(VMT)] contribute proportionally larger amounts of pollution and make greater use of roads cleared with road salt in winter snow.

There is no way to estimate the value of water pollution spillovers due to highway traffic.

CONCLUSION

The SRMC elements of highway use analyzed in this paper are, in many cases, not quantifiable. All the above elements are a function of traffic volumes and therefore vary with highway use. In designing a system of user charges based on SRMC, these elements should be accounted for in the variable-with-use portion of a user charge.

Most of the SRMC elements are not attributable to specific classes of highway users. The following items should be considered common costs, that is, to be shared by all vehicle classes equally: visual effects, most neighborhood disruption (other than noise and vibration), most impacts on rare and unique resources, and ecological impacts.

Heavier vehicles, in general, occasion greater costs in safety, water, and soil impacts because they tend to travel greater distances. These costs should be attributed by the VMT of the vehicle. Larger vehicles occasion greater costs in safety, nonmotorist delay, and rare and unique resources because of their size.

In all, a sum that would be a particular vehicle's short-run marginal cost as considered in this paper would be made up of components for VMT, vehicle weight, vehicle size, and a common cost spread across all vehicles equally. To this sum would be added the other SRMC costs not covered here but in other parts of the Highway Cost Allocation Study. However, as this analysis shows, there is not enough solid cost evidence to place actual values on the cost analyzed.

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Net Benefits from Efficient Highway User Charges

DOUGLASS B. LEE

The purpose of this paper is (a) to estimate what a complete set of efficient highway prices would look like in terms of dollar magnitudes and their relationships to travel by particular vehicles under particular conditions and (b) to measure the gains that would result from imposing the efficient prices instead of the ones now charged. Because the scope of this effort is large and because no comprehensive set of marginal cost highway user charges has been estimated previously, the result of the current work is still very rough. At present, the concepts and methods are at least as important as the numerical results.

Were there no constraints--no budgetary revenue requirements, not more than one level of government involved in setting charges, no concern for income transfers or indirect impacts, and all other public and private enterprises efficiently priced--on setting highway user charges, efficiency (in the allocation of highway investment resources and available capacity) would be the sole objective in designing such charges. In reality, numerous compromises must be made for numerous reasons. The issue then becomes the degree to which efficient resource allocation should be sacrificed for other purposes.

Although whether they are cost occasioned has been routinely cited as a basis for designing highway user charges, efficiency in the utilization of scarce resources has not received much attention until recently. Now, however, highway professionals and policymakers at all levels of government are increasingly interested in finding the most productive use of the nation's resources as well as in the fairness of revenue instruments.

OBJECTIVES IN HIGHWAY PRICING

Application of the economist's concept of efficiency to public policy implies that the government should seek to maximize the net social benefits resulting from the activities in which it engages. Efficient highway user charges are those that will lead to the greatest surplus of benefits over costs for a given stock of capital facilities. Investment in the highway system should follow the same criterion, namely, increase output as long as the marginal benefits exceed the marginal costs. The research reported here, however, is directed at the pricing portion of efficiency rather than the investment portion.

Administrative Costs of Pricing

For prices to serve as guides to efficient resource allocation, they must be clearly tied to use in both reality and the consumer's mind. Annual registration fees that are invariant with respect to the amount or location of travel can only serve as very crude prices at best. This need for prices to be based on the amount of travel and the specific conditions under which it is consumed make accurate pricing difficult and perhaps exorbitantly costly in many circumstances.

The orientation of this report is to estimate what the correct prices would be by cost component and to disregard the means by which the charges might be collected. Qualitative judgments are offered regarding which costs of travel are not likely to be feasibly priced, but no quantitative trade-offs between the benefits of improved capacity utilization and administrative costs of imposing ideal user charges are attempted. These questions are critical and must be addressed eventually, but the initial problem is to gain an idea of the general magnitude of efficient prices. Ultimately, the question is whether some attempt at efficient pricing will be better than the present methods for setting highway user charges, however imperfect the pricing mechanisms. Rough approximations can be improved with experience, and experience may be the most effective way to achieve accuracy.

Second-Best Conditions

Requiring that users of the highway system pay the marginal costs of their use does not necessarily lead to efficient resource allocation unless the rest of the world also prices at marginal cost. Obviously, the rest of the world does not. It is then a matter of judgment whether efficient highway prices will improve or worsen aggregate welfare, and this judgment must be based on knowledge of such things as competition in transportation and related sectors, relationships between marginal costs and prices for goods and services that are substitutes or complements for highway services, and demand elasticities and cross elasticities. The working assumption here is that highway user charges that are closer to marginal cost than present charges will improve efficiency in the economy as a whole as well as in the highway sector.

MEASURES OF HIGHWAY OUTPUT

For the purposes of designing efficient user charges, the highway system has two primary dimensions of output. One is the volume of vehicles that can be moved over the system in a given time period, and the standard unit of measure is the passenger car equivalent (PCE). Each vehicle takes up some effective amount of space, and competition for this space results in congestion. The other dimension is the transport of weight, and here the unit of measure is the equivalent single 18 000-lb axle load (ESAL). Pavement damage is thought to be related to axle weights. Thus the output of the highway system is a combination of PCE-miles and ESAL-miles, or simply PCEs and ESALs.

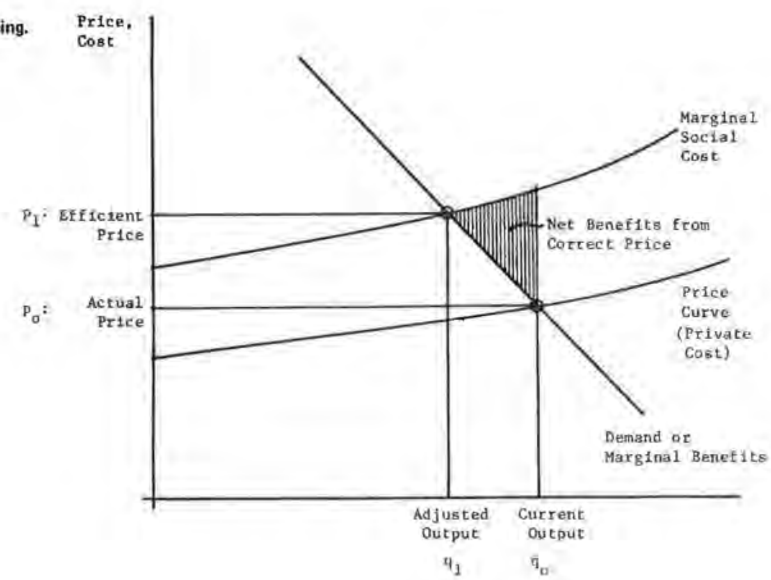
EFFICIENCY GAINS

The net benefits from more efficient prices are called efficiency gains or welfare gains. The nature of the gains depends on the output and the changes contemplated, but inefficiencies stem from either too low a price (marginal costs of some portion of consumption exceed the marginal benefits) or too high a price (users are deterred even though the benefits would exceed the costs). A generalized example is shown in Figure 1, in which the price curve lies below the cost curve. The shaded area represents the net loss from incorrect pricing, or the gains in efficiency that could be obtained by shifting from incorrect to correct pricing. In this instance, the incremental costs to society of the additional output are greater than the incremental benefits to the users. In the reverse case, where price is higher than marginal cost, the incremental benefits of greater output exceed the incremental costs.

ESTIMATION OF EFFICIENT PRICE COMPONENTS

Because efficient prices are based on charging each vehicle the costs that would be avoided if the vehicle were removed from the specific time and location where it is found operating, only variable (not fixed) costs are relevant. The variable costs listed below include those represented by public expenditures and those falling on private users and nonusers. For public costs, the price to the user is zero unless a user charge is imposed. For

Figure 1. Gains from efficient pricing.



private costs, it is the difference between social and private cost that is of interest; if there is no difference, there is no need for a price correction. The variable costs are as follows:

1. Public sector outlays (and associated costs)
   a. Pavement damage
      (1) Pavement restoration or loss of user benefits
      (2) User costs from pavement roughness
   b. Highway administration and services
2. Private user costs
   a. Vehicle interference
      (1) Delay
      (2) Accidents among vehicles
      (3) Increased vehicle operating costs
   b. Negative externalities
      (1) Air pollution
      (2) Water pollution
      (3) Noise
      (4) Visual intrusion
      (5) Danger to nonusers and property

This summary listing of variable costs is meant to be exhaustive in scope, if not in detail. If the highway system has been efficiently designed and maintained and output is subject to neither economies nor diseconomies of scale, then efficient prices to users will be sufficient to recover all the long-run costs of the system. Even though the prices are based on variable costs, under these conditions they will raise revenues that cover fixed costs as well. An important purpose of the attempt to estimate the full magnitudes of efficient prices is to assess the extent to which such prices would finance the construction and operation of the system. The results indicate that the revenues would be far greater than those raised by existing user charges.

Methods and empirical results for estimating efficient highway user charges are described in the next sections. Other references (1) provide a more detailed explanation than is possible in this brief summary.

Pavement Wear

Costs of pavement repair consist of two parts: the cost of repairing the damage to the pavement and the additional user costs to vehicles traveling over damaged pavement. An efficient design, maintenance, and operating program seeks to minimize the sum of the two costs, and correct pavement damage charges will normally include both components.

Pavement Repair

Highway pavements are designed to carry a forecast traffic volume over a lifetime of approximately 20 years. The major design consideration determining the thickness of the pavement is the expected number of axle load repetitions, measured in ESALs. Travel by various weights of vehicles can be translated into ESALs by using factors from the American Association of State Highway Officials (AASHO) Road Test, conducted in the 1950s (2). The factors embody the relationship that pavement damage on a given road increases with the fourth power of the weight on the axle. A fully loaded 72 000-lb five-axle tractor-semitrailor combination truck generates about 2 ESALs/mile of travel. Relatively, this heavy truck is wearing out the pavement at a rate about 5000 times that of the family car and about one quarter the rate of the same truck loaded to 100 000 lb. Each ESAL, however, does less damage on a thicker or stronger pavement, because pavement strength increases with the seventh power of thickness.

Incorporation of these engineering relationships into user charges that encourage efficient utilization of the highway system has several implications:

1. The charges should be high enough so that whenever a vehicle adds to the wear of the pavement, the benefits to the user (as expressed by willingness to pay for the damage through user charges) are at least as great as the costs of the damage to society.
2. Fees should increase steeply with increased axle weight.
3. Vehicles that use more axles to carry the same weight should be charged less.
4. Heavy vehicles should face substantially lower charges when they travel on heavy-duty rather than on light-duty roads.

On the assumption that the amount of pavement damage done by an ESAL is constant over the life of the pavement, the repair cost per ESAL is the total maintenance and restoration cost per highway mile divided by the ESAL life of the particular pavement and discounted from the anticipated time of restoration. Thus, the repair cost per ESAL will increase the nearer the date of restoration is and will decrease the stronger the pavement structure is. Estimated ESAL-mile charges for pavement repair are given in Table 1 by functional system.

User Costs

Pavement damage leads to lower speeds and higher operating costs for all users, whether they damage the pavement or not (3). From the standpoint of the vehicle creating the damage, user costs are external, so efficient pricing requires an explicit recognition of the user costs resulting from pavement wear.

In contrast to pavement repair costs, the time between the damage and the repair increases the user cost because more vehicles have a chance to suffer the effects of lower-quality pavement before the damage is restored. Thus, the marginal cost of an ESAL depends on the strength of the pavement (thicker pavement means less damage from a given axle) and the volume of use (larger volumes mean higher user costs). As seen in Table 1, user costs per ESAL tend to be dominated by the vehicle wear component, and reduced wear from high pavement strength is partly offset by higher average daily traffic (ADT) on heavy-duty pavements.

Administration and Services

Government services provided primarily because of highway users include traffic control, courts, street lighting (part), state highway patrol, and state and federal highway departments. Only some of these costs can be plausibly argued as related to traffic volume. The few studies available place the costs at about 0.4 cent/vehicle mile on the average (4).

Vehicle Interference

As more vehicles occupy space on the same roadway, interactions among the vehicles become increasingly significant. These interactions have three effects: one is the decrease in speed below free speeds, which results in additional travel time or delay; the second is the increase in operating costs caused by congested conditions; and the third is the increase in accidents among vehicles.

Congestion

The microeconomic formulation of the congestion problem (5) is represented in Figure 2. Average variable cost (AVC) includes vehicle wear and operating costs, pavement wear, and travel time and excludes user fees. This curve corresponds roughly to the price to the user and determines the volume of travel by its intersection with the demand curve. Because average cost rises with increasing volumes, the marginal cost of additional trips at any given volume is above the average cost. The major component of the increase in average cost and hence the difference between average and marginal cost is excess travel time or delay. Drivers are assumed to know the average travel times they will face when entering a given traffic stream, but they do not consider the increase in travel time caused by their presence for other vehicles. To internalize this effect--forcing the user to balance benefit against marginal cost--requires a price surcharge or toll that varies with the level of congestion and the PCE space occupied by the vehicle.

For the volume-capacity relationships implied by the cost curves and the demand schedule shown, the correct toll is the difference between p_0 and p_2. The effect will be to reduce vehicle volume from q_1 to q_0, at which point the average cost faced by the vehicle plus the toll will exactly equal the marginal cost. All vehicles in the stream pay this toll.

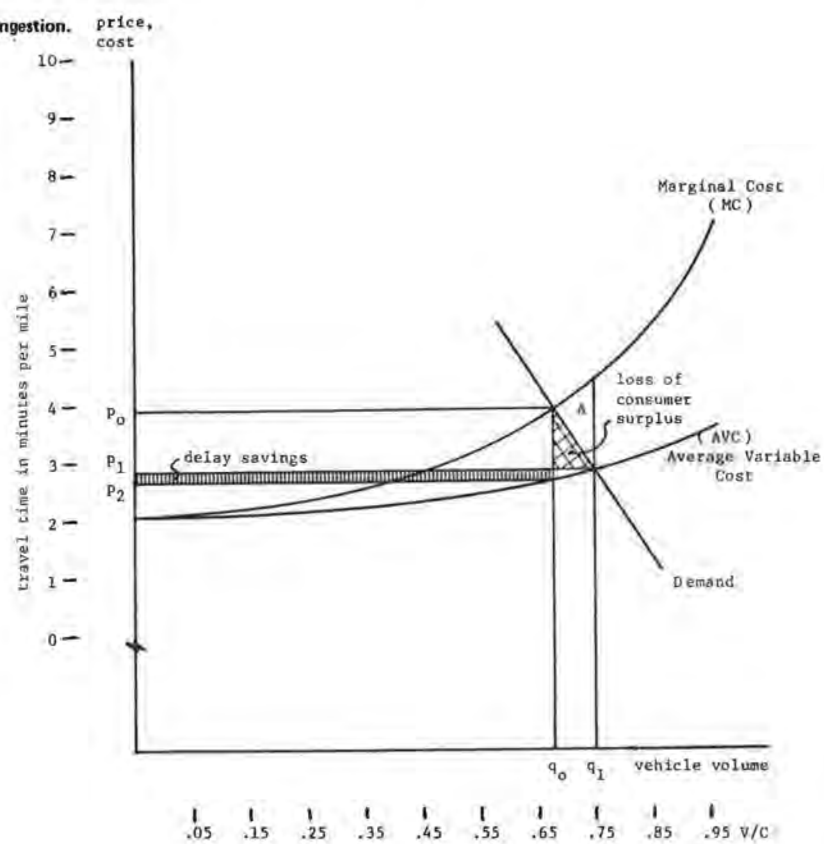
When the vehicle volume drops from q_1 down to q_0, costs are avoided equal to the area under the marginal cost curve, whereas benefits are lost equal to the area under the demand curve. The net effect is an efficiency gain represented by the three-sided area labeled A. This gain is composed of delay savings to vehicles remaining on the facility minus the consumer surplus lost by the vehicles tolled off. The first of these two components is indicated by the vertical shaded rectangle and the second by the hatched triangle. The difference between them is exactly equal to area A.

These abstract concepts can be operationalized directly. By using traffic engineering relationships based on a linear function between speed and density (6-8), average travel-time curves can be constructed for different road types. The curve for urban non-Interstate roads has been calibrated to the left-hand scale. Marginal travel times are derived from the average travel-time function. The horizontal scale has been converted to volume-capacity units and measures both volume and capacity in PCEs. Demand is given by an arc elasticity of -0.33 measured from the observed price-volume combi-

Table 1. Efficient pavement damage charges by functional system.

	User Cost (cents/ESAL-mile)				
Functional System	Pavement Repair	Vehicle Wear	Travel Time	Running Cost	Total
Interstate					
Rural	5.0	3.8	0.9	-0.9	8.7
Urban	15.0	10.6	2.4	-2.9	25.2
Arterial					
Rural	13.0	4.1	1.0	-1.1	17.0
Urban	41.0	7.6	7.0	0.3	55.9
Collector					
Rural	17.0	3.2	0.8	-0.9	20.1
Urban	40.0	6.6	6.1	0.2	52.9
Local					
Rural	31.0	2.4	0.6	-0.7	33.4
Urban	50.0	9.7	9.0	-0.4	69.1

Figure 2. Consequences of efficient pricing of congestion.



nation. This information yields a reduction in vehicle volume from 0.75 to 0.67 for the example in Figure 2, at which point the difference between average and marginal travel time is 1.02 min. By using a value of travel time of 8 cents/min ($4.80/vehicle-h), the efficient toll is 8.2 cents/vehicle mile. An estimated 30 billion vehicle miles of traffic (VMT) occurs annually on U.S. streets at a volume capacity ratio of between 0.7 and 0.8 (6,8,9), which would drop to 27 billion with the toll and produce $2.2 billion in revenues from this portion of total travel. Travel delay charges per PCE mile are shown in Table 2 for urban non-Interstate roads.

Accidents

Highway accidents cause personal injury and property damage. Costs include loss of life, loss of labor resources, medical expenditures, repair or replacement costs, loss of time, inconvenience and disruption, administration of the liability insurance system, public costs of emergency medical treatment and police, and adjudication of liability claims. So far, attempts at quantitative estimation of the relationship of these costs to congestion or particular vehicle types has not been satisfactory. More vehicles in closer proximity tend to increase the number of accidents, but if a fatality is valued in the $300 000 range (10), the benefits of reduced speed in reducing fatalities outweigh the costs of more accidents for at least some speed and volume ranges. Much accident data are available, but they are generally unsuitable for estimating the marginal costs of vehicles in connection with congestion.

Vehicle Operating Costs

Vehicle interference from congestion causes increased fuel consumption from forced speed changes and increased tire and vehicle wear from speed changes and braking. At speeds of more than approximately 45 mph, reduced speed tends to reduce fuel consumption and tire wear per vehicle mile, but it is not apparent what the net effects are if the speed reductions are the result of congestion. No quantitative estimates of changes in vehicle operating costs related to vehicle interference have been included in the figures presented here.

Negative Externalities

Highway users generate negative externalities in the form of air pollution, water pollution, noise, litter, danger to pedestrians, and other undesirable side effects. Air pollution and noise are real costs to members of society even though dollar amounts do not appear in public budgets (prevention or control costs sometimes do appear as expenditures, but these are only weakly related to damage costs). The higher the emissions rate by a vehicle is and the more sensitive and numerous the receivers are, the higher is the marginal cost of a vehicle trip. The essential characteristic of an externality is that it escapes normal market transactions, so that the valuation of negative external effects must be accomplished by political or other surrogate means. An efficient externality charge is one that encourages the producer of the externality to take the most suitable measures to reduce emissions and leaves the potential recipient to make the most suitable choices for ameliorating impacts of residual externality levels.

Methods for estimating the cost of externalities depend primarily on one or both of two strategies:

1. Estimate total expenditures made for the purpose of correcting the damage from the externality on the part of private individuals and
2. Estimate the willingness of individuals to pay for lower externality levels in surrogate (usually real estate) markets.

The aggregate-damage-cost approach has yielded the best results so far with air pollution costs (11), and the revealed-preference approach has been the most effective in evaluating noise costs (12). Air pollution costs average about 1.1 cents/vehicle mile in urban areas; there are wide variations depending on the area and the particular meteorological conditions. Noise costs average about 0.2 cent/vehicle mile in urban areas; heavy trucks create about 40 times as much damage as automobiles per vehicle mile.

Table 2. Time delay charges for urban non-Interstate highways.

Initial V/C	Average Time[a] (min/mile)	Marginal Time[b] (min/mile)	Toll[c] ($/PCE vehicle-mile)	Initial VMT	Revenues[d] ($ billions)
0.05	2.17	2.20	0.0023	15	0.03
0.15	2.23	2.30	0.0074	59	0.43
0.25	2.30	2.47	0.0138	104	1.40
0.35	2.37	2.66	0.0216	142	2.96
0.45	2.46	2.89	0.0314	111	3.31
0.55	2.57	3.19	0.0439	82	3.36
0.65	2.69	3.62	0.0601	52	2.86
0.75	2.86	4.29	0.0817	30	2.20
0.85	3.09	5.53	0.1117	52	5.09
0.95	3.50	9.58	0.1600	96	13.18
					34.83

[a]Average travel time based on linear speed-density and free speed of 28 mph = $4.29/[1 + (1 - V/C)^{1/2}]$.
[b]Marginal travel time = average time $[1 + \{(0.5V/C)/[(1 - V/C) + (1 - V/C^{1/2})]\}]$.
[c]Toll at the adjusted (price elasticity = -0.33) V/C and VMT (neither shown).
[d]Revenues from given toll at adjusted PCE volume.

User Charges for Prototypical Vehicles and Conditions

Of the variable costs listed earlier as relevant to the construction of efficient user charges, six have been quantified to the point of dollar estimates under some limited sets of average conditions: pavement repair, pavement user costs, administration, excess time delay, air pollution, and noise. Pavement damage and congestion delay are the costs of major significance; the others are small as per-vehicle-mile rates. Of the costs not estimated in cents per vehicle mile of travel (VMT), accidents appears to be the only category that might lead to a substantial increase in user charges if more were known about causal relationships. Other marginal costs may be large in the aggregate but small in relation to VMT.

Six vehicle types have been selected for illustration in Table 3; the salient vehicle characteristics are matched to the conditions under which they might be operated. The rural automobile causes little pavement damage because of light axle weights, it encounters little congestion so causes little delay, and the externalities it generates are easily diffused and affect few people. Such a vehicle is probably overcharged by a small amount, because fuel taxes and registration fees are largely insensitive to urban-rural locations and congestion. At the other end of the automobile scale, an urban commuter traveling during peak periods contributes noticeably to both congestion and pollution. A medium truck traveling in lightly congested urban areas incurs a mix of costs that includes damage to light pavements and negative externalities. The typical five-axle combination tractor-

Table 3. Efficient user charges for sample vehicles under specific conditions.

Vehicle Type	Location	Key Parameter	Component of Efficient Price (cents/VMT): Pavement Repair	User Costs	Adminis-tration	Excess Delay	Air Pol-lution	Noise	Total	Existing Average User Fee (cents/VMT)
Automobile (3000-lb gross wt)	Rural	V/C = 0.05			0.3	0.3			0.6	1.3
Automobile (3000-lb gross wt)	Urban	V/C = 0.85			0.7	11.2	1.5	0.1	13.5	1.7
Single-unit three-axle truck (40 000-lb gross wt)	Small urban	V/C = 0.35 PCE = 1.2 ESAL = 0.8	25.6	7.5	0.5	2.2	0.2	0.2	36.2	4.8
Combination truck, five-axle, 3-S2 (72 000-lb gross wt)	Rural interstate	V/C = 0.15 PCE = 1.2 ESAL = 1.6	8.0	5.9	0.3	0.4			14.6	9.0
Combination truck, five-axle, 3-S2 (72 000-lb gross wt)	Urban interstate	V/C = 0.35 PCE = 1.2 ESAL = 1.6	24.0	16.3	0.3	1.4	3.0	4.0	49.0	9.0
Combination truck, four-axle (100 000-lb gross wt)	Rural arterial	V/C = 0.05 PCE = 3.0 ESAL = 27.2	408.0	95.2	0.3	0.3		0.2	504.0	5.0

Table 4. Revenues and net gains from efficient pavement damage charges.

	1981 $ Billions			
		Heavy Vehicles[a]		
Item	Light Vehicles	Under 1.5	Over 1.5	Total
Pavement damage and user costs	0	10.1	15.4	25.4
Efficiency gains	0	0.8	4.1	5.0

[a]Vehicle classes are divided according to the average actual pavement stress applied by the typical vehicle, measured in ESAL miles per vehicle mile of travel.

Table 5. Revenues and net gains from efficient vehicle interference charges.

	1981 $ Billions				
	Rural		Urban		
Item	Interstate	Other	Interstate	Other	Total
Volume-capacity related costs	1.5	4.1	6.5	41.8	54.0
Congestion	1.5	4.1	4.5	33.2	
Externalities and other	0	0	2.0	8.6	
Efficiency gains	0.1	0.1	0.7	4.7	5.6

semitrailor operating entirely on heavy-duty pavements in rural areas creates damages about half again greater than its user charge payments, whereas the same vehicle operating on urban Interstates generates costs more than five times its estimated payments. Last on the list is an extremely destructive vehicle that might be a bulk agricultural hauler exempted from weight limits, a lumber truck, a coal hauler, or an illegally overloaded combination truck. The source of the damage is a very heavy load distributed on too few axles. Considerable guesswork lies behind these examples, and the specific conditions listed and implied may not be average for vehicles in the class represented.

NET BENEFITS FROM EFFICIENT CHARGES

For prices to function as guides to efficient resource utilization, the output that is priced must adjust to the point at which marginal benefits equal marginal costs. Because the existing price per ESAL seems to be below cost for medium and heavy axles, efficiency gains would be derived from reducing total ESAL output. Note, however, that it is not necessary to reduce ton mile output in order to reduce ESALs. With efficient pavement damage charges, heavy vehicles would have incentives to use more axles and stronger roads to carry the same total weights. If other constraints on efficiency were removed, it is possible that total ton miles could go either up or down while ESAL miles declined.

Similarly, efficient vehicle interference charges would be higher than current charges, in most circumstances, so reducing PCE miles of travel would result in savings in delay time far in excess of the lost travel benefits. Person trips, however, would not need to decline at all (through increased vehicle occupancy), and less-costly off-peak PCE mileage could be substituted for peak travel. Thus efficiency gains could be obtained in part from deterring frivolous travel, and the bulk of the net benefits would come from accommodating that travel in less costly ways. Efficient prices would encourage users to find those ways least disruptive to themselves.

Revenues from efficient user charges and net benefits were calculated by applying an estimated elasticity to each vehicle class on each system, combining all the price components into charges on the two (PCE and ESAL) dimensions of highway output. Aggregate results are shown in Tables 4 and 5. Total revenues sum to almost $80 billion, but presumably the actual total would be somewhat less because PCE charges deter some ESAL mileage, and vice versa. The revenues represent transfers, of course, and not net gains. Improved short-run efficiency is measured as something less, of the order of $10 billion annually, but this constitutes real gains in resources available that would be otherwise wasted.

CONCLUSIONS

Although the combined effect of all the components of efficient prices is subject to an additional degree of uncertainty beyond the uncertainty in the cost estimates, the total revenues raised would be more than $70 billion annually. This is more than the total expenditures for highways of $40 billion by all levels of government and more than twice the $22 billion currently collected in user charges. It is less, however, than the more than $100 billion that represents the annual cost of capital replacement to retain the full highway system as it now exists (13).

The most significant attribute of these results is that the user charges do not contain any fixed or annual components, such as registration or weight fees. Efficient prices, based on short-run marginal costs, would be sufficient to raise revenues on the current system that would cover at least a share of the fixed costs of the system without levying any access charges. Unless more revenues are desired, there is no need to allocate fixed costs of highway construction to vehicle classes for purposes of calculating highway user charges. Instead, the task is to estimate more accurately the true marginal costs of highway use and to design collection instruments that approximate the correct prices at the least cost.

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Abridgment

Maintenance Cost-Allocation Study for Virginia's Interstate Highways

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The maintenance cost responsibilities for all classes of highway users on Virginia's Interstate highways are examined. The purpose is to compare the future fuel-tax and registration-fee revenues to the future maintenance expenses contributed by each class of vehicles. The study is composed of four major steps: (a) forecasting travel on each route by each class of vehicles, (b) forecasting general and replacement maintenance expenditures on each route, (c) forecasting of fuel-tax and registration-fee revenues contributed by each class of vehicles on each route, and (d) allocation of maintenance expenditures. The allocation of general maintenance expenditures was performed by using the vehicle miles of travel for each class. The replacement maintenance expenditures, on the other hand, were divided into two categories: weight-related (allocated based on the equivalent single axle load) and environmental-related (allocated according to travel). The results show a cross-subsidy among different classes of vehicles and also among different routes. Heavily traveled routes show high revenue-to-expenditure ratios over the study period (from 1981 to 1990). Based on the present fuel-tax rate and registration fees, the revenue-to-expenditure ratio for the Interstate system in Virginia declines significantly toward the end of the decade, which suggests the need for an increase in fuel-tax rate and registration fees.

The energy shortages in the early 1970s have forced the United States to conserve energy, especially in transportation. The conservation efforts resulted in increased automobile fuel efficiency, which in turn caused a decline in fuel-tax revenue--a major source of highway funding. The decline in revenue coupled with the constantly increasing highway construction and maintenance costs have greatly decreased the ability of state highway agencies to maintain and improve the highway system.