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Economic Analysis of Transportation Pricing, Tax and Investment Policies

DALE O. STAHL II

In response to the ad hoc nature of current transportation user charges and cost allocations, a rigorous analytical framework is presented based on economic welfare theory. A multimodal transportation system model that has explicit price and tax, investment maintenance, service quality, and externality variables is formulated; the optimal decision rules of equating marginal social benefits and marginal social costs are derived and given operational interpretations. Optimal and administratively feasible aggregate prices by user class and mode are derived in terms of aggregate marginal social costs that are not impractical to estimate. An optimal cost allocation is defined as marginal social-cost pricing followed by general taxation of consumer goods (excluding transportation) to cover any deficit.

Considerable confusion exists about economic principles as they are applied to transportation policy analysis. Although a correct operational definition of marginal cost is hard to find in the literature, it is widely assumed that the marginal-cost pricing principle is not relevant to transportation facilities for a number of alleged reasons, e.g., there is no feasible way to (a) cover full costs or (b) implement ideal marginal cost pricing. The principles that find their way to practitioners suggest ad hoc rules of thumb rather than deduced results from a unified theory.

The purpose of this paper is to present an integrated economic transportation model that will clear up some of the confusion and serve as a basis for policy analysis. The model is set in the framework of welfare economics, and the results can be interpreted as the well-known principle of equating marginal social benefits with marginal social costs. Moreover, these concepts and principles are brought in touch with reality by the detailed structure of the model. All relevant investment and maintenance variables of a multimodal transportation system are incorporated in the model; service quality attributes and externalities are made explicit.

The results reported here are a summary of several aspects of an extensive working paper (1). Optimal decision rules for investments, maintenance programs, and prices are derived and interpreted. "Second-best" issues are discussed. An original contribution is the derivation of optimal and administratively feasible aggregate prices by user class and mode. Finally, an optimal cost allocation is defined as marginal-social-cost pricing followed by optimal taxation of consumer goods (which excludes transportation) to cover any deficit.

INTEGRATED MODEL

The task of this section is to model the transportation system and its effects in a manner that facilitates the application of economic welfare theory to transportation policy issues. The level of detail is sufficient for addressing the issues of investment and maintenance policy, service quality and externalities, pricing and cost allocation, and intermodal effects.

The welfare optimization problem can be stated in operations research terms as maximizing a social objective function with respect to control variables subject to constraints given by the system. The direct arguments of the objective function are called the impact variables. The role of the system model is to relate the impact variables to the control variables.

Description of the Model Variables and Relationships

Social Objective Function

The objective is to invest, maintain, and price in order to obtain the highest level of net social welfare possible. The problem can be formalized by letting W(U) be a Bergson-Samuelson type of social welfare function, where U is a vector of individual utilities. As is often done, and to keep this exposition simple, utility indices in terms of dollar values will be assumed, and the social welfare function will be the unweighted sum

$$W(U) = \sum_{i=1}^{N} U_i \tag{1}$$

It should be noted that, although the principles developed in this paper are generalizable to other social welfare functions, the functional form of specific results are critically dependent on this distribution-neutral social welfare function.

The benefits to businesses that use the transportation system must also be included. If a competitive private sector and the distribution-neutral social welfare function are assumed, it is sufficient to assess these benefits at the stage of the businesses as users rather than attempt to trace the incidence through to customers and stockholders. To keep the notation simple, businesses will be included in the set of N individuals (or agents) over which utilities are summed, with the understanding that (for a business) U_i denotes initial benefits as profits.

Two major complicating features of an economic analysis of the transportation system are that the transportation "good" has multiple characteristics and that consumption of transportation services generates numerous externalities. Lancaster's formulation of consumer theory (2) is well suited to handle the multiple-characteristic aspects, and it can easily accommodate the incorporation of externalities. Suppose individual utility (and business profits) can be represented as an explicit function of two sets of variables: U(q,E). Let q be a vector of trip and service-quality characteristics such as trip destination benefits, travel time, operating expenses, safety, comfort, and aesthetics. Let E be a matrix of nonuser externalities such as pollution and noise, with one column for each link in the transportation network. Since these public-good-type externalities depend more on the total traffic level than on any one individual's travel, it is reasonable to view such externalities as impinging on the individual in his or her capacity as a nonuser. In contrast, the trip and service-quality characteristics affect the individual only when the individual makes a trip. This representation admits the possibility that total travel level affects the service-quality level; the potential interuser externalities will be made explicit later.

In the manner of Lancaster, suppose there is a simple linear relation between trips taken and the amount of trip and service-quality characteristics derived from travel. In particular, suppose that $x_{j\ell}$ is the amount of trip and service quality (j) derived from one trip mile on link (ℓ) of the transportation network. (Throughout this paper, a "link of the transportation system" will denote a link of the transportation network, a structure, or a terminal.) Then $q = Zx'$, where x is the row vector of trip miles by link and Z is the corresponding matrix $[z_{j\ell}]$. Thus, individual utility can be written as $U_i(Zx_i', E)$, where the subscripts denote individual (i).

From the representation of the social objective function, it is clear that the pertinent impact variables are Z and E. Further, from the point of view of the individual, x_i is a control variable. Let X be the matrix of trips by all individuals--one row for each individual.

The typical welfare optimization problem is to maximize the social welfare function subject to a number of constraints, among which is the technology constraint--the mathematical description of all technologically feasible combinations of all goods. In a market economy, a convenient way to represent this technology constraint is to require that the total cost of production of all goods equal a fixed nominal gross national product (GNP): $TC(X) = \bar{M}$, where $\bar{M}$ is the fixed nominal GNP and TC( ) is the total (private and public) cost of production of all goods in the economy. TC(X) should be understood to be the total cost of producing transportation services plus the total cost (net of transportation) of producing all final (or consumer) goods, where the final goods are understood to be implicit in this notation. For convenience of exposition, the total cost function is divided into public transportation costs, which are denoted by C( ), and all other public and private costs, which are denoted by c( ); hence TC( ) = C( ) + c( ). If public costs are expressed as gross costs before tax and fee receipts, then private costs clearly should not include taxes and fees.

For the social welfare function used in this paper, in which the social value of $1.00 accruing to anybody is $1.00, maximizing this social welfare function subject to the technology constraint is equivalent to maximizing

$$W(U) + [\bar{M} - TC(X)] \tag{2}$$

Time is implicit in the expression of the social objective function. It should be understood that U_i represents the discounted present value of the stream of dollar-value utilities and that the cost functions represent the discounted present value of the stream of costs, both computed at the same social discount rate.

Control Variables

A control variable is some quantity that the transportation agency has direct control over, e.g., resurfacing intervals and thickness, but not bumpiness. Although there may be a deterministic relation between transportation agency activities and the bumpiness of the road, it is best to define bumpiness as an intermediate state variable and to specify the engineering relationship between control variables proper and the intermediate state variables.

To avoid undue complications of notation, one variable label (s) will be used for two groups of control variables. The first group consists of changes that are determined by investment decisions (such as construction, widening, and resurfacing) and are fixed in the short run. For example, on a given road segment of the highway network, these would include changes in length in miles, number of lanes, width, pavement type and base, shoulder type, signs and signals, geometric design features, scenery, and speed limit. Variables for structures and terminals can also be included. The second group consists of variables that can be adjusted on a day-to-day basis--essentially maintenance activities. These two groups of control variables will be represented by the vector s_ℓ, which will be referred to as the transportation program strategy for a specific link (ℓ). Let S be the matrix of transportation program strategies--one column for each link of the transportation system. Then, the entire transportation construction, rehabilitation, and maintenance work program over time can be represented by S(t).

Intermediate State Variables and Relationships

Let y_ℓ be a vector of aggregate load on a link (ℓ)--for highways, specifically, the number of equivalent vehicles per hour and the equivalent 18-kip axle loads per hour. Let Y(t) be the matrix of aggregate load flows on the transportation system as a function of time.

Assume a simple linear relationship between trip demand by individuals and aggregate load:

$$y_\ell = Bx_\ell \tag{3a}$$

$$Y(t) = BX(t) \tag{3b}$$

where B is a matrix whose elements are equal to the contribution to aggregate load of one trip by a specific individual.

Let r_ℓ be a vector of pertinent serviceability attributes on a link (ℓ). There are two groups of pertinent serviceability variables that correspond to the two groups of control variables. The first group consists of the state variables that result from cumulative past investment decisions and are fixed in the short run; for highways, state variables include length of miles, number of lanes, width, pavement type and base, shoulder type, signs and signals, geometric design features, and scenery. The second group includes state variables affected by maintenance activities and traffic; for highways, state variables include bumpiness, skid resistance, hazards, condition of signs and signals, litter, and condition of rest areas. The American Association of State Highway Officials (AASHO) present serviceability index is a composite of some of these serviceability variables. Let R(t) be the matrix extension of r_ℓ for all links as a function of time.

The state of the system depends on the history of transportation activities and aggregate load flows on the system. One way to represent this relationship is by the differential equation:

$$\dot{R}(t) = F[Y(t), S(t), R(t), t] \tag{4}$$

where the dot over the variable denotes the derivative with respect to t and where F( ) is a general vector function that specifies the rate of change in serviceability as a function of instantaneous load, program strategy, serviceability, and time; F( ) can accommodate any interaction among the variables, including weather (through time).

To complete the model, a relationship is needed between the serviceability variables and the impact variables that has perhaps some dependency on the aggregate load. Specifically, assume that such relationships can be represented in the following forms:

$$Z = G(R,Y) \tag{5a}$$

$$E = H(R,Y) \tag{5b}$$

where, as usual, the capital letters denote the matrix extensions of the vectors to the entire transportation system and time is implicit. An approach similar to that of the Manual on User Benefit Analysis (3) can be employed to determine these relationships.

In summary, the control variables of the model are travel (X), which determines aggregate load (Y), and the transportation-program strategy (S). The serviceability of the system is related to the control variables by a dynamic equation. Serviceability and aggregate load determine the impact variables, which directly affect individual utilities.

Formal Statement of the Optimization Problem and First-Order Conditions for Optimality

A two-state optimization procedure is chosen because it handles the dynamics in a simple manner and is easier to interpret. The first stage is to solve the following public-cost-minimization problem, given a desired serviceability of the system, R(t), and actual loading, Y(t).

1. Minimize C(S) with respect to S(t) subject to $\dot{R} = F(Y,S,R,t)$.

This stage of the optimization process contains most of the complications, in that it contains the dynamics of the serviceability of the system. One could take the Hamiltonian-Lagrangian approach to solving this problem, but a heuristic approach provides more insight. Given R(t) and Y(t), there may be only a few or only one compatible strategy, S(t), i.e., a solution to the constraint equation. Once a set of compatible strategies has been found, it is a simple matter to pick the least costly strategy. Let S*(R,Y) be the least costly strategy compatible with Y(t) and R(t). Note that for some (R,Y) there may be no compatible strategy, in which case the cost is set equal to $+\infty$. The result of stage one is the minimum cost function

$$\tilde{C}(R,Y) \equiv C[S^*(R,Y)] \tag{6}$$

2. The second stage problem is to maximize

$\sum_{i=1}^{N} U_i(Zx_i', E) - \tilde{C}(R,BX) - c(X) + \bar{M}$ with respect to

X,R subject to Z = G(R,BX) and E = H(R,BX), recalling that Y = BX.

Assuming that the set of feasible control variables (that satisfy the constraints) is compact and convex and that the net social objective function is quasi-concave, the solution to this stage amounts to equating marginal benefits to marginal costs. The solution (R*,X*) can be substituted into the solution of the first stage to obtain the optimal transportation-program strategy S*(R*,BX*). The choice of R* can be viewed as the choice of a set of serviceability standards by which the transportation agency can evaluate its performance and needs. A subset of the standards will provide guidelines for maintenance activities; the other standards will provide guidelines for the planning of new construction, improvements, and rehabilitation.

For the concepts of total cost and marginal costs of a good to be well defined, the good must be specified in terms of relevant characteristics, and these characteristics must remain fixed. This is precisely what $\tilde{C}(R,Y)$ does. Given R and Y, all the service-quality characteristics are determined, so $\tilde{C}(R,Y)$ can be interpreted as the minimum public cost of providing the transportation good defined by

(R,Y) or, equivalently, as the economic cost of providing the good.

For the purpose of writing the first-order conditions for optimality, it is convenient to introduce a number of simplifying assumptions and definitions. As an intermediate step, let $x_\ell = \sum_i x_{i\ell}$ be the aggregate travel on link (ℓ) and let $a_{h\ell} = (1/x_\ell)(\sum_i x_{i\ell}\partial U_i/\partial q_h)$ be the weighted social value of quality characteristic h, and assume that it is constant. In other words, assume a constant weighted average value of travel time, etc. Define a serviceability value index to be $V_\ell \equiv \sum_h a_{h\ell} z_{h\ell}$, which has the flavor of the imputed social value of a link per trip. In a similar fashion, let $w_{h\ell} = \sum_i \partial U_i/\partial E_{h\ell}$ be the aggregate social value of nonuser externality attribute h, assume it to be constant, and let $E_\ell \equiv \sum_h w_{h\ell}E_{h\ell}$ be an index of nonuser externalities of a link.

By using these definitions, the first-order conditions can be written as

$$x_\ell(\partial V_\ell/\partial r_{k\ell}) + (\partial E_\ell/\partial r_{k\ell}) = \partial\hat{C}(R,Y)/\partial r_{k\ell} \tag{7}$$

for all (k,ℓ), and

$$\sum_h(\partial U_{i'}/\partial q_h)z_{h\ell} = [\partial c(X)/\partial x_{i'\ell}] + \sum_j\{[\partial\hat{C}(R,Y)/\partial y_{j\ell}] - x_\ell(\partial V_\ell/\partial y_{j\ell}) - (\partial E_\ell/\partial y_{j\ell})\}b_{ji'} \tag{8}$$

for all (i',ℓ).

The left-hand side of Equation 7 is the marginal social benefit (including externalities) from a change in the serviceability of the system, and the right-hand side is the marginal public cost of such a change. The left-hand side of Equation 8 is the marginal private benefit of a trip, and the right-hand side is the marginal social cost (including externalities) of a trip by individual (i') on link (ℓ).

OPTIMAL DECISION RULES

The framework developed in the previous section can be used as the basis for deriving optimal decision rules. First, the conditions for the optimal transportation-program strategy and serviceability standards are interpreted and discussed. Next, optimal ideal and aggregate pricing rules are derived. In addition, second-best issues are briefly discussed.

Optimal Strategies and Serviceability Standards

The optimal serviceability standards are determined by the condition in Equation 7, which is in the familiar form of the Samuelsonian conditions for optimal production of a public good. The marginal social benefits (user and nonuser externalities) are summed over all individuals and equated to the marginal social costs, which is reasonable since serviceability has the character of a public good--all users of a particular link enjoy the same serviceability and all nonusers bear the same externalities. Marginal social benefits are equal to the sum of (a) the marginal effect of a particular serviceability attribute on the serviceability value index times the traffic volume and (b) the marginal effect of the particular serviceability attribute on total nonuser externalities. Marginal social costs are determined by first minimizing total costs (given hypothetical serviceability levels and aggregate loads) and then computing the marginal effect of a change in a particular serviceability attribute on the economic costs, given the same aggregate load. Given the optimal serviceability standards, the optimum program strategy is the minimum cost strategy given by the solution to the stage-one problem: S*(R,Y). The optimality conditions are valid if and only if either the aggregate load is also optimal or the aggregate load is independent of the serviceability. Deviations from these conditions will be discussed under second-best issues.

In general, investment and maintenance strategies are not separable. Moreover, in general, it is not possible to arrive at the optimum system solution by seeking a link-by-link solution. In practice, however, it may be reasonable to assume that the network spillover effects are confined to a manageable subnetwork.

Optimal Pricing Rules

First, the ideal optimal pricing rule is derived from the optimality conditions. Second, an aggregation assumption is made that leads to more feasible, but optimal, aggregate pricing rules. Finally, the issue of cost recovery from optimal pricing revenues is briefly addressed.

Ideal Optimal Pricing Rules

The condition in Equation 8 is the basis for ideal optimal pricing rules. Assume that the individual maximizes a utility function subject to a fixed-price budget constraint, where $p_{i'\ell}$ is the price that individual (i') must pay for a trip on link (ℓ). Then Equation 8 can be rewritten as

$$p_{i'\ell} = [\partial c(X)/\partial x_{i'\ell}] + \sum_j\{[\partial\hat{C}(R,Y)/\partial y_{j\ell}] - x_\ell(\partial V_\ell/\partial y_{j\ell}) - (\partial E_\ell/\partial y_{j\ell})\}b_{ji'} \tag{9}$$

for all (i',ℓ) [see Stahl (1) for a detailed derivation]. At this price, the individual would freely choose the amount of travel required by the social optimum.

The optimal pricing rule can be stated as a marginal-social-cost pricing rule. The first term on the right-hand side of Equation 9 is the private out-of-pocket cost of a trip, e.g., gasoline, oil, and fares. The second term is composed of three components. The first component is the marginal public cost of providing a fixed transportation serviceability level with respect to different traffic loads. The second and third components are the marginal externality costs of travel. The second term captures the effects of travel on the value of serviceability, such as travel time and accident rates; thus, this term includes the familiar congestion and safety externalities that users face. The third term is the marginal externality effect on nonusers; it includes such effects as pollution and noise. These three components are multiplied by the contribution of the individual (i') to aggregate loads.

Moreover, the optimal pricing rule can be stated as a short-run marginal-social-cost pricing rule in the sense that the serviceability characteristics (which it will be recalled include such items as the number of lanes) are held constant in Equation 9. One of the clearest arguments for short-run marginal cost pricing of highways was given by Walters (4). This short-run marginal-social-cost pricing rule is strictly valid if and only if either (a) the total transportation program strategy, all serviceability standards, and all other variables in the economy are optimal or (b) all suboptimal strategies, suboptimal serviceability standards, and other suboptimal variables in the economy are independent of travel demand. Deviations from this rule will be discussed further under second-best issues.

The expression for the optimal price given by Equation 9 is deceptively simple. Notwithstanding the practical difficulties of estimating the terms on the right-hand side, it should not be overlooked that the optimal price for an individual is a function of time and the particular link of the transportation system. For example, the optimal price on an urban road during rush hour may be quite high, whereas the optimal price on a rural road at 3:00 a.m. may be zero. Furthermore, the optimal prices are in units such as vehicle miles of travel and passages over structures, which suggests a different tax base than is currently used. The next topic is concerned with devising feasible prices and taxes.

Feasible Optimal Pricing Rules

Considering the infeasibility of the optimal pricing system derived above, it is imperative that a more feasible system be found that also has some optimality properties. The approach is to use prices explicitly as the control variables in lieu of the travel variables (X). Travel demand can be expressed as a function of prices, $x_{i\ell}(\underline{p})$, with all other variables implicit and perceived to be fixed. These demand functions can be substituted into the formal statement of the optimization problems. Since these results are an original contribution of this paper, the essentials of the derivation will be given.

In optimizing the stage-two problem with respect to transportation prices, the condition in Equation 8 is replaced by

$$\sum_{i'}\sum_{\ell'} p_{i'\ell'}(\partial x_{i'\ell'}/\partial p_{i\ell}) = \sum_{i'}\sum_{\ell'} MSC_{i'\ell'}(\partial x_{i'\ell'}/\partial p_{i\ell}) \tag{10}$$

for all (i,ℓ), where $MSC_{i'\ell'}$ is equal to the right-hand side of Equation 9, i.e., the marginal social costs of a trip by individual (i') on link (ℓ'). Let $\underline{x}$ be the vector of travel demands formed by stacking the columns of X, let $\underline{p}$ be the corresponding price vector and $\underline{MSC}$ the corresponding marginal-social-cost vector, and let H be the Hessian matrix of partial derivatives $\left[\dfrac{\partial x_{i'\ell'}}{\partial p_{i\ell}}\right]$ for all (i',ℓ') and (i,ℓ). Equation 10 can then be written compactly as $H\underline{p} = H\ \underline{MSC}$. The second-order conditions on individual utility maximization ensure that H is invertible, so the optimum prices can be solved for explicitly as $\underline{p} = \underline{MSC}$, which is identical to the result of Equation 9, as should have been expected.

Unfortunately, this "ideal" price system is impractical. More-useful results are obtainable by imposing administrative feasibility constraints on the price system, such as a single aggregate price for a user class and mode.

Let v denote a particular user class (or vehicle class), and let m denote a particular mode (or subsystem of links). For each user in class v ($i \in v$) that takes a trip via a link of mode m ($\ell \in m$), we want a common price, p_{vm}, i.e., $p_{i\ell} = p_{vm}$ for all $i \in v$ and $\ell \in m$. In addition, let $x_{vm} = \sum_{i\in v}\sum_{\ell\in m} x_{i\ell}$ be the aggregate travel by user class (v) on mode (m), and let $\overline{MCS}_{vm} = \sum_{i\in v}\sum_{\ell\in m} MSC_{i\ell}$ (#vm) be the average marginal social cost of a trip by user class (v) on mode (m), where (#vm) is an abbreviation for the number of individuals in user class (v) times the number of links of mode (m). By using these definitions, Equation 10 can be rewritten as

$$\sum_{v'}\sum_{m'} p_{v'm'}(\partial x_{v'm'}/\partial p_{vm}) = \sum_{i}\sum_{\ell} MSC_{i\ell}(\partial x_{i\ell}/\partial p_{vm})$$
$$= \sum_{v'}\sum_{m'} \overline{MSC}_{v'm'}(\partial x_{v'm'}/\partial p_{vm}) \tag{11}$$

where the summations over v' and m' mean all user classes and all modes. The second equality holds under the reasonable assumption that the deviations of $MSC_{i\ell}$ and $\partial x_{i\ell}/\partial p_{vm}$ from their means are independent across all individuals and all links (ℓ). In the manner used for the ideal price system, aggregate vector notation can be introduced, and the aggregate Hessian matrix can be inverted to derive the optimal aggregate marginal-social-cost pricing rule:

$$p_{vm} = \overline{MSC}_{vm} \tag{12}$$

for all user classes (v) and modes (m). [Aggregation by peak and off-peak periods can be handled in a similar way (1).]

Cost Recovery

Suppose optimal pricing is implemented. Is there any hope that full costs can be recovered? Under the assumption that the private cost function [c(X)] is homogeneous of degree one (i.e., constant returns to scale), full private costs would be recovered by marginal cost pricing. Thus, the issue is whether full public costs can be recovered. At the global optimum (R*,X*), sufficient conditions for full cost recovery are that $\hat{C}(R,Y)$ be homogeneous of degree one, that V(R,Y) be homogeneous of degree zero, and that E(R,Y) be homogeneous of degree zero. Under these conditions, the short-run marginal-cost pricing rule would generate a full cost allocation without worry about imputing any common capital costs to users.

However, there is evidence that suggests these homogeneity conditions are not likely to be satisfied. For example, there is evidence of substantial increasing returns to scale in highway pavement thickness. [As an example of how to estimate a component of marginal social costs, the appendix in Stahl (1) estimates the marginal pavement cost of highways by axle-weight class. It is concluded that the component of marginal cost pricing due to pavement wear is not likely to recover more than 10 percent of the cost of pavement rehabilitation.] Also, there appear to be increasing returns to scale in air pollution that are not offset by design considerations. In general, if the homogeneity conditions do not hold, then marginal cost pricing will not recover full costs. With the increasing returns to scale suggested, there will be a deficit. (This result applies equally to the ideal optimal prices and to the optimal aggregate prices.)

Second-Best Issues

The implications of second-best considerations on optimal decision rules have been addressed in detail by Stahl (1); space permits only a brief summary here. The deviation of second-best rules from first-best rules depends on the suboptimality of the investment and pricing rules actually used by the transportation agency. Sound policy advice consists of advocating both optimal investment rules and optimal pricing. If the transportation agency makes a sincere effort to design its program optimally, then even if the existing system is suboptimal and even if the agency makes (uncorrelated) mistakes, the optimal rules are still the marginal-social-cost rules given by Equations 7-9 and 12.

On the other hand, if the transportation agency has a tendency to persist, for example, in overbuilding the highway system and underbuilding the mass transit system, then the optimal prices are higher for highways and lower for transit than the short-run marginal social costs. As another example, if urban roads are consistently underpriced and mass transit overpriced with respect to the marginal social costs, then, based on actual travel demand, urban roads should be underbuilt and transit should be overbuilt to compensate for the suboptimal prices.

A more recent second-best issue concerns optimal deviations from marginal cost pricing to cover nonallocable costs. The issue arises from the realization that the marginal-cost pricing rules generally require lump-sum taxes to cover deficits and that in reality there exists no such thing as a lump-sum tax (i.e., a tax that does not affect the relative prices of goods). The problem of devising a system of taxes on commodities that covers the deficit and causes the least loss in social welfare has been recently addressed in the economics literature; for an excellent survey, see Sandmo (5). A widely popularized result is the "inverse elasticity rule"; this rule states that, if all cross-price elasticities are zero, then the optimal deviation from marginal cost pricing is proportional to the inverse of the own-price elasticity for each commodity. This result has been loosely applied to the problem of highway cost allocation (6). However, the application of this rule to transportation is invalid for the following reason.

A fundamental result of the theory of optimal taxation is that production efficiency is always desirable. Production efficiency requires that all producers face the true marginal social costs of all inputs; therefore, intermediate goods should not be taxed. Optimality calls for taxes on final goods or primary factors, not both, and not on intermediate goods. For the most part, transportation is an intermediate good. Certainly, all business uses of transportation qualify as intermediate goods, and all work commutes should also be considered intermediate goods. Whether to count shopping trips and recreation-destination trips as intermediate or final is debatable. Perhaps only the classic Sunday drive is unambiguously a final good. Thus, it appears that all but a small and perhaps insignificant portion of travel would be exempt from optimal taxes. Thus, a feasible optimal tax system to cover the deficit of the transportation agency would call for no user taxes. (It is necessary to emphasize that "tax" here means any additional payment above the marginal social cost, not to be confused with the optimal price charged by the government.)

Notwithstanding these remarks, if the government should decide on a user-only tax scheme for transportation, the best scheme (in terms of least welfare loss) could be determined by methods analogous to those used in optimal taxation theory. Optimal taxation of intermediate goods is an unsolved problem because of the complex ways such a tax works through the economy and affects final-good prices. Research on this problem is needed and would have important policy implications.

CONCLUSIONS

The integrated economic transportation model is well suited for considering investment, maintenance, pricing, and tax policies. (Cost allocation will also be discussed.) Optimal decision rules were derived in terms of the marginal social cost of travel. Marginal social costs include the marginal private costs, the marginal public costs defined to be the "economic" costs of providing a given quality of service, and the marginal externality costs, such as congestion and pollution.

To operationalize the optimal prices, the marginal social cost can be broken down into the marginal private cost (e.g., gasoline and oil) and the marginal public cost (government agencies and externalities). It is reasonable to assume constant returns to scale in the private sector, so full private costs will be recovered by marginal-private-cost pricing. The government prices can be set equal to the appropriately defined aggregate marginal public and externality costs. The units of the prices could be chosen to be, for example, vehicle miles by vehicle weight class. Prices based on these units could be assessed as part of the annual registration process. The practical issue of how to cover any deficit will be discussed next.

The common notion of a cost allocation is probably best described by a private-sector accountant's spread sheet in which several products are listed across the top and the customers are listed down the left-hand side. The costs of production are allocated to each customer so that the sum of each column is equal to the total cost of production for each product. The sum of each row is equal to the total charges for each customer. The spread sheet balances when the sum of all the columns (costs) equals the sum of all the rows (charges); then, one has a full cost allocation. In a competitive economy, a full cost allocation can be obtained by simply charging each customer the market price for each product, because price is equal to marginal cost, which is also equal to average cost.

Cost allocation is considerably more complex for public-sector activities because they usually involve public good aspects, externalities, and increasing returns to scale. In the presence of these complications, allocation by price is not likely to give a full cost allocation, and one must devise ways to apportion the deficit. The lack of a solid theoretical basis for a cost allocation underlies the criticisms of previous highway cost allocation (7,8).

The major intention behind a cost-allocation study is to provide information relevant to the formation of price and tax policy. But this objective can be met by the direct approach of determining the optimal price and tax policy. Then if one wants the information presented in a cost-allocation format, it can easily be done because any given price and tax policy implies a de facto cost allocation.

The optimal cost allocation is defined as the de facto cost allocation that corresponds to the optimal price and tax policy. The optimal cost allocation can be determined in two steps. First, allocate by pricing at marginal social cost and calculate the revenues and any deficit. Second, apportion the deficit by the principles of optimal taxation.

With a bit of imagination and study, it should be possible to devise an administratively feasible approximation to the optimal price and tax policy and cost allocation that would be superior to the ad hoc methods currently employed. Since this optimal tax system would exempt transportation as an intermediate good, the deficit would in essence be allocated among agents in their role as nonusers. This is really the only valid argument for nonuser taxes to help finance transportation. It arises not from arguing unsoundly that nonusers should help pay because they benefit from transportation but, rather, from arguing that the deficit should be allocated in such a way as not to distort the efficient use of productive resources. A critical review of the incremental-cost method, the benefit principle, and the newest congressionally mandated highway-cost-allocation study is given in Stahl (1). Before the principles advocated in this paper could be implemented, considerably more research is required to estimate properly defined marginal social costs.

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