculated on the basis of resource values of time as recommended by the U.K. Department of Transport. For simplicity, only single-year benefits for the prediction year 2001 were calculated relative to the strategy without congestion pricing.

A range of tests of different charging regimes and charge levels was then conducted, as follows:

Regime A (as described in the 1992 LPAC report): 25p, 50p, and 100p per crossing;

Regime B [three cordons only (without screen lines)]: 25p, 50p, 100p, 150p, and 200p per crossing;

Regime C (central cordon only): 200p, 400p, 500p, 600p, and 800p per crossing (Fowkes, Milne et al. 1993).

Optimum charges (in terms of overall NPV) were identified at 50p for Regime A (Test A50), 100p for Regime B (B100), and in the range 400p to 500p for Regime C (C400 and C500).

Table 3 indicates the distribution of benefits for each of these four optimal cordon charging tests, together with the distributions of trips and households among the six income groups. Regime A achieves the highest overall benefit and Regime C, the lowest, despite the much higher charges that have to be levied to achieve an optimum. It is clear that in all cases the

TABLE 3 Distribution of Benefits for Four Optimal Tests of Cordon Charging in London

	Net Benefit (£Mpa) by Test[a]				Percentage of Trips	Percentage of Households
	A50	B100	C400	C500		
Household types						
No car, low income	−10.7	−7.6	−12.1	−12.1	6	18
No car, medium income	−7.5	−4.1	−7.7	−7.2	4	7
No car, high income	−9.2	−4.1	−10.4	−9.5	6	7
1+ car, low income	−28.5	−21.4	−11.9	−11.4	15	18
1+ car, medium income	−72.6	−52.2	−19.9	−16.4	38	30
1+ car, high income	−43.1	−27.8	−11.2	−7.7	31	20
Households	−171.5	−117.1	−73.1	−64.2	100	100
Freight	19.9	6.9	37.6	40.9		
Operators	44.7	43.2	34.5	36.5		
Local government	150.7	100.4	26.0	12.9		
U.K. government	−5.4	−4.0	−5.5	−5.8		
Total	38.4	29.3	19.6	20.4		

NOTE: £Mpa = millions of pounds sterling per annum.
[a] See text for description of tests.

payments for congestion charges exceed the benefits from reduced congestion for all three categories of car owners. It is also notable that middle-income car owners experience the highest disbenefit per trip (or per household) in all three regimes. More surprisingly, all categories of non-car-owning households experience disbenefits. This may be explained by increased overcrowding on public transport services. This effect is most pronounced in Regime C, in which low-income households with no car have the highest disbenefit per household. Further analysis indicated that, although the distributional effects of Regimes A and B were fairly stable across the range of charges tested, those for Regime C became increasingly severe for low-income travelers as charge levels increased.

The distributional effects will in practice be mitigated or exacerbated by the use to which the revenues raised are put. Further analyses were made assuming a redistribution to households in proportion to their trip making and separately in proportion to their numbers. Table 4 presents the results of the first analysis, with all the net benefits to local and national government redistributed to households in proportion to their trip making. In Regimes A and B, the main disbenefits are now focused on middle- and low-income households with cars; high-income households with cars and, in Regime B, high-income households without cars experience small benefits, and other households without cars experience only small disbenefits. The parallel test with redistribution based on numbers of households produced benefits for households without cars. Regime C, in contrast, performs very differently, with the highest per household disbenefits being experienced by households without cars and with higher per household disbenefits for lower-income households.

It can be seen from this summary analysis that regressivity depends critically on both the design of the cordon structure and the use of the revenue. It is possible to design more complex cordon charges that are progressive in their effects, provided that the net revenue is redistributed to travelers. Conversely, the coarsest cordon charge structure tested has been shown to be highly regressive in its impact, even with revenue redistribution.

Operational Criteria

Point and cordon pricing, together with the next-generation technology described earlier, satisfy Criteria 2, 3, 4, 6, 7, 9, and 10 given in the first section.

TABLE 4 Distribution of Benefits for Four Optimal Tests of Cordon Charging in London with Revenue Redistributed in Proportion to Trip Making

	Net Benefit (£Mpa) by Test[a]				Percentage of Trips	Percentage of Households
	A50	B100	C400	C500		
Household type						
No car, low income	−2.0	−1.8	−10.9	−11.7	6	18
No car, medium income	−1.7	−0.2	−6.9	−6.9	4	7
No car, high income	−0.5	1.7	−9.2	9.1	6	7
1+ car, low income	−6.7	−6.9	−8.8	−10.3	15	18
1+ car, medium income	−17.4	−15.6	−12.1	−13.7	38	30
1+ car, high income	1.9	2.1	−4.8	−5.5	31	20
Households	−26.3	−20.7	−52.6	−57.2	100	
Freight	19.9	6.9	37.6	40.9		
Operators	44.7	43.2	34.5	36.5		
Total	38.4	29.3	19.6	20.4		

NOTE: £Mpa = millions of pounds sterling per annum.
[a] See text for description of tests.

Both forms of pricing satisfy Criterion 1 to a limited extent in that more complex cordon structures can approach the requirement of relating charges to road use. However, additional cordons add considerably to the costs of implementation and enforcement and detract from drivers' comprehension of the charging regime, as well as greatly complicating the process of optimization.

These charging regimes potentially fail Criterion 5 in that they impose the same charge on short and long journeys across cordons, although, interestingly, this issue was not raised strongly in recent attitudinal research in London (Accent 1992). Again, this is a problem that can be partially overcome by adding to the number of cordons. As with all congestion pricing systems they will give rise to other perceived inequities; as noted in the discussion of equity in the first section, these are best resolved by detailed design, exemptions, and complementary transport strategies.

Point and cordon pricing currently do not perform very effectively against Criterion 8 in that the enforcement technology still requires considerable improvement. However, they present fewer enforcement problems than other charging methods.

They will be capable of satisfying Criterion 11 once audit records are available to the user on read-and-write tags or transponders.

They employ a technology that will be less readily integrated with other technologies and thus perform less well against Criterion 12. However, this disadvantage could be overcome, at a cost, by using in-vehicle meters to achieve point pricing.

Time-Based Charges

Congestion Relief

No assessment is known to have been made to date of the impact of time-based charges, although some are envisaged as part of the study of congestion charging in London to be reported in 1994. It is possible to speculate, however, that the performance in terms of economic efficiency will be superior to that for distance-based charging, which is outlined later, since the charges will be higher in situations in which the marginal cost is higher. In other words, time-based charges are better able to approach the requirement of imposing optimal charges per link than other pricing systems.

Revenue Generation

Similarly, no assessment is yet available of the impact of time-based charges on revenue, although data will be forthcoming from London during 1994. In advance of this, it is difficult to speculate on the revenue implications. It is conceivable that time-based charges will generate less revenue than distance-based charges, since they will be more likely to stimulate changes in driver behavior in the areas where charges are highest.

Operational Criteria

Time-based pricing relies on the technologies of automatic debiting transponders and in-vehicle meters, which are as yet unproven. Once it is operational, the system should satisfy Criteria 1, 2, 4, 7, 9, 11, and 12.

Failure to meet Criterion 3—that prices be stable and readily ascertainable in advance—is the system's greatest weakness and may well lead to suboptimal decisions by drivers unless it is combined with a driver information system that provides short-term predictions of likely levels of charge.

Recent attitudinal research in London demonstrated concerns with the fairness of time-based charges (Criterion 5) (Accent 1992). Although the system may be fairer in its coverage of all journeys and particularly of short and long journeys, it is seen as unfair by virtue of its unpredictability and also because many delays are perceived as being caused by others, such as illegally parked cars, accidents, and road work. Moreover, there is considerable public disquiet about its safety implications.

That same attitudinal research indicates that although drivers will understand the principle of time-based charges (Criterion 6), they are concerned that they will find it difficult to know what charges are likely to be incurred and hence the action necessary to avoid them.

Even with the new technology, the system will have difficulty in satisfying Criterion 8. First, any in-vehicle meter may require links with the vehicle's battery, which can be tampered with. Second, automatic debiting is much more difficult to audit and enforce.

The automatic debiting transponder and the in-vehicle meter will not be easy to install in visitors' vehicles, although it will be easier for time-based charges than for distance-based charges, which require a link with the odometer. It is almost certain that Criterion 10 will have to be met by some simpler form of charging for visitors.

Distance-Based Charges

Congestion Relief

The recent Edinburgh tests referred to earlier also included distance-based charges. Five options were tested: distance-based charges limited to the central area but operating throughout the day (Option E); all-day central area distance-based charges, with distance-based charges in the rest of the city during the peak hours only at 25 percent of the central area charging rate (Option F); and distance-based charges throughout the city throughout the day, with the outer area charging rate 25, 50, and 100 percent of the central area rate (Options G, H, and I). Table 5 and Figure 4 summarize the results.

Once again, clear optima are generated by each test, and greater benefits are obtained by extending charges to the whole city. Interestingly, however, this is not the case if outer area charges are limited to the peaks (Option F). All three ratios of outer area to central area charges generate optima at similar levels of NPV, although it does appear that the optimum ratio may be between 25 and 50 percent. This is considered in a different way in Figure 5, which suggests an optimum outer area charge of around 15 to 20 p/km compared with an optimum for the central area alone (Figure 4) of around 35 p/km. As with cordon charges, the true optimum will depend on the interaction between central area and outer area charges and can be identified only by further tests.

Of particular interest is the comparison between Figures 2 and 4. Cordon- and distance-based charges in the central area [which extends over some 12 km^2 (4.6 mi^2)] both achieve the same maximum NPV, and it appears that a distance-based charge of x p/km can be approximated in its effect very closely by a cordon charge of $2x$ p per crossing. Extension of charges to the outer area does identify differences. The maximum NPV is around £135 million with distance-based charges, but only £120 million with cordon charges. However, it may well be that a higher outer-cordon charge of around 150 p combined with the optimum central-cordon charge of 80 p would achieve an NPV similar to that for distance-based charges. Certainly the difference in maximum benefits is not as great as might be expected for systems one of which is much coarser than the other.

It should be noted, however, that neither cordon- nor distance-based charges relate the charge to the intensity of congestion. This may make them both somewhat less effective.

TABLE 5 Distance Charging Tests for Edinburgh: NPV and PVF

Option	Charging Level: Central Cordon Peak	Charging Level: Central Cordon Off-Peak	Charging Level: Outer Cordon Peak	Charging Level: Outer Cordon Off-Peak		Base Charge (pence per kilometer) 15	25	50	75	100
E	1.0	1.0	0.0	0.0	NPV (£millions)		62	71		19
					PVF (£millions)		165	272		425
F	1.0	1.0	0.25	0.0	NPV (£millions)		61	59	22	
					PVF (£millions)		221	369	484	
G	1.0	1.0	0.25	0.25	NPV (£millions)		108	134	111	
					PVF (£millions)		380	663	895	
H	1.0	1.0	0.5	0.5	NPV (£millions)		129	126	45	
					PVF (£millions)		562	952	1249	
I	1.0	1.0	1.0	1.0	NPV (£millions)	117	125	2		
					PVF (£millions)	545	857	1334		

NOTE: NPV = net present value; PVF = present value of financial outlay. 1 km = 0.6 mi.

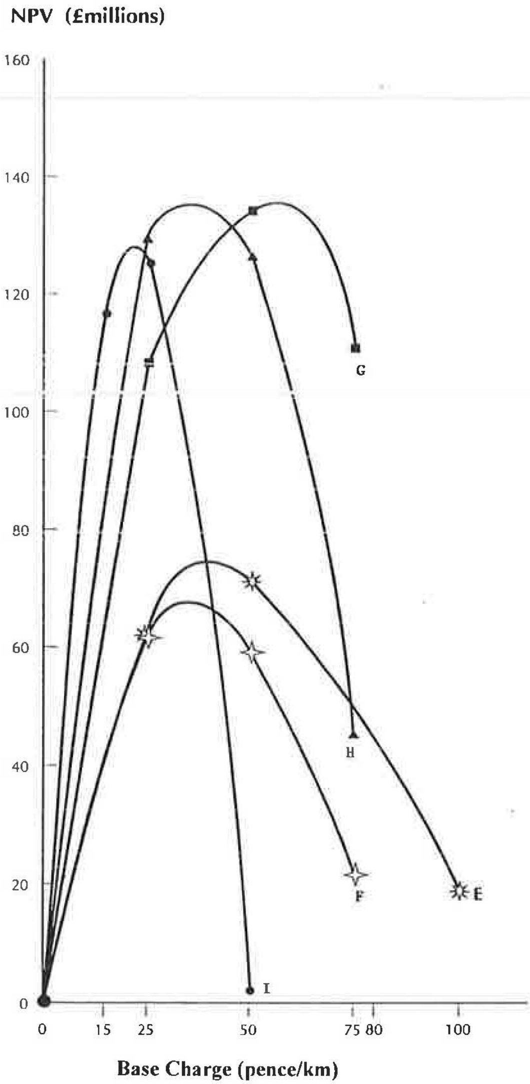


FIGURE 4 NPV for distance charging options (see Table 5) (1 km = 0.6 mi).

Revenue Generation

The data in Table 5 indicate the impact on revenue measured in PVF. Once again, none of the tests has identified a maximum for revenue generated, and any such maximum is likely to arise for a charging level that is extremely suboptimal in terms of economic efficiency. Comparison with

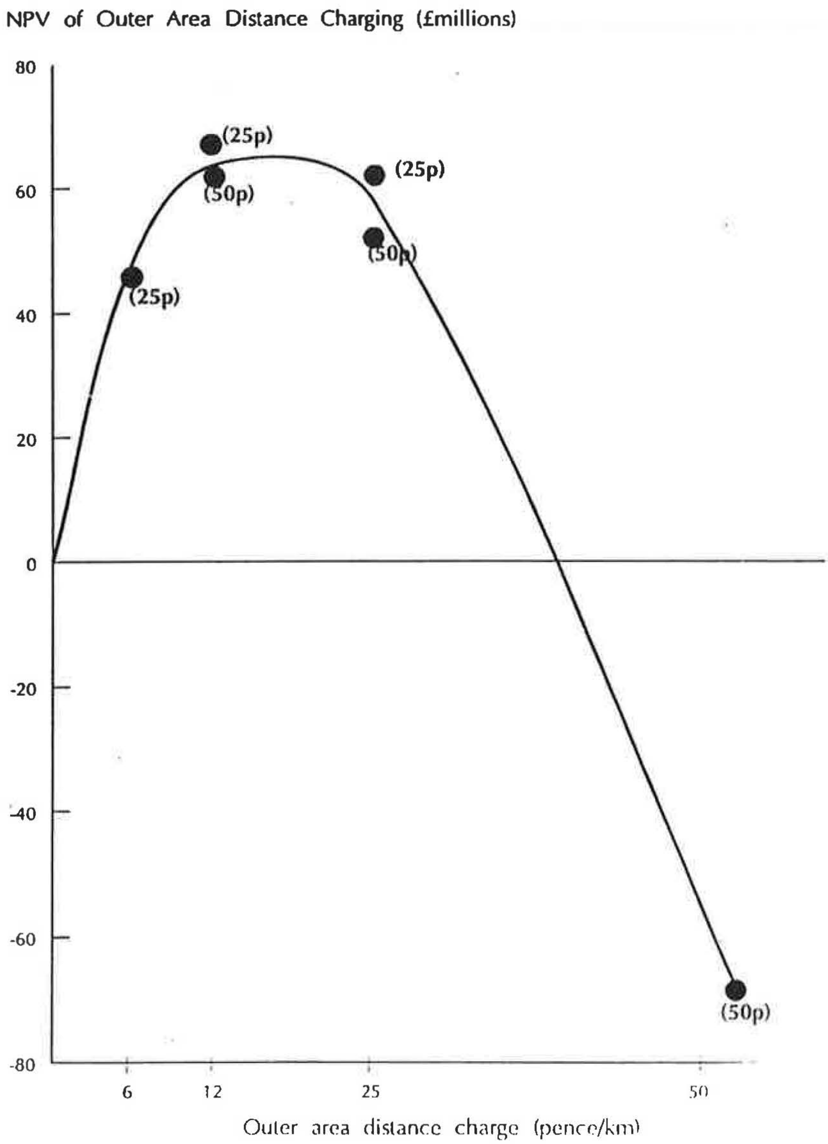


FIGURE 5 NPV for outer-area distance charging (see Table 5) (1 km = 0.6 mi). (Figures in parentheses are central-area cordon crossing charges.)

Table 2 indicates that the introduction of distance-based charging in the outer area generates higher levels of revenue than does outer cordon charging for the same level of benefit.

Operational Criteria

Distance-based charging relies on the technology of in-vehicle meters and automatic debiting, which is as yet unproven. Once it is operational, the system should satisfy Criteria 1, 2, 3, 4, 6, 7, 9, 11, and 12. The only caveat for Criteria 3 and 6 is the interesting result from attitudinal research in London that drivers typically do not know how far they travel on individual journeys in London (Accent 1992). No doubt they would soon rectify this if distance-based charging were introduced.

As regards Criterion 5, distance-based charges may well be seen as fairer than cordon charges, since they do not impose the serious boundary problems for short and long cordon crossings and affect all journeys in the area. There are still, however, the general perceived inequities of any form of congestion pricing.

In terms of Criterion 8, distance-based charging is likely to be less easily enforced than time-based charging, since there is the additional link with the odometer that can be tampered with.

As with time-based charging, distance-based charging is not readily applied to visitors' vehicles, which will almost certainly need a simpler form of charging system.

Congestion-Specific Charges

Congestion Relief

No assessment has yet been made of the impact of congestion-specific charges, and there are no plans currently to test them other than in Cambridge. It may well be that they can achieve a similar level of performance to time-based charges by focusing solely on situations in which congestion occurs. However, they impose the same charge per unit distance no matter how severe the congestion is, and their failure to relate charges to the intensity of congestion may make them less effective.

Revenue Generation

Since congestion-specific pricing imposes charges only when congestion occurs, it is likely to generate significantly less revenue than time- or distance-based pricing.

Operational Criteria

Congestion-specific pricing requires the same technological development as distance-based pricing, but the in-vehicle meter will need to be more complex. It is reasonable to assume that once this technology is available, it will satisfy Criteria 2, 4, 7, 9, and 12.

Congestion-specific pricing will not satisfy Criterion 1, as specified, since charges will not be related to use of roads but to use of congested roads; this could be argued to be a more appropriate definition of the criterion.

Congestion-specific pricing will present considerable problems in relation to Criteria 3, 5, and 6. Prices will clearly not be stable or readily ascertainable in advance; moreover, the pricing mechanism is likely to be difficult for drivers to understand. It is clear that the concerns with unfairness raised for time-based pricing will be even more acute with congestion-specific pricing, for which much of the congestion will appear to be caused by others.

For enforcement, under Criterion 8, congestion-specific pricing is likely to present similar problems to distance-based pricing, given the potential for tampering with the odometer link.

There will be the same problems of application for visitors as with other charging regimes that rely on in-vehicle meters (Criterion 10), and there may well be, because of the system's complexity, some problems for drivers in auditing the charges levied (Criterion 11).

Arrival- and Departure-Based Parking Charges

Congestion Relief

There have been very few studies of the benefits throughout an urban area of increases in parking charges. In one or two of the recent integrated transport strategies, the effects of parking charges have been compared

with those of road pricing, and it has been suggested that the latter produces the greater benefits. This would not be surprising, since parking charges, even if extended to private nonresidential parking, have no impact on through traffic, which often accounts for around a third of traffic entering city centers. The lack of a clear relationship between parking activity and distance traveled will also make it difficult to achieve benefits as great as those from a flexible road-pricing system.

Revenue Generation

The same arguments suggest that parking charges will generate less revenue than road pricing, since these charges have no impact on through traffic and little impact on longer journeys. It seems probable, however, that parking charges, like road-pricing charges, will need to be substantially higher to maximize revenue than they would be to maximize economic benefits.

Operational Criteria

Systems for arrival- and departure-based charges for off-street parking should be able to employ any of the technologies suitable for point or cordon charging. On-street parking charges could not be levied in this way and would require one of the automated systems described earlier, which are dependent on manual enforcement. The combined system should satisfy Criteria 2, 3, 4, 6, 7, 9, and 10.

Criterion 1 is clearly not satisfied, since there is little correlation between parking activity and road use. However, the link between the two is slightly stronger than that for parking duration.

Criterion 5 will be infringed, because parking charges do not affect through traffic and because drivers will perceive that the charge is not related to the congestion caused. Interestingly, though, there is little reference in attitudinal research to concern with vertical equity problems arising from parking charges.

Enforcement (Criterion 8) should be straightforward for off-street parking but will continue to be a significant problem for on-street parking, exacerbated by the greater restriction on off-street parking. With regard to the issues arising under Criteria 10, 11, and 12, arrival- and departure-based parking charges are identical to cordon charging.

Duration-Based Parking Charges

Congestion Relief

The arguments for duration-based parking charges are identical to those for arrival- and departure-based charges, with the exception that duration-based charges are even less well correlated with the marginal costs of road use.

Revenue Generation

Again, the arguments are similar to those for arrival- and departure-based charges. It is not immediately clear whether the revenue impacts will differ between the two charging regimes.

Operational Criteria

Duration-based parking charges would require an in-vehicle meter and this technology could potentially permit duration-based charging both on and off street. On this basis, this system should satisfy Criteria 2, 3, 4, 6, 7, 11, and 12. As noted earlier, duration-based charges are even less well correlated with road use than arrival- and departure-based charges, and thus clearly fail Criterion 1. The performance of this system on Criterion 5 is similar to that for arrival- and departure-based charges. The system is likely to perform better in enforcement terms (Criterion 8) than arrival- and departure-based charges, because the technology can control on-street parking as well.

The performance on Criteria 9 and 10 is identical to that for time-based charging of road use.

CONCLUSIONS

Objectives and Criteria

The principal objectives against which it is appropriate to assess the performance of alternative technologies for congestion pricing are congestion relief, environmental protection (which may in due course be able to be incorporated within a wider efficiency analysis), and, potentially, revenue generation. The objectives of accessibility, economic regeneration,

and equity are secondary and can be achieved by modifying a congestion pricing system designed to achieve economic efficiency. However, arguments under any of these headings may be used to reject the concept of congestion pricing in principle.

Optimum charges can be defined in terms of economic efficiency as the difference between the marginal social cost and the marginal private cost of the journey. However, the determination of marginal social costs in complex urban networks is extremely difficult and results in optimum charges that vary by link and time of day in a markedly nonlinear fashion. As a result, little attempt has been made to specify charges in this way. Instead, most attention has been focused on the definition of simpler charging structures and modification of the parameters of those structures to achieve the maximum NPV of social benefits.

The nine operational criteria defined by Smeed 30 years ago are still wholly appropriate for the assessment of alternative technologies. Three additional criteria have been suggested to meet the needs of occasional users, the requirements of privacy and audit, and the desire for integration with other information technologies.

Nature of Next-Generation Technology

Charges based on vehicle ownership and overall use are inappropriate as a method of congestion pricing.

The main types of charging regime related to patterns of vehicle use are point or cordon pricing, time-based pricing, distance-based pricing, and pricing imposed solely when congestion is incurred (congestion-specific pricing). All of these can be varied by location, time of day, and vehicle type; some permit other forms of variation.

Charges for parking do not offer a very good proxy for congestion pricing, because they are not directly linked to levels of road use. Different approaches to parking charges are needed on and off street, and charging for private nonresidential parking may be very difficult to introduce. With these reservations, the main approaches are charges related to arrivals and departures and charges related to duration. Both can be levied by location, time of day, type of vehicle, and type of parking space.

The technological requirements for automatic congestion pricing include an IVU, a payment and accounting system, a roadside-to-vehicle communications system, a means of detecting and classifying vehicles, and a system for uniquely recording noncompliant vehicles.

- The types of IVU range from read-only tags, which are already fully developed, to automatic debiting transponders and in-vehicle meters, the technology for which still needs to be proven.
- Payment and accounting options involving delayed postpayment and subscription accounts are unlikely to be appropriate for congestion pricing, since they will not send pricing signals that are clearly related to marginal road use. Drawing right accounts with automatic account identification and user-held credit with automatic anonymous debiting are the most appropriate systems; the former is an available technology, whereas the latter is currently under development.
- Communications technologies involving radio frequency and microwave systems are the most likely to be used for congestion pricing. The main area still requiring development is unique communication with different vehicles in multilane sites.
- Vehicle detection and classification using microwave, infrared, and video image processing and automatic license plate reading using video recording are the most likely technologies for enforcement. All these technologies require improvements in reliability by an order of magnitude before they will meet the demanding requirements of multilane sites. One temporary expedient until these improvements are made is to prohibit lane changing at enforcement sites. Even so, the accuracy of license plate reading will be limited to a practical maximum of around 85 percent by the obscuration of plates by adjacent vehicles.

All the IVU technologies could be employed at off-street car parks, but only in-vehicle meters are appropriate for use on street. The only alternative for on-street parking is to use electronic parking meters in various forms, all of which rely on manual enforcement.

Point or cordon pricing and parking charges based on arrival and departure can be implemented using a range of IVU technologies, some of which are currently available. Time-based, distance-based, and congestion-specific pricing and duration-based parking charges require in-vehicle meters, which are still being developed.

Assessment of Performance Against Objectives

Each of the six pricing mechanisms was considered in the previous section and assessed against the objectives of economic efficiency and revenue

generation and the 12 operational criteria discussed at the beginning of the paper. The results are summarized in Table 6.

Although it is difficult to assess how close to optimality the four road pricing systems come, evidence for cordon pricing and distance-based pricing suggests that even though the former is much more coarse, it can achieve similar levels of economic benefit. This suggests that any of these four systems may achieve close to the maximum benefits obtainable. However, even the simplest charging structures are quite difficult to optimize.

Parking pricing systems, in contrast, are much less likely to perform well in terms of economic efficiency, because of the lack of correlation between parking charges and the marginal costs of road use.

Revenue-generating effects are similar, but it may well be that distance- and time-based charges raise higher revenues than true optimal congestion pricing.

Distance-based charges perform well against the 12 operational criteria; their main drawbacks are in terms of enforcement and ease of tampering with the technology, perceived fairness in common with all road pricing systems, and ability to equip visitors.

Point or cordon pricing also performs well. It is easier to enforce and more appropriate for visitors than distance-based pricing, but is less directly related to road use and as a result may be perceived as less fair and be less able to be integrated with other technologies.

Time-based and congestion-specific pricing perform less well. Their major weakness is the lack of predictability of the charges levied, which in turn results in perceived unfairness and difficulties in use.

Parking charges perform badly in terms of relationships of charging to road use and hence in perceived fairness. Arrival- and departure-based charges also maintain the need for manual enforcement of on-street parking. Otherwise their performance is similar to that of the road pricing systems whose technology they use.

Overall, it appears that point- or cordon-based and distance-based congestion pricing systems are likely to perform best and to approach the theoretical optimum in terms of achievable benefits.

TABLE 6 Summary Performance of Congestion Pricing Technologies

System Objective	Point/ Cordon	Time	Distance	Congestion-Specific	Parking Arrivals/ Departures	Parking Duration
Congestion relief	+++	?+++	+++	?+++	+	+
Revenue	+++	?+++	++++	?++	+	+
Criteria[a]						
1	++	++++	++++	+++	−	−−
2	++++	++++	++++	++++	++++	++++
3	++++	−−−	+++	−−−−	++++	++++
4	++++	++++	++++	++++	++++	++++
5	−−	−−−−	−	−−−−	−−−	−−−
6	++++	−	+++	−−	++++	++++
7	++++	++++	++++	++++	++++	++++
8	−	−−	−−−	−−−	−−−	−−
9	++++	+++	+++	+++	++++	+++
10	+++	+	+	+	+++	+
11	+++	++++	++++	+++	+++	++++
12	++	++++	++++	++++	++	++++

(continued on next page)

TABLE 6 *(continued)*

KEY:	+ + + +	+ + +	+ +	− −	− − −	− − − −	? Effect uncertain
	Best ———————————————————————————→ Worst						

[a] Criteria as follows (see section on operational criteria):

1, Charges should be closely related to the amount of use made of the road

2, It should be possible to vary prices for different areas; times of day, week, or year, or year; and classes of vehicle.

3, Prices should be stable and readily ascertainable by road users before they embark upon a journey.

4, Payment in advance should be possible, although credit facilities may also be permissible.

5, The incidence of the system upon individual road users should be accepted as fair.

6, The method should be simple for road users to understand.

7, Any equipment should possess a high degree of reliability.

8, It should be reasonably free from the possibility of fraud and evasion, both deliberate and unintentional.

9, It should be capable of being applied, if necessary, to the whole country and to a vehicle population expected to rise to over 30 million in the U.K.

10, The system should allow occasional users and visitors to be equipped rapidly and at low cost.

11, The charge recording system should be designed both to protect individual users' privacy and to enable them to check the balance in their account and the validity of the charges levied.

12, The system should facilitate integration with other technologies, particularly those associated with driver information systems.

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ABBREVIATIONS

GLC Greater London Council
LPAC London Planning Advisory Committee

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Electronic Toll Collection Systems

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A car passes through a toll plaza without coming to a stop. The tag that the driver has installed on his car communicates with a computer located at the tollbooth. The roadside computer identifies this vehicle and decrements the monetary balance on the tag by the amount of the toll. Two months ago the driver went to a tag store and prepaid a few months' worth of tolls with a credit card. The patron could have paid for the tag in cash to ensure privacy but decided that using credit was more convenient. The long lines of patrons waiting to pay tolls have disappeared. The toll agency's revenue collection process is more efficient and more secure. The detailed information about patrons' travel patterns has enabled the agency to try more experimental pricing policies, such as time-of-day flexible fares and discounts for carpools.

This scenario is not a futuristic dream. It describes electronic toll collection (ETC) projects operating today in the United States and around the world. In Dallas, Houston, New Orleans, Denver, and throughout the Oklahoma Turnpike system, agencies have implemented ETC systems, which have reduced congestion and improved the efficiency of revenue collection. Toll agencies in Florida, Illinois, Virginia, California, Georgia, New Hampshire, New York, New Jersey, and Pennsylvania have considered or committed to ETC system implementation. Many others are investigating the feasibility of ETC implementation.

Automatic vehicle identification (AVI) is the technology that makes these ETC systems possible. AVI works by using wireless communications between a tag (transponder) mounted on a vehicle and a sensor located at the roadside or in the toll lane. Sensors can read the information

whether the vehicle is stopped or moving at a high speed. The communication between the tag and the sensor can be one way (read-only) or two way (read/write). AVI can be used for a variety of purposes in addition to the collection of tolls. For example, transponders can be mounted on trucks to eliminate the need to stop at state and national border crossings or on buses and taxis for more efficient fleet management.

Many of the nation's roads (both free and tolled) are well below acceptable levels of service, and mobility is being threatened. Congestion continues to increase, and the option of building more roads is becoming financially and environmentally unrealistic. Many major roads are being planned, built, and redesigned privately and include ETC. There is no single answer to the set of complex transportation problems that confront the nation. However, ETC systems may reduce congestion, improve energy efficiency, improve air quality, and enhance economic productivity at a cost significantly less than additional road construction.

ETC systems are not a distant vision. Many existing systems, products, and services are being tested and implemented. Automation of toll collection can reduce nonrecurring congestion around toll plazas. Reducing congestion and the number of single-occupant vehicles (through toll reduction incentives for carpools and vanpools) will increase the energy efficiency of the overall transportation system (TRB 1991). Emissions will be reduced by smoother traffic flow and greater usage of public transportation and ridesharing. ETC also allows the implementation demand management programs based on road pricing to shift or limit travel demand. Depending on the toll roads' proximity to other available corridors, fares can be increased or decreased to spread the demand across competing facilities that may be over- or underutilized.

TECHNOLOGIES

Available Technologies and Characteristics

All present AVI/ETC technologies operate by (*a*) intercepting modulated electromagnetic radiation from a vehicle, (*b*) recovering the information contained in the signal, and (*c*) using a computer to identify the tag from a data base. The differences among the technologies lie in the ways that these tasks are accomplished. For example, the relatively rapid evolution of AVI transponders used for ETC has progressed from a Type I transponder that can only be read (or reflect a unique vehicle identification when interro-

gated) to a Type II transponder that can be read from as well as written back to in order to store and update unique variable data such as entry/exit locations along a toll road, account balance, vehicle maintenance and inspection reports, and so forth. In the near future, Type III transponders (just beginning to be developed and marketed) will also be able to interact and communicate with the driver (Lacrampe 1991).

Technologies may be divided according to the frequency of the electromagnetic radiation, the method by which the signal is modulated (tuned or adjusted), and whether the vehicle tag generates or simply reflects electromagnetic radiation. There are three frequency ranges in use: very low frequencies (below 200 kHz), which are used in inductively coupled systems; microwave frequencies (500 to 3000 MHz); and optical or near-optical frequencies (30 to 1000 GHz), which include infrared.

Inductive Loop Systems

The only AVI/ETC technology that uses very low frequencies is the inductively coupled system, which uses a loop antenna embedded beneath the surface of the roadway to communicate with a tag mounted on the underside of the vehicle. The roadway antenna sends out an interrogation signal, and the tag responds by returning a signal containing data stored in the tag. This is normally an active (as opposed to a passive) system, since the tag normally transmits its own signal (rather than reflecting the interrogation signal). This is the oldest of all the AVI/ETC technologies.

Optical Systems

Two basic types of AVI/ETC technologies use optical or near-optical frequencies to identify vehicles. The first reads license plates directly and identifies the vehicle from a data base. As the vehicle passes the tollbooth, a video camera forms an image, which is digitized and processed to extract the license plate number. Typically, the image processing can take nearly 1 sec, so that multiple reads to improve reliability are not possible. The second type of optical or near-optical system uses a vehicle tag that is simply a bar code. A laser continuously scans the area where the tag is expected to be, and the reflected signal is processed to extract the code. This image processing is much simpler than trying to read a license plate, since the reflected laser signal represents a one-dimensional image, whereas the video image of the license plate must be processed in two dimensions.

Active Radio Frequency/Microwave Systems

Active radio frequency (RF) AVI/ETC systems use microwave frequencies to communicate with the vehicle. All active RF systems have high data rates, which allow multiple transmissions (redundancy), resulting in increased reliability. These transmissions are commonly known as "handshakes" in the ETC industry. These systems may be divided into those in which the tag generates its own microwave signal (active tag) and those in which the tag simply reflects the microwave signal that it receives (passive tag). Active tags require a power source (battery or connection to vehicle power), whereas passive tags may or may not require a power source. In an active vehicle tag system, the transmitter sends out a very short interrogation signal that triggers the circuitry in the tag. The tag responds by generating a microwave signal containing the data stored in the tag. This signal is transmitted to a receiver that decodes the data, which are sent to a computer for identification.

Passive RF/Microwave Systems

In a system that uses a passive vehicle tag, the transmitter at the tollbooth usually transmits a signal continuously. The signal is intercepted by the tag and reflected to a receiver. The amount of reflection varies (the reflected signal is modulated) according to the data stored in the tag. The received signal is decoded to recover the data, which are then sent to a computer for identification. Passive RF communication is sometimes called the "backscatter" method.

Surface Acoustical Wave

Surface Acoustical Wave (SAW) operates at much the same frequency as RF systems. The primary difference between SAW and RF microwave systems is that the SAW transponder is nonprogrammable. Under the SAW technology, a low-power radio frequency signal from the AVI/ETC reader is captured by the transponder antenna and energizes a lithium crystal, setting up an acoustical wave along its surface. The acoustical wave travels along the surface of the crystal so that etched metal taps can be used to send back a series of time-delayed reflections of the original signal that uniquely identifies a tagged vehicle.

Advantages and Disadvantages

The advantages and disadvantages of the various technologies are given in Table 1.

Technology Performance Testing

Several of the toll collection agencies that have implemented or are investigating ETC systems have conducted some type of performance testing. However, much of this evaluation has been conducted under uncontrolled conditions. Unfortunately, the findings of these evaluations have not been formally documented and published, and in many cases the results are proprietary. Agencies that have performed some degree of ETC technology performance testing include New Hampshire Bureau of Turnpikes, Interagency Group (New York, New Jersey, and Pennsylvania), Illinois State Toll Highway Authority, Orlando-Orange County Expressway Authority, Virginia Department of Transportation, Caltrans, and Florida Department of Transportation.

DESIGN CONSIDERATIONS

Accuracy and Reliability

The possibility of a failure to properly read a vehicle tag due to the presence of an unacceptable level of electrical interference must be considered when implementing an ETC system. Electrical interference can occur in two ways. The first is due to other (non-ETC) transmitters operating on frequencies that are the same or close enough to produce strong interference. Possible sources of this type of interference are cellular telephones, pagers, police and other mobile communications, and radars. The possibility of this type of interference can be minimized by obtaining a Federal Communications Commission (FCC) license for a dedicated frequency. Obtaining an FCC license for a dedicated frequency has two main benefits. First, a larger transmitted power level may be used, and second, a frequency will be assigned that is different from other radio services operating in the same area. An unlicensed system, which uses a nonunique frequency, can only depend on redundancy of transmission to reduce interference and, according to the FCC, "must accept any interference that

TABLE 1 Advantages and Disadvantages of Various Technologies

Technology	Advantages	Disadvantages
Inductive loop systems	There is potential for greater reliability due to proximity of loop antenna and tag Serviceability is simple Potential for electrical interference is low Potential for interference from adjacent lanes is low due to short coupling range Advanced traffic management and traveler information systems can also use inductive loops, so infrastructure is already in place for more IVHS-related projects	Low frequency results in lower maximum data rate, although it is fast enough to allow multiple transmissions to increase reliability There is medium difficulty in duplicating tags Tag usually requires power from vehicle (active tag) Tag installation is not as convenient as that of a windshield-mounted tag The system is more sensitive to environmental conditions
Optical license plate ID	No special vehicle tag is needed License plates are not likely to be duplicated There is no chance of interference between adjacent lanes	The processing algorithms are computation intensive The relatively long time required for image processing precludes multiple reads to increase reliability The system is subject to failure due to dirty or damaged license plates, the presence of bumper stickers and similar text on a vehicle, and reduction of visibility due to rain and fog Reliability is low (80 to 90 percent) due to the complexity involved in image processing The system requires a fully reflectorized license plate

(continued on next page)

TABLE 1 *(continued)*

Technology	Advantages	Disadvantages
Bar code	Reliability is greater than that of systems reading license plates due to the single dimension The vehicle tag, which is just a bar code imprinted on an adhesive strip, is simple Potential for lane-to-lane interference is low due to limited range System is much faster than those that read license plates	Tags are easier to duplicate than for other AVI technologies Rain, fog, and dirt or moisture on tag cause susceptibility to failure The necessity of image processing for finding the returned signal results in less reliability than systems using transponders (microwave systems) The position and speed of the vehicle as it passes the reader are highly restricted
Active RF/microwave systems	Operating range is greater than that of a passive system since the tag is not powered by interrogating beam Reliability is greater than that of a passive system since the return signal from the vehicle is stronger There is less chance of electrical interference since the signals are stronger	Tag circuitry is more complex Lane-to-lane interference is more probable because of the stronger signal The tag must have a battery or be connected to vehicle power

Passive RF/microwave systems	The tag does not have to be connected to vehicle power The tag is less complex than in an active system There is less chance of lane-to-lane interference due to the lower signal power levels	Reliability is lower than for an active system Susceptibility to electrical interference is greater due to lower signal levels The operating range is shorter since tag is powered by the interrogating beam
SAW	It is virtually impossible to duplicate the vehicle tag The tag circuitry is much simpler and thus lower in cost No power is required to operate the tag	The tag cannot be reprogrammed The operating range is limited (up to 15 ft) since it is normally part of a passive system

may be received including interference that may cause undesired operation." However, obtaining a license for a unique frequency through FCC is an extremely difficult process.

The second type of electrical interference in the ETC system is due to improper design or installation. This can occur if the transmitted signal from one ETC lane of traffic is allowed to overlap into another ETC lane, and it can result in multiple recordings of the same vehicle or failure to record vehicles. The remedy for this type of interference is proper design of the ETC system and, in particular, proper selection and placement of all antennas. It also helps if the antenna beam pattern being emitted is well defined.

Metal oxide windshields also can provide attenuation of ETC signal transmission. Some luxury cars are being equipped with a metal oxide coating on the windshield. This coating reduces solar radiation by 30 percent and ultraviolet radiation by 45 percent, resulting in improved air conditioner performance and prolonged interior material life. The metal oxide coating causes disruptions and weakening, or attenuation, in ETC signals that must pass through the windshield. (Other types of windshields, such as variable tint and InstaClear, can cause some problems for ETC as well.) At this time it is not certain how widespread the use of metal oxide windshields will be by the time ETC systems are deployed throughout the United States. Currently, industry experts estimate that less than 2 percent of the nation's vehicle fleet is equipped with metal oxide windshields. However, it is an important implementation issue to consider. It is expected that the disruptions caused by metal oxide can be minimized by adjusting the placement of the transponder/tag (i.e., exterior mounting location).

The reliability of AVI/ETC tags can be affected by the method of tag installation. For guaranteed reliability, vendors prefer, and sometimes require, that tags be permanently mounted by experienced toll agency personnel. However, for patron convenience, some tags are installed such that they can be removed. This convenience may cause "misreads" when tags are incorrectly placed. It is believed that a severely angled windshield may also affect performance reliability, and thus placement of transponders is critical in this situation (higher location for mounting is generally better).

The actual reliability of ETC technology varies. Most vendors claim reliability in the range of 99.95 to 99.99 percent. However, recent field performance evaluations conducted by the Center for Urban Transporta-

tion Research (CUTR) in Florida and the Interagency Group in New York indicated average reliability for various technologies to be slightly below this range. Depending on the vintage, conventional toll collection equipment has been known to operate in the 93 to 98 percent reliability range.

Traffic Operations

Traffic operations with and without ETC will differ significantly. In particular, current conventional treatments and methods for vehicle classification, toll collector safety, toll lane gates, and advance signing and channelization will need to be reevaluated. The issue of dedicated versus mixed-use lanes for ETC is dependent on two basic characteristics: capacity by lane type and the expected levels of ETC participation.

Capacity by Lane Type

Existing and future toll plaza lanes can be categorized into five basic lane types: attended, automatic, mixed AVI, dedicated AVI (within a conventional plaza), and express AVI. Attended toll lanes require all toll transactions to be handled by a toll collector. Automated lanes collect tolls by providing coin machines. Mixed AVI lanes combine AVI with toll collection that is either manual or automatic, or both. Dedicated AVI lanes are contained within conventional toll plazas but permit AVI patrons only. Express AVI lanes are physically separated from all other types of toll lanes, permitting free-flow speeds [55 mph (89 km/hr) or more].

Capacities for attended, automatic, and mixed AVI lanes were determined from observations and counts from existing toll facilities such as the Florida Turnpike, Tampa Crosstown Expressway, the New Jersey Turnpike, and the Dallas North Tollway. Capacities for automatic lanes were determined from Florida Turnpike automatic lanes, which all have gates. No other capacities were determined for lane types with gates. Average capacities are typically reduced by 10 to 20 percent when gates are used on automatic lanes. The higher capacity effect due to increased gate sensitivity is not known at this time. Capacities for mixed-use AVI lanes were obtained from observations on the Dallas North Tollway. Mixed AVI lanes at this site include AVI on both manual and automatic lanes (with no gates). Capacities for dedicated AVI and express AVI lanes were estimated on the basis of reasonable average speeds and vehicle spacing (i.e., headways). Figure 1 shows the general relationship of average capacity for the

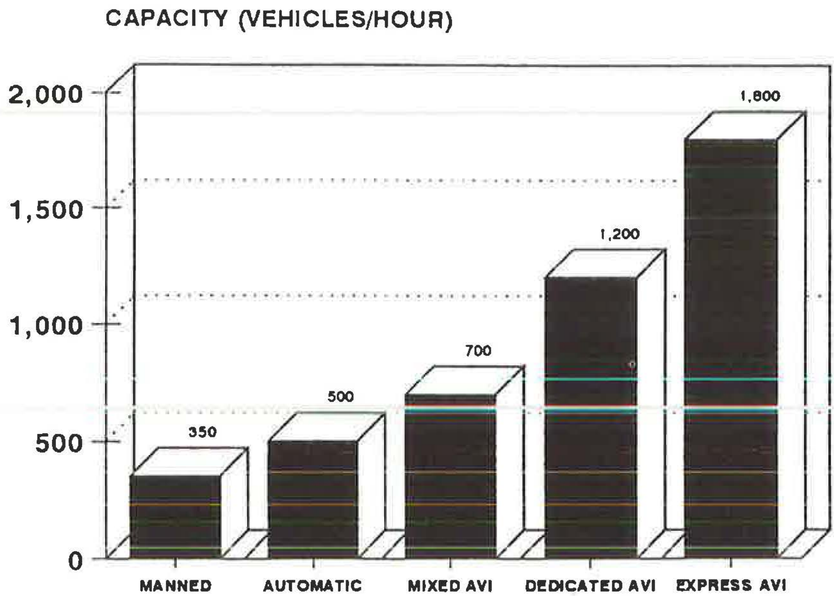

FIGURE 1 Average capacity, toll plaza lane types. (Source: average of counts obtained from Florida Turnpike, New Jersey Turnpike, and Dallas North Tollway. Express lane is Level-of-Service D capacity on freeway lane.)

basic types of toll plaza lanes. Depending on plaza lane configuration, the inclusion of ETC has the potential to increase conventional plaza lane capacity by 50 to 160 percent.

Levels of ETC Participation

Actual patronage levels for ETC are extremely difficult to estimate. Therefore, full use of toll lanes that are retrofitted with AVI or physically separated from the conventional plaza for express AVI usage can only be assumed, for an estimated level of ETC participation. The highest current ETC participation rates being experienced are on the Lake Pontchartrain Causeway in Louisiana (80 percent); Treasure Island Causeway (60 percent) and Bay Harbour Island Causeway (40 percent), both located in Florida; the Oklahoma Turnpike (40 percent); and the Dallas North Tollway (25 percent). These levels of ETC participation do not come without some additional cost for marketing or publicity, such as the professionally operated, high-profile tag purchasing store in Dallas. Likewise, ETC

patrons using the Lake Pontchartrain Bridge enjoy a 50 percent discount from the cash price for tolls.

Serviceability and Maintenance

The frequency, extent, and costs associated with the serviceability (operations) and maintenance of AVI/ETC systems are difficult to assess, primarily because working AVI/ETC systems have not been in operation long enough to establish these factors. In general, on the basis of very limited maintenance cost data, maintenance costs per lane associated with ETC appear to be about 10 to 20 percent less than conventional toll lanes. Costs related to employee salaries, which constitute most operational costs, would obviously not be associated with ETC lanes.

Regulation

Analysis is needed to determine the communication-related requirements for ETC product areas. Designs should be selected to minimize the number of communication technologies, and it may also be important to consider the same communication frequencies for other traffic control and information systems. RF spectrum matters usually involve extensive analysis as well as negotiation. A number of regulatory agencies, processes, and requirements could affect the rate of ETC deployment. If an already dedicated portion of the RF spectrum is needed, a long process may be needed for approval (GAO 1991). In September 1992, IVHS America began discussions and negotiations with FCC spectrum allocation. Although no spectrum has yet been dedicated to ETC usage, most existing systems operate in the 900- to 930-MHz band, which is dedicated to industrial, scientific, and experimental usage. Several frequencies in this bandwidth are currently licensed to personal communication services manufacturers and providers (e.g., pagers, mobile cellular phones). Interference with these and other similar devices has already been experienced in the testing and evaluation of ETC systems. Assignment of a bandwidth not currently used by ETC systems would cause additional investment in research and development before other ETC systems could become operational (TRB 1983).

INSTITUTIONAL AND IMPLEMENTATION ISSUES

Ownership Arrangements

There are three major ownership arrangements to consider in negotiating the implementation of an ETC system: ownership and operation by the agency, ownership and operation by a vendor, and various lease agreements. Each of these arrangements is characterized by numerous advantages and disadvantages. ETC vendors are usually flexible with respect to the administrative arrangement that is selected for the ownership and operation of an ETC system. However, the ability of a toll agency to select an arrangement is controlled by the agency's charter. In some instances, an agency is not permitted to subcontract the responsibility of fare collection. This would limit the ability to subcontract ETC under the vendor operation arrangement.

Ownership and Operation by Agency

In this ownership arrangement, the toll or traffic management agency would purchase the entire ETC system and then operate the system independent of the vendor. All responsibilities would be with the implementing toll facility with the exception of warranties and maintenance agreements.

Ownership and Operation by Vendor

This arrangement involves the authority hiring an independent contractor to install, operate, administer, and maintain the ETC system. A typical vendor ownership arrangement would preclude the applicable toll facility from purchasing any AVI equipment or software. An arrangement could be made whereby a vendor could be paid a flat fee to install, administer, and operate the system, or, once the system became fully operational, the facility could be required to pay a fee for each transaction processed through the ETC system. This fee could then be passed on to the patrons in the form of premium tolls, unless a volume discount can be provided. In addition, each ETC patron could be required to pay a monthly fee for the use of the AVI tag. This arrangement could also tie into a lease-purchase agreement after a time period agreed upon by both parties.

This type of arrangement can be termed an operating or service lease, since it provides for financing, operation, and maintenance. One advantage of an operating lease is that it frequently contains a cancellation clause, which gives the lessee the ability to cancel the lease and return the equipment before the expiration of the basic lease agreement. This type of agreement is already being used on the Dallas North Tollway in Dallas, Texas.

Lease Agreements

There are numerous lease arrangements in which an agency could become involved. A lease arrangement results in sharing responsibilities between the agency and the independent contractor. The burden of these responsibilities would be negotiated in the lease contract. Probably the most popular type of lease arrangement gives the implementing agency the choice of purchasing the equipment at the end of the lease agreement.

Cost Considerations (CUTR 1990b)

Lane Construction Cost and Right-of-Way

Industry standards suggest that the engineering and construction cost for the average toll lane ranges from $150,000 to $750,000, plus the cost of the booth and equipment placed in the lane. Costs will vary significantly by region and location throughout the United States. This estimate includes planning, concept design, lane construction, right-of-way, and other associated lane construction costs.

Cost of Equipment by Lane Type

Table 2 gives costs for various lane types including manual lane, automatic coin machine, AVI dedicated lane (retrofit), mixed-use lane (AVI and manual), and mixed-use lane (AVI and automatic coin). Costs were averaged on the basis of several toll agency bids for AVI lane equipment procurement obtained during the last 18 months. Equipment costs for AVI on a per lane basis are typically less than 30 percent of the cost for conventional toll lane equipment.

Operating and maintenance costs by lane type (given in Table 2) are based on Florida averages for conventional lanes and system averages in Dallas and Oklahoma for ETC-related operations and maintenance. The

TABLE 2 Equipment, Operating and Maintenance Costs by Lane Type

LANE TYPE	LANE EQUIPMENT COSTS PER LANE	OPERATING & MAINTENANCE COSTS PER LANE
Manual	$58,500	$141,900
Automatic	$58,000	$43,300
Manual/Automatic	$107,500	$111,000*
Manual/AVI	$72,700	$146,100
Automatic/AVI	$69,500	$47,500
Manual/Automatic/AVI	$121,300	$115,200*
AVI Dedicated	$15,400	$4,200
Express AVI	$15,400	$4,200

* Based on operation at 16 hrs Manual & 8 hrs Automatic Coin

Source: Florida Toll Operations Office (conventional lanes), and Dallas North Tollway and Oklahoma Pikepass, and related industry bid tabs (AVI lanes).

cost estimates provided are extremely conservative in nature to virtually eliminate any possibility of underestimating equipment costs. The equipment depicted under each configuration assumes the maximum use of various equipment components. Some of the equipment would certainly be optional depending on the specific location and configuration. On a per lane basis, operating and maintenance costs for AVI are between 3 and 10 percent of conventional toll lane operating and maintenance costs (CUTR 1992).

Transponder Cost

The unit price to the agency of a one-way, read-only radio frequency transponder ranges from $5 to $50, depending on the technology, the vendor, and the quantity of transponders purchased. Type III transponders, mentioned earlier, cost more. Alternatively, the unit price of a bar code decal ranges from $1.00 each for large quantities (100,000) to $2.00 each for smaller quantities (2,000 to 3,000).

Patron Payment Options

In evaluating payment systems, there are three areas to be reviewed: prepayment versus postpayment, actual methods of payment (cash, check, or credit card), and toll fare structures.

Prepayment Versus Postpayment

An ETC system requires either pre- or postpayment of tolls. The operational procedures for these two methods are quite different. In an ETC prepayment toll system, ETC users establish individual accounts with a prepaid balance by cash, check, credit card, or electronic funds transfer. Subsequently, when the patron passes through a toll lane with ETC equipment, the toll amount is debited (subtracted) from the user's prepaid account balance. The postpayment system operates differently. It is based on a billing process whereby the ETC user is charged on the basis of actual usage of the toll system in the preceding month.

In evaluating pre- and postpayment toll systems, there are numerous implementation costs and issues to be considered. A prepayment system requires the establishment of locations for opening and replenishing ETC accounts. Locations can be at various fixed office sites or advertised mobile van sites. Accounts opened and replenished through the mail can also be processed at the office sites. At a fixed office site, an ETC service center could be established. Costs associated with the center would include but not be limited to construction costs or leasing costs, operational costs, computer costs, and maintenance costs. Another option is a program whereby opening of accounts and distribution of tags could be accomplished through the mail. The mail program would still require a central processing location. A final option is to dispatch a mobile unit to register patrons.

In considering a postpayment plan, additional operational costs would need to be evaluated, including monthly statement account mailings and collections on delinquent accounts receivable. The collection process is viewed by many to be time-consuming and undesirable. The San Diego Coronado Bridge is one of the few systems to have offered a postpayment option. During a trial period last year, patrons were allowed to settle accounts after a certain amount of debt was incurred. The trial was a success; however, the San Diego system was a demonstration project only and has never been implemented on a full scale.

Payment Methods (CUTR 1990a)

ETC-generated tolls can be paid by cash, check, electronic funds transfer, or credit card. In addition, tolls can be either prepaid or postpaid (billed). According to a survey of patron perceptions taken in Florida, most potential ETC customers preferred prepayment. Generally speaking, one would

assume that the user would prefer postpayment and the agency would prefer prepayment. In Oklahoma, 90 out of 180,000 patrons use a postpayment option, but that is only provided the payment is made in cash. Unless the toll agency also desires to assume the added responsibilities of bill collection, a postpayment option should not be considered.

Prepayment of ETC-generated tolls by cash may require that the patron visit an AVI center once to open an account and subsequently to replenish the account (unless this service is available by mail). Prepayment by check can be accomplished either by visiting the ETC center or by using a mail program. Prepayment by electronic funds transfer requires that the patron visit an ETC center only once to open an account (unless this service is available by telephone). An agreement is signed that allows funds from the patron's bank to be automatically transferred to the patron's ETC account when a preset minimum balance is reached.

Prepayment by major credit card is the same as by electronic funds transfer except that the patron's account is replenished by charging a credit card. Since the use of electronic funds transfer and credit cards does not require the handling of money, operational costs are reduced and implementation and maintenance of the payment program are simplified.

Currently, most operators of ETC toll facilities accept cash or check for payment of tolls. These are the most popular toll payment options. The number of toll facilities that also accept a credit card or electronic funds transfer varies. For example, Houston ETC patrons may use Discover cards for fare payment. Dallas North Tollway offers patrons the option of opening an anonymous account under which all transactions can take place without providing the ETC toll facility personal information.

Toll Structures (CUTR 1990a)

There are three AVI toll structure options. The first is to charge premiums in addition to existing tolls. Advocates of premium tolls believe users of ETC should pay an extra charge for these special services. The second option is to discount existing tolls. Advocates of discounted tolls believe users need to be encouraged to use ETC by offering discounts on services. They also contend that increased patron participation resulting from discounts would fully offset any declines in revenue. Experience from the Oklahoma Turnpike indicates that reduced personnel expenses more than offset the 25 percent discount for ETC. The third option is to keep the toll structure the same, neither offering discounts nor charging premiums. Advocates of the third option contend that implementation problems

would not exist and any governing legal documents would not need to be reviewed for compliance.

Premium and discount toll structures were found to be equivalent in ease of implementation and associated costs. An extensive marketing campaign would be needed to educate potential ETC patrons on the new toll structure. An accounting and billing program would need to be instituted to keep track of patron toll charges and payments. Additional signage and literature detailing the new toll structure would need to be purchased, installed, and published.

Information based on experiences of existing ETC systems is not widely available for evaluating toll structures. The Dallas North Tollway is the only large-scale functioning ETC system charging premiums. Careful consideration must be given to area demographics, traffic volume, and unique system characteristics before applying this system elsewhere. On the other hand, most other ETC systems, large and small, offer discounted tolls. Most systems confirmed that discounts encourage ETC patronage. The Harris County Toll Road Authority reduced fares by 50 percent on its Hardy Toll Road during non-peak-hour periods only and experienced a 20 percent increase in ETC participation during nonpeak periods (Harris County Toll Road Authority 1992). Oklahoma Turnpike experienced a 20 percent increase in ETC participation after offering a 30 percent discount from cash toll rates.

System Benefits

Throughput Efficiency

The implementation of ETC will increase toll lane capacity, reducing toll processing time and queue lengths at toll plazas. Most important, ETC can substantially reduce or, in some cases, eliminate the need for expansion of toll plaza lanes. Depending on the participation rate for ETC, the reserve capacity for plaza lanes can be "banked," and additional right-of-way may not be needed. Significant cost savings can be realized, especially in urban areas (Chang et al. 1991).

Payment Alternative for Patrons

ETC allows toll patrons more flexibility and convenience in paying tolls. The opening of prepayment accounts eliminates the need for patrons to be concerned with having cash ready for each toll plaza passage. Prepayment

provides patrons the flexibility of paying tolls by cash, check, credit card, or electronic funds transfer. ETC reduces the need for the handling of hard currency by toll system operators. Furthermore, commercial users of ETC are given a faster and more reliable way to track when and where their vehicles use the toll system.

Environmental Issues

Pollution in any form is a great concern of environmental groups, and as gas prices rise, fuel consumption will become a priority among ETC patrons. Dedicated AVI/ETC lanes can eliminate the need for vehicles to stop at toll plazas, which can reduce noise pollution, air pollution, and fuel consumption. Fewer vehicles stopping means less gear shifting during acceleration. In the case of trucks and other heavy vehicles, this could dramatically reduce noise pollution.

Reduced Construction Costs

An agency can select among three alternatives when a plaza is at or near capacity: expand the number of lanes at the plaza, increase traffic through the existing configuration, or accept a lower level of service.

Acceptance of a lower level of service is unlikely due to the loss of revenue and reduction in safety that would likely occur. Expansion of the plaza has typically been the solution implemented in toll facilities across the United States. However, expansion involves significant capital outlays. In addition, in many cases expansion may be impossible because no right-of-way is available. A third alternative is the implementation of ETC on the existing configuration, which can significantly increase capacity. The increase in capacity can significantly reduce lane construction that may otherwise be necessary. Perhaps an even more feasible alternative is to implement ETC in conjunction with some expansion, as was done on the Florida Turnpike.

Reduced Operating Cost

The operating costs associated with a typical manual lane include maintenance of the lane equipment, collector and supervisor salaries, auditing functions, banking and cash handling, and the lighting and environmental control of the booth that houses the toll collector. Similarly, the costs of operating an automatic coin machine lane include those associated with maintaining the lane equipment, supervisory salaries, auditing, and bank-

ing and cash handling. For each manual lane eliminated as a result of ETC, these operating costs will be significantly reduced. The collection costs for an ETC system include those associated with maintaining the ETC equipment, issuing tags, and servicing accounts. In addition, the system operates 24 hr per day. These collection costs will be partially offset by amounts collected as part of the sale or lease of the tags and the interest realized on prepayments and deposits.

Psychological Benefits

Several nonquantifiable benefits can also be attributed to ETC implementation. These include nonuser benefits, non-peak-hour ETC user benefits, potential for variable (or congestion) pricing of tolls, and shared commuting costs with increased ridesharing. Non-ETC patrons would benefit to some degree by less overall plaza congestion, particularly in mixed-use lanes. Since differences in vehicle delay cost are typically considered for the peak-direction, peak-hour analysis, additional benefits can be expected in the nonpeak direction and during nonpeak time periods. As other facilities become congested, variable toll pricing (reducing normal toll rates) can be used as an incentive for patrons to divert their travel to the uncongested or less congested toll facility. ETC can also be an incentive for ridesharing, since travel costs could be shared more conveniently (Fleming 1991).

Standards and Protocols

The communication, software, and hardware industries, all suppliers of ETC technology, play a crucial role in successful long-term product development and broad-based consumer acceptance. Establishing standards too early can stifle innovation. However, the ETC industry cannot realistically be expected to curtail product development while waiting for nationwide standards to be defined.

The state of California has taken the first steps toward ETC technology standardization (*Inside IVHS* 1992). However, the California state standard cannot currently be achieved by many technologies. As a result, a group of local toll authorities and vendors have gained an exemption from the new state standard. The exemption permits toll agencies to use ETC equipment that does not comply with the state standard for a period no longer than 5 years. Meanwhile, Caltrans is forging ahead with procurement of state-specified ETC equipment. According to Caltrans, the ex-

emption allows for an interim ETC system to be installed to appease the investment community and demonstrate ETC cost-effectiveness.

Benefits to be gained from standardization at the appropriate time include the following:

1. Interchangeability of system components,
2. Elimination of unnecessary product development costs caused by changes in product interaction,
3. Fostering of areawide deployment,
4. Promotion of application stability, and
5. Establishment of a basis for liability limitation.

The standards process for ETC systems and technologies has already begun, although no specific standards have been established. An IVHS America Committee on Standards and Protocol has been established. The purpose of the committee is to serve as an oversight and coordinating agency for all standards activities in the United States relating to ETC. The committee does not expect to create or promulgate standards itself, except as a last resort. Rather it will rely on other established standards-generating bodies (e.g., ANSI, ISO, IEC, ASTM, SAE, IEEE, etc.) to carry out the work of defining, publishing, and securing industry acceptance of standards. The objective of the committee will be to ensure that appropriate attention is given to ETC needs, promote effective communication among standards-interested parties, and minimize duplication of effort. Specifically, the committee will perform the following tasks:

- Determine the most appropriate group to set a given standard;
- Identify all ETTM interfaces, subsystems, and elements that require standards;
- Act as a liaison in international standard efforts;
- Encourage the inclusion of standards and protocols in the definition of future operational tests;
- Adopt or upgrade existing standards whenever required;
- Assist organizations responsible for the tests in defining, acquiring, and analyzing standard-related data; and
- Coordinate standards-related information between operational tests and standards-making organizations.

As an example, the committee is already working with the Society of Automotive Engineers Map Database Standards Committee. Several

other organizations, such as the American Society for Testing and Materials, have also established committees for the standardization of these technologies.

PRIVACY AND LEGAL ISSUES

Enforcement

ETC lane violations are important both to the customers, because of the delays and inconvenience that violators can create, and to the agency, because of lost revenue. A successful ETC system will probably need a high-speed video camera system to deter violators. Most states where ETC systems are located have passed laws enabling ETC violators to be legally identified and cited on the basis of videotape evidence.

In Colorado the toll authority entered into an agreement with local law enforcement specifically for the prosecution of ETC violators who will be using the new E-470 toll highway. As another example, speeding tickets are being enforced in Pasadena, California, by using a photographic system called PHOTO-COP. This system photographs speeders and sends a preprinted citation through the mail. State laws allowing pictures generated from remote video cameras to support prosecutions are not uniform. However, Illinois is the first state to win conviction of a driver using this evidence. Photo enforcement has been used in Europe for almost a decade. A photo enforcement component was added to the toll collection system of Zurich, Switzerland, in 1983. Several years ago, ETC patrons incurring violations on the Dallas North Tollway were sent numerous letters detailing their alleged violations. It took Dallas patrons only a short time to realize that evidence generated from the tollway's video cameras was not supportable in the state court system. At this point, violators on the Dallas North Tollway continue to be issued citations on site by state highway patrol officers. No video enforcement legislation has yet been proposed. The laws in New York are another example. Legislation was recently passed in New York detailing the need for an "enforcement agent" to witness the patron avoiding the payment of toll and to issue a summons at that time. Florida has a similar situation. The infraction must be witnessed by an officer, and the citation must be issued to the driver of the vehicle avoiding the toll and not the registered owner of the vehicle. Toll violation enforcement legislation was recently passed in the state of Florida. This

legislation will provide for photographic imagery as evidence against an alleged toll violator.

Video camera equipment is an important part of the ETC enforcement system, and specifications should be reviewed carefully. All lanes should contain remote-control, high-speed video cameras. This enables the recording of all lane violations, whether the lane is open for operation or not. As a violation occurs, the camera is actuated. It records the offending vehicle, its license plate, the lane's traffic signal, and the violation indicator as the vehicle travels over the lane's exit loop. It is believed that some cameras in operation can provide legible vehicle license plate pictures for speeds up to 100 mph (161 km/hr). The specific capabilities of the video cameras and related equipment should be flexible to meet the needs of various ETC systems. However, all video enforcement systems should detail on the video picture the date and time of the infraction and the lane number where it occurs. The system-generated video picture should also be recorded on a computer disk and retrieved when a hard copy of the picture needs to be reviewed. The software that drives the operation of the video lane cameras should trigger the cameras to record not only when nonpayment violations occur but also when a vehicle passes that is using a reported lost or stolen tag, when the patron's account is below a predetermined minimum balance, when the account has been suspended, or when the axles classified do not match the treadle count indicated.

Security

ETC will allow toll agency operators to automate cash transactions through automatic debiting and electronic funds transfer. As ETC participation increases, more and more of the total revenue collection process will be performed automatically. Reconciliation of each transaction can be isolated and checked more readily, and audit trails generated by system software will deter collector fraud and misreporting. However, integration of conventional and ETC accounting reports poses a very challenging task.

Privacy and Equity

Appropriate safeguards and guidelines on the control and use of ETC information must be established to protect the privacy of individual vehicle users. On the other hand, according to surveys conducted among San

Francisco Bay Area motorists, only 7 percent of the respondents indicated a strong concern that electronic tags could permit tracking of their vehicles. The law of privacy regarding information that is collected through electronic means is undergoing rapid change. The Electronic Communications Privacy Act (ECPA) was adopted in 1986 to protect wire or electronic communications from illegal interception by unauthorized third parties. This act creates standards and procedures for court-authorized electronic surveillance, regulates when electronic communication firms may release information, and provides legal protection of the privacy of stored electronic communications from intruders and unauthorized government officials. Because of changes that have occurred in the last 5 years, a major revision of the ECPA is under consideration. The revision may include privacy protection for ETC travelers. In most places, toll road use is essentially voluntary because toll roads usually run parallel to a "free" facility. In addition, participation in an ETC system is voluntary. A driver who does not want to be tracked or photographed can use the "free" facility or pay in cash.

The implementation of an ETC system creates alternative methods for customer payment, and the possibility also may exist for discounts or premiums for ETC users. As stated previously, an ETC account may be initiated through cash, check, or credit card down payment, and in selecting a method of payment patrons should not have to face discrimination. For example, if the only form of payment or account replenishment is through a major credit card, as in Denver, some potential patrons may be excluded from participation. Also, if ETC patrons are required to pay an additional transaction fee (as in Dallas) or get a reduced toll fare (as in Oklahoma), further discrimination may result. The toll agency bond indenture must be reviewed carefully to assess the legal options, if any, that can be offered to toll patrons. If it can be proved to the bondholders that projected revenue will not be jeopardized, payment and transaction options can be created.

Other Legal and Institutional Issues

There are a number of other legal and institutional issues that could greatly affect ETC deployment: product liability and other tort liability, antitrust, procurement, and intellectual property rights. Liability doctrines and practices may significantly deter private-sector designers and manufac-

turers from developing new technologies and introducing them to the surface transportation system. Exposure to risk of expensive product liability suits raises the cost to the private sector. Vehicular accident cost, primarily borne by the driver today, may fall on ETC product manufacturers.

There has also been some uncertainty about the extent to which antitrust law applies to collaborative research. Although the United States is more concerned with industrial collusion than are the Japanese or Europeans, in reality there is a wide latitude in the types of ETC research activities that can now be undertaken. Another issue is how toll agencies may effectively fund productive, creative research and development and whether current contracting and procurement practices support or delay that goal.

CURRENT STATUS OF ETC PROJECTS

According to IVHS America and previous CUTR research there are currently 22 ETC facilities/systems operating or under development in the United States. Tables 3 and 4 give the operating and planned ETC projects by location. Table 5 indicates the characteristics of ETC systems, as compiled by the International Bridge, Tunnel, and Turnpike Association (IBTTA) in its 1993 survey.

FUTURE TRENDS

The transportation system has shaped U.S. society. Cities are built, houses are bought, and jobs are chosen on the basis of the premise that the transportation system provides reasonable mobility. In recent years, however, the ability to travel freely in many areas has become constrained by congestion, the cost of highway travel, and the financial problems that reduce the services offered by public transportation. Despite soundly engineered roads, mobility is declining and safety is at risk. The U.S. transportation system is at a crossroads. Public transit, which should be a relief and a welcome alternative, is too often viewed as an unattractive alternative to driving. Commercial vehicles spend significant time not moving efficiently but waiting in line to be weighed, paying tolls, and handling paperwork. Furthermore, mobility and safety have depended on decisions by individual drivers who based their decisions on past experience

TABLE 3 Operating Electronic Toll Collection Projects

Project Name	Description
Dallas North Tollway - TX	The system is 17 miles in length with 62 toll stations equipped with coin counting and AVI equipment, encompassing all of the toll collection stations and plazas. Technology: Radio Frequency (RF) - Amtech
Greater New Orleans (GNO) Bridge and Lake Pontchartrain Causeway - LA	The GNO bridge consists of two parallel bridge spans of four and six lanes each. The six-lane east bank span is a 12-lane AVI-equipped toll facility. Technology: Radio Frequency (RF) - Amtech
San Diego-Coronado Bay Bridge - CA	In late 1988, a six month AVI test was conducted to determine the feasibility of implementing an AVI system at each of the other nine toll bridges in the state. The project began with 1,000 volunteer users, but this demonstration has now ended. Technology: Radio Frequency (RF) - X-Cyte
Grosse Ile Bridge - MI	The system has two two-lane, two-way bridges that provide the only access to the primarily residential island. The northern most point of the two bridges is an AVI equipped facility. Technology: Surface Acoustical Wave (SAW) - X-Cyte
Pinellas Bayway - FL	The system is a series of causeways and bridges that connects the lower Gulf Beaches of Pinellas County, with three toll collection points on the 15.2-mile facility. AVI users comprise 30 percent of the total Bayway users. Technology: Bar Code - LazerData

(continued on next page)

TABLE 3 *(continued)*

Project Name	Description
Treasure Island Causeway - FL	The system consists of a single toll plaza with two east lanes and two west lanes, all of which are equipped for AVI use. Approximately 16,000 AVI passes are purchased annually for use on this facility. Technology: Bar Code - Leased from Automatic Toll System
Sanibel Causeway & Cape Coral Bridge - FL	**Sanibel Causeway is comprised of two manned booths and one unattended lane. Tolls are collected in one direction only, as motorists are traveling to Sanibel Island.** The Cape Coral Bridge toll plaza consists of four manned booths and six unattended lanes. Tolls are collected both directions. Technology: Bar Code - Automatic Toll Systems & LazerData
Broad Causeway - FL	The Broad Causeway connects the Bay Harbor Island to mainland Florida, about 10 miles north of Miami. Bar code readers can identify a car traveling at 6 to 7 miles per hour. Technology: Bar Code - Cubic Toll Systems
Delaware River Port Authority - PA	The Delaware River Port Authority owns and operates four toll bridges in the greater Philadelphia area. AVI patronage on all four bridges is 30 percent of total traffic. Technology: Bar Code - LazerData
Port Authority of New York and New Jersey - NY,NJ	The Lincoln Tunnel AVI lane, used by buses only, was established to expedite bus movement entering Manhattan on weekday mornings. Approximately 3,000 buses are equipped with transponders travelling 1.5 miles on a dedicated contraflow lane for buses only. Technology: Radio Frequency (RF) - Amtech

Nassau County Bridge Authority - NY	The system consists of a 11-lane toll plaza with two lanes in each direction that have been retrofitted with AVI equipment. Technology: Bar Code - LazerData & Automatic Toll Systems
Maryland Transportation Authority - MD	The Thomas J. Hatem Memorial Bridge (1.6 miles) is an eight-lane toll bridge with two lanes in each direction that are designated for AVI purposes. Technology: Bar Code System
Express Toll - E-470 Public Highway Authority - CO	E-470 is a 5.5 mile four-lane highway just outside of the metropolitan Denver area. The facility is equipped with manual, automatic, and AVI toll equipment. This is the only facility that was designed with AVI in mind. The facility has two lanes in each direction exclusively for AVI operating at 55-60 mph. Technology: X-Cyte
PIKEPASS - Oklahoma Turnpike Authority - OK	The Oklahoma Turnpike system is comprised of six rural interstate routes totaling 478 miles with 37.9 million transactions per year. Amtech has been selected to handle the installation of an AVI system. Technology: Radio Frequency (RF) - Amtech

Source: Compiled from previous Center for Urban Transportation Research reports and telephone interviews of agencies.

TABLE 4 Planned Electronic Toll Collection Projects

Project Name	Description
Dulles Fastoll - VA, D.C.	The System is a 13-mile east-west toll facility, currently handling over 125,000 vehicles per day. VaDOT has selected Kiewit Technologies as their vendor. Technology: Radio Frequency (RF) - TIRIS-I
E-Zpass Interagency Group - NY, NJ, PA	The Interagency Group is made up of 7 toll agencies in the region that have decided to test, procure, and use a unified AVI system. The group is now testing Mark IV and Amtech.
Illinois State Toll Highway Authority - Il	The Illinois State Toll Highway Authority has tested several technologies. The Authority issued an RFP for the "Design, Installation and Testing of a Pilot AVI Toll Collection System." AT/Comm has been selected.
Orlando/Orange County Expressway Authority (OOCEA)- FL	The OOCEA will conduct a 60 day acceptance test of Mark IV/SAIC. Original installation was planned for September, 1992 but has been delayed. Technology: Radio Frequency (RF) - Mark IV/SAIC
Rickenbacker Causeway - FL	The Dade County Public Works Department is planning to install AVI on bridges which connect Virginia Key, Key Biscayne and Miami Beach to the mainland. The Department has sent out a preliminary bid for vendors; responses are due April 1993. Technology: read-only with capability to expand to read-write

Sam Houston Tollway and Hardy Road Tollway - TX	The agency which manages this pair of tollways has selected Cubic as their prime vendor. Operation began October 1992. Technology: Radio Frequency (RF) - Amtech
Caltrans Bridges - CA	California Department of Transportation has sent out an RFP for AVI on seven of its bridges; responses are due April 1993. Technology: modulated backscatter Radio Frequency (RF)
Georgia 400 - Georgia State Department of Transportation	6.4-mile extension of 6-lane State Road 400, just north of Atlanta, will have one toll plaza with 9 lanes in each direction. Seven lanes in each direction will be mixed AVI, and two lanes in each direction will be dedicated AVI. Anticipated opening date is July, 1993. Technology: Read-only, radio frequency (Amtech)
California Private Toll Roads	Four proposed private toll roads (one east of San Francisco, one south of San Diego, and two southeast of Los Angeles). Franchise teams are seeking the necessary environmental clearances. Most ambitious private road building program in the U.S.

Source: Compiled from previous Center for Urban Transportation Research reports and telephone interviews of agencies.

TABLE 5 ETC System Characteristics

Project Name	ADT	% ETTM	Lanes	Vendor	AVC	Enforcement	ETC Discount
E-470 Public Highway	3,250	43%	4 dedicated 2 mixed	X-Cyte	Yes	video camera	none
Lake Pontchartrain Causeway	22,500	60%	6 mixed	Amtech	No	manual	50% discount
Crescent City Demonstration	60,000	30%	3 dedicated 9 mixed	Amtech	No	none	30% discount
Thomas Hatem Bridge - MD	21,382	80%	5 mixed	LazerData	No	automatic gates	none
Oklahoma Turnpike	100,000	32%	46 automatic 56 dedicated 117 mixed	Amtech	Yes	video camera	30% discount
Lincoln Tunnel	57,313	3% buses only	12 manual 1 dedicated	Amtech	No	video camera	10% discount
Dallas North Tollway	196,700	25%	4 dedicated 59 mixed	Amtech	No	video camera	none

E-Zpass Interagency Group	2.6 million	30%	277 manual 273 automatic	not decided	Yes	video camera* & manual	yes, amount not decided
Private Toll Roads - California	697,108	30%	73 manual	not decided	Yes	video camera	yes, amount not decided
Florida Turnpike	407,000	20%	32 dedicated 213 mixed	not decided	Yes	video camera*	none
Golden Gate Bridge	113,550	45%	11 manual	not decided	No	video camera	probably
Illinois State Toll Authority	694,366	25%	179 manual 49 automatic 167 mixed	not decided	No	video camera	none
New Hampshire Turnpikes	195,700	40%	34 manual 13 automatic 31 mixed	not decided	Yes	video camera	yes, amount not decided

(continued on next page)

TABLE 5 *(continued)*

Project Name	Number of Tags Issued	Deposit Required	Available At	Payment Options	Pre-Payment	Minimum Balance
E-470 Public Highway	1,460	$20 tag	toll plaza	check, credit	Yes	$5
Lake Pontchartrain Causeway	11,500	$25 tag	tag store	cash, check, credit	Yes	$5-$20
Crescent City Demonstration	25,000	$25 tag	toll agency	cash, check, credit	Yes	$10
Thomas Hatem Bridge - MD	110,000	$2 tag	N/A	cash, check	N/A	N/A
Oklahoma Turnpike	99,553	$30 tag	retail mall outlets	cash, check, credit card	Yes	$40
Lincoln Tunnel	55,752	$60 tag	bill by mail	cash, check, credit card	Yes	2 months of usage
Dallas North Tollway	not available	$2 tag	tag store	cash, check, credit card	Yes	$40

E-Zpass Interagency Group	80,400	$10 tag	contract to vendor	cash, check, credit card	Yes	not decided
Private Toll Roads - California	250,000	not decided	retail mall outlets	cash, check, credit card	Yes	not decided
Florida Turnpike	92,000	$50 tag	800 number & mail	cash, credit card	Yes	not decided
Golden Gate Bridge	not decided	not decided	not decided	not decided	Yes	not decided
Illinois State Toll Authority	157,000	$35 tag	not available	not decided	Yes	$10
New Hampshire Turnpikes	55,000	not decided	bill by mail & tag stores	cash, check, credit card	Yes	$5

* Change in legislation required for video enforcement

Source: IBTTA

with little guidance from advanced technology and real-time traffic information.

A technological revolution in transportation information and communication has transformed individual mobility into an integrated, coordinated system by providing more travel choices and assistance in selecting the best trip for a particular traveler. AVI/ETC technologies have already begun to interconnect formerly independent traffic management jurisdictions and transit dispatch centers, and new systems are already collecting tolls automatically (Koelle 1992). The AVI/ETC programs developed to this point represent just the beginning. According to the Strategic Plan for IVHS in the United States, we can also expect to see the following developments during the next decade (IVHS America 1992):

1. Improved access to information on the availability, schedules, and proximity of public transportation;
2. Transportation management systems that adjust lane usage, speed limits, traffic signals, and road access on the basis of actual traffic conditions;
3. Traffic information and communication systems that advise drivers about current and expected traffic conditions, road hazards, weather, recreational and tourist attractions, and where to park;
4. On-board electronics in vehicles to assist drivers in planning and following safe and efficient routes;
5. Additional capabilities allowing commercial fleet and transit operators to track their vehicles and communicate with their drivers to offer alternative routes;
6. New interactions between roadway jurisdictions and vehicles that will allow all tolls to be collected, trucks to be weighed, truck permits to be issued, and cargos to be checked and monitored, largely without requiring vehicles to stop; and
7. The first demonstration of an automated vehicle/highway control system.

These impressive gains cannot be made without first overcoming some formidable obstacles, however. Assessments of this new technology list three barriers to the widespread implementation of ETC and other IVHS technologies: scarcity of financial resources, difficulty in coordinating among many diverse systems, and difficulty in reaching consensus on technical standards. Already, several large IVHS projects are selecting vendors with different (and sometimes incompatible) systems. At present, the battle over standards for short-range vehicle-to-roadside communica-

tion used in AVI/ETC is hotly contested. Without strong leadership from industrywide standard-setting associations, a nationwide compatible toll collection program may never become a reality.

According to the Strategic Plan for IVHS in the United States, if these barriers can be overcome, we can expect to see implementation of a national program in IVHS in the next 20 years (IVHS America 1992). Designs for this program are comparable in scope with the Interstate highway system, and participation of both the private and public sectors is required (TRB 1985). The primary focus of this program is a balanced transportation system including a national system of travel-support technology; a new level of cooperation between public and private sectors, government, and academia to create the infrastructure of the mobility revolution; a vigorous IVHS industry supplying both domestic and international needs; and an attractive, efficient public transportation system that complements and interacts effectively with improved highway operations.

CONCLUSIONS

ETC systems are made up of advanced technologies in information gathering, processing, and communication. ETC offers a feasible alternative to improving the efficiency of transportation systems. ETC enhances existing road systems so that vehicles can operate more efficiently, safely, and economically. This paper represents a snapshot of the ETC industry, an industry which is constantly growing and changing.

Even though few ETC technology performance evaluation data are available, basic operational differences are generally known. It appears that for any given set of operational parameters and protocol, a compatible ETC technology can be developed. However, trade-offs exist between such operating characteristics as data rate transmission and information storage capabilities. Most technologies have advanced to the second or third generation to keep up with market demands for performance. ETC standards are not yet in place, but they are being rigorously discussed and evaluated in transportation applications.

More important than the technology issues are the system design considerations. For example, ETC systems present additional computer system requirements, different traffic operational factors to assess, and financial and user payment options. With the implementation of ETC, many benefits can be expected from more efficient and safer flow of traffic. Lane equipment costs can be reduced up to 70 percent, and operating and

maintenance costs per lane are substantially less (approximately 90 percent less). Market identification and user perception surveys will be essential for project success.

Issues also exist with enforcement, privacy, and equity in providing ETC systems. The implementation of ETC will most likely necessitate the passage of legislation regarding access to information that is retrieved electronically. Management systems involving improved traffic flow and early incident detection also have evolved from AVI/ETC technologies. Commercial carriers as well as public transportation vehicles will be able to more efficiently carry on highway operations on the basis of ability to pass on real-time traffic information to users. Commercial fleets will be able to transport their cargos more efficiently, and transit services will become an attractive alternative to the single-occupant vehicle.

Many ETC projects and programs are being developed and implemented throughout the country and abroad. Their common feature is providing more convenience to the motoring public. However, the evaluation of these systems remains to be accomplished, documented, and shared. ETC is on a course to completely modernize how decisions are made during travel. Current research efforts and operational tests provide the opportunity for everyday usage of ETC systems to become a reality. For the transportation industry, advances in computer and information technologies have arrived just at the time they are most needed.

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ABBREVIATIONS

CUTR	Center for Urban Transportation Research
GAO	General Accounting Office
TRB	Transportation Research Board

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Impacts of Congestion Pricing on Transit and Carpool Demand and Supply

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The benefits and costs of implementing congestion pricing would differ greatly from one metropolitan area to another. Within any large metropolitan area, moreover, the impacts would depend on the preferences, incomes, and travel patterns of millions of individual trip makers. As a consequence, the magnitude of benefits and costs and the distributional implications of congestion pricing in any particular metropolitan area can only be determined, albeit with some uncertainty, from detailed simulations of the responses of trip makers to the implementation of specific congestion pricing schemes.

Ideally this paper would have presented the results of simulation studies of alternative congestion pricing schemes for three or four representative metropolitan areas, selected to represent different land use patterns, levels of transit use, and congestion levels.[1] Since I have been unable to complete the travel demand simulations that would be required to provide fully adequate assessments of the impacts of congestion pricing and, in particular, to explore the implications for transit and carpool supply, I instead provide a conceptual discussion of the way in which I would expect areawide congestion pricing to affect transit and carpool supply and demand and provide some illustrative examples.

This conceptual discussion is followed by a review of available data on the extent of congestion in metropolitan areas and by the use of these data to identify 15 large and heavily congested metropolitan areas that are plausible candidates for congestion pricing. Then I examine the extent and

nature of the transit systems serving these 15 areas and discuss the various ways in which congestion pricing would be expected to affect the quantity and quality of transit services provided. The final section presents a plea for caution in embracing the argument that revenues from congestion pricing should be used to increase transit subsidies. Instead, congestion revenues (net of administrative costs) should be used to reduce other taxes. In his discussion of congestion pricing, Downs (1992, 51) notes that a "predominant objection" to congestion pricing is that it is widely perceived "as merely a way for the government to tax the citizenry." This obstacle to congestion pricing ought to be removed by returning all congestion pricing revenues, net of collection costs, to taxpayers in the form of a highly visible tax rebate.

Congestion pricing, by eliminating the gross mispricing of roads and streets, would provide an opportunity to reduce transit subsidies. If real transit fares were increased and transit subsidies were decreased, the privatization of many services would be possible, and if these measures were combined with significant deregulation, many new and innovative forms of transit would very likely emerge. These new services would benefit all citizens, but would particularly aid those who are too young, too old, or have disabilities that prevent them from driving; those who do not own cars; and those from poor households, who, if they own cars, must spend too much of their limited incomes on transportation.

CASE FOR CONGESTION PRICING

The case for congestion pricing is well known, having been articulated in dozens, if not hundreds, of reports and papers.[2] As a result, I will provide only the briefest exposition of the theoretical argument in this paper, emphasizing what I believe are important errors or omissions in most discussions. The most serious of these errors is insufficient attention to the nature of the alternatives available to users of the single-occupancy-vehicle (SOV) mode and the impacts that congestion pricing would have on the time and money cost of these alternatives.

Figure 1 (Hau 1992, 74) illustrates the simple analytics of congestion pricing. The average variable cost (AVC) and short-run marginal cost (MC), which are at the heart of the analysis, are usually defined for a particular street, road, or highway segment and depend crucially on a speed-flow (volume) function, such as that shown in Figure 2b, which describes the relationship between average vehicle speeds and the number

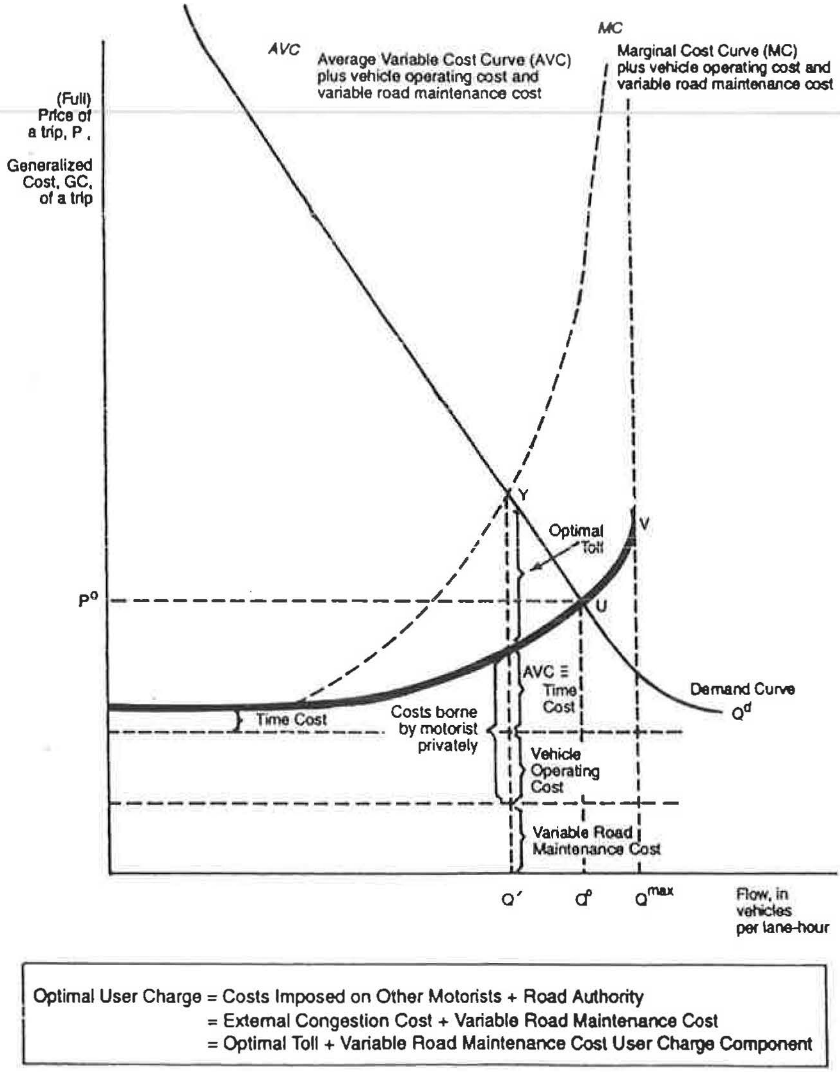

FIGURE 1 Derivation of the marginal cost curve and congestion toll (Hau 1992).

of vehicles using the particular facility. The analysis usually refers to a single uninterrupted section of an arterial street or expressway.

Speed-flow relationships vary for different kinds of facilities, but in every case they have the property, evident in Figure 2b, that speeds initially decline very little as volume increases, but as the maximum capacity of a particular facility is approached, the relationship between average vehicle

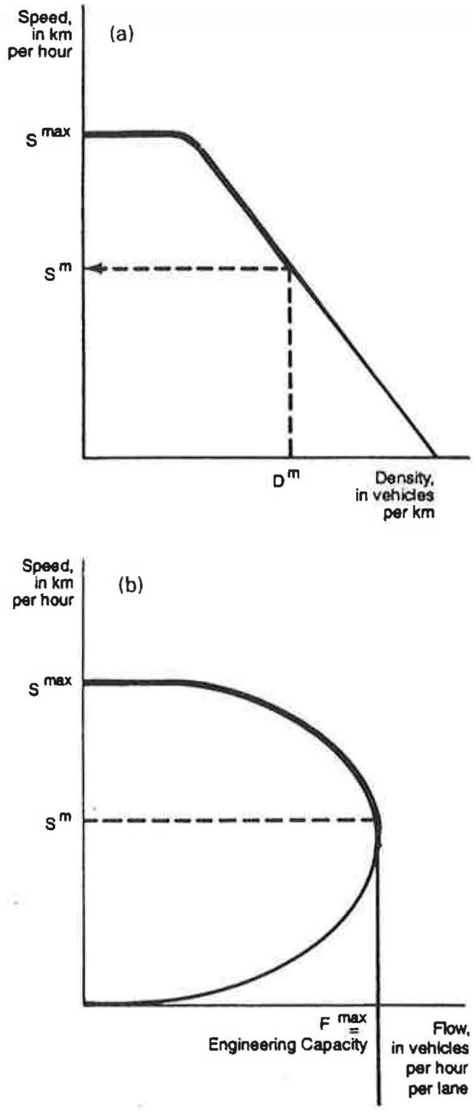

FIGURE 2 Derivation of a curve for travel time versus flow for an urban highway (Hau 1992) (1 km = 0.6 mi): (*a*) speed-concentration relationship, (*b*) speed-flow relationship.

speed and vehicle volume becomes increasingly nonlinear with further increases in volume. The backward-bending portion of the speed-volume curve illustrates situations in which both speeds and capacity decline as too many vehicles attempt to use a particular stretch of road. Highway and traffic engineers make every effort to design or manage facilities so as to prevent the saturated flow that produces these highly undesirable outcomes. The interest of highway engineers in ramp metering, for example, arises from its demonstrated usefulness as a tool for avoiding these saturated conditions.

In large-scale network simulations, highway networks are represented by thousands of individual links, and the relationship among traffic volume, congestion, and speed for each network is represented by a link-specific speed-flow relationship. These link-specific speed-flow relationships are at the heart of analyses of areawide congestion pricing and many other kinds of analyses that are concerned with congested networks.

The nonlinear character of the AVC curve in Figure 1 results from the nonlinearity of the speed-volume curve. AVC is the sum of out-of-pocket costs for vehicle operation (including variable road maintenance costs) and time costs per mile. Out-of-pocket costs are roughly proportional to miles driven; the more-than-proportional increases in AVC are due to the more-than-proportional increases in time costs per mile that occur as volumes approach a facility's maximum capacity. Time costs are the product of the value of time per minute and the number of minutes required to travel a given distance. As link or network speeds begin to slow, minutes per mile increases and thus AVC per mile increases.

As is evident from Figure 1, short-run MC is always higher than short-run variable cost, and it increases more rapidly than AVC as volumes increase. This property of the MC curve is the result of a "congestion externality" and reflects the fact that each additional user of a road increases the trip times of all previous users. When users are not charged for the use of the road at all or are charged by means of gasoline and vehicle ownership fees, which are unrelated to either the long-run cost of producing additional highway capacity or the extent of current use, they consider only their individual time and money costs, represented by the AVC curve, in deciding whether to use the road. Under these circumstances, the number of vehicles using the road will be determined by the intersection of the demand curve (Q^d) and the AVC curve. As Figure 1 makes clear, the resulting volume of vehicles using the road is Q^o. At volume Q^o, each user pays P^o in out-of-pocket and time costs (AVC), and the added time and out-of-pocket costs imposed on all previous users at this volume far

exceeds the time and money costs of the marginal user. The welfare losses that arise from this mispricing can be avoided by charging a congestion toll equal to t, which makes the cost of using the road for the marginal user equal to p. This toll is equal to the congestion externality, which is the difference between the cost an individual traveler imposes on society, shown by MC, and his or her private costs, shown by AVC. The volume of travel becomes Q'. The congestion toll is a transfer, since it involves no resource costs, either real resources, such as gasoline or deterioration of the road, or time costs.

Ideally the tolls charged the individual users of particular facilities would equal, or at least come close to, the long-run MC of providing additional capacity, including the cost of operating and maintaining the road. Since the prices charged vehicle users for the use of streets and highways in the United States currently bear little or no relationship to these long-run costs, however, it is likely that the capacities of these facilities are far from optimal. My hunch is that the full-scale implementation of congestion pricing would demonstrate that existing highway networks are generally overbuilt but that some segments, particularly relatively inexpensive roads in rapidly growing areas, are underbuilt. Short-run congestion tolls for facilities with more than the optimal peak-period capacity would be less than the long-run MC of additional capacity. Short-run congestion tolls for facilities that have too little peak-period capacity, by contrast, would exceed the long-run MC of providing additional capacity. In these cases congestion tolls would provide clear evidence that more capacity should be provided.[3] Even if some form of congestion pricing is implemented, however, I would be surprised if tolls were set at the levels suggested by Figure 1. It is more likely that they would be set so that they would achieve some arbitrary congestion level.

Still another observation needs to be made about the analyses in Figure 1. Most analyses using this framework focus on a single road or street and explicitly, or implicitly, assume that users of the facility make their trips by private cars. However, in recognition of the extensive research by highway and traffic engineers showing that larger vehicles, such as heavy trucks and buses, use more capacity than smaller and more maneuverable vehicles, hourly vehicle volumes are usually represented as passenger car units (pcu's). Considerable emphasis, moreover, has been given to the income heterogeneity of private car users. These discussions generally suggest that since higher-income trip makers, on average, value their travel time more than lower-income users, low-income users will be "tolled" off the facilities by congestion pricing, a conclusion that has spawned an extensive

literature on the income distribution effects and fairness of congestion tolls. As Kulash (1974) makes clear in one of the few efforts to examine the issue empirically, the question is considerably more complex. Although household income, or the hourly wage of commuters, would affect who continues to use a facility after the implementation of congestion pricing, the origin and destination patterns of existing users, the extent to which substitutions by time of day or by destination are attractive alternatives, and the nature of modal alternatives are likely to be as important, if not more important, than income and wage differences.

The failure of most if not all theoretical discussions of congestion pricing to more fully consider the likely impacts of reduced congestion on transit supply and on the performance of carpools has contributed to what has long seemed to me to be a remarkably muddle-headed debate about the redistributive effects of congestion pricing. A common theoretical argument against congestion pricing is that it will hurt the poor. According to this line of argument, high-income trip makers, with high values of travel time, will be the principal beneficiaries of congestion pricing; their time savings (value of time per minute times minutes saved) will easily exceed the tolls required to achieve low-congestion or uncongested conditions, leaving them unambiguously better off. By contrast, low-income trip makers, the argument goes, will either be tolled off the road or, if they must make the trip, be forced to pay a toll that makes them worse off than they were before the congestion pricing regime was introduced. That is, the value of their time savings for low-income households is less than the toll. The tone of these discussions is that congestion pricing is a zero sum game: high-income trip makers are winners and low-income trip makers are losers.

Although I would not deny that some low-income trip makers would be made worse off by congestion pricing, I expect that many more would be made better off by the improvements in transit and carpooling alternatives that would result from congestion pricing. Of the remaining low-income trip makers, moreover, I suspect that most, if not all, could be made whole by a per capita rebate of the toll revenues or by the use of these revenues to reduce other taxes. An analysis by Small (1992b) for Los Angeles is broadly consistent with this view, but because it does not fully consider the potential impacts of congestion pricing on transit, my sense is that it understates the benefits of congestion pricing to low-income consumers.

The argument that congestion pricing would hurt the poor, which at minimum is exaggerated, arises from the failure to meaningfully consider,

or be explicit about, the nature of the alternatives available to trip makers in congested urban environments, in which the justification for congestion pricing is likely to be the most compelling. In addition to failing to stipulate revenue neutrality, which should be the starting point of any discussion of congestion pricing, most discussions of the impacts of congestion pricing also fail to consider the full range of urban transport technologies and the likely impacts that congestion pricing would have on the level of service provided by these alternatives.

In spite of concerns about the distributional impacts, discussions of congestion pricing, with the exception of the few empirical analyses of the problem, seldom, if ever, consider the implications of modal heterogeneity for the AVC and MC curves. Yet the transit and carpool shares of traffic using particular facilities would obviously have a major impact on both. Roads and streets with high fractions of buses or carpools, or both, will have AVC and MC curves that are considerably higher than otherwise identical ones that are predominately used by single-occupancy vehicles. It follows that congestion tolls and speeds should be higher for facilities that are extensively used by buses and carpools.

Any assessment of the quantitative impacts of congestion pricing on the welfare of urban trip makers in general and on groups such as the poor in particular depends on at least three factors:

- Preferences of individual trip makers;
- Travel demands of individual trip makers by purpose, origin and destination, and time of day and the substitutability of these various dimensions of travel (these, of course, depend on preferences, but they also depend on the supply characteristics of alternative modes); and
- Impact of congestion pricing on the supply characteristics of alternative modes.

The factors given above, which are core elements of travel demand, have been the subject of a great deal of research. At the same time, it is clear that we know much more about some aspects of travel demand than we do about others. Thus, for example, there is an extensive empirical literature on the choice of mode by urban trip makers, particularly for work trips.[4] In contrast, the empirical literature on the willingness of urban trip makers to reschedule their trips for other times of day in response to either congestion or differential money prices, to substitute one destination for another in the short run, or to change their residence or place of work in the long run is quite sparse (Small 1982). Yet the potential effects of these kinds of changes

in trip-making behavior, particularly on the volume of travel on heavily congested facilities during peak periods, could be quite large. We also know that the length of the peak period varies widely from place to place and that its duration is related to city size and to the extent of transport capacity relative to demand. Finally, there is clear evidence that the average distance traveled to work increases as average network speeds increase, confirming the expectation from simple theoretical models that the quantity of travel by individual consumers increases as both the money and time costs of travel decline.[5]

As noted earlier, of the several ways in which trip makers might be expected to respond to congestion pricing, we clearly know the most about their probable changes in mode. Even in this area our empirical evidence is uneven, however. Although there are large numbers of studies and mode-choice models that examine the choice between transit and automobile, there are many fewer that explicitly consider SOV, transit, and carpool modes.[6] This is unfortunate because the ability or willingness of SOV users to switch to the carpool mode would be crucial to assessments of the impacts of areawide congestion pricing, particularly to assessments of the impacts on commuters employed at suburban workplaces that have little or no transit service.

Impact on Generalized Cost and Mode Choice

Evidence relating to the potential impact of congestion pricing on the shares of trips by the SOV mode, carpools, and buses is presented in Tables 1 through 5. The calculations in Table 1 show how a congestion tax averaging 15 cents/mi (10 cents/km) would affect the total generalized cost of making a hypothetical 10-mi (16-km) trip to work as an SOV user, by local or express bus, or as a member of a two-, three-, or four-person carpool. Also given is the total generalized cost of making the same trip by each mode before the congestion toll was imposed.

Total generalized cost is the sum of both out-of-pocket dollar expenditures and monetized time costs. The estimates in Table 1 assume that a 15-cent/mi congestion tax would reduce peak-period vehicle use by enough to increase average peak-period speeds for the SOV and carpool modes from 20 to 30 mph (32 to 48 km/hr). The 15-cent/mi toll assumed for this analysis is equal to the average peak-period congestion toll that Harvey determined, from his simulations for Los Angeles (Cameron 1991), would be required to restore level-of-service (LOS) D or E opera-

TABLE 1 Value of Travel Time and Total Generalized Cost for a 10-Mi Trip by Single Occupancy Vehicle, Carpool, and Bus Transit with and Without Road Pricing for Average, Rich, and Poor Commuters

	Walk + Wait Time		Speed (mph)		In-Veh Time (Min.)		Weighted (2.5) Trip Time		Value of Commuting Time with and w/o Pricing						Total Generalized Cost Per Trip with and w/o Pricing					
									Avg. = $5/hr		Rich = $10/hr		Poor = $2.5/hr		Avg. = $5/hr		Rich = $10/hr		Poor = $2.5/hr	
	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with	w/o	with
Single Occ Veh (SOV)																				
Free Parking	5	5	20	30	30	20	42.5	32.5	3.54	2.71	7.08	5.42	1.77	1.35	4.38	5.05	7.92	7.76	2.61	3.69
$2.00 day	5	5	20	30	30	20	42.5	32.5	3.54	2.71	7.08	5.42	1.77	1.35	5.38	6.05	8.92	8.76	3.61	4.69
$4.00 day	5	5	20	30	30	20	42.5	32.5	3.54	2.71	7.08	5.42	1.77	1.35	6.38	7.05	9.92	9.76	4.61	5.69
$6.00 day	5	5	20	30	30	20	42.5	32.5	3.54	2.71	7.08	5.42	1.77	1.35	7.38	8.05	10.92	10.76	5.61	6.69
Carpool: Free Parking																				
2 persons	5	5	20	30	38	28	50.5	40.5	4.21	3.38	8.42	6.75	2.10	1.69	4.67	4.59	8.88	7.96	2.57	2.90
3 persons	5	5	20	30	40	30	52.5	42.5	4.38	3.54	8.75	7.08	2.19	1.77	4.71	4.38	9.09	7.92	2.52	2.61
4 persons	5	5	20	30	42	32	54.5	44.5	4.54	3.71	9.08	7.42	2.27	1.85	4.81	4.36	9.36	8.06	2.54	2.50
Carpool: $4.00 per day																				
2 persons	5	5	20	30	38	28	50.5	40.5	4.21	3.38	8.42	6.75	2.10	1.69	5.67	5.59	9.88	8.96	3.57	3.90
3 persons	5	5	20	30	40	30	52.5	42.5	4.38	3.54	8.75	7.08	2.19	1.77	5.38	5.04	9.75	8.59	3.19	3.27
4 persons	5	5	20	30	42	32	54.5	44.5	4.54	3.71	9.08	7.42	2.27	1.85	5.31	4.86	9.86	8.56	3.04	3.00
Carpool: $6.00 per day																				
2 persons	5	5	20	30	38	28	50.5	40.5	4.21	3.38	8.42	6.75	2.10	1.69	6.17	6.09	10.38	9.46	4.07	4.40
3 persons	5	5	20	30	40	30	52.5	42.5	4.38	3.54	8.75	7.08	2.19	1.77	5.71	5.38	10.09	8.92	3.52	3.61
4 persons	5	5	20	30	42	32	54.5	44.5	4.54	3.71	9.08	7.42	2.27	1.85	5.56	5.11	10.11	8.81	3.29	3.25
Local Bus																				
Headway: 15 min	12.5	12.5	12	18	50	33	81.3	64.6	6.77	5.38	13.54	10.76	3.39	2.69	7.52	6.13	14.29	11.51	4.14	3.44
Headway: 7.5 min	NA	8.8	12	18	50	33	NA	55.2	NA	4.60	NA	9.20	NA	2.30	NA	5.35	NA	9.95	NA	3.05
Express Bus																				
Headway: 15 min	12.5	12.5	20	30	30	20	61.3	51.3	5.10	4.27	10.21	8.54	2.55	2.14	6.10	5.27	11.21	9.54	3.55	3.14
Headway: 7.5 min	NA	8.8	20	30	30	20	NA	41.9	NA	3.49	NA	6.98	NA	1.74	NA	4.49	NA	7.98	NA	2.74

1 mi = 1.6 km.

TABLE 2 Impacts of Congestion Pricing on Mode Choice and Before-and-After Comparisons of Total Generalized Cost (Assuming Free Parking for SOV and Carpool and 54-Cent/Trip Rebate)

Mode and Comparison	Rich Commuter: $10.00/hour (30 mph)				Poor Commuter: $2.50/hour (30 mph)				Average Commuter: $5.00/hour							
									$.10/mile		$.15/mile		$.20/mile		$.25/mile	
	$.10/mi	$.15/mi	$.20/mi	$.25/mi	$.10/mi	$.15/mi	$.20/mi	$.25/mi	30mph	35mph	30mph	35mph	30mph	35mph	30mph	35mph
Impact on Mode Choice																
Carpool minus SOV																
2 persons	0.46	0.21	(0.04)	(0.29)	(0.54)	(0.79)	(1.04)	(1.29)	(0.21)	(0.21)	(0.46)	(0.46)	(0.71)	(0.71)	(0.96)	(0.96)
3 persons	0.50	0.16	(0.17)	(0.50)	(0.75)	(1.09)	(1.42)	(1.75)	(0.34)	(0.34)	(0.67)	(0.67)	(1.00)	(1.00)	(1.34)	(1.34)
4 persons	0.68	0.31	(0.07)	(0.44)	(0.82)	(1.19)	(1.57)	(1.94)	(0.32)	(0.32)	(0.69)	(0.69)	(1.07)	(1.07)	(1.44)	(1.44)
Local Bus minus SOV																
Headway: 15 min	4.26	3.76	3.26	2.76	0.25	(0.25)	(0.75)	(1.25)	1.58	1.42	1.08	0.92	0.58	0.42	0.08	(0.08)
Headway: 7.5 min	2.69	2.19	1.69	1.19	(0.14)	(0.64)	(1.14)	(1.64)	0.80	0.64	0.30	0.14	(0.20)	(0.36)	(0.70)	(0.86)
Express Bus minus SOV																
Headway: 15 min	2.29	1.79	1.29	0.78	(0.06)	(0.56)	(1.06)	(1.56)	0.72	0.72	0.22	0.22	(0.28)	(0.28)	(0.78)	(0.78)
Headway: 7.5 min	0.72	0.22	(0.28)	(0.78)	(0.45)	(0.95)	(1.45)	(1.95)	(0.06)	(0.06)	(0.56)	(0.56)	(1.06)	(1.06)	(1.56)	(1.56)
Before and After Comparison																
SOV w. CP minus SOV w/o. CP	(1.21)	(0.71)	(0.21)	0.29	0.04	0.54	1.04	1.54	(0.37)	(0.61)	0.13	(0.11)	0.63	0.39	1.13	0.89
Carpool minus SOV w/o. CP																
2 persons	(0.75)	(0.50)	(0.25)	(0.00)	(0.50)	(0.25)	(0.00)	0.25	(0.58)	(0.82)	(0.33)	(0.57)	(0.08)	(0.32)	0.17	(0.07)
3 persons	(0.71)	(0.54)	(0.38)	(0.21)	(0.71)	(0.54)	(0.38)	(0.21)	(0.71)	(0.95)	(0.54)	(0.78)	(0.38)	(0.62)	(0.21)	(0.45)
4 persons	(0.52)	(0.40)	(0.27)	(0.15)	(0.77)	(0.65)	(0.52)	(0.40)	(0.69)	(0.93)	(0.57)	(0.80)	(0.44)	(0.68)	(0.32)	(0.55)
Local Bus minus SOV w/o. CP																
Headway: 15 min	3.05	3.05	3.05	3.05	0.29	0.29	0.29	0.29	1.21	0.81	1.21	0.81	1.21	0.81	1.21	0.81
Headway: 7.5 min	1.49	1.49	1.49	1.49	(0.10)	(0.10)	(0.10)	(0.10)	0.43	0.03	0.43	0.03	0.43	0.03	0.43	0.03
Express Bus minus SOV w/o CP																
Headway: 15 min	1.08	1.08	1.08	1.08	(0.02)	(0.02)	(0.02)	(0.02)	0.35	0.11	0.35	0.11	0.35	0.11	0.35	0.11
Headway: 7.5 min	(0.48)	(0.48)	(0.48)	(0.48)	(0.41)	(0.41)	(0.41)	(0.41)	(0.43)	(0.67)	(0.43)	(0.67)	(0.43)	(0.67)	(0.43)	(0.67)

1 mi = 1.6 km.

TABLE 3 Impacts of Congestion Pricing on Mode Choice and Before-and-After Comparisons of Total Generalized Cost (Assuming $4.00/Day Parking for SOV and Carpool and 54-Cent/Trip Rebate)

Mode and	Rich Commuter: $10.00/hour (30 mph)				Poor Commuter: $2.50/hour (30 mph)				Average Commuter: $5.00/hour							
									$.10/mile		$.15/mile		$.20/mile		$.25/mile	
Comparison	$.10/mi	$.15/mi	$.20/mi	$.25/mi	$.10/mi	$.15/mi	$.20/mi	$.25/mi	30mph	35mph	30mph	35mph	30mph	35mph	30mph	35mph
Impact on Mode Choice																
Carpool minus SOV																
2 persons	(0.54)	(0.79)	(1.04)	(1.29)	(1.54)	(1.79)	(2.04)	(2.29)	(1.21)	(1.21)	(1.46)	(1.46)	(1.71)	(1.71)	(1.96)	(1.96)
3 persons	(0.84)	(1.17)	(1.50)	(1.84)	(2.09)	(2.42)	(2.75)	(3.09)	(1.67)	(1.67)	(2.00)	(2.00)	(2.34)	(2.34)	(2.67)	(2.67)
4 persons	(0.82)	(1.19)	(1.57)	(1.94)	(2.32)	(2.69)	(3.07)	(3.44)	(1.82)	(1.82)	(2.19)	(2.19)	(2.57)	(2.57)	(2.94)	(2.94)
Local Bus minus SOV																
Headway: 15 min	2.26	1.76	1.26	0.76	(1.75)	(2.25)	(2.75)	(3.25)	(0.42)	(0.58)	(0.92)	(1.08)	(1.42)	(1.58)	(1.92)	(2.08)
Headway: 7.5 min	0.69	0.19	(0.31)	(0.81)	(2.14)	(2.64)	(3.14)	(3.64)	(1.20)	(1.36)	(1.70)	(1.86)	(2.20)	(2.36)	(2.70)	(2.86)
Express Bus minus SOV																
Headway: 15 min	0.28	(0.22)	(0.72)	(1.22)	(2.06)	(2.56)	(3.06)	(3.56)	(1.28)	(1.28)	(1.78)	(1.78)	(2.28)	(2.28)	(2.78)	(2.78)
Headway: 7.5 min	(1.28)	(1.78)	(2.28)	(2.78)	(2.45)	(2.95)	(3.45)	(3.95)	(2.06)	(2.06)	(2.56)	(2.56)	(3.06)	(3.06)	(3.56)	(3.56)
Before and After Comparison																
SOV w. CP minus SOV w/o. CP	(1.21)	(0.71)	(0.21)	0.29	0.04	0.54	1.04	1.54	(0.37)	(0.61)	0.13	(0.11)	0.63	0.39	1.13	0.89
Carpool minus SOV w/o. CP																
2 persons	(1.75)	(1.50)	(1.25)	(1.00)	(1.50)	(1.25)	(1.00)	(0.75)	(1.58)	(1.82)	(1.33)	(1.57)	(1.08)	(1.32)	(0.83)	(1.07)
3 persons	(2.04)	(1.88)	(1.71)	(1.54)	(2.04)	(1.88)	(1.71)	(1.54)	(2.04)	(2.28)	(1.88)	(2.12)	(1.71)	(1.95)	(1.54)	(1.78)
4 persons	(2.02)	(1.90)	(1.77)	(1.65)	(2.27)	(2.15)	(2.02)	(1.90)	(2.19)	(2.43)	(2.07)	(2.30)	(1.94)	(2.18)	(1.82)	(2.05)
Local Bus minus SOV w/o. CP																
Headway: 15 min	1.05	1.05	1.05	1.05	(1.71)	(1.71)	(1.71)	(1.71)	(0.79)	(1.19)	(0.79)	(1.19)	(0.79)	(1.19)	(0.79)	(1.19)
Headway: 7.5 min	(0.51)	(0.51)	(0.51)	(0.51)	(2.10)	(2.10)	(2.10)	(2.10)	(1.57)	(1.97)	(1.57)	(1.97)	(1.57)	(1.97)	(1.57)	(1.97)
Express Bus minus SOV w/o. CP																
Headway: 15 min	(0.92)	(0.92)	(0.92)	(0.92)	(2.02)	(2.02)	(2.02)	(2.02)	(1.65)	(1.89)	(1.65)	(1.89)	(1.65)	(1.89)	(1.65)	(1.89)
Headway: 7.5 min	(2.48)	(2.48)	(2.48)	(2.48)	(2.41)	(2.41)	(2.41)	(2.41)	(2.43)	(2.67)	(2.43)	(2.67)	(2.43)	(2.67)	(2.43)	(2.67)

1 mi = 1.6 km.

TABLE 4 Total Generalized Cost for a 10-Mi Trip by Single Occupancy Vehicle, Carpool, and Bus Transit with and Without Road Pricing for Rich, Poor, and Average-Income Commuters by Level of Congestion Toll and Speed Improvement

Mode and Parking Fee	Rich Commuter: $10.00/hour					Poor Commuter: $2.50/hour				
	w/o. Toll	$0.10 /mile	$0.15 /mile	$0.20 /mile	$0.25 /mile	w/o. Toll.	$0.10 /mile	$0.15 /mile	$0.20 /mile	$0.25 /mile
Single Occ Veh (SOV)										
Free Parking	7.92	7.26	7.76	8.26	8.76	2.61	3.19	3.69	4.19	4.69
$2.00 day	8.92	8.26	8.76	9.26	9.76	3.61	4.19	4.69	5.19	5.69
$4.00 day	9.92	9.26	9.76	10.26	10.76	4.61	5.19	5.69	6.19	6.69
$6.00 day	10.92	10.26	10.76	11.26	11.76	5.61	6.19	6.69	7.19	7.69
Carpool: Free Parking										
2 persons	8.88	7.71	7.96	8.21	8.46	2.57	2.65	2.90	3.15	3.40
3 persons	9.09	7.75	7.92	8.09	8.25	2.52	2.44	2.61	2.77	2.94
4 persons	9.36	7.94	8.06	8.19	8.31	2.54	2.38	2.50	2.63	2.75
Carpool: $4.00 per day										
2 persons	9.88	8.71	8.96	9.21	9.46	3.57	3.65	3.90	4.15	4.40
3 persons	9.75	8.42	8.59	8.75	8.92	3.19	3.11	3.27	3.44	3.61
4 persons	9.86	8.44	8.56	8.69	8.81	3.04	2.88	3.00	3.13	3.25
Carpool: $6.00 per day										
2 persons	10.38	9.21	9.46	9.71	9.96	4.07	4.15	4.40	4.65	4.90
3 persons	10.09	8.75	8.92	9.09	9.25	3.52	3.44	3.61	3.77	3.94
4 persons	10.11	8.69	8.81	8.94	9.06	3.29	3.13	3.25	3.38	3.50
Local Bus										
Headway: 15 min	14.29	11.51	11.51	11.51	11.51	4.14	3.44	3.44	3.44	3.44
Headway: 7.5 min	NA	9.95	9.95	9.95	9.95	NA	3.05	3.05	3.05	3.05
Express Bus										
Headway: 15 min	11.21	9.54	9.54	9.54	9.54	3.55	3.14	3.14	3.14	3.14
Headway: 7.5 min	NA	7.98	7.98	7.98	7.98	NA	2.74	2.74	2.74	2.74

Mode and Parking Fee	Average Commuter: $5.00/hour								
	w/o	T=$0.10/mile		T=$0.15/mile		T=$0.20/mile		T=$0.25/mile	
	Toll	30mph	35mph	30mph	35mph	30mph	35mph	30mph	35mph
Single Occ Veh (SOV)									
Free Parking	4.38	4.55	4.31	5.05	4.81	5.55	5.31	6.05	5.81
$2.00 day	5.38	5.55	5.31	6.05	5.81	6.55	6.31	7.05	6.81
$4.00 day	6.38	6.55	6.31	7.05	6.81	7.55	7.31	8.05	7.81
$6.00 day	7.38	7.55	7.31	8.05	7.81	8.55	8.31	9.05	8.81
Carpool: Free Parking									
2 persons	4.67	4.34	4.10	4.59	4.35	4.84	4.60	5.09	4.85
3 persons	4.71	4.21	3.97	4.38	4.14	4.54	4.31	4.71	4.47
4 persons	4.81	4.23	3.99	4.36	4.12	4.48	4.24	4.61	4.37
Carpool: $4.00 per day									
2 persons	5.67	5.34	5.10	5.59	5.35	5.84	5.60	6.09	5.85
3 persons	5.38	4.88	4.64	5.04	4.81	5.21	4.97	5.38	5.14
4 persons	5.31	4.73	4.49	4.86	4.62	4.98	4.74	5.11	4.87
Carpool: $6.00 per day									
2 persons	6.17	5.84	5.60	6.09	5.85	6.34	6.10	6.59	6.35
3 persons	5.71	5.21	4.97	5.38	5.14	5.54	5.31	5.71	5.47
4 persons	5.56	4.98	4.74	5.11	4.87	5.23	4.99	5.36	5.12
Local Bus									
Headway: 15 min	7.52	6.13	5.74	6.13	5.74	6.13	5.74	6.13	5.74
Headway: 7.5 min	NA	5.35	4.95	5.35	4.95	5.35	4.95	5.35	4.95
Express Bus									
Headway: 15 min	6.10	5.27	5.03	5.27	5.03	5.27	5.03	5.27	5.03
Headway: 7.5 min	NA	4.49	4.25	4.49	4.25	4.49	4.25	4.49	4.25

1 mi = 1.6 km.

TABLE 5 Impacts of Congestion Pricing on Mode Choice and Before-and-After Comparisons of Total Generalized Cost (Assuming $6.00/Day Parking for SOV and Carpool and 54-Cent/Trip Rebate)

Mode and	Rich Commuter: $10.00/hour (30 mph)				Poor Commuter: $2.50/hour (30 mph)				Average Commuter: $5.00/hour							
									$.10/mile		$.15/mile		$.20/mile		$.25/mile	
Comparison	$.10/mi	$.15/mi	$.20/mi	$.25/mi	$.10/mi	$.15/mi	$.20/mi	$.25/mi	30mph	35mph	30mph	35mph	30mph	35mph	30mph	35mph
Impact on Mode Choice																
Carpool minus SOV																
2 persons	(1.04)	(1.29)	(1.54)	(1.79)	(2.04)	(2.29)	(2.54)	(2.79)	(1.71)	(1.71)	(1.96)	(1.96)	(2.21)	(2.21)	(2.46)	(2.46)
3 persons	(1.50)	(1.84)	(2.17)	(2.50)	(2.75)	(3.09)	(3.42)	(3.75)	(2.34)	(2.34)	(2.67)	(2.67)	(3.00)	(3.00)	(3.34)	(3.34)
4 persons	(1.57)	(1.94)	(2.32)	(2.69)	(3.07)	(3.44)	(3.82)	(4.19)	(2.57)	(2.57)	(2.94)	(2.94)	(3.32)	(3.32)	(3.69)	(3.69)
Local Bus minus SOV																
Headway: 15 min	1.26	0.76	0.26	(0.24)	(2.75)	(3.25)	(3.75)	(4.25)	(1.42)	(1.58)	(1.92)	(2.08)	(2.42)	(2.58)	(2.92)	(3.08)
Headway: 7.5 min	(0.31)	(0.81)	(1.31)	(1.81)	(3.14)	(3.64)	(4.14)	(4.64)	(2.20)	(2.36)	(2.70)	(2.86)	(3.20)	(3.36)	(3.70)	(3.86)
Express Bus minus SOV																
Headway: 15 min	(0.72)	(1.22)	(1.72)	(2.22)	(3.06)	(3.56)	(4.06)	(4.56)	(2.28)	(2.28)	(2.78)	(2.78)	(3.28)	(3.28)	(3.78)	(3.78)
Headway: 7.5 min	(2.28)	(2.78)	(3.28)	(3.78)	(3.45)	(3.95)	(4.45)	(4.95)	(3.06)	(3.06)	(3.56)	(3.56)	(4.06)	(4.06)	(4.56)	(4.56)
Before and After Comparison																
SOV w. CP minus SOV w/o. CP	(1.21)	(0.71)	(0.21)	0.29	0.04	0.54	1.04	1.54	(0.37)	(0.61)	0.13	(0.11)	0.63	0.39	1.13	0.89
Carpool minus SOV w/o. CP																
2 persons	(2.25)	(2.00)	(1.75)	(1.50)	(2.00)	(1.75)	(1.50)	(1.25)	(2.08)	(2.32)	(1.83)	(2.07)	(1.58)	(1.82)	(1.33)	(1.57)
3 persons	(2.71)	(2.54)	(2.38)	(2.21)	(2.71)	(2.54)	(2.38)	(2.21)	(2.71)	(2.95)	(2.54)	(2.78)	(2.38)	(2.62)	(2.21)	(2.45)
4 persons	(2.77)	(2.65)	(2.52)	(2.40)	(3.02)	(2.90)	(2.77)	(2.65)	(2.94)	(3.18)	(2.82)	(3.05)	(2.69)	(2.93)	(2.57)	(2.80)
Local Bus minus SOV w/o. CP																
Headway: 15 min	0.05	0.05	0.05	0.05	(2.71)	(2.71)	(2.71)	(2.71)	(1.79)	(2.19)	(1.79)	(2.19)	(1.79)	(2.19)	(1.79)	(2.19)
Headway: 7.5 min	(1.51)	(1.51)	(1.51)	(1.51)	(3.10)	(3.10)	(3.10)	(3.10)	(2.57)	(2.97)	(2.57)	(2.97)	(2.57)	(2.97)	(2.57)	(2.97)
Express Bus minus SOV w/o. CP																
Headway: 15 min	(1.92)	(1.92)	(1.92)	(1.92)	(3.02)	(3.02)	(3.02)	(3.02)	(2.65)	(2.89)	(2.65)	(2.89)	(2.65)	(2.89)	(2.65)	(2.89)
Headway: 7.5 min	(3.48)	(3.48)	(3.48)	(3.48)	(3.41)	(3.41)	(3.41)	(3.41)	(3.43)	(3.67)	(3.43)	(3.67)	(3.43)	(3.67)	(3.43)	(3.67)

1 mi = 1.6 km.

tion on the region's heavily congested roads and streets. LOS D and E correspond to freeway speeds in the range of 35 to 40 mph (56 to 64 km/hr).

Harvey's analysis, which was done for the Environmental Defense Fund (EDF) and which was based on projected travel in Los Angeles in 2010, determined that a peak-period toll averaging 15 cents/mi would reduce daily vehicle miles of travel (VMT) by 5.0 percent and automobile vehicle trips by 3.8 percent (Cameron 1991, 37). Since most of the reductions would presumably occur during peak periods, the percentage reductions in peak-period VMT and peak-period automobile trips would be much larger. Unfortunately, the EDF report does not provide these, or for that matter many other, crucial data. Cameron (1991, 41) does provide a brief discussion of the distributional impacts of congestion pricing in which he reports that the "analysis indicates significant variations in impact by income category, trip type, place of residence and place of work," adding that "as might be expected, a disproportionate amount of the predicted VMT reduction appears to come from reduced travel by low and middle income drivers."

Operating speeds of local buses for the example calculations in Table 1 are assumed to be 0.6 of automobile speeds, whereas express buses are assumed to travel at the same speed as SOVs and carpools. Both the level of congestion tolls and the resulting improvements in average trip speeds, which, of course, are related, would be expected to vary greatly by origin and destination pair. In his description of the EDF study of congestion pricing for Los Angeles, Cameron (1991, 40) reports that although peak-period tolls averaged 15 cents/mi (10 cents/km), tolls of as much as 60 cents/mi (37 cents/km) were required for some trip segments.

Following the lead of Small (1992b), Table 1 provides estimates of total generalized trip cost for a representative commuter with average income (value of time equal to $5.00/hr), as well as for a representative rich commuter (value of time equal to $10/hr) and a representative poor commuter (value of time equal to $2.50/hr). On the basis of an extensive body of evidence that commuters have a greater disutility for time spent waiting or walking than for in-vehicle time, these calculations further assume that trip makers value time spent waiting and walking at 2.5 times in-vehicle time (Hensher and Dalvi 1978; Bruzelius 1979). In contrast to Small's (1992b) calculations for Los Angeles, which assume that poor workers travel only half as far to work as average-income and rich workers, the estimates in Table 1 use the same trip length for all workers.

The calculations in Table 1 assume further that the hypothetical trip in question is made between origins and destinations that have relatively frequent and direct (no-transfer) service by bus transit. The transit generalized cost estimates assume alternatively that the trip is made (*a*) by a local bus that averages 12 mph (19 km/hr) without congestion pricing and 18 mph (29 km/hr) with congestion pricing or (*b*) by an express bus that has an average speed of 20 mph (32 km/hr) without congestion pricing and 30 mph (48 km/hr) with congestion pricing. In anticipation of a point that will be developed in greater detail later in the paper, the calculations also show the effect on generalized cost of halving bus headways from 15 min without congestion pricing to 7.5 min with congestion pricing. The reduction in headways with congestion pricing results from assumed increases in bus operating speeds and increases in transit ridership.

The calculations in Table 1 also assume that the users of all modes incur 5 min of terminal (walking and waiting) time on each trip, and the estimates for carpools assume that members of carpools incur a circuity cost consisting of 8 min of additional travel time for a two-person carpool, 10 min of additional travel time for a three-person carpool, and 12 min of additional travel time for a four-person carpool, plus 1 mi (1.6 km) of additional distance per carpool member.[7] The full circuity penalty is applied to all carpool members even though only the driver would incur the full additional time cost. In the case of four-person carpools, for example, the circuity penalty for all members is 12 min, even though it would be zero for the last person picked up on the inbound trip and for the first person dropped off on the outbound trip and less than 12 min for all members of the four-person carpool except the driver. It is acknowledged that parking costs are important in determining the cost of commuting by automobile, and total generalized cost is calculated for the SOV mode on the assumption that parking is free or that it costs $2.00, $4.00, or $6.00/day. Parking for carpools is either free or it costs $4.00 or $6.00/day. Carpools, which may have two, three, or four members, share the cost of parking equally.

Free Parking and Mode Choice

Whether commuters pay market prices for their parking, have it provided at subsidized rates, or pay nothing has a tremendous impact on their choice of mode. The effect of free parking on mode choice has been ably documented by Shoup and several coauthors in a series of related papers dealing

mostly, but not exclusively, with Los Angeles.[8] In discussing the prevalence of free parking, Wilson and Shoup (1990b, 141) cite a 1989 national survey indicating that "nine out of ten American commuters who drive to work park free at work," and data from a survey of 172,000 office workers in the Los Angeles central business district (CBD) indicating that nearly a one-third park in employer-provided spaces. Wilson and Shoup illustrate the impact of free parking on the money costs of SOV commuting by comparing the $1.75/day cost of gasoline for the average commute to the average daily equivalent market cost of monthly parking, which is $4.52/day, noting that "when employers provide free parking, it thus reduces the daily out-of-pocket costs of the average commuter to the Los Angeles CBD from $6.07 to $1.75 per day or by 75 percent."

Wilson and Shoup (1990) also present before-and-after data from five natural experiments in which employers who previously had provided free parking discontinued the practice. In four Los Angeles cases, they found that ending employer-paid parking reduced the SOV mode share by 81 percent (Mid Wilshire), 49 percent (Warner Center), 19 percent (Century City), and 44 percent (Civic Center). Mid Wilshire is an employment concentration located near the CBD, the Warner Center is a suburban office center, and Century City is a large office complex on the west side of Los Angeles. The fifth case documents the results of a 1974 Canadian government decision to stop providing free parking for its employees in Ottawa where, as a result of this action, use of the SOV mode fell by 20 percent. In three of these cases sufficient information was available to calculate parking elasticities for the SOV mode. The resulting before-and-after parking elasticity estimates were −0.68 for the Mid Wilshire employer, −0.32 for the Warner Center, and −0.11 for the federal government in Ottawa.

In addition to the five natural experiments, Wilson and Shoup (1990) present modal share comparisons for workers employed at the same locations but whose employers have different parking policies. A 1969 survey for the Los Angeles CBD, for example, compared the mode choices of Los Angeles County employees, who received employer-paid parking, with those of similar federal government workers who had to pay for their parking. The share of federal workers who commuted as solo drivers was 44 percent less than the share of the county workers. The parking price elasticity of demand for solo driving implied by these results is −0.29. Similarly, a 1976 survey of workers employed in Century City (Shoup and Pickrell 1980) found that the share of SOV trips was 19 percent less for workers who had to pay for their parking than for those who received

free parking. The parking price elasticity for solo driving for this case was −19.

In still another study for Los Angeles, Wilson (1991) used data from a 1986 mode-choice survey of downtown office workers to estimate a multinomial logit model of mode choice and parking demand. His model is particularly valuable because it is one of a relatively small number that includes the carpool-vanpool and drive-alone modes as well as transit. Wilson (1991, 140) reports estimates for five model specifications that differ in terms of whether the cost of parking is represented by a free parking dummy variable or by a daily parking cost variable and by the specification of household income. When he used the better of his two dummy variable equations to predict modal shares, he found that eliminating free parking would reduce the SOV share from 72 to 41 percent, increase the carpool share from 13 to 28 percent, more than double the transit mode share from 15 to 31 percent, and reduce the number of cars that would be driven to work (cars used for SOV trips plus cars used by carpools) by 34 percent. The parking cost elasticity for the same equation is −0.27 for the SOV mode, and the cross elasticity for transit is 0.35.

The powerful impact of employer-paid parking is also evident from the estimated differences in generalized costs between the SOV mode and carpools and buses shown in the top half of Table 2. These estimates were obtained by subtracting the estimates of generalized cost for the SOV mode with congestion pricing in Table 1 from each of the alternative modes with congestion pricing. Comparing the categories included in Table 2 with those in Table 1, however, reveals that there are four more cases for the average-income commuter. For these cases, the assumption that congestion pricing would increase average vehicle speeds from 20 to 30 mph (32 to 48 km/hr) is replaced with the assumption that congestion pricing would increase average vehicle speeds from 20 to 35 mph (32 to 56 km/hr). All the comparisons in Table 2 assume that SOV commuters and carpools do not pay for parking. The variations in generalized cost in Table 2 that result from parametric variations in average congestion tolls and from different toll-speed response functions might reasonably be interpreted as resulting from variations in the trip patterns (origins and destinations) of specific commuters, as well as from the severity and extent (in miles) of pre-congestion-tax congestion that they experienced in making their individual 10-mi (16-km) journeys to work before congestion pricing was implemented.

Examination of the resulting estimates for poor commuters reveals that congestion pricing would make either carpooling or bus cheaper in terms

of generalized cost than the SOV mode in every case but one, local bus with a 15-min headway. If increases in transit ridership induced by congestion pricing led to a doubling of frequencies, however, even local buses would be cheaper than the SOV mode for poor commuters. If we could be confident that the generalized cost used for the estimates shown in Table 2 included all aspects of utility that determine modal choice, we could safely conclude that implementation of any of the congestion toll regimes would cause all poor commuters to switch to carpool or bus. Of course, many specific personal (preference and utility) or trip characteristics that are known to affect travel behavior have been ignored in defining these representative rich, poor, and average-income commuters.

Of the omitted personal or trip characteristics that might affect mode choice, differences in the feasibility, ease, and convenience of forming carpools and in carpool circuity are likely to be the most important. In recognition that many important determinants of preferences and trip times are difficult or impossible to measure or are likely to be unavailable to the analyst, the differences in generalized cost shown in the top half of Table 2 are probably best thought of as point estimates with unspecified, but significant variances. This is hardly a novel notion and, in fact, is central to the behavior choice models that are now generally used to analyze and predict travel behavior (McFadden 1973, 1984; Ben-Akiva and Lerman 1985; Train 1986). Similar problems exist for the two transit modes, but my sense is that the variances in generalized cost for transit are likely to be smaller than those for carpools.

The results for rich commuters in Table 2, not surprisingly, are very different from those for poor commuters. When parking is free, the SOV mode is always cheaper than either the bus or carpool mode when congestion tolls are 15 cents/mi (10 cents/km) or less. When tolls are 20 cents/mi (12 cents/km) or more, however, carpools become slightly cheaper than the SOV mode, and this advantage increases for congestion tolls averaging 25 cents/mi (16 cents/km). Local bus trips, moreover, always have a higher generalized cost for rich commuters, but express buses with 7.5-min headways become cheaper than either the carpool or SOV mode for congestion tolls of either 20 or 25 cents/mi.

The results for the average-income commuter, not unexpectedly, are intermediate to those shown for rich and poor commuters. All of the combinations of congestion tolls and congestion toll speed response functions examined cause carpooling to be cheaper than the SOV mode. In interpreting this result, however, it is important to keep in mind the previous discussion about the likely impact of unobserved personal and

trip characteristics on carpool generalized cost. The importance of bus speeds and frequency is also strongly indicated by these data. A doubling of local bus frequencies causes generalized cost to become less for local buses than the SOV base case for congestion tolls above 20 cents/mi.

Impact on SOV Commuters

The data presented in the lower half of Table 2 are designed to answer the question whether commuters would in general be made better or worse off by the implementation of congestion pricing. These data compare (take the difference between) the estimate of generalized cost from Table 1 for each individual who used the SOV mode before congestion pricing was implemented and the after-congestion-pricing estimate of generalized cost from the same table for the SOV, carpool, or bus mode. As was true for the mode-choice data, parking is assumed to be free in all these comparisons . A positive value of generalized cost indicates that the commuter's generalized cost for a particular mode is greater with congestion pricing than it would have been if he or she had used the SOV mode before congestion pricing was introduced. Since the difference in generalized cost for all modes is compared with a pre-congestion-pricing SOV trip, all the mode specific values for a particular type of commuter (rich, poor, or average income) may be compared directly. The mode with the largest (in absolute value) negative number provides the largest reduction in generalized cost, and, on the assumption that the generalized cost estimate embodies all personal and trip-specific elements that affect generalized cost, it is also the mode that a utility-maximizing traveler would choose.

The calculations for the data presented in the before-and-after comparison of Table 2 include a 54-cent/trip rebate of congestion toll revenues. They thus assume, as I have argued they should, a revenue-neutral congestion toll scheme that returns all toll revenues, net of the costs of operating the system, to taxpayers. The 54-cent/trip rebate used in Table 2 and in Tables 3 through 5 is based on analyses by Small. Using data from EDF's analysis of congestion pricing for Los Angeles, Small (1992b, 17) concluded that if a peak-period congestion pricing policy had been applied to that city, it would have produced about $3.1 billion in revenues in 1990. After subtracting collection costs, which he estimated would have been on the order of $137 million for the same year, he obtained estimated net congestion toll revenues of just under $3.0 billion.

Data on total population and automobile registrations for the Los Angeles urbanized area in 1988 (Hanks and Lomax 1990) provide numbers of sufficient precision to indicate the approximate size of the potential annual rebates from congestion pricing. Estimates based on these data indicate that annual rebates of $269 per capita could be provided. Since very few persons presumably make more than two peak-period trips a day, it is reasonable to divide these annual figures by 500 trips a year for a congestion toll rebate of 54 cents per peak-period trip. Assuming a rebate of 54 cents/trip, if the representative poor SOV commuter (the least favorable case in Table 2) was able to join a two-person carpool, he or she would receive a net benefit of 50 cents/trip for tolls averaging 10 cents/mi (6 cents/km) or 25 cents/trip for tolls averaging 15 cents/mi (10 cents/km). At a toll of 20 cents/mi (12 cents/km), the same representative poor SOV commuter would break even and at 25 cents/mi (16 cents/km) he or she would be made worse off by 25 cents/trip. All these calculations, it should be recalled, assume that the toll in question would increase SOV and carpool average speeds from 20 mph (32 km/hr) without the congestion toll to 30 mph (48 km/hr) with the toll. The data in Table 2, moreover, indicate that poor SOV commuters faced with a congestion toll averaging 25 cents/mi would be able to increase their welfare by an amount equal to 25 cents/trip by switching to a three-person carpool and by 40 cents/trip by switching to a four-person carpool.

Carpooling would not be a feasible alternative for many commuters. Some who did not have good carpooling opportunities, however, would be well served by transit. The data in the last four rows of Table 2 (Local Bus minus SOV w/o. CP and Express Bus minus SOV w/o. CP) indicate the gains or losses to individual poor commuters who had previously been SOV commuters. Of course, all previous users of road-based transit vehicles would benefit from congestion pricing because lower levels of congestion would increase transit operating speeds. This issue is discussed in greater detail later in this paper. The estimates for poor SOV commuters indicate that they would be made worse off by 29 cents/trip if the only alternative available was a local bus with a 15-min headway. If congestion pricing led to a 7.5-min headway, however, the welfare gain would be 10 cents/trip. If the same commuter had access to an express bus with a 7.5-min headway, the net benefit would be 41 cents/trip.

The before-and-after comparisons for rich commuters provide support for the view that most rich commuters would benefit from road pricing. Starting with the case of no change in mode (SOV after minus SOV before), rich commuters benefit from congestion pricing, assuming a

54-cent/trip distribution of the toll revenues for congestion tolls of 10, 15, and 20 cents/mi (6, 10, and 12 cents/km). They are made worse off by congestion tolls of 25 cents/mi (16 cents/km), but those able to join three- or four-person carpools or with access to a high-performance express bus alternative with a 7.5-min headway would obtain welfare increases of between 15 and 48 cents/trip by switching to one of these alternatives.

The results for the average-income commuter are more complex. Average-income SOV commuters who continue to drive alone are made worse off by tolls of 20 cents/mi or more. In all four cases, however, the estimates in Table 2 suggest that they would receive a welfare gain of between 7 and 68 cents/trip by switching to a carpool or an express bus with a frequency of 7.5 min or better, if these options are available to them. For tolls averaging 15 cents/mi, the average-income SOV commuter who remains an SOV commuter is made worse off by congestion pricing if average speeds increase from 20 to 30 mph (32 to 48 km/hr), but better off if average speeds increase from 20 to 35 mph (32 to 56 km/hr). Average-income SOV commuters who are made worse off by the combination of 15-cent tolls and 20- to 30-mph speed improvements, however, would be made better off if they were able to join a carpool or had access to express bus services with 7.5-min headways.

The cases shown in Table 2 are those least favorable to congestion pricing, at least in terms of the narrow question of whether users of the SOV mode before congestion pricing would be made better or worse off by its implementation. Although the preceding calculations are quite favorable to congestion pricing, the case is even stronger when commuters are required to pay market prices for parking. There is a strong case for eliminating employer-paid free parking as the first step in rationalizing the pricing of urban transport infrastructure. As Shoup and his several coauthors have shown, this could be done in a way that makes both the employers who currently provide free parking and their employees who receive it better off (Shoup 1992a, 1992b; Shoup and Pickrell 1980; Shoup and Wilson 1992).

The results of repeating the analyses presented in Table 2 for SOV commuters and carpools that are required to pay $4.00/day for parking are shown in Table 3. (Table 5 presents these same calculations for $6.00/day parking.) When poor commuters must pay $4.00/day for parking and pay congestion tolls of at least 10 cents/mi (6 cents/km), the calculations suggest that none would use the SOV mode if carpool and transit alternatives with the characteristics assumed for this analysis were available to them. The calculations indicate further that carpools would usually be

preferred by these commuters, but that the relative attractiveness of the bus modes increases as the level of congestion charges increases. The before-and-after comparison in Table 3, moreover, indicates that when poor commuters must pay $4.00/day in parking costs, they obtain a significant benefit from choosing either the carpool or bus mode over the SOV mode.

The estimates for rich and average-income commuters who pay $4.00/day for parking indicate that they would always reduce their generalized cost by switching to an express bus. Since average speed in this analysis does not vary with the level of the toll, the savings in generalized cost from switching to express bus is not affected by the level of the toll either. Higher bus speeds do increase the welfare gain, however; the decrease in generalized cost to the average-income commuter who switches from SOV commuting to a 7.5-min headway express bus is $2.43/trip when average speeds increase to 30 mph (48 km/hr) and $2.67/trip when speeds increase to 35 mph (56 km/hr). Access to an express bus with a 7.5-min headway instead of a 15-min headway increases the benefit gain from $1.65/trip to $2.43/trip for the average-income SOV commuter who changes mode assuming an increase in average speed from 20 to 30 mph.

It cannot be overemphasized that although every effort was made to select reasonable values for trips made on heavily congested facilities, the results shown in Tables 1 through 3 are highly specific. The way in which the implementation of congestion pricing would affect the total generalized cost of SOV, transit, and carpool trips of individual trip makers would differ greatly by trip purpose, by origin and destination pairs, and particularly by how congestion pricing affected the time and money costs of the several modes. A realistic assessment of these issues requires detailed simulations of the effects of congestion pricing for specific metropolitan areas. Nonetheless, I would hope that the illustrative calculations shown in Table 1 will persuade most readers that the implementation of congestion pricing would reduce the generalized cost of most trip makers in heavily congested metropolitan areas and in addition would benefit most poor commuters.

At the same time, the illustrative calculations of welfare gains and losses in Tables 2, 3, and 5 also understate the likely gains to peak-period trip makers in congested urban areas from the implementation of congestion pricing. Many of these representative commuters would have children who, under a per capita rebate scheme, would receive a rebate of $1.08/day or $269/year even if they made no peak-period trips. In addition, congestion pricing would reduce travel times for commercial vehicles. These

include trucks carrying goods, but, perhaps even more important, passenger vehicles and small vans making service calls or other business-related trips. High levels of congestion, and the increased travel times and scheduling distortions associated with them, significantly increase the cost of producing goods and services. These higher costs reduce the international competitiveness of U.S. firms, increase domestic prices, or result in lower wages. Various estimates suggest that these costs may be quite high.

Whether the benefits from congestion pricing exceed the costs of such a system by enough to make the concept worth considering varies from one metropolitan area to another, depending principally on the extent of congestion. Thus, I now consider the extent of congestion in U.S. metropolitan areas and identify a number of candidate areas for congestion pricing.

EXTENT OF CONGESTION

In recent testimony before the Senate Committee on Environment and Public Works, I repeated an observation I had made a quarter century earlier that "90 percent of the urban transportation problem (and congestion) was caused by the gross pricing of perhaps five percent of the nation's highway capacity" (Kain 1991a, 48). Table 6, which presents 1990 data on the mileage of urban roads and streets operating at various volume-to-capacity ratios and total VMT by major road categories for the entire United States, indicates that my claim had some validity. The share data, in the bottom half of the table, indicate that in 1990 only 3.5 percent of total urban mileage had a *V*/*C* ratio greater than .95, 2.1 percent between .80 and .95, and an additional 1.4 percent between .71 and .79. In calculating these percentages, I assume that local streets, which account for 70.4 percent of the mileage and an estimated 15.4 percent of daily VMT, were uncongested.

Although the data in Table 6 demonstrate that serious congestion is limited to a small fraction of all urban roads and streets, they are obviously far too aggregate to be of much value in assessing the potential benefits and costs of congestion pricing or its likely impact on carpool and transit performance and demand. Fortunately, Hanks and Lomax (1990, 1992) have carefully analyzed data on levels and trends in congestion in 50 urbanized areas for the period 1982 through 1989.[9] Their estimates, though far from ideal, provide a much clearer picture of the extent and nature of urban congestion.

TABLE 6 Congested Mileage in Urban Areas by Functional System and *V/C* Ratio in 1990: Entire United States (FHWA 1990, 162, 163, 173, 174)

	Mileage of Road by Peak Period Volume/Capacity Ratio							Urban 1990
System	LT .21	.21 - .40	.41 - .70	.71-.79	.80 - .95	GT .95	Total	VMT
Interstate	565	1,586	3,285	877	1,699	3,515	11,527	278,404
Other Fways & Xways	758	1,722	2,155	474	796	1,765	7,670	127,431
Other Principal Arterials	5,461	11,355	16,194	3,772	6,115	9,090	51,987	335,687
Minor Arterials	20,520	18,755	18,753	3,650	4,757	8,221	74,656	235,036
Collectors	41,807	16,807	11,899	1,785	2,292	3,658	78,248	103,756
Local							533,275	196,778
All	69,111	50,225	52,286	10,558	15,659	26,249	757,363	1,277,092
	Percent of Total Urban Mileage by Peak Period Volume/Capacity Ratio							
System	LT .21	.21 - .40	.41 - .70	.71-.79	.80 - .95	GT .95	Total	VMT
Interstate	0.1	0.2	0.4	0.1	0.2	0.5	1.5	21.8
Other Fways & Xways	0.1	0.2	0.3	0.1	0.1	0.2	1.0	10.0
Other Principal Arterials	0.7	1.5	2.1	0.5	0.8	1.2	6.9	26.3
Minor Arterials	2.7	2.5	2.5	0.5	0.6	1.1	9.9	18.4
Collectors	5.5	2.2	1.6	0.2	0.3	0.5	10.3	8.1
Local	0.0	0.0	0.0	0.0	0.0	0.0	70.4	15.4
All	9.1	6.6	6.9	1.4	2.1	3.5	100.0	100.0

1 mi = 1.6 km.

Using FHWA data on daily VMT per lane-mile for expressways and arterials, Hanks and Lomax (1990) constructed a Roadway Congestion Index (RCI) for each of 50 urbanized areas. The RCI for each urbanized area is a VMT-weighted average of two ratios (VMT per lane-mile/13,000) for freeways and (VMT/5,000) for principal arterial streets. The constants, 13,000 (freeways) and 5,000 (principal arterial streets), are based on an earlier study by the authors in which they indicated that when "areawide freeway volumes reached 13,000 daily vehicle-miles of travel per lane mile, congested conditions (level of service D) . . . occur" and that the "corresponding level of service for principal arterial street travel volumes is represented by a system average of 5,000 daily vehicle miles of travel per lane mile" (Hanks and Lomax 1990, 5). Since Hanks and Lomax's methodology relies heavily on earlier, more detailed research by TTI on congestion for Texas metropolitan areas, particularly Houston, they are careful to warn the reader that the "current methodology" may underestimate "congestion in the NE and Midwest" (Hanks and Lomax 1990, ix).

Hanks and Lomax take the position that "values equal to or greater than 1.0 indicate undesirable levels of congestion," adding that, although "ur-

banized areas with a roadway congestion index less than 1.0 may have roadway sections which experience intense traffic congestion, the average mobility level for the urbanized area could be defined as desirable" (Hanks and Lomax 1990, vii). Shown in Table 7 are data for half of the metropolitan areas included an earlier study of 32 urbanized areas by Hanks and Lomax (1990). These 16 metropolitan areas include all that had RCIs greater than 1.05 in 1988 plus Dallas (RCI = 1.02), Baltimore (RCI = 0.92), and Corpus Christi (RCI = 0.70). Corpus Christi, which is the least congested urbanized area studied by Hanks and Lomax (1990, 1992), provides a kind of baseline of uncongested conditions.[10] The data used in the analyses that follow are from Hanks and Lomax's 1990 study of 32 metropolitan areas because I did not have access to their more recent study at the time I completed these analyses. Of the 18 urbanized areas that were not included in their 1990 study, only four, San Bernadino-Riverside (1.16), New Orleans (1.13), Honolulu (1.09), and San Jose (1.02), had RCIs greater than 1. The most congested of these, San Bernadino-Riverside, ranked eighth among the nation's most congested urbanized areas as measured by the RCI.

The 15 heavily congested areas in Table 7 are ranked by delay and fuel costs per registered vehicle, which, of the several indexes developed by Hanks and Lomax, seems to me to be the most appropriate one for identifying metropolitan areas that would be strong candidates for congestion pricing. Delay and fuel costs per capita and total congestion costs per vehicle are also included in Table 7. Subsequent analyses of the impacts of congestion pricing on carpooling and transit use in this paper focus on these 15 heavily congested areas. I find it impossible to avoid commenting on the fact that in their otherwise superb analysis of congestion, Hanks and Lomax (1992) make no reference to congestion pricing in their enumeration of possible remedies.[11] This omission, however, may contain valuable information about the acceptance and appreciation of congestion pricing as a tool for improving conditions in heavily congested urban areas.

Delay and fuel costs are the sum of time and extra fuel costs due to recurring and incident delay. Total congestion cost consists of delay and fuel costs plus extra insurance costs. Incident delay depends on the ratio of incident to recurring delay for each metropolitan area and facility type; this parameter has a large impact on the estimates by Hanks and Lomax of total congestion cost. They assume that the ratio of incident to recurring delay for principal arterials, which is 1.1, is the same for all areas studied. The ratio they use to calculate incident delay for freeways, however, which is

TABLE 7 Congestion Indexes for Highly Congested Urbanized Areas (Hanks and Lomax 1990)

Urbanized Area	Population ('000) 1988	Total DVMT 1988	Percent Fwy & Prin. Arterial	Roadway Congestion Index	% Change in RCI 1982-88	Congestion Cost ($) Total per vehicle	Congestion Cost ($) Delay & fuel per vehicle	Congestion Cost ($) Delay & fuel per person	Fwy Ratio ID/RC	Capital Cost for RCI=1.0
Washington, DC	3,040	61,480	69	1.32	23.0	1,050	9[illegible]0	500	2.2	1,220
Boston	2,910	49,260	72	1.12	24.0	830	7[illegible]0	400	3.5	490
New York, NY	16,320	221,430	57	1.10	9.0	1,030	7[illegible]0	260	2.5	1,370
Los Angeles	11,140	234,410	77	1.52	25.0	880	6[illegible]0	470	1.2	8,040
SF-Oakland	3,610	74,790	72	1.33	32.0	780	6[illegible]0	560	1.3	1,650
Seattle-Everett	1,630	39,030	67	1.17	23.0	680	6[illegible]0	460	1.4	460
Houston	2,850	69,170	54	1.15	-2.0	660	5[illegible]0	410	1.4	620
Dallas	1,950	49,500	61	1.02	21.0	600	500	410	1.8	70
Miami	1,810	33,540	65	1.18	12.0	770	4[illegible]0	330	1.5	390
Atlanta	1,780	57,210	57	1.10	24.0	480	4[illegible]0	360	1.1	370
Detroit	3,900	76,620	57	1.09	-4.0	520	3[illegible]0	270	2.1	440
Baltimore	1,910	33,330	69	0.92	10.0	520	3[illegible]0	170	2.2	NA
Chicago	7,340	113,010	51	1.18	16.0	470	3[illegible]0	180	1.2	1,060
San Diego	2,180	47,480	72	1.13	45.0	410	3[illegible]0	210	0.6	480
Philadelphia	4,130	64,250	60	1.07	7.0	570	2[illegible]0	190	2.3	310
Mean of Heavily Congested Areas	4,433	81,634	64	1	18	683	5[illegible]7	345	2	NA
Corpus Christi	280	6,260	47	0.70	4.0	60	[illegible]0	30	NA	NA

Note: Estimated capital cost of achieving a Roadway Congestion Index of 1.0 assumes at-grade congestion costs of $25/sq. ft. for freeways and $10/sg. ft. for principal arterial streets.

1 mi = 1.6 km.

based on earlier research by Lindley (1986), varies greatly among metropolitan areas. This ratio, for example, is 0.40 for freeways in Phoenix and 3.5 for freeways in Boston. As indicated by the unweighted mean in the next-to-last column of Table 7, labeled Frwy Ratio IC/RD, the average ratio of freeway incident to recurring delay for the 15 heavily congested urbanized areas was 1.8.

Table 7 also gives the percentage change in RCI for each area between 1982 and 1988. As these data indicate, the RCI increased in all but two areas (Detroit and Houston), and it grew by more than 20 percent in 8 of the 16 areas. The first and second columns give the total population and the total daily VMT for each urbanized area in 1988, and Column 3 gives the percent of daily VMT on freeways or principal arterial streets in heavily congested areas in the same year. Los Angeles (77 percent), San Francisco-Oakland (72 percent), San Diego (72 percent), and, somewhat surprisingly, Boston (72 percent) had the highest fractions of daily VMT on freeways and principal arterials, whereas Chicago had the lowest (51 percent). Table 7 also provides provocative ballpark estimates, prepared by Hanks and Lomax, of the capital costs of building enough freeway and arterial capacity in each area to reduce congestion levels to the RCI = 1.0 threshold. These estimates range from a high of more than $8.0 billion for Los Angeles to a low of $70 million for Dallas.

Table 8 provides estimates by Hanks and Lomax (1990) of the percentages of peak-period VMT that occurred on "uncongested" and on moderately, heavily, and severely congested freeways and principal arterial streets for each of the 15 metropolitan areas in 1988, as well as the average speeds that Hanks and Lomax assume correspond to each level of congestion. Using these data, I calculated average speeds for each metropolitan area for (*a*) existing conditions and, on the assumption that congestion tolls eliminate enough peak-period VMT from congested roads, (*b*) no worse than heavy congestion on all roads, and (*c*) no worse than moderate congestion on all roads. According to Lomax, their category of moderate congestion corresponds roughly to LOS D, their heavy congestion to LOS E, and their severe congestion to LOS F. Using the calculations for Washington, D.C. (Row 1 of Table 8) as an example, my estimate of average peak-hour speed with existing conditions in 1988 was 29.0 mph (47 km/hr) for the entire urbanized area. The average peak-period speed in the Washington, D.C., area would increase to 29.9 mph (48.2 km/hr) if congestion tolls were set at levels that eliminated the worst congestion (conditions defined as severe). Finally, if tolls were set at levels that eliminated both heavy and

TABLE 8 Estimates of Congestion by Type of Facility for 15 Heavily Congested Urban Areas (Hanks and Lomax 1990)

Urbanized Areas	Percent Congested		Percent of Freeway and Expressway					Percent of Principal Arterial Streets					Peak Avg Speed (mph) All Highways			Percent Reduction Congested PVMT		Percent Reduction Total PVMT	
	Fwy+ PA	(incl. other)	Uncon 47mph	Mod 40mph	Heavy 35mph	Severe 32mph	Total Conges	Uncon 36mph	Mod 32mph	Heavy 28mph	Severe 25mph	Total Conges	Exist Cond	w/o Severe	w/o Heavy	w/o S	w/o H&S	w/o S	w/o H&S
Washington DC	74	51	35	14	39	12	65	15	8	32	45	85	29.0	29.9	32.1	4.6	22.5	3.4	16.6
Boston	43	31	55	6	17	22	45	60	7	15	18	40	32.7	33.4	34.9	5.0	20.0	2.2	8.6
New York	65	37	45	10	37	8	55	20	11	24	45	80	28.8	29.6	31.4	4.5	21.4	2.9	13.9
Los Angeles	64	49	25	4	10	61	75	50	9	18	23	50	29.8	31.0	33.3	7.0	22.4	4.5	14.4
SF-Oakland	75	54	20	8	17	55	80	40	10	11	39	60	29.7	31.0	33.6	6.8	20.1	5.1	15.1
Seattle-Everett	65	43	30	18	32	20	70	46	8	25	21	54	30.3	31.0	32.9	3.4	17.0	2.2	11.0
Houston	65	35	30	8	28	34	70	50	5	37	8	50	28.1	29.0	30.9	3.9	18.4	2.5	11.8
Dallas	48	29	46	8	31	15	54	70	5	24	1	30	31.4	32.0	33.6	2.2	15.5	1.0	7.4
Miami	66	43	41	7	16	36	59	30	1	22	47	70	27.5	28.7	30.8	8.1	30.0	5.4	19.8
Atlanta	52	30	54	2	36	8	46	35	21	13	31	65	29.9	30.6	32.2	3.5	18.1	1.8	9.4
Detroit	50	29	59	7	18	16	41	40	9	8	43	60	28.8	29.7	31.2	7.4	25.1	3.7	12.6
Chicago	59	30	45	8	21	26	55	36	11	26	27	64	27.2	28.1	29.7	5.1	22.0	3.0	13.0
San Diego	41	29	55	9	18	18	45	71	1	27	1	29	33.5	34.0	35.5	3.0	16.7	1.2	6.8
Baltimore	30	20	74	5	17	4	26	65	6	9	20	35	33.7	34.3	35.3	4.5	20.7	1.3	6.1
Philadelphia	54	33	75	8	16	1	25	24	10	20	46	76	29.1	30.0	31.5	6.9	27.8	3.7	15.0
Heavily Congested Urbanized Areas																			
Weighted average	60	38	41	8	23	29	59	39	9	20	31	61	NA	28.9	32.3	5.5	21.6	3.3	12.9
Unweighted average	57	36	46	8	24	22	54	43	8	21	28	57	30.0	30.8	32.6	5.1	21.2	2.9	12.1
Corpus Christi	7	3	90	1	9	0	10	96	0	4	0	4	31.3	31.9	32.5	0.0	17.0	0.0	1.2

1 mi = 1.6 km.

severe congestion, my calculations suggest the average peak-hour speed in the Washington, D.C., urbanized area would be 32.1 mph (51.7 km/hr).

The last four columns in Table 8 give the percentage reductions in peak-period VMT that would be required to achieve no worse than heavy congestion (w/o S) and no worse than moderate congestion (w/o H&S) as a percent of congested peak-period VMT (Congested PVMT) and as a percent of total peak-period VMT (Total PVMT). Again taking the first row (Washington, D.C.) for illustrative purposes, my calculations suggest that eliminating the worst congestion would require a 4.6 percent reduction of congested peak-period VMT or alternatively a 3.4 percent reduction of total peak-period VMT. Similarly, eliminating both heavy and severe congestion would require a 22.5 percent decrease in congested peak-period VMT and a 16.6 percent decrease in total peak-period VMT. As noted previously, in the EDF study of congestion pricing in Los Angeles, Cameron (1991, 47) determined that achieving a LOS of D or E in 2010 would require a 5.0 percent decrease in daily VMT and a 3.8 percent decrease in daily vehicle trips. LOS D or E corresponds to the Hanks and Lomax "moderate" and "heavy" categories. On the assumption that all the congested VMT occurs in the peak period, my estimates that a 3.4 percent decrease in peak-period VMT would have been required to eliminate severe congestion in Los Angeles in 1988 and that a 16.6 percent decrease in peak-period VMT would have been required to eliminate both severe and heavy congestion translate to 1.9 and 7.9 percent decreases in daily VMT. These reductions bound the estimates obtained in the EDF study for Los Angeles in 2010.

TRANSIT SUPPLY RESPONSES TO CONGESTION PRICING

The impacts of reductions in peak-period congestion on the speed, reliability, service frequency, and coverage of public transit systems have been largely ignored in the assessments of the impacts of congestion pricing on urban commuters, particularly in discussions of the income distributional impacts of such policies. As a result, previous analyses and discussions have very likely underestimated the shift to transit that would take place with the implementation of congestion pricing and overestimated the level of tolls that would be required to achieve desired congestion levels.

Discussions of congestion pricing have tended to give too little attention to or have underestimated the likely impacts of congestion pricing on transit use because (*a*) the effects are complex and (*b*) obtaining estimates about the effects of congestion pricing on transit use requires detailed and explicit assumptions about both the level of congestion tolls and their effects on the speeds of roadway segments that are used by transit vehicles. These, in turn, depend on the responses of transit providers and funding agencies to the dramatically changed operating environment that would result from the implementation of congestion pricing in a heavily congested urban area.

In the relationship between congestion pricing and transit, it is important to recognize from the outset that in even the largest and most congested metropolitan areas, transit accounts for a relatively small fraction of daily trips and only a slightly larger fraction of peak-period trips. With the exception of the New York region, transit accounts for less than 18 percent of all work trips and presumably for an even smaller fraction of all peak-period trips. As the 1990 work-trip mode share data in Table 9 show, in all of the remaining 14 heavily congested urbanized areas more than 60 percent of all trips to work by vehicular modes were by drivers of single-occupant vehicles. It follows that even fairly modest declines in SOV trips could produce very large increases in public transport use. In the case of

TABLE 9 Vehicle Ownership and Work-Trip Modal Share in Heavily Congested Metropolitan Areas, 1990

Urbanized	Percent of Households with			Worktrip Mode Share				
Area	No veh.	1 veh.	2+ veh.	SOV	Carpool	Transit	Others	Total
Washington, DC	11.9	33.2	55.0	66.3	12.4	13.7	7.6	100.0
Boston	16.9	36.9	46.2	68.2	7.4	14.2	10.2	100.0
New York, NY	50.2	31.6	18.2	36.1	3.5	47.3	13.1	100.0
Los Angeles	11.2	35.7	53.1	72.3	13.3	6.5	7.9	100.0
SF-Oakland	17.6	36.9	45.5	60.2	8.4	19.5	11.9	100.0
Seattle-Everett	8.0	31.5	60.5	74.6	9.8	7.4	8.2	100.0
Houston	8.4	37.5	54.1	77.1	13.2	4.1	5.6	100.0
Dallas	6.9	35.8	57.2	78.7	12.8	3.2	5.3	100.0
Miami	16.0	37.3	46.7	74.3	13.7	5.9	6.1	100.0
Atlanta	8.9	29.9	61.2	79.2	11.5	4.7	4.6	100.0
Detroit	12.5	32.6	54.9	84.1	9.4	2.4	4.1	100.0
Baltimore	16.4	31.6	52.0	73.0	12.1	7.7	7.2	100.0
Chicago	19.4	37.0	43.6	66.8	9.1	17.1	7.0	100.0
San Diego	7.9	34.1	58.0	73.0	11.7	3.3	12.0	100.0
Philadelphia	18.3	35.1	46.5	70.2	9.5	11.6	8.7	100.0
Unweighted Mean								
All Areas	15.4	34.4	50.2	70.3	10.5	11.2	8.0	100.0
Without New York	12.9	34.7	52.5	72.7	11.0	8.7	7.6	100.0

Los Angeles, for example, the previously mentioned study of congestion pricing by Harvey (Cameron 1991) predicted that a peak-period congestion toll averaging 15 cents/mi (10 cents/km) would reduce daily automobile trips by 3.8 percent. A large fraction of these former automobile trips was undoubtedly SOV trips to work. If half of these trips were diverted to transit, they could easily account for a doubling of transit ridership. An increase in transit use of this magnitude would clearly have a major impact on the nature of transit service in the region.

Public transit in the United States is currently heavily subsidized. Operating deficits for the 15 metropolitan areas I have identified as the most likely candidates for the implementation of congestion pricing were in excess of $10 billion dollars in 1990. If the 1990 average operating deficit of $1.02 per boarding (Table 10) was maintained, the increases in transit ridership that would result from implementation of congestion pricing would greatly increase transit deficits and create serious fiscal problems for already hard-pressed local governments, who currently directly or indirectly fund the bulk of operating losses. Of course, whether the deficit per boarding passenger remained unchanged, increased, or decreased would depend on decisions by transit operators and their benefactors about the amount of service provided and the fare levels. These issues are examined below.

Transit Speeds and Reliability

The effect of congestion pricing on transit speeds and reliability would depend both on how much congestion was reduced and on the relationship between bus speeds and the average speeds of other vehicles. Lave (1991, 116) in his provocative study of transit productivity defended the use of operating costs per bus hour as his principal measure of bus productivity by arguing that "it would be unfair to use bus miles . . . since that quantity is largely determined by the amount of traffic-congestion in the service area" and that "increases in congestion over time would automatically lower the apparent productivity of a transit agency even though it is not a factor within their control." In spite of the widespread acceptance of the view that congestion on surface streets and expressways increases the operating costs of road-based transit vehicles, I have been unable to locate any persuasive time series evidence on the impact that changes in congestion have had on the operating speeds of road-based transit.[12] Systemwide time series data on average bus operating speeds are available, but because

TABLE 10 Summary Statistics on Transit Operations in Heavily Congested Metropolitan Areas, 1990

		Percent Road Based/Total															
Urbanized	Operators		Capacity	Passenger	Revenue	Operating	1990 Passenger Load Factor (000s)					Average Bus Speed (mph)			Fares/	Average	Oper Cost/	Deficit/
Area	Number	Boardings	Miles	Miles	Miles	Cost	Bus	R Rail	DR	C. Rail	Total	1980	1990	90/80	Oper Cost	Fare	Trip	Trip
Washington, DC	2	51.1	28.1	38.2	58.4	55.3	0.21	0.13	0.16	NA	0.15	11.0	11.7	1.06	49.6%	0.73	1.46	-0.74
Boston	2	30.4	30.3	30.7	41.8	35.7	0.16	0.16	NA	NA	0.16	12.7	12.7	1.00	29.7%	0.40	1.61	-1.21
New York, NY	36	37.3	20.6	24.2	35.7	31.8	0.22	0.16	0.05	0.23	0.19	8.5	11.2	1.32	61.6%	0.98	2.07	-1.09
Los Angeles	16	99.95	99.5	99.2	99.5	99.7	0.25	NA	0.14	NA	0.25	13.4	12.6	0.94	38.9%	0.54	1.39	-0.85
SF-Oakland	10	70.8	50.3	48.2	57.5	62.5	0.20	0.20	0.14	0.35	0.20	13.0	12.9	0.99	32.9%	0.55	1.72	-1.17
Seattle-Everett	7	97.4	99.2	99.5	83.2	99.3	0.19	0.12	0.71	NA	0.19	13.3	15.1	0.82	21.3%	0.47	2.19	-1.72
Houston	3	100.0	100.0	100.0	100.0	100.0	0.25	NA	0.14	NA	0.24	13.6	14.3	1.05	32.7%	0.51	1.56	-1.05
Dallas	2	100.0	100.0	100.0	100.0	100.0	0.14	NA	0.18	NA	0.14	15.8	14.8	0.94	23.3%	0.54	2.30	-1.77
Miami	2	78.3	57.0	69.4	82.1	70.2	0.21	0.12	0.23	NA	0.17	11.7	11.9	1.01	35.0%	0.73	2.09	-1.36
Atlanta	1	53.4	36.8	43.1	62.6	62.3	0.15	0.11	0.08	NA	0.13	13.1	13.0	0.99	35.0%	0.39	1.12	-0.73
Detroit	2	100.0	100.0	100.0	100.0	100.0	0.21	NA	0.11	NA	0.21	13.5	13.7	1.02	23.1%	0.44	1.90	-1.46
Baltimore	1	88.0	75.1	82.9	85.8	78.5	0.27	0.16	0.17	NA	0.24	12.1	12.0	0.99	43.5%	0.58	1.34	-0.76
Chicago	11	66.7	46.9	40.4	53.8	47.6	0.18	0.20	0.11	0.29	0.21	12.1	11.2	0.92	64.7%	0.75	1.56	-0.81
San Diego	4	76.6	64.1	69.6	86.6	85.6	0.19	0.15	0.22	NA	0.18	16.3	14.5	0.89	40.6%	0.55	1.36	-0.81
Philadelphia	2	51.3	31.8	34.0	46.5	36.7	0.22	0.21	0.12	0.19	0.21	10.2	10.3	1.01	70.0%	0.80	1.57	-0.77
Mean of All HC Areas																		
Unweighted	7	73.4	62.6	65.3	72.9	71.0	0.20	NA	NA	NA	0.19	13.0	12.8	1.00	40.1%	0.60	1.68	-1.09
Weighted	101	55.1	36.8	40.6	74.6	74.6	0.21	0.16	0.15	0.23	0.19	11.4	12.1	1.06	40.6%	0.77	1.79	-1.02

1 mi = 1.6 km.

of changes in the mix of service by type of route and type of service, these data are of little or no use.

Somewhat more surprisingly, there are almost no studies that use route-specific, cross-sectional data on bus speeds and congestion levels, or average vehicle speeds, to quantify the relationship between bus speeds and congestion levels. The few bus speed studies I was able to find focus primarily on the effects on bus speed of stop frequency, numbers of passengers, and fare collection methods (Abkowitz and Engelstein 1983; Alfa 1988; Seneviratne and Choo 1986). Although it would presumably be possible to obtain route-specific data on bus speeds from individual transit operators, these data would have to be merged with data on congestion levels for the streets used by these services. I tried but was unable to obtain any summary data from large transit operators on the extent to which road-based transit services are currently adversely affected by congestion, although all of those I talked to claimed that the problem is very serious.

Lave (1991, 125), to his surprise, found that average (unweighted) bus speeds for the sample of 64 transit agencies he used in his study "actually increased from 11.22 in 1964 to 12.64 in 1985." These increases were even greater for a subsample of larger firms. Average bus speeds for firms with revenues in excess of $5 million in 1964 increased from 10.68 to 12.75 mph (17.20 to 20.53 km/hr) over the same time period. Lave concludes, correctly I believe, that these increases in average bus operating speeds are due to the widespread "expansion of bus routes into the suburbs, and the initiation of express bus routes" by most transit operators during this period (Lave 1991, 123).

As Lave's data illustrate, the connection between systemwide bus speeds and congestion levels is by no means simple or obvious. There is no doubt that congestion on central city arterials, where local bus services are presumably concentrated, increased by large amounts immediately after World War II in most U.S. metropolitan areas. Congestion levels, however, then generally declined as a result of extensive post-World War II road building and street improvement programs. In addition, during the past decade or so, large declines in central city employment and population have undoubtedly led to lower levels of congestion on many central city arterials, even though these declines were often accompanied by declines in transit use and the growing use of private cars. During the same period, congestion became much worse in many suburban areas, particularly on roads serving large suburban subcenters.[13]

The only systematic analyses of the relationship between congestion and bus operating speeds that I was able to locate are those by Levinson

(1991b), and these analyses, which are more illustrative than systematic empirical analyses of actual experience, emphasize the role of stop frequency and boarding times more than the role of congestion. Levinson (1991a) is apparently also responsible for the treatment of the relationship between congestion and bus operating speeds in the transportation modeling package INET. This package, which is part of the travel forecasting modeling package developed by several consultants under the auspices and funding of the Urban Mass Transportation Administration (UMTA) (now the federal Transit Administration), calculates the travel times and speeds of local buses over a particular link as a fraction of passenger car travel times and speeds over the same link (Dial 1979). This parameter for bus speed versus automobile speed may vary depending on the extent of congestion and, more important, on the number of stops and boarding times, but a value of 0.6 is commonly used for local and arterial streets outside the CBD.

Independent support for the widely used value of 0.6 for the ratio of bus speeds to automobile speed is provided by analyses I completed for this paper. Equations 1 and 2 are regressions of the average speed of bus trips on the average speed of automobile drive-alone trips and on average bus trip length for 58 U.S. metropolitan areas in 1975, 1976, and 1977. The data used in this analysis are from the Annual Housing Survey (Bureau of the Census 1981, 1982). Both the bus and drive-alone trip times, which are used in calculating average speeds, include walking and waiting times. Equation 1, which simply regresses the average speed of bus trips on the average speed of drive-alone automobile trips, almost exactly reproduces the 0.6 value recommended as the default value in INET for local buses. Equation 2 adds the ratio of average bus trip distance to average drive-alone trip distance as a way of correcting for differences in trip length. Although the addition of this ratio increases the equation's explanatory power by a substantial amount, it has almost no effect on the coefficient of drive-alone automobile speeds.[14] This paper accepts the view implied by Equations 1 and 2 and the INET default that bus operating speeds increase or decrease by 0.6 for each 1 mph (1.6 km/hr) increase or decrease in automobile speeds.

$$\underset{}{BS} = \underset{(3.09)}{-2.344} + \underset{(4.87)}{0.625 DAS} \qquad R^2 = 0.297 \tag{1}$$

$$BS = \underset{(-2.53)}{-6.237} + \underset{(6.33)}{0.627 DAS} + \underset{(6.25)}{4.255\ BD/DAD} \qquad R^2 = 0.589 \tag{2}$$

where

BS = average speed of bus trips for area i (mph),
DAS = average speed of drive-alone automobile trips for area i (mph),
BD/BAD = average distance of bus trips divided by average distance of drive-alone automobile trips.

In assessing the impacts of congestion pricing on transit, it is important to keep in mind that road-based transit accounts for only part of the transit services supplied in many metropolitan areas. This is particularly true for the 15 heavily congested urbanized areas I have identified as candidates for congestion pricing. Table 10 provides four measures of the share of transit services that are provided by road-based transit (motor bus plus demand responsive). Road-based trips (boardings) are usually shorter than rail trips (heavy rail, light rail, and commuter rail). For all 15 congested metropolitan areas combined, road-based transit modes accounted for 55.1 percent of boardings, 36.8 percent of capacity miles, 40.6 percent of passenger miles, and 74.6 percent of revenue vehicle miles. When equal weights are used for the 15 areas, road-based modes account for 73.4 percent of boardings, 62.6 percent of capacity miles, 65.3 percent of passenger miles, and 72.9 percent of revenue vehicle miles. Road-based modes have the smallest role in Boston and New York, where they account for only 30.4 and 37.3 percent of all boardings and 30.7 and 24.6 percent of passenger miles, respectively. In contrast, the modes accounted for 100 percent of boardings, capacity miles, and passenger miles in Houston, Dallas, and Detroit in 1990 and nearly 100 percent in Los Angeles and Seattle-Everett. Los Angeles now has both light and heavy rail service and a light rail line is under construction in Dallas.

Congestion pricing would affect the demand for rail transit by increasing the money cost per mile of SOV trips, but it will have no effect on the speed or reliability of rail transit trips, with the important exception of rail trips that involve transfers from or to road-based services. In these cases, congestion pricing would reduce trip times by increasing the speed and reliability of feeder bus services. Although feeder bus trips are less likely to be made on heavily congested streets than are local or express bus trips, they would nonetheless receive some benefit from congestion pricing.

Transit Ridership

Implementation of congestion pricing in a metropolitan area with extensive peak-period congestion would have at least two immediate effects on transit ridership. First, the dollar cost of SOV trips between many origins and destinations would increase, in some cases by substantial amounts. Second, average vehicle speeds on most previously congested facilities would increase. These higher vehicle speeds would of course make commuting by private car even more attractive. Congestion tolls would have to be set at levels that were sufficiently high to reduce the vehicle use on currently congested facilities by amounts large enough to achieve desired congestion levels. Estimates of the peak-period VMT reductions that would be required to achieve significant reductions in congestion are shown in Table 8.

As discussed previously, two changes in supply characteristics would make carpooling and transit more attractive. First, the relative money cost of both carpools and transit would decline as the money cost of SOV trips increased. Second, the service quality in terms of trip times and reliability of both transit and carpools would improve relative to the pre-congestion-pricing SOV alternative, although of course not relative to post-congestion-pricing SOV trips. The most obvious way in which congestion pricing would improve the service quality of both carpools and buses is by increasing vehicle speeds and reliability (reducing the variance of travel times). There are other effects, however, that may be even more important. In the case of carpools, for example, the implementation of congestion pricing would tend to increase the supply of potential carpool matches for origin and destination (O&D) pairs that experience large increases in money costs and large decreases in carpool travel times.

The supply effects of congestion pricing are likely to be even larger for bus transit. To the extent that congestion pricing increases the number of transit users, this increased demand, depending on how transit operators respond, may lead to increased frequencies (reduced headways) on existing routes. Mode-choice studies have shown that trip makers have a much greater disutility for time spent walking to and from and waiting for transit vehicles. If the first round of increases in fares and reductions in transit in-vehicle transit times led to a doubling in transit demand, this increase in demand could reduce headways on many routes by one-half or more. Of course, if there had been excess capacity on a particular route during peak periods before the introduction of congestion pricing, the operator of this

route might well chose to less than double frequencies, opting for a higher load factor and higher farebox recovery ratio over greater patronage.

In addition, or as an alternative, to increasing frequencies on existing routes, transit operators might respond to increases in demand induced by congestion pricing by providing more coverage, that is, by providing direct or transfer service between O&D pairs that previously had no direct service or no service at all. Similarly, they might provide new nonstop or limited-stop services, and thereby further reduce transit trip times between previously served O&D pairs. Each of these reductions in transit trip times, of course, would produce additional increases in transit ridership and further opportunities to increase transit frequencies, coverage, and the number of nonstop, nontransfer, or limited-stop services. It is impossible to estimate the magnitude of the resulting increases in transit service without a detailed knowledge of trip patterns by O&D and of the post-congestion-pricing vehicle speeds on the streets that are used by existing services and might be used by new services, and without a knowledge, or very specific assumptions, of how transit operators would respond to the new opportunities.

It is important to emphasize once again that transit providers are currently heavily subsidized. Reductions in congestion would not only make transit more attractive to individual trip makers, they would also reduce the operating and capital costs of services that use previously congested streets and roads. The extent of these cost savings would depend in the first instance on the nature of the transit systems serving a particular metropolitan area and particularly the extent to which these systems are road based. As Table 10 reveals, the 15 metropolitan areas I have identified as candidates for congestion pricing differ greatly in the extent to which their transit systems are road versus rail based.

Of the four measures of transit service and usage included in Table 10, revenue vehicle miles is the best indicator of the initial operating cost savings that might accrue to existing transit operators as a result of significant decreases in congestion. The fraction of revenue vehicle miles by road-based modes varies from a low of 35.7 percent for the New York metropolitan area to 100 percent for three metropolitan areas that in 1990 had no, or insignificant, rail service (Dallas, Detroit, and Houston). The weighted share of revenue vehicle miles that is provided by road-based transit vehicles in the 15 heavily congested areas is 74.6; the unweighted share is slightly less, 72.9 percent.

Higher levels of transit demand in a corridor provide numerous opportunities for cost savings and improvements in trip speeds. In low-volume

situations, frequencies may be determined by policy headways, and all vehicles frequently have to operate over the entire route. As demand increased, it would be possible to introduce limited-stop services (these reduce both per mile operating costs and trip times) or turn a fraction of the buses back and thereby achieve higher overall load factors, or both. These issues have been discussed by Kerin (1990).

Transit Load Factors

Deich and Wishart (1988, 33), authors of a controversial study by the Congressional Budget Office, *New Directions for the Nation's Public Works*, argue that in the United States "transit fleets in general are greatly underutilized, and the new transit systems have for the most part added to costs and to unused capacity without attracting riders from cars." They state further, "[A]fter 25 years of federal aid, transit agencies have modern fleets and many own considerably more vehicles than they need for rush hour traffic," "most of the equipment is underused," and "federal operating subsidies go largely to pay for buses and trains running empty rather than for service improvements or fare discounts" (Deich and Wishart 1988, 33). Further arguing their case, they present two measures of overcapacity, the fraction of transit vehicles used regularly in peak hours and load factors, which they define as the ratio of passenger miles to capacity miles. They observe that "only about 80 percent of the national bus fleet is regularly used in peak service" and that "the percentages of capacity miles of service used by passengers . . . are low, averaging less than 30 percent for all major modes" (Deich and Wishart 1988, 35–36). In all but one of five agencies that had recently built new or extended existing rail systems, moreover, they found significant declines in load factors between 1980 and 1985.

The Deich-Wishart study was severely criticized by the transit industry. Spokespersons for the industry charged the authors with naiveté for suggesting that industry load factors were unreasonably low. They argued that because of directional imbalances on many routes, the peaking of transit demand, and the normal taper in demand from the start to the end of most routes, a large fraction of transit seats are unavoidably empty most of the time. Indeed, some critics went so far as to argue that many systems have serious overcrowding during peak periods and that these systems have too little rather than too much capacity. Critics might also have legitimately pointed out that transit ridership was abnormally high in 1980

as a result of price controls and lines for the purchase of gasoline, and that the 1980 and 1985 comparisons used by Deich and Wishart therefore exaggerated the decline in system load factors. Although much of what the critics have said about the uncritical use of load factors is correct, it is nonetheless difficult to avoid the impression that transit systems in many metropolitan areas have substantial excess capacity, even during peak periods. In 1990, for example, as the load factor data in Table 10 indicate, the combined average load factor for the 15 heavily congested areas was 21 percent for bus, 16 percent for rapid rail, 15 percent for demand-responsive modes, and 23 percent for commuter rail.

Insofar as the transit systems serving congested metropolitan areas have excess capacity, the increases in ridership that would result from the implementation of congestion pricing could reduce the per trip and systemwide deficits of these systems. As the statistics on farebox ratio (fares/operating costs) in Table 10 reveal, the combined farebox ratio for the 15 metropolitan areas shown was 40.6 percent. This ratio, moreover, varies from a low of 21.3 percent for the seven systems serving Seattle-Everett to a high of 70.0 percent for the two operators serving the Philadelphia metropolitan area.

It is impossible to determine how much excess capacity exists in these systems without a detailed analysis of each system. Nonetheless, it is likely that at least some of any congestion-pricing-induced increases in transit demand could be accommodated without increases in capacity. In many systems "policy headways" on lightly traveled routes result in large numbers of empty seats even during peak periods. If congestion pricing increased the demand for these routes, part or all of the increased ridership on these currently underutilized routes could be accommodated with no increase in service and without overcrowding. Increases in fare revenues and farebox ratios would be the result. In other situations, increases in demand would require the provision of additional service on the most heavily traveled portions of existing routes, but they might also enable operators to better tailor service to demand on these routes by operating some buses only over the most heavily traveled portion of the route. In still other cases, it would be possible to combine such changes with the introduction of skip or limited-stop services, thereby both improving trip times for users and reducing per mile operating costs for the transit operator. However they are achieved, through increases in ridership with less than proportional increases in service or through speed-induced reductions in operating costs per mile, the resulting increases in farebox revenue should go right to the bottom line, thereby reducing the very large deficits of these systems.

Service Expansion

As discussed in the preceding section, I anticipate that part of the increases in transit ridership that would result from an increase in the relative money cost of SOV trips and reductions of travel times for road-based transit modes could be accommodated by improvements in load factors. Congestion pricing would also lead to reductions in the per mile operating costs of road-based transit vehicles, as buses operating in less congested conditions would be able to make more round trips per hour. These savings could be used either to reduce subsidies or, more likely, if the increase in demand is substantial, to provide additional service to accommodate the larger number of riders. The previously discussed improvements in load factors similarly would reduce the per trip subsidy required for existing services or, if the aggregate subsidy for an urbanized area was kept the same, they would permit an expansion of service levels.

As discussed previously, these service expansions could take several forms. First, more buses or trains could be run on existing routes and lines. Research on the impact of increases in service frequencies indicates that reductions in headways on routes and lines with relatively infrequent service are likely to have a larger impact than increases in frequencies on lines that already have very frequent service (Jacobs et al. 1984). Increases in demand on routes and lines that already have frequent service may, however, enable operators to reduce per trip subsidies even if load factors are not increased by substituting larger vehicles or longer trains. The extent of capital and operating cost savings that might arise from the substitution of larger buses for smaller ones or longer trains for shorter trains would be highly specific to particular systems, routes, and lines. Train lengths on rail systems are limited by the length of station platforms, and the cost of lengthening platforms can be prohibitive, particularly in the case of systems with large amounts of subway. Rebuilding stations to accommodate longer trains can also take several years. The replacement of standard size buses with articulated buses can be done more quickly and can provide significant labor and operating cost savings, even though these large vehicles are quite expensive.

In considering the impacts of congestion pricing on existing rail transit systems, it should be noted that the implementation of congestion pricing would reduce the relative attractiveness of rail modes. Much of the attraction of rail transit systems, particularly those that have their own rights-of-way, is that they are able to avoid congested streets and thereby provide higher line-haul times. As Meyer et al. (1965) and others have pointed out,

however, this advantage of grade-separated rail systems in congested metropolitan areas is offset to some extent by the fact that station spacing is greater on rail than on at least local bus routes and that the use of rail transit frequently requires an automobile-to-rail or a bus-to-rail transfer. Where congestion is serious, commuters are often willing to accept the inconvenience of these transfers in order to obtain the benefit of the higher line-haul speeds provided by rail transit. The implementation of congestion pricing, however, would reduce or eliminate congestion on urban streets and arterials and permit significant improvements in bus speeds and reliability. In many cases, with lower congestion levels, direct buses would be able to provide significantly lower door-to-door travel times, especially when the disutility per minute that urban trip makers attach to transfers is taken into account. If buses were permitted to compete with rail transit for many trips that are currently made by rail, they would very likely be able to supply many of the trips at lower generalized cost than rail does currently. Thus, rather than produce a huge increase in demand for rail transit, congestion pricing might actually reduce rail ridership on many systems as many trips that are currently made by rail are transferred to more direct, faster, nontransfer bus services.

In addition to more frequent service on existing routes and lines, the expansion of transit services could take many other forms, in particular the provision of service to previously unserved origins and destinations or the replacement of service between specific origins and destinations that previously required one or more transfer with more direct service. One approach to quantifying the impact of these various forms of service expansion on transit ridership is to estimate time series models of transit ridership in which systemwide annual, quarterly, or monthly ridership is regressed on systemwide revenue miles of service, real fares, and a variety of other variables including real gasoline prices, metropolitan area employment, and per capita levels of car ownership. In unpublished time series models that I estimated for Atlanta, Ottawa, and San Diego; similar estimates by Liu (1993) for Portland, Oregon; and several other studies, the transit ridership elasticity of revenue service miles is 0.5 or larger. Thus, increases in revenue miles of service, whether they are financed by savings in bus operating costs per mile, higher load factors, other efficiencies, or increases in aggregate subsidy levels, would lead to further increases in transit ridership on the order of a 0.5 percent increase in ridership for each increase in total revenue miles of service (Goodman et al. 1977; Jacobs et al. 1984; Lago et al. 1981).

PRIVATIZATION, CONTRACTING OUT, AND DEREGULATION

Transit operating deficits are a relatively recent phenomenon. Lave (1991, 118) in his analysis of 62 transit agencies over the period 1950 through 1985 found that as late as 1964, 49 of the 62 firms included in his study had ratios of revenue to operating expenses higher than 1.0, 6 more had ratios between .95 and 1.0, and only 3 were lower than 0.91. The only really low ratio was 0.70 for the San Francisco Muni system, which had been publicly owned and operated since 1912. The picture is less favorable when the operators' estimates of depreciation are included; the unweighted average of commercial revenue to operating expense plus depreciation for the 62 systems was slightly less than 1 (0.92) in 1964 and this figure had fallen to 0.87 by 1970. The unweighted average of commercial revenue to operating expense when the operators' estimates of depreciation were included was 0.92 in the same year. Fifteen years later, in 1985, the unweighted ratio of commercial revenues to operating expense had declined precipitously from 1.05 in 1964 to 0.34. The unweighted ratio of commercial revenues to operating expense plus depreciation was the same, reflecting the practice in which publicly owned and operated transit systems do not include estimates of depreciation in their operating statements.

From further analysis of his sample of 62 transit firms, Lave (1991, 115) concludes that "if transit productivity had merely remained constant from 1964, the year the federal subsidy program began," through 1985, the last year covered by his analysis, "total operating expenses would be 40% lower." He adds that "this is enough cost reduction to erase most of the current operating deficit—without raising fares." Lave (1992, 115) observes further that "it is uncommon to find such a long-term productivity decline in any industry," that "the productivity decline in the transit industry is notable for both its direction (a decline), and its magnitude," and, citing unpublished 1988 data by Cox, he adds that there is "nothing inherent about the public transit industry that produces such a decline" since productivity in the private bus industry "rose by 8.3 percent over the 1970–1985 period."

The causes of the growing per trip and systemwide transit subsidies during the past three decades are numerous and complex. Lave (1991) and others emphasize "inefficiencies" that appear to be related to the shift from nearly 100 percent private ownership and operation 30 years ago to nearly 100 percent public ownership and operation today. At the same time, the declines in transit ridership and the worsening financial position of private

operators were caused in part by the steady suburbanization of jobs and residences in combination with the public policy decision to provide at least minimal levels of transit service to these increasingly dispersed workplaces and decentralized residences, and to limit fare increases (Liu 1993; Kain 1991a). Finally, growing levels of congestion and the gross mispricing of many streets and roads in dense and congested centers made it nearly impossible for private, for-profit transit to provide the combination of fares and service demanded by the public and its representatives and still make a profit. Analyses by Lave (1991) and others strongly suggest that the level of subsidy required might have been much smaller if governments had responded to this dilemma by providing subsidies to private firms to provide the desired combinations of fares and service. Whatever the merits of these arguments, and I would contend that they are considerable, the reality is that the deep subsidies provided to public agencies currently make private, unsubsidized transit operation uneconomic except in situations where subsidized public transit agencies choose not to provide service.

Among the many potential benefits of congestion pricing is the possibility it offers of reversing the ruinous past three decades of public ownership and operation of transit services. In this regard, I would strongly urge caution in accepting the frequent arguments in favor of using a significant part of the large revenues from congestion pricing to provide additional transit subsidies. Although some additional subsidy might be required in the short run if large congestion-price-induced increases in transit use require large service expansions, serious consideration should be given to implementing fare increases that, in combination with the reductions in operating costs that could accrue to some systems, could permit either significant reductions or even the elimination of public subsidies for urban public transport.

The analyses by Lave and others suggest, moreover, that congestion pricing and fare increases should be accompanied by efforts to privatize all or large parts of publicly owned and operated transit systems. If Lave's analyses are correct, privatization, possibly in combination with somewhat higher fares, could eliminate the need for subsidy altogether in many situations. Even if existing public transport authorities are not fully privatized, fare increases and reductions in subsidies to these firms, in combination with the elimination or reduction of barriers to entry, could permit new private operators to begin providing private unsubsidized service. This has been the experience in Mexico City, where after 30 years of massive subsidies to the metro and the public bus company, the govern-

ment has raised fares substantially and has begun encouraging private operators to compete for a growing share of Mexico City's transit market (Kain 1991b).

In a somewhat unconnected observation, I would reiterate my previous observation that the elimination of existing subsidies to private vehicle users in the form of employer-provided free parking should be the first step toward charging vehicle users appropriately for the use of streets and roads in congested urban centers. The elimination of free parking might substantially reduce peak-period congestion in many urban areas and make more extensive forms of congestion tolls, such as areawide congestion pricing, unnecessary. In addition, congestion tolls are unlikely to work very well as long as free (untaxed, employer-provided) parking exists. Finally, requiring commuters to pay market prices for their parking would have a huge effect on public transit use, since parking subsidies are greatest in those markets where transit is most competitive with private automobile use. Increases in transit use that resulted from the elimination of free parking would produce many of the benefits to transit discussed in previous sections.

The principal potential weakness of higher parking prices as the sole instrument relative to an areawide congestion pricing scheme is that they would not ensure that roads used by public transport vehicles would remain uncongested. Because vehicle users would still not be charged for their use of urban streets and roads, the decreases in automobile use and higher speeds brought about by higher parking charges would be an invitation to other vehicle users to make greater use of these facilities. Nonetheless, the elimination of public subsidies for parking should be the first step in our efforts to rationalize the use of urban transportation facilities. As Shoup (1992a, 1992b) has shown, there are schemes for cashing out free parking that would benefit employees and employers alike, although their impact on SOV commuting and transit and carpool use would be smaller than simply removing the current exemptions for employer-paid parking in the federal income tax.

NOTES

1. Preparation of this paper has been a rewarding but frustrating experience. The frustration arises from a lack of time and money to complete the analyses this important subject deserves, increased by the fact that the technology and know-how exist for making the needed calculations with acceptable levels of precision. Indeed several colleagues and I carried out analyses of the type required several years ago in two case studies of the Boston metropolitan area

(Fauth et al. 1978; Gomez-Ibañez and Fauth 1980; Kain and Fauth 1979). Although I have not attempted to estimate just how much such a study would cost, I am certain that a good and highly useful analysis could be completed for a representative selection of U.S. metropolitan areas for significantly less than the U.K. Department of Transport is currently spending to complete an assessment of road pricing for London. According to Richards (1992), the budget for this study is approximately $5.0 million U.S.

2. Some of the most notable of this large number of studies, papers, and reports are those by Boardman and Lave (1977), Borins (1982, 1984), Foster (1974), Gomez-Ibañez and Fauth (1980), Hau (1992), Hendrickson and Wohl (1982), Keeler and Small (1977), Kerin (1990), Kraus (1981, 1982, 1989), Kraus et al. (1976), Kulash (1974), Morrison (1986, 1992), Small (1983b, 1992b), Smeed (1968), Vickrey (1965, 1967), Viton (1980), and Walters (1961, 1968).
3. The relationship between short-run and long-run MC has been discussed by numerous authors. Some of the best discussions include those of Hendrickson and Wohl (1982), Hau (1992), Kraus et al. (1976), and Keeler and Small (1977).
4. Important contributions to this extensive literature include those by Ben-Akiva and Atherton (1977b), Ganek and Saulina (1976), Hensher and Dalvi (1978), McFadden and Talvitie (1977), Quarmby (1967), Richards and Ben-Akiva (1975), and Train (1980).
5. Some evidence on the relationship between average network speeds and average work trip length is provided by regression analyses I completed for my recent testimony before the U.S. Senate Committee on Environment and Public Works (Kain 1991a). I found, using a cross-section regression of average work trip distance traveled at average speeds in 41 metropolitan areas, that a 1 percent increase in average speeds (for all trips) would lead to about a 1 percent increase in work trip length in miles. The natural logarithm of average journey-to-work-trip length (in miles) is the dependent variable in this regression and the natural logarithms of average speed, median family income, and metropolitan area population are the explanatory variables. Since all variables are logarithms, the individual coefficients are constant elasticities. This equation explains nearly 80 percent of the variance in average trip length, and the t-statistics for individual coefficients were average speed ($t = 9.2$), Standard Metropolitan Statistical Area (SMSA) population ($t = 5.4$), and median family income ($t = 1.6$). The coefficient of average speed, moreover, remains approximately 1 when automobile and truck drive-alone trip distances and speeds are used instead of all trip distances and speeds. Including the natural logarithms of percent single family and the percent of units in structures with five or more units increases the coefficient (elasticity) for speed to 1.08.
6. Among the relatively small number of mode-choice models that explicitly consider carpools are those of Ben-Akiva and Atherton (1977b), Ganek and Saulina (1976), Wilson (1991), Small (1983a), and COMSIS Corporation (1989). In addition to discrete-choice models, Parody (1982, 1983) and Christiansen and Morris (1989, 19) have used other methods to assess the response of urban trip makers to the time savings provided by high-occupancy-vehicle (HOV) lanes. These and other studies related to HOV facilities are reviewed by Kain (1992).

7. This carpool penalty is smaller than was assumed by Small (1992b), who added 15 min to a two-person carpool. Small's carpool penalty is meant to allow for the demonstrated lack of enthusiasm of commuters for the carpool mode, even when it would seem to have lower time and money costs than other modes. My sense, however, is that low carpooling rates have more to do with free (employer-paid) parking, the difficulties associated with carpool formation, issues relating to inconvenience and scheduling, problems associated with matching trips made to widely dispersed origins and destinations, and the weak incentives for carpooling than with the time and dollar costs of circuity per se. The method used to estimate the full cost of carpooling in Table 1, moreover, is clearly more conservative than the approach used by Bailey (1982) for a sample of Baltimore residents in 1980. Bailey assumed that the carpool would meet at a "central place that is an average distance ($\bar{d}$) from the homes of the carpool members." Bailey's approach significantly reduces the "cost" of carpooling, particularly for larger carpools but it also reduces the benefits by requiring carpool members to own a second or third car or to be dropped off at the pickup location.
8. These are papers by Shoup (1982, 1992), Shoup and Pickrell (1980), Pickrell and Shoup (1980), Shoup and Wilson (1992), Surber et al. (1984), Wilson (1992), and Wilson and Shoup (1990a, 1990b).
9. Hanks and Lomax's definition of "urbanized area" appears to differ somewhat from that of the Census Bureau. They state that "in defining urbanized areas, it was not always possible to use jurisdictional limits as the defining boundaries due to either lack of data on related travel measures or non-comparability of information. County boundaries may appear to provide consistency, but variations in county size, as well as percentage of urbanization, significantly impaired the utility of county-based data. This study uses a population density of more than 1,000 persons per square mile as the criterion for urbanized area delineation" (Hanks and Lomax 1990, A-2). In discussing their analyses and data, I use the terms "urbanized area" and "metropolitan area" interchangeably.
10. Other metropolitan areas with RCIs greater than 1.0 in 1988 were Phoenix, Ariz. (1.00), Portland, Oreg. (1.05), Sacramento, Calif. (1.03), and Tampa, Fla. (1.03). Large metropolitan areas with RCIs below the 1.00 threshold in 1988 included Cleveland, Ohio (0.97), Denver, Colo. (0.99), Minneapolis–St. Paul, Minn. (0.88), Pittsburgh, Pa. (0.81), and St. Louis, Mo. (0.98).
11. Hanks and Lomax (1992, 1) in the introduction ask, "Why should we research and investigate effects of urban congestion?" Their answer, which excludes any mention of congestion pricing as a possible tool, is, "Quite simply, old solutions are not working any more. The current mobility situation in most metropolitan areas leaves the limited choices of controlling area growth, large expenditures for general use and transit facility improvements, or accepting intercity and suburb decline."
12. No one who has regularly used buses in Bangkok, as I did in summer 1982 and tried to do again in summer 1990 after congestion had all but destroyed the city's bus system, could doubt that there is a connection between bus speeds and reliability for at least extreme congestion levels. I observed a similar,

though less dramatic deterioration of bus speed and reliability in central London between the time I first lived there in 1964 and during my several, much shorter visits in subsequent years.

13. I have personal, anecdotal evidence that supports these arguments. First, I still vividly remember discussions I had with the general manager of Denver's private transit firm in the early 1960s while I was teaching at the U.S. Air Force Academy. He complained vociferously about the steady declines in average bus speeds they had experienced since the end of World War II and indicated that these declines had been caused by a steady growth in vehicle use and congestion on the streets used by their buses. Two decades later, my wife and I spent a year in Dallas, Texas, where we rented a condominium located in Oak Lawn, an inner city residential area close to downtown. One of the joys of living in Oak Lawn was the total absence of congestion. The Central Expressway, which connected Dallas' prosperous northern suburbs to downtown and bounded Oak Lawn on the east, was fairly congested at the time, but there was almost no congestion on the arterials that connected Oak Lawn and other central city neighborhoods to downtown. At the same time, heavy congestion was beginning to appear in the northern suburbs and on LBJ Expressway. This congestion is now much worse.
14. An alternative log-log specification, Equation 3, shown below, regresses the natural log of average speed of bus trips on the natural logs of average drive-alone automobile speed and average bus trip distance. This specification yielded a constant elasticity of 0.6 for the average speed of drive-alone automobile trips and an elasticity of 0.4 for the average length of bus trips. Adding total work trips as a proxy for metropolitan area size has almost no effect on the coefficients of either average automobile speed or bus trip length, and its coefficient is not statistically significant ($t = 1.44$). The R^2 for Equation 3 is 0.662 and the t-ratios are -0.27 for the constant term, 3.27 for ln AS, and 7.24 for ln BD.

$$\ln \text{BS} = -0.149 + 0.600 \ln \text{AS} + 0.407 \ln \text{BD} \qquad (3)$$

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