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5 Welfare Effects of Marginal-Cost Taxation of Motor Freight Transportation: A Study of Infrastructure Pricing

Kenneth A. Small and Clifford Winston

5.1 Introduction

Recent physical failures in the United States highway system, resulting in vehicle damage and even catastrophic accidents, have lent urgency to a growing perception that our highway infrastructure is seriously degraded. Repair estimates run in the hundreds of billions of dollars.

While this problem is nationwide in extent, much of the financial burden rests squarely on state and local governments. In 1982, state and local tax revenues financed about three-fourths of all U.S. highway expenditures, consuming over 8% of all state and local own-source revenues.[1] Virtually every state has a list of defective bridges for which repairs await funding, and several have raised fuel taxes and license fees. Individual cities such as New York responded to fiscal pressure for many years by deferring highway maintenance; now they face a seemingly impossible catch-up task, made more difficult by recent congressional delays in appropriating interstate highway funds.

The most dramatic response has been the Surface Transportation Assistance Act of 1982, which increased federal fuel and truck-weight taxes in order to finance more federal highway assistance. Yet neither of these taxes bears a close relationship to the highway wear caused by various motor vehicles. Only the state weight-distance or ton-mile taxes vary with both weight and mileage, and only ten states have them.[2] Furthermore, gross weight is a poor proxy for the damage done to a highway. Highway wear depends critically on weight per axle,

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hence it is not necessarily the heaviest vehicles that are most responsible for current conditions.

Thus, neither federal nor state policy seriously attempts to align motor vehicle taxes with the damage the vehicles inflict on highways, as would be required under a policy of marginal-cost pricing. The state weight-distance taxes come closest. They also use administrative mechanisms that could be adapted to such a policy, as recently proposed by staff members of the Oregon Department of Transportation.[3] At present, however, little is known about what impact such a policy would have.

The purpose of this paper is to estimate the welfare effects of instituting nationwide marginal-cost pricing for heavy highway vehicles, with marginal cost defined as the incremental contribution of a vehicle to repaving costs. We first describe such a tax, using existing evidence on the marginal costs of various vehicle movements. Next, we outline a procedure for estimating the tax's impact on the distribution of vehicle-miles traveled by different types of heavy trucks, and on shippers' modal choice between truck and other forms of freight transportation. We then show how to calculate net benefits and the distribution of costs and benefits among shippers, carriers, and the public treasury. These calculations are carried out using 1982 data. Even though we have attempted to be conservative throughout, we still find that such a tax could go a long way toward solving the physical and financial problems of maintaining a sound infrastructure.

5.2 The Size and Structure of Marginal Cost Highway Taxes

Conventional highway engineering practice defines a unit of road wear called the equivalent single axle load (ESAL), which refers to the amount of wear caused by a single axle bearing 18,000 pounds. A highway is designed to withstand a given number of ESAL applications, after which major repairs such as resurfacing become necessary.[4] This implicitly assumes that the passing of a given vehicle does the same pavement damage as the passing of a particular number of single axles each bearing 18,000 pounds. That number is called the load equivalent factor, or ESAL number of the vehicle, and it is a very sensitive function of the weights on each of its axles. As a rough approximation, the load equivalent factor of a truck (or tractor-trailer combination) is the sum for each of its axles of $(w/18)$ to the fourth power, where w is the weight on that axle in thousands of pounds. This relationship is based on a test-track experiment completed in the early 1960s,[5] and is further supported by mechanical models of pavement stress.[6] Corroborating evidence from actual highways is weaker but not entirely absent.[7]

Besides hastening the need for major repairs, pavement deterioration adversely affects user costs of all vehicles using the highway because of the lower average speeds and greater vehicle wear it entails. These costs are at present only very imprecisely known, and are not included here.

In an appendix to the recent Federal Highway Cost Allocation Study, the Federal Highway Administration (FHWA) included estimates of the properly discounted highway repair costs caused by an ESAL under various conditions (U.S. FHWA 1982a, p. E-28). These range from \$.05 to \$.50 per ESAL-mile. As a fairly conservative estimate, we use the average of rural interstate and rural arterial roads, which is \$.09.

To avoid double-counting, we do not include any allocation of the extra construction costs required to build the original highway to heavy-duty specification. In future work, we intend to refine these estimates and possibly the ESAL unit itself as a measure of highway damage. There seems no doubt, however, about the basic premise: highway damage varies steeply with axle weight.

The Cost Allocation Study also provides estimates of the load equivalent factors for selected motor vehicle types and gross weights. We have adapted these to the vehicle types and weight classes chosen for our analysis,[8] then multiplied by the \$.09 figure. Selected results are presented in table 5.1. Each vehicle type is identified by a code giving the basic configuration (SU for single unit, CS for conventional tractor and semitrailer, DS for tractor and double-trailer) followed by the number of axles. The vehicle types used in this study are displayed in figure 5.1.

Of the thirteen vehicle types distinguished in our data set, we have selected five as the starting points for what we think will be the most significant shifts, because of either high usage (e.g., the five-axle tractor-semitrailer combination designated CS5) or high load equivalent factor (e.g., the two-axle vans designated SU2 and registered above 33,000

Table 5.1 **Marginal Costs (\$/vehicle mile)**

Vehicle type	Gross vehicle weight (thousands of pounds)				
	26	33	55	80	105
SU2	.066	.171	1.319		
SU3	.012	.031	.236	1.058	
CS4		.012	.090	.404	
CS5		.006	.046	.207	.614
CS6			.027	.120	.356
DS5			.080	.360	1.068
DS9			.007	.030	.090

KEY: SU = single unit truck
CS = conventional tractor and semi-trailer
DS = tractor and double-trailer
The number following the letter code is the number of axles.

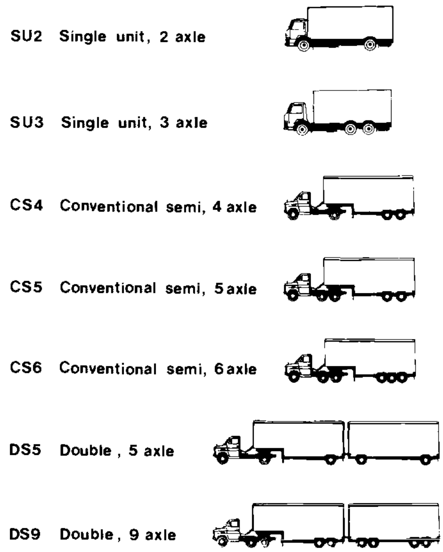

Fig. 5.1 Truck types

pounds). In 1982 these five accounted for 90% of all vehicle-miles by vehicles larger than pickup trucks. Similarly, of all the possible vehicle types to which truckers initially using each of these five might shift, because of the new tax, our analysis is restricted to the one that is likely to be the most important. The resulting shifts are: from two-axle to three-axle single-unit trucks (SU2 to SU3); from SU3 to five-axle tractor-semitrailer combinations (CS5, also known as "eighteen-wheelers"); from four-axle to five-axle semitrailer combinations (CS4 to CS5); from CS5 to the relatively rare six-axle semitrailer combination (CS6); and from five-axle to nine-axle double-trailer combinations (DS5 to DS9).

The double-trailers are of greater interest than their small vehicle populations would suggest, because the 1982 federal legislation forced all states to legalize them. This raises a safety issue that is ignored here but that needs resolution before such a tax is adopted.

In order to translate the marginal costs into tax rates, we assume that each vehicle is taxed at 80% of its mileage. This is to account for the fact that between 10 and 25% of truck mileage is with no load, and that another 10% or so is with less than three-fourths of a load.[9] We also assume that each tax rate is an accurate reflection of the highway damage that vehicle produces. Finally, we assume that the tax replaces the existing (1982) federal and state mileage-related taxes, including fuel taxes, but not those taxes levied as an annual fee per vehicle. Our rationale is that annual fees are payments for services or externalities such as police, signaling, and congestion that are predominantly urban, and therefore not proportionally related to vehicle utilization.

A practical issue concerns implementation. As a first approximation, the tax could be collected on the basis of registered maximum gross weight, which is how we have modeled it and which accords with current taxing practice in those states that levy a weight- distance tax. A more fine-tuned tax could allow firms to document their actual load distributions and pay tax based on actual weight carried. A further refinement would be to vary the tax by road type, levying a higher rate for travel on noninterstates to reflect their greater vulnerability to wear from heavy loads. Each of these refinements requires greater record keeping, but if applied only to larger firms this does not seem an insurmountable burden. States with weight-distance taxes already require considerable record keeping and have extensive auditing capabilities (New York State Legislative Commission 1983).

5.3 Welfare Analysis Methodology

Instituting marginal-cost pricing for motor vehicles will have a number of effects, not all of which we can model here. Truckers themselves would potentially respond in at least three ways. They might redistribute the loads on existing vehicles more evenly in order to reduce their highest gross weights (since the tax rises more than proportionally with weight). They might expand their fleets so as to operate at lower average loads. Finally, they might shift their fleet composition toward vehicles with more axles, either by selling and buying vehicles or, where possible, by retrofitting existing vehicles. Based on conversations with industry experts, we believe the last to be the most likely, and model it under the heading of vehicle-type shifts.

Since in most cases the new tax would be higher than the one it replaces, trucking rates would rise (though not by as much as would be predicted ignoring vehicle-type shifts). Shippers would respond by shifting some traffic to other transportation modes, particularly rail. We also model this modal shift.

For each of these two shifts, we calculate the change in tax revenues and in road maintenance and repair expenditures, the difference between which measures the effect on governments' budget balance. From that is subtracted the loss of producers' and shippers' surplus to obtain the net welfare gain.

5.3.1 Vehicle-Type Shifts

We analyze shifts within the five vehicle-type pairs described previously by assuming that exactly the same payloads will be carried in the new vehicles.[10] We originally planned to model vehicle-type choice as one of simply using the vehicle type with lowest cost including tax.

In reality, however, firms have greatly varying needs that may make them favor some vehicles over others for reasons other than relative costs. To approximate this, we assume that shifts between vehicle types are proportional to the change in their relative costs. We accomplish this by postulating a fixed elasticity of substitution. By doing this we implicitly assume that the shift is also proportional to the extent to which the new vehicle type is in use initially; this recognizes that it will take a long time to alter habits, vehicle stocks, and truck manufacturing capacity.

Each shift is measured as the change in vehicle-miles traveled by the new vehicle type. For the given vehicle-type pair and weight class under consideration, let $i = 0,1$ denote the initial and new vehicle type, respectively, let q_i be the corresponding number of vehicle-miles, and let p_i be the average cost per vehicle-mile including taxes. Let t^f_i be the fuel and weight-distance tax per mile, which we estimate from U.S. FHWA 1982b, and which is to be replaced by the new marginal-cost tax of t_i. Letting Δ denote a change, the changes in the two tax rates are $\Delta t_i \equiv t_i - t^f_i$, $i=0,1$; and the vehicle-type shift as defined above is $\Delta q_1 = -\Delta q_0$.

The elasticity of substitution σ between vehicle types 0 and 1 is defined (so as to be positive) by:

$$(1) \qquad d(\log q_1) - d(\log q_0) = \sigma[d(\log p_0) - d(\log p_1)],$$

where d denotes a differential and log the natural logarithm. Since taxes are the only part of costs that change, we can write the approximation of this for discrete changes as:

$$(2) \qquad (\Delta q_1/q_1) - (\Delta q_0/q_0) = \sigma[(\Delta t_0/p_0) - (\Delta t_1/p_1)].$$

The vehicle-type shifts will tend to come from firms that are nearly indifferent between the two vehicle types in the initial equilibrium. We represent this by the approximation $p_1 = p_0$. Setting $\Delta q_1 = -\Delta q_0$ and rearranging terms, we therefore have:

$$(3) \qquad \Delta q_1 = -\Delta q_0 = \sigma[q_0 q_1/(q_0 + q_1)](\Delta t_0 - \Delta t_1)/p_0.$$

Since we have chosen our vehicle types so that type 0 has a larger tax rise than type 1, expression (3) is positive.

All welfare effects refer to those shipments originally using type 0 vehicles. These represent q_0 vehicle-miles of travel, both before and after the shift. To avoid double-counting, no welfare effects are measured for shipments originally using type 1 vehicles, since in most cases those vehicles are also treated as type 0 vehicles in another pair. Tax revenues from these shipments were originally $q_0 t^f_0$ and become $(q_0 - \Delta q_1)t_0 + (\Delta q_1)t_1$. Using the above definitions, this change in revenues can be written:

(4) $$\Delta R = q_0 \Delta t_0 - \Delta q_1 (t_0 - t_1).$$

Note that $(t_0 - t_1)$ is positive since the new tax rewards carrying a given load in a vehicle with more axles.

Because t_0 and t_1 reflect highway maintenance and rehabilitation expenditures caused by the respective shipments, the shift causes those expenditures to change by

(5) $$\Delta M = \Delta q_1 (t_0 - t_1).$$

This quantity will usually be negative, reflecting a cost saving. The change in the government budget balance is

(6) $$\Delta B = \Delta R - \Delta M = q_0 \Delta t_0.$$

Expression (6) is independent of the amount of shifting because the new tax is assumed exactly equal to the maintenance cost caused by the vehicle paying it.

The marginal cost tax will generally lead to higher trucking costs, some or all of which will be passed on in higher shipping charges and, ultimately, in higher consumer prices. This will cause a loss in producers' and consumers' surplus that can be computed in the usual way using the simultaneous demand for services of the two vehicle types as a function of prices p_0 and p_1. Because of the absence of income effects in our model, it is independent of the particular path by which the prices are assumed to change. We use the path shown in figure 5.2. First we simultaneously raise p_0 and p_1 by an amount Δt_1; since this does not change q_0, it causes a change in surplus of $-q_0 \Delta t_1$. Next, holding p_1 constant, we raise p_0 by an amount $(\Delta t_0 - \Delta t_1)$, causing the shift Δq_0 and consequent change in surplus $-(q_0 + \Delta q_0/2)(\Delta t_0 - \Delta t_1)$. Thus we can write the total change in surplus as

(7) $$\Delta S = -q_0 \Delta t_0 + (1/2) \Delta q_1 (\Delta t_0 - \Delta t_1).$$

The first term in (7) represents a näive calculation of the loss to truckers and shippers; the second term is an offset representing ability to reduce

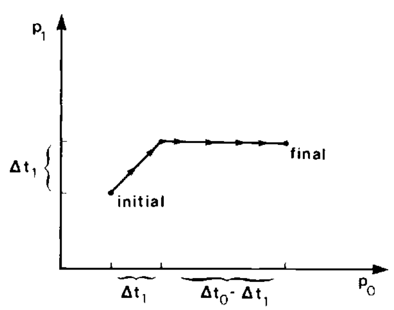

Fig. 5.2 Price path

the tax burden through vehicle-type shifting. Noting that ΔS is negative, it is useful to restate (7) as

(8) $$\Delta p \equiv -\Delta S/q_0 = \Delta t_0 - (1/2)\,(\Delta q_1\,/\,q_0)\,(\Delta t_0 - \Delta t_1).$$

If truckers earn no economic profits, this is the cost increase per vehicle-mile passed on to shippers through higher rates. It is used in the next subsection as the basis for computing shippers' response through modal shifts.

Combining equations (6) and (7), we obtain a net welfare gain from the vehicle-type shifts of

(9) $$\Delta W = \Delta B + \Delta S = (1/2)\Delta q_1\,(\Delta t_0 - \Delta t_1).$$

This equation should be recognized as an example of the "rule of a half" for measuring the welfare effects of simultaneous changes in tax rates on several goods (Harberger 1964, 40).

5.3.2 Modal Shifts

With the higher trucking rates expressed in equation (8), some shippers will shift to other modes of freight transportation such as railroads. Use of trucks will therefore be reduced still further. Assuming an own-price elasticity of demand for trucking of $-e_m$ from this effect, the resulting change in vehicle-miles is $\Delta q_m = -q_0 e_m \Delta p/p_0$. Using (8), this can be written as:

(10) $$\Delta q_m = -e_m q_0 \Delta t_0/p_0 + (1/2)e_m \Delta q_1\,(\Delta t_0 - \Delta t_1)/p_0.$$

Note the loss in tax revenue from this shift, $t_0\Delta q_m$, just cancels the reduction in highway maintenance and rehabilitation expenditures. Hence there is no net effect on the budget balance: $\Delta B_m = 0$. However, the existence of the rail option does offset the loss of producers' and consumers' surplus calculated above. Analytically, allowing for this shift is equivalent to adding a new transportation option at the old price, which is Δp below the new price. Shippers and consumers therefore realize an increase in surplus of one-half the demand for the option $(-\Delta q_m)$ times the price reduction (Δp):

(11) $$\Delta S_m = -(1/2)\Delta q_m \Delta p = (1/2)e_m(q_0/p_0)\,(\Delta p)^2.$$

Finally, we note that net welfare gain from modal shifting is

(12) $$\Delta W_m = \Delta B_m + \Delta S_m = \Delta S_m.$$

To summarize, equations (9) plus (12) capture the net welfare gain from instituting a marginal cost taxation policy for trucks, accounting for vehicle-type and modal shifts. In the next section, we calculate this welfare gain and the other quantities defined above using data on U.S. highway transportation for 1982.

5.4 Data

Our basic traffic and cost data were compiled by the U.S. Department of Transportation's Transportation Systems Center for use in a large computer model of highway operations.[11] The data are for 1982, reflecting the situation before implementation of the Surface Transportation Act of that year. Data on numbers and usage of vehicles were derived from the U.S. Census Bureau's 1977 Truck Inventory and Use Survey, and were updated using the Federal Highway Administration's Revenue Forecasting Model. Since the weight classes used in that survey were too broad for our purposes, we allocated the totals for each class to finer categories within that class in proportion to that vehicle type's registrations as reported in the FHWA's Truck Weight Study of 1979–82. The cost information is based on 1977 figures derived by the Transportation Systems Center as part of the Highway Cost Allocation Study and the Truck Size and Weight Study, updated using truck cost indices published by Data Resources, Inc. The initial fixed and variable taxes reflect the actual 1982 situation.

For reasons of data availability, we use registered weights as proxies for actual weights. This raises the question of whether this procedure systematically over- or underestimates the gains to be reaped from marginal-cost taxation. While legally operated vehicles will often weigh less than they are registered for, there is also widespread overloading (U.S. General Accounting Office 1979). On balance we suspect average highway damage from vehicles in a given registered gross weight class exceeds the damage that would done if, as we assume, every vehicle traveled 80% of its mileage loaded to exactly its registered weight. Thus if anything this procedure probably underestimates benefits from the tax.

There is no direct empirical measurement of the elasticity of substitution among vehicle types, σ. However, Friedlaender and Spady (1981, 271) did estimate trucking firms' elasticity of substitution between capital and "purchased transportation," which means expenditures on rail, air, water, and hired-out trucking services. This elasticity, which they found to be roughly 1.25, provides an indication of the degree to which trucking firms respond to changing vehicle costs by substituting other carriers' services for their own vehicles. The substitutability among firms' own vehicles ought to be much higher than this, particularly if there are low-cost possibilities for retrofitting existing vehicles with more axles.[12] Hence we have assumed a value of 5.0. We discuss later the sensitivity of our results with respect to this parameter.

For the modal diversion elasticity, e_m, there is considerable empirical evidence (see Winston 1985) suggesting a figure of about 1.0. Although it is known that this elasticity varies considerably with commodity shipped, we are not able to disaggregate our analysis by commodity.

5.5 Results

The results of our calculations are summarized in table 5.2. For each of the five initial vehicle types, the figures shown are the totals for between seven and fourteen distinct weight categories.

The welfare gain is substantial, roughly $1.2 billion per year. This represents real resources saved: the savings in highway maintenance and repair expenditures less the increase in real resources used in shipping. Keeping in mind that we have tried to make this estimate a conservative one, it seems large enough at least to arouse interest.

The policy contributes significantly to solving the "infrastructure problem." Not only does it raise $10 billion of additional tax revenues annually, it also reduces annual highway maintenance and repair expenditures by nearly $3 billion, or about 17% of total expenditures incurred because of these five truck types.

Accompanying these gains is a very sizable redistribution from truckers, shippers, and consumers to the public treasury. The nearly $12 billion reduction in producers' and consumers' surplus is, in effect, collected through the trucking industry, which can be relied upon to resist strenuously. However, the total rise in after-tax trucking costs is less than 4%, and much of this will be passed on to the public at large—which is also the beneficiary of the redistribution. Furthermore, there seems to be a growing public awareness that the current excess of highway damage costs of heavy vehicles over the taxes they pay, which averages about $3,000 per vehicle annually from our figures, can be regarded as an unjustified subsidy. Thus we do not think the policy should be ruled out immediately as politically infeasible, especially if the possibilities for reducing its initial impact through vehicle-type shifting are adequately publicized.

Another possible distributional effect is a one-time capital loss on trucking firms' vehicle stock. Marginal-cost taxation might render certain vehicles economically obsolete and thereby lower their resale value, so that their owners would incur a disproportionate share of the tax burden. In other words, some of the loss of surplus could be capitalized into lower asset values for certain vehicles. (This represents a redistribution of costs we have already accounted for, not an additional cost.) Given the possibilities of retrofitting and an international resale market, we doubt that capital losses would be very important. But if they are, one way to mitigate them is for the government to purchase obsolete vehicles for domestic use (but with smaller loads!) or for resale abroad. To ensure that government vehicles themselves do not obstruct the policy, the tax should also apply to them.

Table 5.2 **Welfare Calculations**

		Vehicle type					
Initial values:		SU2	SU3	CS4	CS5	DS5	Total
Vehicles	v	4226.20	749.01	328.30	625.63	40.51	5969.65
Vehicle-miles traveled	q_0	56.40	14.70	10.97	36.39	2.58	121.03
Maint. & repair expend.	M	4.88	3.30	1.31	4.95	0.65	15.09
Total trucking costs	C	111.76	39.04	29.45	76.06	7.63	263.95
Changes from vehicle shifts:							
Vehicle-miles traveled	Δq	−1.60	−2.39	−0.50	−0.22	−0.09	−4.80
Revenue	ΔR	3.61	2.01	1.08	4.13	0.56	11.38
Maint. & repair expend.	ΔM	−0.43	−1.02	−0.04	−0.02	−0.03	−1.54
Budget balance	ΔB	4.03	3.03	1.11	4.15	0.59	12.92
Producer & consumer surplus	ΔS	−3.82	−2.52	−1.09	−4.14	−0.58	−12.14
Net welfare gain	ΔW	0.22	0.52	0.02	0.01	0.02	0.78
Changes from modal diversion:							
Vehicle-miles traveled	Δq	−1.78	−0.79	−0.43	−2.05	−0.24	−5.29
Revenue	ΔR	−0.23	−0.30	−0.08	−0.35	−0.08	−1.05
Maint. & repair expend.	ΔM	−0.23	−0.30	−0.08	−0.35	−0.08	−1.05
Budget balance	ΔB	0.00	0.00	0.00	0.00	0.00	0.00
Producer & consumer surplus	ΔS	0.10	0.11	0.04	0.15	0.04	0.44
Net welfare gain	ΔW	0.10	0.11	0.04	0.15	0.04	0.44
Total changes:							
Vehicle-miles traveled	Δq	−3.38	−3.18	−0.93	−2.27	−0.32	−10.09
Revenue	ΔR	3.37	1.71	0.99	3.78	0.48	10.33
Maint. & repair expend.	ΔM	−0.66	−1.32	−0.12	−0.37	−0.11	−2.59
Budget balance	ΔB	4.03	3.03	1.11	4.15	0.59	12.92
Producer & consumer surplus	ΔS	−3.72	−2.41	−1.06	−3.99	−0.54	−11.71
Net welfare gain	ΔW	0.31	0.63	0.06	0.16	0.05	1.22

NOTE: All figures are in billions of vehicle-miles or billions of dollars, except v, which is in thousands of vehicles. Notation is explained in text.

Table 5.2 shows a $15 billion estimate of total highway expenditures caused by these five truck types. This is based on our marginal cost estimates and on the assumed linear relationship between total ESAL applications and highway expenditures.[13] One check on our assumptions would be to compare this estimate with actual highway expenditures in 1982, which were $41 billion.[14] The latter figure includes new construction as well as maintenance and repair. Furthermore, our estimate is of the annual expenditures needed over a period of many years to maintain the infrastructure at a constant level of service, whereas current expenditures may be either lower (allowing the level of service to deteriorate) or higher (compensating for past neglect). Nevertheless, it is reassuring that our numbers are of the right order of magnitude.

Two other interesting points emerge from a close look at table 5.2. First, more than one-third of the net benefits are attributable to modal diversion. This suggests that if highways were priced as we recommend, any private or public actions that were to improve railroad pricing and service quality would generate additional benefits heretofore overlooked.

Second, in contrast to conventional thought,[15] we find that the smaller vehicles, the single-unit trucks, are the largest potential source of welfare improvement. Perhaps too much attention has been focused on the heaviest trucks as the cause of our infrastructure problem. Indeed, highway maintenance officials often cite cement mixers and garbage trucks as the worst culprits. The latter are often municipally owned: again, it is better that the tax apply to the public as well as the private sector.

The most uncertain of our numerical assumptions is the elasticity of substitution between vehicle types, σ. If there is more substitutability than our figure of 5.0 suggests, overall benefits would be larger and the loss to the truckers and shippers smaller. Table 5.3 shows that the main

Table 5.3 **Sensitivity of Selected Results**

	Elasticity of substitution		
	2.5	5.0	10.0
Modal shift:			
Δq_m	−5.54	−5.29	−4.87
Total changes:			
ΔM	−2.04	−2.59	−3.01
ΔS	−11.99	−11.71	−11.47
ΔW	0.94	1.22	1.45

NOTE: All figures are in billions of vehicle-miles or billions of dollars, and are totals for the five vehicle types shown in table 5.2. Except for Δq_m, they include the effects of both vehicle type and modal shifts.

results change by at most 25% from their baseline values as the elasticity of substitution varies between 2.5 and 10.0.

5.6 Qualifications and Suggestions for Future Work

There are several factors omitted from our analysis that may be important. We discuss three below. The first two would cause us to underestimate the benefits of marginal cost taxation, while the third would cause an overestimate.

First, there is a reason to believe that prices exceed marginal costs in many rail markets (Keeler 1983). If so, there are additional benefits from modal diversion in the form of producers' surplus to railroad firms. We note in passing that, from a second-best perspective, uncorrectable distortions in rail prices would call for compensating distortions in motor carrier markets; however, the latter should be done through shipping rates, not infrastructure taxes.

Second, we would expect some net improvement in highway safety to result from these taxes. The major reason is simply the reduction in number of trucks and perhaps, though we have not modeled it, a reduction in average payloads. In addition, improved pavement quality should have some positive effect on safety. Offsetting these somewhat is the relative increase in larger vehicles, including double-trailer combinations.

Third, our calculation assumes that truckers' earnings reflect their opportunity costs in other occupations. This is not the case if displaced drivers or other trucking employees are unable to secure comparable employment elsewhere.

Regardless of how precise our numerical results prove to be, one point stands out: the current basis for taxing trucks is the wrong one. Neither gross weight, fuel consumed, nor number of axles (the sole basis for Ohio's distance-related tax and for many turnpike tolls) is a suitable proxy for contribution to highway costs. Although we have argued for a tax that is higher and more complex than current taxes, even a less thoroughgoing reform might be worthwhile. Switching to *any* distance-related tax based on a schedule increasing sharply with weight per axle would very likely bring substantial benefits, even if it were no more complex than current taxes and brought in the same revenues. In this respect, the recent congressional directive to study the feasibility of a nationwide weight-distance tax threatens to lock us into an unsatisfactory solution for many years. Attention should instead be focused on an axle-weight-distance tax.

We have not discussed the related question of choosing axle weight limits. Given that most states already have such limits, adjusting them is an alternative to the tax policy analyzed here. Indeed, Weitzman

(1974) identifies certain conditions when such quantity controls are superior to corrective taxes. However it is doubtful that the trucking industry, with its large number of firms with independently varying marginal costs, would meet those conditions.

Methodologically, at least three extensions to our work are worth pursuing. First, the assumption that the distribution of payload weights carried would be unchanged should be replaced by an optimization model of vehicle loading. Second, our knowledge of the kinds and magnitudes of vehicle substitutions that would take place could be greatly improved by developing and estimating an empirical model of motor vehicle type choice.

Finally, it would be worthwhile to analyze the welfare effects of an optimal highway maintenance policy that corresponds to our optimal pricing policy. It seems likely that some of the enormously expensive one-time highway rehabilitation being considered would be done differently, or not at all, if marginal-cost pricing were in effect. Furthermore, ongoing maintenance policies, often based on long-standing rules of thumb developed in an era of more or less unrestricted truck traffic, probably would need revision. Indeed, this might reduce the magnitude of the marginal-cost taxes through the adoption of maintenance procedures better suited to the altered vehicle mix. This in turn would soften the impacts of the tax change on the trucking industry, while adding to the net welfare gains.

Despite these qualifications, our results suggest that significant benefits can be realized through a realistic and operationally feasible policy of marginal-cost taxation of truck transportation. Such a policy has the appealing feature of providing significant new public revenues while correcting, rather than aggravating, economic distortions. Over a longer period, it promises to help solve the problem of how to maintain the very large and important portion of the nation's capital stock represented by its highway system.

Notes

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1. Advisory Commission on Intergovernmental Relations 1984, 6, 20.
2. See Merriss and Henion 1983, 4, 6. Recently the U.S. Congress has ordered the secretary of transportation to evaluate the feasibility of nationwide weight-distance taxes.
3. See Merriss and Krukar 1982.
4. Peattie 1978; U.S. Federal Highway Administration 1982a, pp. IV-42 to IV-43.
5. See American Association of State Highway and Transportation Officials 1981.
6. See U.S. Federal HighwayAdministration 1982a, appendix D, pp. D-12 to D-22.
7. Elliott 1981.
8. The CS4 and CS6 were not included in the FHWA figures; their ESAL numbers are derived from those of the CS5 assuming that weight on each axle is inversely pro-

portional to number of axles and that each axle's contribution to ESAL is proportional to the fourth power of its weight. Similarly. we use the fourth-power law to adapt the FHWA figure for a given vehicle type at a given gross weight to each of the gross weights considered.

9. U.S. Interstate Commerce Commission, 1977. 9. 11.

10. This means the gross weight (which includes the vehicle itself) is slightly higher after the shift. Based on data in U.S. FHWA 1982b. 12–13. it appears that each of the shifts we are considering is to a vehicle that is about 5.000 pounds heavier (8.000 in the case of DS5 to DS9). The tax rates for the new vehicles are adjusted accordingly. using the fourth-power law discussed in the text and in note 8. The increase in gross weight will slightly lower fuel efficiency and hence increase truckers' costs. This small effect is excluded here.

11. We are grateful to Mike Nienhaus and Mark Hollyer of the Transportation Systems Center for providing these data. and for many helpful discussions of how best to use them for our purposes.

12. We are grateful to Paul Courant for suggesting the possibility of retrofitting.

13. Specifically. total initial maintenance and repair expenditures are taken to be the sum over all truck types of $M_0 = q_0t_0$. This implied linearity assumption is consistent with the methodology used by FHWA to estimate the marginal costs. though there is no direct evidence for or against it.

14. U.S. FHWA 1983. 40. table HF-10.

15. See. for example. U.S. FHWA 1982a and the written testimony of Alice M. Rivlin. director of the Congressional Budget Office. before the U.S. Senate Committee on Environment and Public Works. 18 August 1982.

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Comment Paul N. Courant

It is always a pleasure to be called upon to discuss a topic that one knows nothing about, and it is a double pleasure to be introduced to a whole new family of acronyms in the process. In just the first few pages of this paper, we are introduced to RGW, kips, ESAL, VMT SU2, SU3, CS4, CS5, CS6, DS5, and the terrifying DS9, also known as the "rocky mountain double." I certainly can't say that I didn't learn anything reading this paper.

The new acronyms were the least of what I learned. Far more important, the authors make a convincing case that marginal-cost pricing of the road wear imposed by trucks could lead to substantial welfare improvement and also relieve a good deal of the fiscal burden imposed by the "infrastructure problem" facing the U.S. highway system. I find the case convincing in spite of the fact that the authors fail to

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consider a number of plausible changes in trucker and shipper behavior that might occur in response to the imposition of marginal-cost taxes, and in spite of the fact that I have a few quibbles with their particular implementation of the adjustments that they did consider. Before going into a summary and criticism of the paper, I note that the authors are to be commended on their frankness regarding the limitations of the data and assumptions they employed. They do not make overblown claims for their work, and, indeed, the issues that I raise below tend to strengthen their case rather than weaken it.

Summary of the Paper

The paper begins by noting that there is a widely perceived fiscal problem associated with the nation's roads and bridges, and that current "user fees" on trucking bear little relationship to the costs actually imposed by the vehicles. (Note that costs here are limited to resurfacing and rebuilding costs. Safety, environment, and other issues are absent from both the paper and this discussion.) It turns out that the actual costs imposed by trucks depend critically on axle loadings, and that there is a standard measure, called an ESAL (equivalent single-axle load) that can be used to calculate the costs imposed, per vehicle-mile, by a truck. Moreover, there is tremendous variation in the ESAL numbers of different types of trucks currently in service, leading to tremendous variation in estimated costs per vehicle-mile. (In table 5.1, the range of these costs for the types of vehicles considered is from .012 dollars to 1.068 dollars.) If ever there were a potential role for marginal-cost pricing, this looks like it, and authors devote the bulk of the paper to estimating and evaluating the effects of replacing current fuel taxes with taxes equal to the marginal road repair and maintenance costs that trucks impose.

The authors consider two types of responses to the imposition of such taxes. First, truckers will shift to vehicles with more axles carrying the same load, thus reducing their ESAL numbers and their tax. Second, shippers will shift to other modes of transportation, specifically rail. Regarding the first type of adjustment, the authors consider such shifts for five initial truck types and numerous vehicle weights, each holding payload constant in each case. They then calculate Harberger triangles for each of the shifts and add them up.

The procedure employed is straightforward and the resulting welfare measures are as accurate as the Harberger triangle procedure and the estimates of marginal costs themselves.[1] Three important assumptions are made in implementing the procedure: (1) The elasticity of substitution between each pair of truck types is assumed to be 5.0. (2) The only form of trucker adjustment that takes place is switching between truck types. (3) The magnitude of the shipments shifted to the lower-

ESAL truck types in each of the pairs considered is proportional to the number of vehicle mile tons currently provided by those truck types. (This last is an artifact of the constant elasticity of substitution.) The authors themselves do some sensitivity testing regarding the elasticity of substitution, and show that the overall results are not much affected over much of the relevant range. I comment further on the latter two assumptions below.

The second adjustment, that toward rail, is also handled via the Harberger triangle approach, and again depends on an assumed elasticity, namely the own-price elasticity of demand for shipments by truck. The authors provide some justification for their assumption that unity is the right value.

To get their overall welfare measure, the authors add the intra-trucking welfare estimates to the modal shift estimates, and the numbers that emerge from this exercise are striking. The authors calculate the overall welfare gain from imposition of the marginal-cost tax (making allowances for the fact that not all trucks operate at full load all of the time) would be on the order of $1.22 billion annually. Tax revenues would rise by about $10 billion, road wear would decline by $2.6 billion,[2] and producers' and consumers' surplus would decline by $11.7 billion. Moreover, the authors calculate that the current net subsidy to the five truck types from which their model shifts is about $3,200 per vehicle per year. Imposition of the marginal-cost tax would eliminate the subsidy. Further, there are good reasons to believe that the positive effects of imposing the new tax are understated. The truck types considered do not exhaust the fleet (although the authors do not tell us what fraction of vehicle ton miles they account for), and the estimate of maintenance and repair costs per ESAL mile that the authors use in the paper is by their own admission a conservative one. Finally, there are lots of other types of adjustment that might take place, both in the short and long run,[3] that would tend to attenuate the politically difficult transfers implicit in the new taxing system, and that would also increase the net benefits.

Other Adjustments

Not knowing anything about the trucking industry, my first response to reading the Small and Winston paper was to turn to that tried and true method of empirical research, introspection. Suppose I were a trucker, cheerfully running an SU2 (two-axle van) rated at 55 kips (55,000 pounds), and were suddenly faced with a tax of $1.32 per mile. Would I, as Small and Winston argue implicitly, be limited to switching to an SU3 (24 cents tax per mile for the same load), switching to rail, or eating the tax increase, or might there be other things I could do? A number of other things came into mind. (1) I would downrate my truck to something less than 55 kips. This looks especially promising in light of the fact that the tax rate is strictly convex in kips, while revenues are at worst linear, and may be concave under some circumstances. (2) I could switch to some truck other than an SU3, reducing my taxes still further. (3) I could, using my knowledge of the industry, respond optimally to the changed circumstances.

Downrating the vehicle weight and adhering to the downrating will be profitable if the marginal revenue lost from reduced loads is less than the marginal tax reduction, both evaluated at the initial registered rate. It seems plausible that this condition would hold given the extremely steep marginal tax function that obtains for high ESAL values under the Small-Winston scheme, but I do not know enough about trucking rates (nor have any of the experts I have talked to been willing to give simple enough answers to my questions) for me to be sure.

What is important here is to recognize that there are many types of adjustment that neither Small and Winston nor I consider. In order to model them properly, and derive detailed estimates of welfare gains and losses and the distributional consequences of imposing marginal cost taxes, a detailed model of trucker behavior would be required, with the full range of long-, medium-, and short-term technologies available well specified. Small and Winston recognize this in their paper, and quite properly leave the job to someone else. However, it is important to recognize the true ratio of welfare gains to changes in producers' and consumers' surplus could be very different from the ones shown here in the paper, and that the policy implications of the paper depend crucially on this ratio.

In a way, the key policy implication in the paper derives directly from the large misallocation of resources that is implicit in table 5.1. To the extent that much truck traffic imposes costs that are widely at variance with what is paid by the truckers, then there is clearly great scope for efficiency gains through the imposition of marginal-cost taxation. Small and Winston have made an estimate of these gains under a particular set of assumptions about how the industry would respond. Allowing a broader range of responses (assuming that fraud is not one of them—this is to be considered below) can only increase the scope for welfare gains and for the ratio of welfare gains to transfers.

Politics and Policy

Political Acceptability

In arguing for the political feasibility of their scheme, Small and Winston note that the tax should not be viewed as an increased source of revenue from the trucking industry, but rather as a removal of a large subsidy to that industry. Additionally, they note that to the extent that the industry is competitive, the burden of the tax will be borne by the public at large (the end users of shipping services). Since the public at large is a net winner in welfare terms, it is implied that if the proposal is marketed honestly, it should be politically feasible for it to be adopted. I have some fear that the "should" in the last sentence may have more normative than positive content. It is a commonplace of political life that well-organized interest groups can set much of the political agenda in domains that affect their direct interests, and in this case I would imagine that truckers and shippers would have considerable influence. Moreover, the industry will be able to correctly tell the general public that a consequence of the tax will be higher prices for goods. The fact that lower road use taxes imposed on individuals (or at least better roads enjoyed by individuals) will also be a consequence may be harder to sell. To the extent that the case can be made that the ratio of transfer elements to net social benefits is small, however, it should be easier to implement the policy. Here the existence of adjustments other than those considered by Small and Winston becomes more than an academic issue. Their paper establishes that the net benefits of the marginal cost tax warrant its adoption. Unfortunately, they also estimate a large increase in tax revenues, because the adjustments available to the industry are fairly expensive. If there are easier ways to adjust, the net benefits remain, but the direct costs perceived by truckers and shippers are smaller, and thus the political difficulty of implementing the policy may be reduced. In short, convincing economists that something is a good idea is hardly sufficient for its adoption, and it may well be worth the considerable research effort involved in finding out if this particular good idea places smaller direct burdens on the parties who will see themselves as most directly affected, and who will make their perception known in the political arena.

Interstate Competition

To this point, we have framed the issue as if we were considering a uniform national tax. In fact, the bulk of the relevant taxes are imposed by states, and only a few states currently have the apparatus necessary to impose a tax of the kind proposed. It is interesting to speculate on what might happen if (say) Kansas imposed the marginal cost tax and Nebraska did not.[4] Clearly, traffic would be diverted from Kansas to Nebraska, and Kansas would gain less revenue than it would under a uniform tax system but it would also have reduced wear and tear on its highways. Traffic that stayed in Kansas after the change would clearly do so only if there was considerable rent involved, and Kansas would be able to tax some of the rent. Traffic that was diverted to Nebraska would not pay taxes, but would not impose costs of the same magnitude. Without having worked out a model, it would seem that the states that imposed the tax would be better off than those that did not, and that the process of interstate competition in this dimension would tend to lead to everyone imposing the tax. (There is one potential interest group that might get in the way—truck-stop owners.)

Enforcement Problems

Successful imposition of the marginal-cost tax would require that truckers pay what will in some cases be large taxes based on their mileage and their registered gross vehicle weight. The incentives to dissemble regarding both of these variables would be considerable. Indeed, even under current laws, where much smaller taxes are imposed on vehicle weight, popular wisdom has it that there is a considerable amount of traffic above the rated weights, and that there is an effective CB network among truckers to assist each other in avoiding those weigh stations that happen to be open. I have no great insights about how to resolve the enforcement problem, but I suspect that successful monitoring of truck traffic is not a trivial exercise, and that before the Small-Winston proposal can be considered as a viable policy option, a careful analysis of the enforcement mechanisms available, and their costs, must be undertaken.

Accounting for Different Costs in Different Places

The tax schedule proposed by Small and Winston is based on estimates of the costs imposed on rural highways. The estimated cost for urban roads is over seven times higher. While it seems unlikely that there is much opportunity for urban/rural substitution in transportation, there is certainly an opportunity for mode shifting, and there is no compelling reason why urban residents should be transferring large sums of money to the trucking industry. Thus, the ideal form of the Small-Winston scheme would have much higher tax rates applied to urban miles driven. This would clearly complicate administration of the scheme, but an estimate of the potential gains would be worth undertaking in order to find out if they would be worth the costs.

Conclusion

One of the most popular papers to assign in urban economics courses is William Vickrey's old analysis of marginal congestion cost pricing of urban roadways. The idea behind that paper is similar to the idea behind this one, and the paper's conclusions are beloved by economists and opaque to the policy community. The Small-Winston tax has a number of advantages relative to the Vickrey proposal. Politically, it can be attached to the infrastructure issue, which is a fairly hot topic, and the tax provides the hope of real resources to deal with that problem. Moreover, while the problems of administration and enforcement are by no means trivial, and need much more study, at least they do not seem to require adoption of an as yet untried technology. In any event, Small and Winston have made a convincing case for their proposal. We can hope that their paper is the beginning of a policy, rather than something that we will merely enjoy assigning to our classes in the years to come.

Notes

1. Small and Winston's discussion leaves this issue open to some doubt. Before a tax scheme of the kind proposed here were implemented, one would have to do very careful engineering studies of the marginal cost imposed by truck traffic.
2. Another quibble: throughout the paper, the authors call what is plainly road wear "repair and maintenance expenditures" and term the difference between new revenue raised and this value "budget surplus." This terminology implies that current maintenance and repair policy exactly maintains the current capacity of the highway system. Such an assumption seems implausible at best.
3. In the long run we should see a change in the mix of vehicles manufactured, and perhaps in road construction and maintenance policy to adjust to the new load mix. In the shorter run, truckers will make adjustments other than the vehicle-type shifts considered in the paper, easing their transition and reducing the lost shippers' and truckers' surplus.
4. I am grateful to Roger Gordon for suggesting that I think about this.