# Pricing the Use of the Automobile to Achieve Environmental and Energy Goals

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Pricing policies designed to control the use of the automobile have traditionally been discussed in the context of congestion relief. It is argued (1, 2) that motorists who use congested facilities do not fully pay for the delays they impose on others. If motorists were made to pay for these delays through the application of appropriate pricing measures, the demand for the use of congested roadways would decrease, congestion would be reduced, and the efficiency of the transportation system would be improved.

In recent years, two additional automobile-related problems that might be alleviated, or possibly solved, through the use of appropriate pricing measures have been recognized. These problems are excessive emissions of air pollutants by automobiles and excessive energy consumption by automobiles (3, 4, 5, 6, 7, 8). From a theoretical viewpoint, it can be argued that motorists are not assessed the full social costs of the air pollution they cause and the energy they consume. If emissions and gasoline were priced appropriately, motorists would adjust their behavior so as to cause less air pollution and use less gasoline. From a practical viewpoint, the argument is more straightforward: If polluting the air and consuming gasoline were made to cost more, people probably would travel by car less or buy cars with lower levels of emissions and better fuel economy or both. In either case the results would be beneficial to air quality and energy conservation.

Although pricing measures can contribute to the solutions of the problems of congestion, air pollution, and energy consumption, it is not necessarily the case that the same pricing measures can be used to address all three problems. Congestion, pollution, and gasoline consumption are different things, and they have, to some extent, different physical remedies. For example, emissions and energy consumption can be reduced substantially by changing the design of automobiles. However, such design changes are not likely to reduce congestion. Moreover, the design changes needed to control automobiles' emissions are not necessarily the same as the design changes needed to reduce their energy consumption.

If the physical remedies for congestion, pollution, and energy consumption problems differ, then the changes in motorists' behavior needed to effect the physical remedies and the pricing measures needed to stimulate the behavioral changes may also differ. In the following sections of this paper, some of the physical characteristics of the congestion, pollution, and energy consumption problems are described, and qualitative implications of these characteristics for the design of pricing measures are discussed. An illustration of the potential differences among the effects of pricing measures designed to remedy each of the three automobile-related problems is presented. Finally, some generally applicable conclusions are reached concerning the design of automobile pricing measures to reduce congestion, air pollution, and energy consumption.

## CONGESTION

Severe congestion occurs most frequently on roadways that serve high-density activity centers and during periods of peak travel demand. For example, roadways in and around the downtown areas of cities are often badly congested during the morning and afternoon peak periods, whereas congestion is less common in the suburbs and during off-peak periods. Congestion tends to be a problem that affects relatively small geographical areas and relatively few hours of the day. The downtown areas of large cities, for example, typically occupy less than 10 percent of the surface area of the metropolitan region, and the combined duration of the morning and afternoon peak periods usually is only 4 to 6 h.

The physical remedy for congestion is to reduce the volume of traffic on congested facilities. This can result from any of several changes in motorists' behavior, including (a) substituting nonpeak travel for peak-period travel; (b) altering routes or destinations so as to avoid congested areas; (c) substituting transit, car pools, or nonvehicular travel for automobile driving; or (d) forgoing trips that are normally made to congested areas. Because severe congestion occurs at relatively few places and times of day, pricing measures to reduce congestion should discriminate among geographical areas and times of day. Pricing measures applied by means of tolls, supplementary licenses, automatic vehicle identification, on-vehicle meters, and increases in parking fees can do this. Pricing measures applied by such means as gasoline taxes affect all travel at all times of day and are therefore inappropriate if the sole objective of pricing is to reduce congestion.

## AIR POLLUTION

The two most troublesome automobile-related air pollutants are carbon monoxide (CO) and oxidants. Excessive CO concentrations, like congestion, occur principally in areas of high traffic density. However, CO tends to be a problem during more hours of the day than congestion does. Typically, excessive CO concentrations occur as violations of the 8-h CO air quality standard, which means that the CO concentration averaged over an 8-h period is too high.

Excessive 8-h CO concentrations can be reduced by reducing total CO emissions in the affected areas during the affected 8-h periods. One way of reducing CO emissions is to reduce automobile traffic in areas in which CO concentrations are excessive. Pricing measures to achieve the necessary traffic reductions can be implemented by using the pricing techniques appropriate to congestion pricing. However, it may be necessary to keep the pricing measures in effect during the entire 8-h periods of concern rather than during peak periods only.

Reductions in peak-period traffic will, of course, reduce CO emissions during the 8-h periods that include the peaks. However, peak-period traffic typically accounts for only about one-third of the total traffic in an 8-h period that includes a peak (9). Thus, moderate

reductions in peak-period traffic may have relatively minor effects on troublesome CO concentrations. Alternatively, if CO is to be controlled by reducing peak-period traffic only, very large traffic reductions may be needed. Another disadvantage of using only peak-period traffic controls to reduce 8-h CO concentrations is that the controls may encourage the substitution of non-peak-period travel for peak-period travel. This would cause CO emissions during peak periods to be replaced by CO emissions during nonpeak periods. The net effect on 8-h CO concentrations could be insignificant.

CO emissions can be reduced without reducing traffic volumes by changing the design of cars. The use of cars with low emission levels in areas in which CO concentrations are excessive might be encouraged by taxing emissions of CO in areas with high CO concentrations. The tax might be assessed by any of the means used for congestion pricing. In the short run, motorists might respond to the tax by reducing automobile travel to areas with high CO concentrations. Thus, in the short run, the CO tax would tend to reduce both CO concentrations and congestion. In the long run, the CO tax would tend to encourage the accelerated replacement of old cars with high emission levels by newer and cleaner ones. This would cause the tax to decrease. Although the beneficial effects of the tax on CO would endure, the effects of the tax on congestion would gradually diminish.

Oxidants, unlike CO, are not emitted directly by automobiles or any other source. Rather, they are the product of atmospheric chemical reactions involving hydrocarbons (HC) and nitrogen oxides ($NO_x$). The latter substances are emitted by automobiles, among other sources. The chemical reactions that produce oxidants require at least 3 h to take place and, under appropriate conditions, may continue for several days. During this period the atmosphere is being mixed by winds and is receiving new injections of pollutants from automobiles and other sources. Consequently, elevated oxidant concentrations tend to occur over entire metropolitan regions rather than in small geographical subareas. Moreover, oxidants are produced by total regional emissions of HC and $NO_x$ rather than by emissions in certain subareas or at certain times of day.

To significantly reduce the automobile's contribution to excessive oxidant concentrations, it is necessary to significantly reduce regional automobile emissions, particularly HC emissions. This can be accomplished most effectively through the use of measures that reduce automobile travel in the entire metropolitan region or that encourage the replacement of cars with high emission levels by those with low ones. Measures that affect only peak-period travel to congested areas and even measures that achieve moderate reductions in total daily downtown travel, as CO control measures might do, are likely to have relatively minor effects on oxidant concentrations. Similarly, measures that simply alter the temporal distribution of travel or the choice of travel routes are unlikely to have significant effects on oxidants.

The pricing techniques most likely to be effective in reducing the automobile's contribution to elevated oxidant concentrations are ones that are applicable over broad geographical areas. These may include parking taxes, HC emissions taxes, and vehicle metering. They are likely to exclude tolls, supplementary licenses, and automatic vehicle identification. Gasoline taxes might also constitute an effective approach to controlling oxidants, at least in the short run. In the long run, however, gasoline taxes would tend to encourage replacement of cars with poor fuel economy by cars with good fuel economy. The resulting improvements in fuel economy would reduce the effects of the gasoline tax on the cost of automobile travel and thus reduce the effects of the tax on the demand for automobile travel and on HC emissions.

## ENERGY CONSUMPTION

Energy consumption by automobiles, like production of oxidants, is a consequence of total regional travel. Thus, with two possible exceptions, pricing measures that are effective in reducing the automobile's contribution to excessive oxidant concentrations are also likely to be effective in reducing energy consumption by automobiles. Conversely, measures that are ineffective for oxidant control are likely to be ineffective for reducing energy consumption as well. The two possible exceptions are the emissions tax and the gasoline tax. The effects of an emissions tax on the cost of automobile travel are likely to decrease over time as old cars with high levels of emissions are replaced by new cars with lower levels of emissions. Accordingly, the effects of an emissions tax on the demand for automobile travel and on energy consumption by automobiles are likely to decrease over time. On the other hand, it is likely that the long-run price elasticity of demand for gasoline is greater than the short-run elasticity (7, 8). Thus, the beneficial effects of a gasoline tax on energy consumption are likely to increase over time, although the effects of the tax on emissions may decrease.

The qualitative characteristics of the congestion, air pollution, and energy consumption problems and of the pricing approaches suitable for dealing with these problems are summarized in Table 1. Quantitative differences among pricing measures designed to remedy each of the three problems are discussed in the next section.

## QUANTITATIVE ILLUSTRATION

To illustrate the quantitative differences among automobile pricing measures to alleviate congestion, improve air quality, and reduce energy consumption, some examples of pricing measures have been developed for a hypothetical city. The streets in and around the downtown area of the hypothetical city have a volume-to-capacity ratio near 1.0 during peak periods. During nonpeak periods between 6:00 a.m. and 8:00 p.m. the volume-to-capacity ratio on downtown streets is 0.6. The speed-volume relationship on downtown streets is

$$\begin{aligned} s &= 44.2 - 20.1(V/C);\ 0.6 < V/C < 1.0 \\ &= 35.4 - 5.36(V/C);\ 0 < V/C < 0.6 \end{aligned} \qquad (1)$$

where

s = speed (kilometers per hour),
V = traffic volume (vehicles per hour), and
C = roadway capacity (vehicles per hour).

Equation 1 is a piecewise linear approximation of the relationship between speed and volume for urban arterials with a 40-km/h (25-mph) speed limit given in the Highway Capacity Manual (10).

The 8-h air quality standard for CO is violated during the period from 6:00 a.m. to 2:00 p.m. in the downtown area of the hypothetical city. A 20 percent reduction in CO emissions from automobiles in the downtown area in this period is needed to achieve compliance with the 8-h CO standard. In addition, the air quality standard for oxidants is violated in the hypothetical city. A 20 percent reduction in daily HC emissions from automobiles in the entire metropolitan region is needed to achieve the standard for oxidants.

Table 1. Qualitative characteristics of congestion, air pollution, and energy consumption problems.

| Problem | Geographical Extent | Temporal Extent | Behavioral Changes to Alleviate the Problem[a] | Appropriate Pricing Techniques[b] |
|---|---|---|---|---|
| Congestion | Small areas | Morning and evening peak periods; and some non-peak periods | 1, 2, 3, 4 | 1, 2, 3, 4, 5 |
| Carbon monoxide | Small areas | 8-h periods | 2, 3, 4, 5 | 1, 2, 3, 4, 5, 6 |
| Oxidants | Regional | All day | 3, 4, 5 | 4, 5, 7, 8 (short run) |
| Energy consumption | Regional | All day | 3, 4, 6 | 4, 5, 7 (short run), 8 |

[a] 1 = travel in off-peak periods instead of peak periods, 2 = choose routes or destinations outside the affected area, 3 = switch to high-occupancy or nonvehicular modes, 4 = forgo trips to the affected area, 5 = switch to automobiles with lower emissions, 6 = switch to automobiles with better fuel economy.
[b] 1 = tolls, 2 = supplementary licenses, 3 = automatic vehicle identification, 4 = on-vehicle meters, 5 = parking taxes, 6 = carbon monoxide emissions tax, 7 = hydrocarbons emissions tax, 8 = gasoline tax.

Table 2. Automobile trip lengths and costs in a hypothetical city.

| Item | Downtown Trips | | All Trips in Metropolitan Region |
|---|---|---|---|
| | Peak | Off Peak | |
| Average round-trip length, km | 22.5 | 19.3 | 16.1 |
| Average round-trip distance in downtown area, km | 11.3 | 11.3 | – |
| Average round-trip cost exclusive of parking[a], $ | 1.12 | 0.96 | 0.80 |
| Average parking cost per trip, $ | 0.50 | 0.25 | 0.10 |

Note: 1 km = 0.62 mile.
[a] Automobile operating cost is $0.05/km.

The relationship between the demand for automobile travel and the cost of automobile travel in the city is

$$N = Ap^e \tag{2}$$

where

N = number of automobile driver trips in a given time period,
A = constant,
p = average cost of a round trip, and
e = price elasticity of demand for automobile travel.

It is assumed that e = -0.5. The value of travel time is assumed to be $3.00/h.

The relationship between gasoline consumption by automobiles and the price of gasoline in the hypothetical city is

$$G = Bg^d \tag{3}$$

where

G = daily gasoline consumption by automobiles,
B = constant,
g = price per liter of gasoline, and
d = price elasticity of demand for gasoline.

Peak-period travel accounts for one-third of the CO emissions from automobiles in the downtown area from 6:00 a.m. to 2:00 p.m. Downtown peak-period travel is responsible for 15 percent of the daily HC emissions and fuel consumption by automobiles in the metropolitan region. Non-peak-period downtown travel between 6:00 a.m. and 8:00 p.m. causes 16 percent of the daily HC emissions and fuel consumption by automobiles in the metropolitan region. The lengths and costs of automobile trips in the city are shown in Table 2.

If the ratio of volume to capacity on downtown streets is assumed to be proportional to the total volume of downtown travel, then the optimal downtown congestion charge is given by

$$p_c = ZR(dT/dR) \tag{4}$$

where

$p_c$ = congestion charge (dollars per kilometer),
Z = value of time,
R = volume-to-capacity ratio on downtown streets, and
T = travel time per kilometer.

Equations 1, 2, and 4 determine the value of $p_c$. In the case of the hypothetical city, the appropriate congestion charge is 7 cents/km (11 cents/mile) during peak periods and 2 cents/km (3 cents/mile) during nonpeak periods between 6:00 a.m. and 8:00 p.m. These charges are equivalent to 77 cents per peak-period round trip and 21 cents per non-peak-period round trip. The charges reduce downtown traffic by 17 percent in peak periods and 8 percent in nonpeak periods. Average travel speeds increase 3 km/h (2 mph) in peak periods and negligibly in nonpeak periods.

The effects of the congestion charges on air quality and fuel consumption depend on what happens to the trips that are tolled off the road. In this illustration it is assumed that such trips switch to the use of car pools or transit if the trips have origins or destinations in the downtown area. Tolled-off trips through the downtown are assumed to detour to alternative routes or destinations. However, to keep the illustration relatively simple, it is assumed that such detours have negligible effects on emissions and fuel consumption.

On the basis of these assumptions, the peak-period congestion charge reduces downtown CO emissions from 6:00 a.m. to 2:00 p.m. by 8 percent, compared with the 20 percent reduction that is needed to achieve the CO air quality standard. This CO reduction includes the effects of both the reduction in peak-period traffic and the increase in peak-period speeds that result from the congestion charge. If both the peak and nonpeak congestion charges are applied, then the reduction in CO from 6:00 a.m. to 2:00 p.m. is 13 percent. The peak-period congestion charge reduces regional HC emissions from automobiles by 3 percent, compared with the 20 percent reduction needed to achieve the oxidant standard. The peak and nonpeak congestion charges together reduce regional HC emissions by 4 percent.

The effect of the congestion charges on energy consumption depends on the energy characteristics of the alternative modes to which tolled-off automobile trips are assumed to switch. Three possibilities are considered here: (a) Tolled-off trips switch to car pools, (b) tolled-off trips switch to buses with average occupancies

Table 3. Summary of results of pricing measures in a hypothetical city.

| Objective | Price per Round Trip ($) | | Area of Application | Reduction of Peak-Hour Carbon Monoxide (%) | Reduction of Hydrocarbons (%) | Energy Savings (%) | | |
|---|---|---|---|---|---|---|---|---|
| | Peak | Off Peak | | | | Car Pools | 10-Passenger Buses | 20-Passenger Buses |
| Relief of congestion | 0.77 | 0 | Downtown | 8 | 3 | 3 | 2 | 2 |
| | 0.77 | 0.21 | Downtown | 13 | 4 | 4 | 3 | 3 |
| Control of carbon monoxide | 4.40 | 0 | Downtown | 20 | 8 | 8 | 4 | 6 |
| | 0.77 | 0.37 | Downtown | 20 | 6 | 6 | 3 | 4 |
| Control of oxidants | 0.50 | 0.50 | Regional | 17 | 20 | 20 | 12 | 16 |
| Energy conservation[a] | — | — | Regional | | | | | |
| Short run | | | | 17 | 20 | 20 | 12 | 16 |
| Long run | | | | | | | | |
| High elasticity of demand for gasoline | | | | 9 | 9 | 41 | 39 | 40 |
| Low elasticity of demand for gasoline | | | | 17 | 19 | 22 | 14 | 18 |

[a]Gasoline tax of 20 cents/L (75 cents/gal).

of 10 passengers, and (c) tolled-off trips switch to buses with average occupancies of 20 passengers.

The energy consumption of the various modes is assumed to be 5.24 MJ/passenger-km (8000 Btu/passenger-mile) for cars during peak periods (prior to any changes of mode), 3.87 MJ/passenger-km (5900 Btu/passenger-mile) for cars during nonpeak periods, 2.03 MJ/passenger-km (3100 Btu/passenger-mile) for 10-passenger buses, and 1.02 MJ/passenger-km (1550 Btu/passenger-mile) for 20-passenger buses (3). In addition, the total number of passenger-kilometers traveled is assumed to be independent of mode.

On the basis of these assumptions, the peak-period congestion charge reduces regional energy consumption by automobiles plus transit vehicles by 3 percent under the first possibility described above and 2 percent under the second and third possibilities. The peak and off-peak tolls together reduce energy consumption by 4 percent, 3 percent, and 3 percent under each of these possibilities respectively. The energy savings in the second and third are less than those in the first because of the energy consumed by buses.

To achieve the CO standard in the downtown area by charging for peak-period travel only, it would be necessary to set the charge at $4.40/round trip. Such a charge would achieve an 8 percent reduction in regional HC emissions by automobiles and energy savings for automobiles and transit vehicles of 8 percent, 4 percent, and 6 percent for the three possibilities respectively. The charge would also reduce peak-period downtown traffic by 61 percent, compared with the 17 percent reduction produced by the optimal congestion charge. An alternative, and possibly less extreme, way of achieving the CO standard downtown would be to charge $0.77/round trip (the congestion charge) for peak-period downtown travel and $0.37/round trip for nonpeak downtown travel. These charges would reduce regional HC emissions by 6 percent. They would reduce energy consumption by automobiles and buses by 6 percent, 3 percent, and 4 percent respectively in the three possibilities described above.

The relatively small effects on regional HC emissions and energy consumption of the various charges for downtown travel that have been considered are a reflection of the relatively small proportion (roughly one-third) of regional HC emissions and energy consumption that is attributable to downtown travel. A more productive approach to reducing HC emissions and energy consumption would be to charge for automobile travel over the entire metropolitan region. In the hypothetical city being considered here, the 20 percent reduction in automobile HC emissions needed to achieve the oxidant standard could be obtained by assessing a surcharge of 50 cents/round trip on all automobile travel in the metropolitan region. Such a charge would reduce energy consumption by 20 percent, 12 percent, and 16 percent in the three possibilities respectively. However, it would reduce downtown CO emissions from 6:30 a.m. to 2:00 p.m. by only 17 percent, compared with the 20 percent reduction needed to achieve the air quality standard. Moreover, the charge of 50 cents/round trip would not increase peak-period downtown speeds as much as the optimal peak-period congestion charge.

The charge of 50 cents/round trip is equivalent to an increase in the price of gasoline in the hypothetical city of 20 cents/L (75 cents/gal), assuming average automobile fuel economy of 6.4 km/L (15 miles/gal). Thus, one means of assessing a 50-cent trip charge might be to increase the price of gasoline in the city by 20 cents/L. [To achieve equality in the effects of the 50-cent trip charge and a 20-cents/L increase in the cost of gasoline, the short-run price elasticity of demand for gasoline must be roughly -0.27; this value is approximately double the published elasticity estimates (7, 8) but is adequate for illustrative purposes.] Although the gasoline charge and the 50-cent trip charge might have equal short-run effects on automobile use, in the long run the gasoline charge, unlike the 50-cent trip charge, would tend to encourage an improvement in automobile fuel economy. This would be beneficial for energy consumption. However, it would reduce the effect of the gasoline charge on the cost of automobile travel and therefore reduce the effects of the charge on automobile emissions.

The long-run effects of the gasoline charge on fuel economy, energy consumption, travel demand, and automobile emissions can be estimated for the hypothetical city by solving equations 2 and 3 and the following equation simultaneously.

$$G = LNf \tag{5}$$

where

L = average length of a trip and
f = fuel consumption (liters per kilometer).

If the long-run price elasticity of demand for gasoline is -0.3 (8) and other conditions in the hypothetical city are as previously described, then the long-run improvement in automobile fuel economy is only 4 percent, and the long-run effects of the gasoline charge on automobile emissions and energy consumption are roughly equal to the short-run effects. This rough equality of short-run and long-run effects results from the approximate equality of the assumed values of the short-run and long-run

price elasticities of the demand for gasoline. However, if the long-run price elasticity of demand for gasoline is -0.65 (7), then the long-run improvement in automobile fuel economy is 35 percent. The long-run reductions in downtown CO emissions and regional HC emissions are only 9 percent each, compared with 17 percent and 20 percent respectively in the short run. However, the energy savings are 39 percent to 41 percent under all three possibilities. The energy savings are nearly the same for all three because approximately 90 percent of the energy savings is caused by improved fuel economy. Only 10 percent of the energy savings is affected by variations in the energy efficiency of the alternative modes.

## CONCLUSIONS

The results obtained in the quantitative illustration are summarized in Table 3. These results are based on a hypothetical example and are unlikely to apply with precision to any real city. Indeed, conditions in many real cities may be considerably different from the conditions assumed in the example. Nonetheless, the results do show that there can be significant differences among the automobile pricing approaches that are appropriate for treating the separate problems of congestion, air pollution, and energy consumption. Optimal congestion charges for downtown travel, particularly peak-period downtown travel, may have little effect on either air quality or energy consumption. Pricing measures designed to remedy localized violations of the CO air quality standard may have little effect on either oxidant concentrations or energy consumption. Pricing measures that are effective in reducing oxidant concentrations may have comparable effects on energy consumption, at least in the short run, because both oxidants and energy consumption result from total regional automobile use. However, pricing measures to control oxidants are not necessarily as effective in controlling localized congestion and CO concentrations as are measures that are specifically oriented toward these latter problems.

The quantitative results also suggest that pricing techniques that are suitable for dealing with one type of automobile-related problem may not be suitable for dealing with other automobile-related problems. For example, area licenses and automatic vehicle identification might be appropriate techniques for effecting price changes to reduce localized congestion or CO concentrations. However, these techniques are unlikely to be suitable for effecting price changes to reduce oxidant concentrations or energy consumption because of the large geographical areas over which these price changes must take place. Parking fees, vehicle metering, and gasoline taxes might be more appropriate means of implementing the price changes needed to reduce oxidant concentrations and energy consumption. However, a gasoline tax tends to encourage improvements in automobile fuel economy. Over the long run, this can result in substantial energy savings. However, improvements in fuel economy reduce the costs of travel and, hence, the congestion and pollution control benefits of the gasoline tax.

It is likely that no single pricing approach can achieve the appropriate degrees of control of congestion, air pollution, and energy consumption simultaneously. At best, several different approaches would have to be applied together to achieve this ideal result. For example, one might consider separate taxes on CO emissions, HC emissions, gasoline consumption, and the use of congested facilities. However, even if such an approach were technically feasible, anyone thinking of implementing it would have to give serious consideration to the social and administrative burdens it might entail. Thus, pricing approaches to controlling the automobile and its use, by themselves, are unlikely to solve all of the problems associated with automobile use. Pricing approaches certainly can contribute to the solution of these problems, but, even if the application of pricing approaches becomes widespread, other means of controlling automobile use are still likely to be needed, and it will still be necessary to make trade-offs and compromises between solving one automobile-related problem and solving another.

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