Table 10. Net future value analysis.

End of Year t	Cash Flow in Year t($)	Prior-Year Net Future Value Compounded to Year t ($)	Net Future Value at End of Year t ($)
0	-1000	-	-1000, compound at 35 percent
1	+3700	-1000(1.35) = -1350	+2350, compound at 32 percent
2	-4520	+2350(1.32) = +3102	-1418, compound at 35 percent
3	+1820	-1418(1.35) = -1914.3	-94.30

analysis (of the sort alluded to by Bergmann and described in the previous two paragraphs) must be used only when a firm cannot be a lender, cannot acquire capital except from outside sources, and has a borrowing rate greater than its MARR.

Bergmann also maintains that any benefits received by the public are consumed or reinvested at the social rate of discount. Many other economists argue differently and with persuasion. Not only is this a murky subject, but it also is one that is fraught with difficulty when we attempt to determine the appropriate social rate of discount. In sum, there is only an arbitrary basis for deciding on the propriety of its use as well as its value. [See Margolis's (18) review of this subject.]

Two final comments: One, Bergman is wrong in saying "...Wohl would have us never calculate a rate of return on an investment proposal." To the contrary, and as noted in my paper, if a rate-of-return figure is necessary (say, because of budget constraints) before the fact, then an effective rate of return should be calculated rather than the internal rate of return. Moreover, it is perfectly obvious that we need the actual effective yield that is being obtained from other ongoing (or past) projects. Two, Bergmann is clearly wrong in saying that: "Use of the internal-rate-of-return method does not imply, as Wohl and others suggest it does, that the positive cash flows from an investment alternative are reinvested at the internal rate of return." On the contrary, if the internal rates of return are used as the sole guide to make economic choices among mutually exclusive choices, then certainly he is wrong. Assume for the Table 7 example that the MARR is 20 percent (and equal to the borrowing rate). Then, what else other than an assumed reinvestment of the $10 000 in year 1 at 20 percent could have caused the two alternatives to be exactly equivalent for the two-year period? In a word, nothing.

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Potential of Pricing Solutions for Urban Transportation Problems: An Empirical Assessment

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This paper surveys the available empirical evidence on the elasticity of travel demand to assess the potential of pricing policies to alter travel behavior and thereby to solve various urban transportation problems. The first set of studies considers the responsiveness of fuel use to changes in gasoline price. The second set, econometric models of urban travel demand, estimates the direct and cross-price elasticities of the use of different modes with respect to different components of trip cost. The third set of evidence is composed of arc elasticity estimates based on the impacts on travel behavior of actual changes in the levels of roadway user charges and transit fares. For each study dealt with, the paper briefly summarizes its methodology, data base, and findings and subjects these to critical evaluation. The paper concludes with an evaluation of the body of results for the usefulness of pricing policies in urban transportation.

Economists have criticized perverse pricing as the crux of the urban transportation problem and, thus, have regarded corrective pricing policy as the key to the solution. The theoretical basis for such alternative pricing involves the need to internalize the often significant external social costs associated with urban travel (such as congestion, air pollution, and noise), particularly as these vary with respect to time of day, route, and mode of travel.

The objective of this paper is to determine how responsive urban travel behavior would be to various corrective pricing strategies:

1. To what extent, for example, could peak-period pricing alleviate congestion by diverting automobile drivers to other modes or to use of their automobiles at less-congested times or on less-congested routes?
2. To what degree might higher gasoline prices encourage motorists to economize on fuel by driving fewer kilometers or by purchasing smaller, more fuel-efficient automobiles? and

3. How much would transit ridership increase as a result of surcharges on automobile use or reductions in transit fares?

Elasticity of demand is a useful measure for answering these questions. It is defined as the ratio of the percentage change in demanded use to the percentage change in the relevant exogenous variable. This dimensionless measure indicates the relative sensitivity of the demand for a specific type of travel to the cost of such travel, the cost of competitive or complementary travel, and to performance levels or other aspects of the quality of travel alternatives. The degree of price elasticity is important for public policy purposes because, in general, the more elastic is the demand, the greater is the potential leverage of pricing policy in altering urban travel behavior and thus in helping to solve various transportation problems.

This paper assembles information about the size of relevant demand elasticities from a variety of recent empirical studies. Our first set of studies considers the responsiveness of fuel use to changes in gasoline prices. Next, we examine a number of urban travel-demand models, which yield estimates of direct and cross-price responsiveness for different urban travel modes and for different components of travel cost. Finally, we note the wide range of arc elasticity estimates based on impacts of actual changes in the levels of roadway user charges and transit fares. For each study dealt with, we briefly summarize its methodology, data base, and findings and subject these to critical evaluation. We compare results of studies based on different methodologies to test for robustness of elasticity estimates. The paper concludes with an evaluation of the body of results for the use of pricing in public policy.

PRICING GASOLINE TO CONSERVE FUEL

Public interest in fuel conservation peaked in intensity during the energy crisis of 1973-1974 and has remained an important consideration of federal policy in the years since. Because the highway use of gasoline has been a large percentage of the total demand for petroleum products, such transportation fuel usage, particularly by automobiles, has been a prime target for energy conservation. In the short run, gasoline savings can be achieved by (a) the elimination of nonessential trips, (b) a shift to modes less energy-intensive than single-occupant automobile use (such as transit or carpooling), or (c) a reduction in driving speeds to increase kilometers per liter of fuel. Additional means of conservation include a reduction in the level of automobile ownership, technical development and market penetration of smaller, more fuel-efficient automobiles, and a transformation of urban land-use patterns toward decreased spatial diffuseness.

Each of these fuel-conservation measures is to some extent automatically encouraged by higher gasoline prices, which signal to consumers the increased scarcity of energy resources and force them either to conserve or pay the price for not doing so. Without government intervention, fuel prices would be expected to rise as a result of the interaction of diminished fuel supply and increased demand and thus to induce some amount of conservation, but policy intervention can mitigate or even accentuate the rise.

In addition to leverage for overall energy use, gasoline prices can be the instrument for influencing the absolute and relative use of automobiles in urban transportation. Whatever its policy goal, however, its potential effectiveness depends on the demand responsiveness to its use. A useful approximation to this demand sensitivity is the own-price elasticity of demand for gasoline. The following section reviews several different types of econometric models of gasoline demand that yield estimates of this price elasticity measure.

Econometric Models

The econometric models described below are roughly of two broad types. Flow-adjustment models generally express the demand for gasoline in the current period as a function of the consumption of gasoline in the previous period, the real price of gasoline in the current period, real personal income per capita, and a variety of other variables thought to influence the level of fuel use (see Table 1, studies 1, 2, and 5) (1-5). The identifying characteristic of this approach is the use of last period's gasoline consumption to predict the current period's consumption.

It is assumed that the degree of consumer response to any change in price is a function of the length of time allowed for the response to occur. For example, in the long run, extensive adjustments in travel behavior are possible through changes in the level of automobile ownership, vehicle efficiency, and residential and workplace locations. Lags in the adjustment process are not explicitly represented in flow-adjustment models. Rather, to proxy for these complex initial influences and the time-phased adjustment, past levels of the dependent variable are used to explain current levels of that variable.

The more significant the lagged variable is in explaining current levels of gasoline demand, the greater the friction of adjustment and the longer the implied period of time requisite to a full adjustment. The actual importance of such momentum can be calculated in these models. Through the estimated coefficient of the lagged dependent variable, the time period considered to be the long run is mathematically inferrable from the estimated equation. Both short- and long-term impacts can be measured. The former is the estimated parameter weight on each explanatory variable. The latter are the weights of the steady-state equilibrium of the system.

Unfortunately, flow-adjustment models provide no specific information on the nature of the adjustment process, only on the implicit timing and overall size. Yet, for policy purposes, it is important to know to what degree a price-induced reduction in gasoline use stems differentially from changes in the number, length, timing, or location of automobile trips; changes in gasoline efficiency; changes in automobile ownership; or shift in modal choice. The specific nature of the adjustment process can influence significantly the relative attractiveness of different fuel-conservation policies because they differ with respect to other public policy objectives.

A variant on the flow-adjustment models substitutes measures of vehicle fleet size and gasoline efficiency for the lagged dependent variable. Thus, the drag on adjustments in travel behavior to gasoline price attributable to these two long-term considerations is estimated directly. The short-term models of the Rand Corporation and Charles River Associates are of this type (see Table 1, studies 3 and 4).

The Rand Corporation's multiequation recursive model distills the long-term adjustment process into an assumed sequence of component stages (Table 1, study 6). In contrast to the flow-adjustment models, each aspect of the long-term impact is explicitly represented.

The effect of gasoline price on the level of fuel use is estimated both directly (through its impact on vehicle kilometers traveled by a given automobile stock with a fixed average vehicle efficiency) as well as indirectly (through its influence on new and used automobile ownership and vehicle fuel efficiency). By breaking down the long-term adjustment process into its components, the relative importance of each is determined as well as the total impact. Unfortunately, however, this approach fails to represent explicitly the time phasing of adjustment, the main advantage of the flow-adjustment models.

Table 1. Aggregate econometric models of gasoline demand and vehicle kilometers of travel.

Study	Dependent Variable	Independent Variables	Functional Form	Sample	Estimation Technique	Short-Range Elasticity*	Long-Term Elasticity
Data Resources (1)	Highway motor fuel use per capita	Real gasoline price by state, real disposable income per capita, lagged per capita highway gasoline consumption	Log linear	Quarterly data, 1963-1972, 48 states and DC	Error components	-0.23 to -0.30	-0.32 to -0.54
McGillivray-Urban Institute (2)	Automobile gasoline use per capita	Real gasoline price, new passenger automobile registration per capita, average gasoline consumption per automobile, lagged per capita automobile gasoline consumption	Linear	National total, United States, ordinary least squares 1951-1969, annual	Ordinary least squares	-0.23	-0.76
Rand I (single-equation, short run) (3)	Highway motor fuel use per capita	Real gasoline price, disposable (per capita) personal income, total vehicle registrations per capita, fuel efficiency of vehicle fleet by state, trucks as percentage of total vehicles	Log	Annual, pooled time-series cross-section, 1955-1970 for 48 states	Ordinary least squares	-0.26	
	Automobile gasoline use per capita	Real gasoline price, vehicle registrations per capita, dummy variable for safety and emissions standards	Log	Annual national total, 1950-1972	Ordinary least squares	-0.38 to -0.43	
	Vehicle kilometers traveled per capita	Real gasoline price, vehicle registrations per capita, dummy variables for safety and emissions standards	Log	Annual national total, 1950-1972	Ordinary least squares	-0.37 to -0.39	
Charles River Associates (short run) (4)	Highway gasoline consumption per licensed driver	Real gasoline price, stock of automobiles per licensed driver, stock of trucks per licensed driver, augmented fuel efficiency of automobile stock, number of post-1968 registered vehicles on road in each year per licensed driver	Linear	Annual, pooled time-series cross-section, 1950-1971, annual, 48 states and DC	Two-stage least squares	-0.18	
Charles River Associates (long run) (5)	Highway gasoline consumption per licensed driver	Real gasoline price, real disposable income per capita, lagged highway gasoline use per licensed driver, six dummy variables for each of six different types of gasoline consumption characteristics of state	Log	1951-1971, annual pooled, 48 states and DC	Two-stage least squares	-0.29	-1.37
Rand II (5-equation, recursive, long run) (6)	Used automobile price	New automobile price, real gasoline price, disposable income, lagged automobile stock, automobile strike dummy variable	Linear	Annual, national total, United States, 1950-1972	Two-stage least squares, ordinary least squares		
	New automobile sales	New automobile price, used automobile price, growth in disposable income, automobile strike dummy variable	Linear		Two-stage least squares, ordinary least squares		
	Used automobile stock	Used automobile price, new automobile price, real gasoline price, disposable income, strike dummy variable	Linear		Two-stage least squares, ordinary least squares		
	Average kilometers per liter	Real gasoline price, dummy variable for safety and emissions standards	Log		Ordinary least squares		
	Automobile kilometers driven per capita	Automobile stock, real gasoline price, safety and emissions dummy variables	Log		Ordinary-least squares		
	Automobile gasoline consumption per capita	Average km/L × automobile-km driven per capita					-0.64 to -0.68
Chase Econometrics (7)	Total vehicle kilometers traveled	Total automobile ownership, relative price of gasoline and oil, change in consumer price index, average price of new automobiles lagged two periods, growth in wages and salaries	Linear	Annual, national total, United States, 1956-1972	Ordinary least squares	-0.5	-0.72
Federal Energy Administration (8)	Vehicle kilometers traveled per capita	Automobile operating costs per kilometer, real disposable income per capita, unemployment rate, lagged vehicle kilometers of travel	Linear	Annual, national total, United States, 1950-1972	Nonlinear least squares with first-order automobile-regressive transformation	-0.12	-0.72

*Short range means no more than one year.

Each of these three types of model yields a different type of elasticity estimate. The short-term elasticity derived from lag-adjustment models is calculated directly from the estimated equation by specification of an arbitrary short-term period (set here to one year for comparability). Short-term elasticities derived from models other than the flow-adjustment type are the estimated effects of gasoline price on fuel consumption, holding automobile ownership levels and vehicle efficiency constant. So in the former model type the short term is an arbitrary time period; in the latter it is the period for which automobile ownership and fleet efficiency are fixed.

Similarly, for the second and third types of models, the long-term period is implicitly that length of time after which price will also have affected gasoline consumption indirectly through changes in automobile ownership and vehicle efficiency. One cannot infer from these models the actual number of years required for such adjustment. The length of the long run can be explicitly calculated, however, in lag-adjustment models. It is equal to the number of periods subsequent to some price change required for the difference equation to reach a steady-state equilibrium solution. The Data Resources study, for example, implies a long term of about 2.5 years; McGillivray's long-term period is 10 years, and the Charles River Associates long term slightly exceeds 12 years. Thus, the duration of the long term varies significantly from one lag-adjustment model to another. These varying interpretations of short and long term make comparisons of elasticity estimates from different models dubious.

Empirical Results

Despite a wide variety of specifications, estimation techniques, and data bases, most of the recent econometric studies of the demand for gasoline indicate that the short-term direct elasticity of gasoline use with respect to gasoline price falls within the range of about -0.2 to -0.3 (see Table 1). In contrast, long-term elasticity estimates from this same set of studies vary substantially, ranging from -0.32 to -1.37. The duration of the long-term ranges (implicitly from 2.5 to 12 years) makes comparison of the results especially difficult because the specific durations are not deliberately chosen but rather are the statistical outcome of the type of demand modeling employed. Estimates of the elasticity of new automobile sales with respect to gasoline price range from -0.7 to -1.0 (3, 5). [Corresponding estimates of the elasticity of new automobile sales with respect to new automobile price ranged from -0.88 to -1.6 (3, 5).] Especially in light of the extremely important effect of automobile ownership on urban travel behavior, these figures suggest that public policies that affect the price of gasoline may substantially alter travel behavior. The short-term, direct effect of gasoline price is reinforced by the indirect, long-term effect of price on automobile ownership and, in turn, on travel behavior.

Most of the studies reviewed here are beset by statistical problems of estimation—multicollinearity and simultaneous-equations bias being the most important. [For a detailed analysis of the methodology, statistical limitations, and data bases of each of the studies, consult the background report on which this paper is based (6). This report also contains a lengthier discussion of the empirical results and their policy implications.] The convergence of the short-term estimates lends credence to a -0.2 to -0.3 range of elasticity values; however, despite divergence, the long-term elasticity estimates uniformly increase over longer periods, especially as turnover occurs in the automobile fleet. None of the studies explicitly examines the possibility that large, long-lasting changes in fuel price might also significantly affect locational decisions over time, thereby further increasing the long-term price elasticity.

Because the gasoline studies differentiate neither between urban and rural demand nor (more importantly) among regions of the country, income classes, trip purposes, or trip routes, they are of limited usefulness in the determination of the potential leverage of pricing to alter specifically urban travel behavior. Yet they do suggest considerable aggregate gasoline conservation in response to higher gasoline prices, especially in the long run.

SENSITIVITY OF URBAN TRAVEL DEMAND

Three types of studies have examined the elasticity of demand for urban travel. Direct travel-demand models estimate total zone-to-zone traffic volumes, by mode and trip purpose, as a function of various cost and performance variables. In contrast, disaggregate travel-demand models use individual household observations to determine the independent influence of each of a number of cost, performance, and socioeconomic variables on the probability that individuals with specific socioeconomic characteristics will select particular origin-destination pairs, travel times, modes, and trip frequencies. Finally, highly fragmentary evidence of the effect on travel behavior of changes in transit fares, bridge and tunnel tolls, and parking charges has been used to calculate arc elasticities, measures of demand sensitivity that are based on only the two price-quantity observations of a single price change.

Evidence from Direct Demand Models

The aggregate version of the behavioral travel-demand model estimates the total number of round trips between each origin and destination zone in an urban area as a function of the travel times and money costs of each of the available alternative modes, the socioeconomic characteristics of the origin zones (usually income per household and per capita automobile ownership), and the employment density of destination zones. A separate equation is estimated for each mode and trip purpose combination on the basis of aggregate, not individual, interzonal variations in the variables. Simultaneous determination of mode choice, trip frequency, trip distribution, and trip generation is assumed.

The earliest, most fully developed, and best-known of the aggregate models is the Charles River Associates direct-demand model designed to assess the impact of free transit in Boston (7). Four separate mode and trip purpose demand equations are estimated: automobile work trip, automobile shopping trip, transit work trip, and transit shopping trip. For each, the dependent variable is the total number of round trips taken between each origin and destination zone by the specified mode. The explanatory variables are socioeconomic characteristics of each origin (reflecting trip generation and modal preferences), land use characteristics of each destination (reflecting the relative trip attractiveness of these), and performance and cost measures for both automobile and transit on each specific origin-destination link (reflecting the relative desirability of alternative destinations and modes). All independent variables were included in both linear and logarithmic forms to capture the effect on travel behavior of both absolute and relative changes in ex-

Table 2. Elasticities from direct demand models.

Independent Variable	Automobile Work Trips: Charles River Associates	Automobile Work Trips: Fulkerson	Automobile Shopping Trips: Charles River Associates	Transit Work Trips: Charles River Associates	Transit Work Trips: Talvitie: Rail	Transit Work Trips: Talvitie: Bus	Transit Work Trips: Talvitie: Pooled Transit	Transit Work Trips: Fulkerson	Transit Shopping Trips: Charles River Associates
Automobile									
In-vehicle time	-0.82	-0.39	-1.02	0	0.84	0	0.37		0
Access time	-1.44		-1.44	0	0	0	0		0
Line-haul operation cost	-0.49	-0.12	-0.88	0	1.34	0.36	0.80		0
Out-of-pocket cost	-0.07		-1.65	0	0	0	0		0
Transit									
Line-haul cost	0.14	0.15	0	-0.09			-0.38	-0.40	
Access cost	0		0	-0.10			-0.08		-0.32
Line-haul time	0		0.10	-0.39			-0.20	-0.19	
Access time	0.37		0	-0.71			-0.69	-0.38	-0.59
Bus									
Out-of-vehicle time					0	-1.84			
In-vehicle time					0.23	-1.10			
Access cost					0.08	0			
Line-haul cost					0	-0.51			
Rail									
Out-of-vehicle time					-1.74	1.00			
Access-in-vehicle time					-0.55	0.25			
Total access time					-2.06	1.15			
Line-haul time					-0.80	1.02			
Access cost					-0.30	0.28			
Line-haul cost					-1.80	0			

planatory variables. To counter the inevitable multicollinearity among explanatory variables, which necessarily accompanies such a dual specification, the ordinary least-squares estimation procedure was modified to constrain direct elasticities to be nonpositive and cross-elasticities to be nonnegative. Almost half of the coefficients in the four demand equations were set equal to zero because the imposed constraints were binding. Explanatory variables (primarily cross-price effects) whose logarithmic- and linear-form parameters were both set equal to zero for this reason had their predicted signs rejected but were not actually estimated as zero.

The statistical reliability of the four estimated equations is dubious. Multicollinearity is an obvious problem for several reasons: (a) the log and linear specification of each variable; (b) the pervasive effect of income on automobile ownership, on the degree of disutility represented by any measured level of time or cost, and on modal choice and the total demand for travel; and (c) the inevitable correlation between travel times on different modes between the same two zones. However, no analysis of the effect of the multicollinearity problem was made in the Charles River Associates study. Although the constrained estimation process is employed specifically to mitigate collinearity problems of the first type, it may have exacerbated the estimation bias induced by the relationship across modes between travel times and costs or the multifaceted impact of income on the other explanatory variables. Moreover, it is likely that the partial effects of travel time and cost on travel demand depend importantly on consumer income levels; a multiplicative specification would probably have been more appropriate to capture this influence.

The form in which the model is estimated assumes that each of the right-hand explanatory variables is truly exogenous and not mutually a function of the dependent variable (traffic volume). Yet travel times, and thus also gasoline operating costs, are dependent on traffic volumes via the level of traffic congestion. They vary nonlinearly as such volumes change. The failure to account for this joint determination may have introduced serious simultaneous-equation bias into the estimation process—another reason to regard the coefficient estimates with suspicion. The direction of multicollinearity-induced bias is ambiguous, but one consideration suggests that it understates elasticities. Nominal trip costs omit congestion (time) costs. So, heavily used origin-destination pairs have higher real costs than are measured; real costs for lightly used pairs are as measured. Large differences in levels of route use are associated generally with smaller real cost differentials than are measured; estimated elasticities are thereby understated.

Another problem is that the mode alternative to automobiles was taken as an assumed homogeneous transit mode—simply the sum of all nonautomobile trips. In fact, these nonautomobile trips are quite heterogeneous. The described treatment may impart another bias toward understating the potential substitutability of automobile with nonautomobile modes, since actual changes in modal-split behavior will be influenced by the most substitutive of alternative modes, not the average of such modes. The behavior of such closer substitutions is hidden (indeed, distorted) by the present treatment: Aggregations probably understate behavioral sensitivity toward actual intermodal competition.

The elasticity results given in Table 2 were computed from estimated regression parameters. (Unfortunately, the statistical significance of the latter was not reported; hence, there is no way to gauge the reliability of the derived elasticity values.) These elasticities indicate that automobile travel demand is moderately responsive to the time components of real trip cost, more for out-of-vehicle time (walking) than for in-vehicle time. Transit demand is less sensitive to time, but only the elasticity with respect to line-haul time is really low. Use of both modes is less responsive to money costs than to travel time. Automobile demand is more responsive than transit demand—the latter shows a near zero sensitivity. The few estimated cross-elasticities are extremely low. In terms of trip purpose, work trips are generally less responsive to cost components than are shopping trips, an expected result given the largely fixed number and geographic pattern of commuting trips in the short run.

Overall, the Charles River Associates direct-demand results indicate that, although transport prices affect travel demand in the manner predicted, several effects tend to be quite small. Socioeconomic factors are overwhelmingly more important than cost or performance in determining travel behavior, especially modal choice. These results have been the basis of pessimistic appraisals of the usefulness of pricing in urban transportation policy; however, such appraisals may not, in fact, be justified.

The econometric problems of multicollinearity, misspecification, simultaneous-equations bias, and overly aggregative treatment of nonautomobile trips may have understated sensitivity to cost. There are other grounds as well for suspecting downward bias of the demand elasticities. Time of day and specific route of travel are important policy issues. Neither of these is treated in the Charles River Associates model. Differentiation by these trip dimensions would expose a wider variety of travel substitutes and, thus, reveal inherently higher elasticities with respect to crucial aspects of travel. Moreover, the measured elasticities represent an average responsiveness of travel among all origin-destination zone pairs. Insofar as pricing policy can be designed to differentiate both by route and time of day, demand responsiveness will be greater than suggested by the Charles River Associates estimates. This omission of specific route and time-of-day aspects of trips may be a serious bias because travel externalities vary significantly with time of day and specific route; optimal pricing policy would presumably differentiate according to these dimensions. The Charles River Associates estimates are probably lower bounds of demand responsiveness to the variety of cost-impacting policies that might reasonably be employed to achieve public policy goals.

Almost identical in structure to the Charles River Associates model, Talvitie's direct demand model of transit work trips in Chicago is subject to virtually all the criticisms levied at the Charles River Associates model (8). As Table 2 indicates, however, disaggregation of the transit mode into bus and rail results in substantially larger elasticities. Even in his pooled transit version, Talvitie estimates cross-elasticities of transit demand with respect to automobile in-vehicle time and automobile operating cost of 0.37 and 0.80, respectively—values large enough to cast further doubt on the Charles River Associates estimates obtained by constraining these cross-elasticities to zero.

The Moses and Williamson study of modal choice by Chicago commuters also found a considerable elasticity of transit demand with respect to the level of automobile operating costs (9). These survey results indicated that lowering transit fares to zero would have diverted to the bus only 13 percent of the automobile drivers who reported that this was their next most preferred mode; however, the imposition of a $1.00 round-trip surcharge on automobile commuting for work trips would have shifted to the bus 47 percent of automobile drivers who indicated that the bus was their second-best mode. The reliability of the survey data on which these estimates are based is questionable, and the shift estimates are upper bounds. Nevertheless, it is noteworthy that the cross-price effect of automobile costs on transit demand not only appears to be significant, but even exceeds the own-price effect of fares on transit demand.

The direct-demand model of work trips that Fulkerson estimated for Louisville is of interest primarily because, although it employs most of the same explanatory variables, it exposes several of the deficiencies of the aggregate model that the Charles River Associates and Talvitie versions conceal (10). The avoidance of the dual log and linear specification of each explanatory variable and the straightforward use of ordinary least squares without a priori constraints facilitate the isolation of multicollinearity problems other than those obviously associated with the dual variable specification. Not surprisingly, an analysis of the correlations among explanatory variables indicated that system performance and cost variables (both within and across modes) are highly interrelated and that this was particularly serious in light of the low coefficient of determination of the estimated direct-demand equations. Due to the fragmentary reporting of the Charles River Associates and Talvitie models, one can only surmise the degree to which the estimated demand equations were distorted, but the Fulkerson results suggest that the problem is not minor.

Fulkerson facilitates interpretation of the results by reporting t-statistics. The uniformly low magnitude of the estimated coefficients of travel cost and time variables (as well as the insignificant t-statistics) may be at least partly the result of the reported multicollinearity among variables. Interestingly, by far the variable that most affects both automobile and transit travel demand is automobile ownership. Not only are the parameter coefficients of high statistical significance, but the associated demand elasticities exceed 1.0 in absolute value. For automobiles, in-vehicle time and money operating cost elasticities are considerably smaller than the Charles River Associates estimates (see Table 2). The cross-elasticity with respect to transit line-haul money cost is essentially the same as in the Charles River Associates study. For transit work trips, transit line-haul time and money cost have the same elasticities as in Talvitie's study. But the travel-time elasticity is considerably less and the cost elasticity is greater than the comparable Charles River Associates values for Boston. The elasticity for transit access time in the Fulkerson model is only half that estimated in the other two studies.

Fulkerson attributes her generally lower elasticities to the much less extensive and varied transit network in Louisville relative to those in Boston and Chicago. Despite the variables that express performance characteristics of the different modes, the variety and availability of modes alternative to automobiles is not captured, especially where observations are zoned aggregates. Thus, in the three cities being compared, a different spatial conformation in conjunction with a different availability of nonautomobile modes in each will result in different automobile driver and transit rider populations in each city. Since they will typically have different trade-off valuations, measured sensitivity to the various trip price components can be expected to differ. In effect, the closer and more plentiful are the substitutes to a given mode, the greater will be the price sensitivity. Talvitie's disaggregation of the transit mode into rail and bus reflects this.

Evidence from Disaggregate Demand Models

Disaggregate demand models have been developed to overcome many of the deficiencies of direct travel-demand models. They do this by basing their predictions of group behavior on the choice situation of the individual. The probability of making each kind of trip (defined in terms of mode, frequency, time of day, destination, and purpose) is formulated as a conditional logit model, where the equation is a ratio of the exponent of the household's utility level for the specific travel choice to that of the sum of the exponentials for all alternative travel decisions. The exponents in this expression are weighted linear combinations of the explanatory variables. The coefficients, which represent the independent effect of each variable on the utility level of household, are estimated by maximum likelihood. The explanatory variables fall into three classes: socioeconomic characteristics of the individual decision maker that might influence travel choice, comparative characteristics of alternative travel options, and comparative characteristics of the alternative destinations that relate to their relative attractiveness. They can be summarized crudely as household income levels, travel times and costs, and destination employment levels, respectively. [For a more detailed discussion of the disaggregate modeling technique, see the full report (6) or McFadden and Domencich (11).]

Disaggregate work-trip models restrict the range of travel choices to mode only, assuming that trip frequency, destination, and time of day remain unchanged for work commuters. To the extent that the journey to work is subject to time, frequency, or destination variation, this assumption imparts a downward bias to be the estimated responsiveness of work travel to pricing policy. Disaggregate shopping models allow for a fuller range of variation in travel behavior, although to varying degrees and employing different assumptions on the structure of travel decisions. Destination and frequency of shopping trips (as well as mode choice) are usually allowed to vary. In addition, one allows a very limited but interesting choice between peak and off-peak travel.

Two basic equation structures have been employed in the estimation of the shopping model. Charles River Associates estimates a set of up to four conditional probability equations: (a) modal split, (b) time of day, (c) destination, and (d) trip frequency (11). This assumed separability of shopping travel demand requires that mode choice be independent of the time of day, destination, and frequency of trip making and be a function only of the relative travel time and cost characteristics of the available modes. Also, it is assumed that destination, frequency, and time of day of travel are similarly conditionally layered in a sequence of separable decisions. Through the successive estimation of these four equations, the probability that an individual will make a shopping trip with a given frequency, to a certain destination, and via a particular mode is a function of the costs and travel time of all available modes, the relative attractiveness of alternative destinations, and a set of socioeconomic traits of the individual.

The assumption that shopping travel demand is separable facilitates estimation; however, it is dubious. Characteristics and availability of each mode are not independent of destination and time of day. So modal choice, for example, will be influenced by trip destination. Travelers are more likely to use the automobile for a circumferential suburban trip and transit for a radial central business district (CBD)-oriented trip. Moreover, even for shopping trips, transit is more likely to be chosen during peak hours of travel.

To avoid this weakness, Ben-Akiva and Adler estimated what they term a joint-probability shopping model. In this model, the probability that an individual will make a shopping trip with a certain frequency, by a given mode, and to a particular destination is estimated in a single equation, which includes all explanatory variables that influence one or more of the identifying aspects (e.g., mode choice, frequency) of the trip (12). Although it avoids separability, the combination of all variables into one equation introduces multicollinearity and simultaneous-equations bias.

Elasticity Results from Work Trip Models

Demand elasticity information provided by disaggregate models is obtained either through simulation (with real data) or by the substitution of hypothetical variable values, by using the probability equations estimated econometrically. Alternative values of policy variables are fed into the estimated equations. The price elasticity is then calculated by comparing the size of the resulting predicted change in travel behavior with the various initiating cost changes. It is considerably less straightforward to evaluate the reliability of the elasticity estimates so derived. However, the statistical reliability of the underlying disaggregate probability equations from which the simulations are generated can be assessed. Most of the studies report indices of statistical reliability that indicate an impressively good fit for whole equations and significance for many coefficients. The simulation estimations are, however, separated from these equations by an additional stochastic step that blurs the reliability of the final results.

Simulations of the Massachusetts Institute of Technology (MIT) - Cambridge Systematics disaggregate demand model of work trips in Washington, D.C., suggest that modal split sensitivity to trip costs is quite low (13). Even large increases in the money cost of automobile use are predicted to only slightly affect the overall distribution of work trips among modes in the metropolitan area. For example, a quadrupling of the price of gasoline would presumably reduce the drive-alone share by less than five percent. Similarly, large parking surcharges are predicted to have only a minor impact. Adding \$3/day to the cost of a downtown parking place would only diminish the drive-alone share of work trips by 6.5 percent. This extreme insensitivity to price suggests that price would not be an efficient lever to help relieve rush-hour congestion or reduce fuel use by diverting automobile drivers to transit or carpools. However, these results are highly suspect. They involve extrapolation far outside the range of observed data. Although there is no reason to believe that demand responsiveness remains constant at all price levels, the Cambridge Systematics policy simulations are necessarily based on this assumption.

In contrast to the low elasticity implicit in the Cambridge Systematics results, the McFadden model of travel demand in the Oakland-Berkeley area suggests considerable responsiveness of travel to price (14). It reveals interesting differences in elasticities with respect both to different components of real trip cost and to different components of alternative mode characteristics. Time and money cost sensitivity differ, as do different components within each of these broader categories. Cross-mode effects differ as well. Strongly confirmed is the Moses and Williamson survey finding that transit demand is more sensitive to the cost of automobile use than it is to its own price (9). For example, in the two-mode case, although the elasticity of bus trips with respect to bus fare is only -0.45, the cross-elasticity of bus trips with respect to automobile operating and parking costs is more than twice as great—nearly 1.0. It is greater, in fact, than either the cross-mode or the own-mode effect of travel time. This result is not quite as striking in the three-mode case; nevertheless, the bus trip cross-elasticity with respect to automobile costs is 0.81 (considerably greater than the own-elasticity with respect to bus fare of -0.58, which in itself is substantial) and the rapid transit trip cross-elasticity with respect to automobile costs is 0.82 (only slightly less than the own-elasticity of -0.86 with respect to rapid transit fare). This is an important result. It appears to contradict the Cambridge Systematics results by indicating the possibility of significant leverage for public policy use of the pricing instrument to change modal split. The suggested diversion to transit effected by the increased cost of work-trip automobile use might, for example, significantly alleviate rush-hour road congestion.

On closer examination, the discrepancy between the two studies is hardly surprising and is, in fact, quite illuminating. McFadden measures modal-split elasticity only in corridors that have extensive transit service—that is, where transit is a feasible alternative to the use of the automobile for the work trip. In contrast, the Cambridge Systematics model estimates modal shifts for the metropolitan area as a whole. Thus, its sample includes travelers who reside in areas where residents could not possibly opt for transit over the automobile in the short run, regardless of the magnitude of the economic incentives. Since, in fact, this infeasibility of the transit choice applies for most suburban portions of American urban areas, whatever modal shift occurs in those corridors where transit is available is greatly diluted by the inevitable lack of responsiveness in the suburbs, where transit is not an available alternative. Although Washington, D.C., traffic corridors well served by transit might display the same degree of work-trip sensitivity as that estimated by the McFadden study, this sensitivity would not be evident in the Cambridge Systematics-type of aggregate, metropolitan-wide results. Thus, a seemingly low aggregate responsiveness may conceal important variations in responsiveness among the hundreds of individual traffic corridors that comprise the urban transportation network.

This does not deny the usefulness of the Cambridge Systematics results, however. For energy conservation questions, for example, the Cambridge Systematics results are clearly more appropriate, since the amount of gasoline saved is more a function of total automobile use than of distribution of automobile traffic among specific urban corridors. But, for urban transportation problems that arise from the externalities of automobile use, the spatial and temporal composition of automobile use determine the social costs associated with any level of automobile driving. The severity of congestion, in particular, is almost entirely dependent on the density of traffic, which varies greatly from one part of the metropolitan area to another.

Significantly, transit is most frequently available in those corridors that have the highest traffic density—precisely those routes where modal shift away from the private automobile would be most beneficial in terms of mitigating congestion and other externalities. Consequently, the McFadden results suggest that properly targeted pricing of automobile use would have maximum impact where it is most needed. That the impact of automobile pricing policies would be minimal in low-density suburbs is of little importance with regard to the potential effectiveness of public policy use of pricing to mitigate the social costs of the automobile. The problems associated with automobile use are least serious in these areas.

Price elasticity estimates can also be inferred from the Charles River Associates work-trip model originally estimated with Pittsburgh data and subsequently recalibrated with Los Angeles data to simulate the effects of various pricing policies in promoting energy conservation, pollution abatement, and road congestion reduction (15). Results indicate an elasticity of automobile work trips with respect to automobile line-haul costs of -0.27 and of automobile vehicle kilometers traveled with respect to line-haul costs of -0.38, which suggests only slightly less responsiveness to price than does the McFadden study.

Elasticity Results from Shopping Models

The shopping-trip model in the McFadden and Domencich Charles River Associates studies is especially rich. Unlike the work trip, where frequency, destination, and time of day are assumed to be constant, most dimensions of shopping trips are allowed to vary and are explained in a set of equations that represent a recursive, sequential decision structure. Two sets of shopping demand-responsiveness results have been assembled by Charles River Associates. The first stems from a four-equation conditional probability model, which uses Pittsburgh household survey data in conjunction with calculated trip time and cost values relevant to surveyed households. In this model, automobile line-haul cost has an elasticity of -0.17 with respect to modal choice and destination in automobile trips. Trip frequency, time of day of travel, and trip destination are significantly more responsive to shifts in relative trip times and money costs than is modal choice. Sample calculations for a hypothetical individual suggest, for example, that trip time of day is approximately twice as responsive as modal choice to variations in transportation cost and performance measures.

Even the elasticities of trip frequency and destination significantly exceed the modal-choice responsiveness when account is taken of the greater number of alternative destinations than modes. Because the problem of road congestion is basically one of timing, location, and frequency, these results indicate that a selective pricing of urban transport facilities targeted to influence the timing and destination of trips would be more successful in reducing congestion than would a pricing policy aimed at inducing a shift away from the use of the private automobile to other modes. The absolute size of each of the former adjustments is not large, but together they represent a substantial impact.

Of further relevance to our study is the finding that, although average modal-choice elasticity for work trips vis-à-vis cost is low, it is increased by the introduction of additional, closely substitutable modes. Thus, a modal-shift-oriented price policy for work trips, combined with a pricing policy aimed at influencing the frequency, destination, and time of day as well as mode of shopping trips, and the introduction of substitutive modes, might be a quite effective policy package to counter congestion and pollution.

The second set of Charles River Associates results is derived from a simulation of the Pittsburgh-type disaggregate shopping model by using Los Angeles data. The elasticity of vehicle kilometers of travel with respect to automobile line-haul costs is estimated to be -0.17 with mode and destination variable and -0.34 with mode, frequency, and destination variable.

EVIDENCE OF TRANSIT FARE ELASTICITY

The degree of sensitivity of transit use to fares is important to transit operators, who must set fare and service levels that will minimize the operating deficit but maintain ridership. An elastic transit demand implies revenue loss by operators if they raise fares but revenue gains if they lower them. Conversely, the more inelastic is transit demand, the more revenues can be increased by fare hikes.

Although the assembled estimates of fare elasticity range widely (from -0.09 to -1.8), most of the estimates fall substantially short of 1.0. The travel demand models suggest an average elasticity of around -0.4 or -0.5, although there is a great deal of variation [see

Table 3. Transit fare elasticities derived from travel demand models.

Model	City	Transit Mode	Short-Term Elasticity	Comments
Warner	Chicago	Aggregate transit	-0.96	Applies only to those travelers not restricted to a single mode (i.e., noncaptive)
Lisco	Chicago	Aggregate transit	-0.4	Noncaptive travelers
Lave	Chicago	Bus	-0.7	
Charles River	Boston	Aggregate transit	-0.09	
McGillivray	San Francisco	Aggregate transit	-0.11	All trip types
			-0.19	All trip types (noncaptive)
			-0.87	Work trips (noncaptive)
Talvitie	Chicago	Aggregate transit	-0.38	Noncaptive
		Bus	-0.51	Noncaptive
		Rail	-1.8	Noncaptive
McFadden	Berkeley-Oakland	Bus	-0.45	In absence of BART
		Bus	-0.58	In conjunction with BART
		Subway	-0.86	BART
Fulkerson	Louisville	Bus	-0.4	
Regional Plan Association	New York	Bus	-0.31	Time series analysis from 1950 to 1974
		Subway	-0.16	

Table 3 (7, 8, 10, 14, 16-20)]. Of note is the deviance of the Charles River Associates estimate of -0.09, which is exceeded significantly not only by the results of most of the other models listed in the table but also by most arc elasticity estimates that have been calculated. These latter, with a mean value of about -0.4 (but ranging widely), can at least be said not to contradict the formal model estimates (6).

Of course, the reliability of both types of estimates is limited to those conditions under which they were estimated. Extrapolation to other cities, other transportation environments, and other price-service levels is dangerous. This is especially so in the case of the arc elasticities, which do not control for nonfare variables. Moreover, since the models are calibrated on the specific transportation situations of particular cities, the estimated demand parameters are similarly constrained by this structural dependence on the specific data base.

The generally inelastic demand for transit use ensures that fare decreases will almost certainly increase the operating deficits of transit authorities in the short run and that fare increases will reduce deficits. A number of considerations may, however, dictate against the upward adjustment of fares simply to reduce deficits. Long-term transit fare elasticities, which have not been estimated, definitely exceed corresponding short-term elasticities because a wider range of transportation choices and residential as well as workplace locations become available over time. Indeed, long-term elasticities may actually exceed unity and thus make fare increases ultimately perverse. Moreover, the economies of scale in transit operation complicate the adverse effects of price increases. Not only does ridership decrease (albeit at a lesser percentage than that of the price increase), but operating costs per passenger rise and service levels usually fall (especially frequency and geographic coverage). This stimulates the need for additional fare increases and subsequent patronage declines. Finally, to whatever extent external social benefits accrue to the provision of transit service, these may justify the public subsidization of transit so that these services can be provided at below cost.

EVIDENCE OF AUTOMOBILE TRAVEL ELASTICITY

Traffic Response to Tolls

Especially in densely developed northeastern American cities, bridges and tunnels are important access links to the congested CBDs of metropolitan areas. Moreover, limited-access expressways are also significant feeder routes to the downtown areas of almost all metropolitan areas in the United States. In contrast to the great difficulty of imposing ideal marginal congestion cost charges on users of most city streets, the limited points of access to expressways, bridges, and tunnels improve the feasibility of appropriate congestion pricing of these arterial routes, which so exacerbate the congestion problems of central urban districts.

Although evidence on the effectiveness of expressway pricing is not available (most urban freeways are free to users), the limited experience analyzed for bridge and tunnel toll surcharges indicates an average arc elasticity of automobile traffic with respect to tolls of -0.13 for New York City and -0.17 elsewhere. Little can be inferred from these data, as no effort is made to control for other variables that might have altered traffic levels. An interesting result, however, is that bridges and tunnels that have a number of substitute routes exhibit the most elastic demand response, as economic theory would predict (21).

Traffic Response to Parking Charges

In lieu of ideal marginal social cost pricing of urban roads (technically difficult and politically infeasible), a less controversial and more easily implementable approximation to congestion pricing is the coordinated use of parking taxes, meters, and supply restrictions to parking availability, which is crucially complementary to automobile use. Parking charges may be especially effective in reducing traffic levels in congested downtown areas, for the number of parking spaces tends to be scarce relative to demand at peak hours and is sensitive to public regulation.

Hard evidence on the indirect effect of parking policies on traffic levels, as reviewed by Kulash, is virtually nonexistent (22). Even studies of the direct, and less policy-significant, effect of such charges on parking demand are seriously flawed. Most conclude that parking demand is inelastic with respect to own-price, averaging around -0.3 or -0.4. However, the extent of the direct influence on parking demand per se is of less importance than the indirect effect of these fees as a component of trip costs on overall automobile travel demand. The evidence on this issue of primary importance is of a hypothetical nature. Not only is it based on the dubious reliability of survey data, but it involves radical extrapolations to price levels many times higher than those that have actually been obtained in any American metropolitan area. It does suggest, however, the need for pricing policies to be comprehensive and coordinated in order to have any impact on the level and pattern of traffic and thus, indirectly, on the levels of road congestion and automobile pollution.

CONCLUSIONS

Some of the elasticity estimates we have examined have been interpreted by observers as testifying that price is an ineffective tool for helping to cope with urban transportation problems. We do not share this interpretation. It reflects an incorrect view of the role that pricing policy should perform. The objective of public pricing policies for urban transport is not simply to reduce aggregate automobile use. Specific program goals may be formulated that require such decreases, and pricing may be considered a tool for helping to bring them about. The natural role for public pricing is to force users of any scarce resource to confront the full social costs and benefits to the community of their use of that resource, so that the resource will be allocated most beneficially with respect to the overall amount and distribution of use.

Urban travel, especially via private automobile, involves several kinds of indirect effects on users and nonusers, which do not now enter into private travel decisions. The distinctive goal of pricing is to incorporate these externalities (e.g., congestion, air pollution, and noise) into the decentralized urban travel decisions of the population. Elasticity values indicate how much alteration in urban travel behavior would occur under this form of price policy. They suggest how serious a distortion of resource use occurs because of externalities, although they shed no light on the magnitude of these social costs. In this sense, the smaller the elasticity numbers, the less serious is the resource distortion that pricing policy is called on to rectify. But this is not the same as the usefulness of pricing policy.

The magnitude of the transport externality problem varies crucially over times of day and at different locations within the metropolitan area. Therefore, improved public pricing policy should impose significantly different charges, depending on time, location, and the social as well as natural environmental context. Studies that differentiate the demand response to pricing by changes in trip frequency, route, and time of day as well as modal choice tend to find much greater responsiveness to price than do those studies that assume travel demand to be homogeneous. The particularly keen leverage of pricing in altering the composition of automobile use makes pricing an especially attractive policy instrument. The social costs of the automobile involve less the aggregate level of use than the nature and composition of this use. Thus, improved pricing might, for example, decrease urban congestion problems significantly without reducing the total number of kilometers driven in the metropolitan area.

Perfect pricing of automobile use (sensitive to every variation in social cost) is impossible; however, some differentiation by type of automobile use can probably be achieved through the appropriate orchestration of the various pricing instruments that are available. For example, parking charges could be made to vary with location, gasoline taxes could be increased, and tolls could be imposed at entrances to key congested links. A suitable degree of differentiation among automobile uses should result in the imposition of charges on some uses but not on others. Therefore, the specific automobile uses for which a surcharge is levied will inevitably have a set of closer substitutes than would aggregate automobile use. As confirmed by the disaggregate studies, the demand responsiveness to price will be greater for these specific uses than aggregate use elasticities indicate.

Almost all of the estimates of elasticity are dependent, at least to some extent, on the specific city from which the data are assembled. Urban transportation demand depends importantly on city-specific characteristics (such as density, area, urban land-use patterns) and the extensiveness and quality of the existing road system and transit network. Elasticity estimates derived from demand studies that have not been sensitive to these interurban differences cannot be reliably extrapolated to predict the travel response of pricing policies in cities other than the one on which they were calibrated. An advantage of the disaggregate modeling approach is that this limitation has been mitigated, at least to some degree.

There are other aspects of the extrapolation problem, however. Elasticity estimates of even the best demand studies are less reliable outside the observed range of cost and performance characteristics of the transportation system. Forecasts of the policy impact of transport prices that are either substantially higher or more differentiated than past or present levels on the basis of historical elasticities are of dubious validity. Not only may the magnitude of the effect change, but the nature of the impact may also change. For example, as travel prices increase to levels previously unobserved, responsiveness may increase at some nonlinear rate, or travel choices might shift radically on reaching some crucial price threshold.

Furthermore, it is important to note the short-term nature of the urban travel-demand studies. Although the effect of automobile ownership levels on travel behavior has been estimated to be considerable, in no model is the indirect effect of price on travel behavior through changes in automobile ownership taken into account. Yet the Chase Econometrics and RAND models estimate equations of automobile demand that suggest an extremely strong impact of gasoline price both on the level of automobile sales and on the composition of the automobile stock by size, class, and fuel-efficiency characteristics. Because urban travel-demand models have not incorporated this indirect response to pricing, the calculated elasticities almost certainly underestimate the longer-range impact of pricing.

A potentially even more important, indirect effect of price on travel demand is that of a changing structure of transportation prices on the pattern of land use in metropolitan areas. This avenue of change has been given almost no serious attention in empirical demand studies. The ramifications of the land-use impact are extremely varied and complex. The difficulties of modeling the effect are, therefore, considerable and empirical estimation has so far proved infeasible. Nevertheless, the exclusion of this indirect long-term locational effect of price on travel demand certainly understates the total responsiveness induced by price changes. It would seem that an alternative evolution or redirection of urban development patterns would represent the most fundamental solution to many urban transportation problems.

In sum, even on the basis of the underestimates of elasticity values that have been calculated, the potential of corrective pricing policies to aid in the solution of urban transportation problems is significant. We would argue, however, that this potential is, in fact, considerably greater than can be inferred from the existing empirical work.

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Abridgment

Gasoline Rationing Based on Licensed Drivers or Vehicles: Potential for Coupon Sales Between Income Groups in Michigan

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In a proposed standby gasoline rationing plan released for public comment in June 1978, the U.S. Department of Energy (DOE) proposed that the unit of allocation for gasoline be registered vehicles rather than licensed drivers. It was asserted that this would make rationing quicker to implement and be a more realistic response to existing use than driver-based allocation (1). The plan also emphasized the value of a "white market" for the unrestricted exchange of rationing rights at uncontrolled prices. The vehicle-based allocation and white-