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PRICE DISTORTIONS, FINANCING CONSTRAINTS AND SECOND-BEST INVESTMENT RULES IN THE TRANSPORTATION INDUSTRIES*

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Abstract

This paper analyzes the second-best pricing and investment rules to be followed in the transportation industries in the presence of intermodal competition, exogenous price distortions, and financing constraints, using both theoretical and simulation analysis. It shows that price distortions and financing constraints in one mode will not only affect the investment rules in that mode, but will also affect the pricing rules and investment decisions in all other modes. While the theoretical discussion indicates that the second-best pricing and investment rules are quite complex, the simulation analysis indicates that the benefit function is relatively flat, suggesting that the costs of using simpler first-best rules may be relatively small.

1. Introduction and Overview

The conventional first-best rule for determining the optimal level of public investment in transportation infrastructure is the equalization of marginal investment benefits and cost. With this perspective, a number of studies have argued that there has been excessive investment in transportation infrastructure, e.g., Friedlaender (1965), Haveman (1972).

However, the first-best rules may be misleading as a specific guide for policy in a situation which is characterized by price distortions and institutional linkages of transportation investments to specific distortionary taxes. If these impediments to first-best optimization cannot be eliminated, the investment rules must be modified to take account of them.

There are significant deviations between prices and marginal costs in the rail and trucking industries,[1/] and the bulk of highway investment is financed by user charges via a trust fund. Further, beginning in October 1980, a modest user charge was imposed on barge operators and a waterway trust fund was established.

These distortions imply that the evaluation of transport investments should be made within a second-best framework. Thus in this paper we analyze the second-best structure of user charges and investment rules in the context of the distortions and constraints that exist in the intercity freight industries. Our analysis of the relationship between fuel taxes, output taxes, and investment rules shows that second-best policies generally require the use of both fuel and output taxes to finance transportation investments. Whether the second-best rules imply higher or lower investment levels than the first-best rules cannot be determined *a priori*, since this depends upon the nature of the existing distortions and the general equilibrium elasticities of output with respect to fuel taxes, output taxes and infrastructure investment.[2/]

This paper takes the following form. Section 2 analyzes the second-best structure of user charges and investment rules in a multi-modal, multi-commodity setting and shows that it is not generally possible to derive explicit analytic solutions for the quasi-optimal tax structure or investment rules. Section 3 provides a simulation analysis of the second-best user taxes and infrastructure levels in the railroad indsutry under a number of different price distortions and financing constraints and discusses the policy implications of the analysis.

2. Second-Best Taxes and Investment Rules

Since each mode typically carries a wide range of freight, there is a high degree of substitutability among the demands for the various modes. Thus price distortions or financing constraints in one mode will imply that offsetting distortions should be made in other modes, e.g., Brauetigam (1979). Consequently, a full analysis of second-best pricing and investment rules requires a multi-modal framework. However, while we keep the realism of a multi-modal, multi-commodity framework, we assume that each mode can be described by a single representative firm and hence ignore problems posed by interfirm competition. Since we are viewing the problem from a public policy perspective of social welfare maximization, this simplification seems acceptable.

In our model the optimization process takes place in two steps. Each mode is assumed to maximize profits, taking as exogenous the taxes and the level of infrastructure determined by the government. From this step, we determine the reduced-form relationships for output and factor demands as a function of the policy variables. In the second step the government determines the tax structure and level of infrastructure to maximize social welfare, given the relevant price distortions and/or financing constraints.[3/] For convenience we assume that price and output changes in the transportation sector do not cause price changes throughout the economy.

2.1. Market Equilibrium

We first obtain the reduced-form relationships for output of the transportation firm. Let X_{ij} be the amount of commodity j carried by mode i, where $j = 1,\ldots,n$ and $i = 1,\ldots,m$. We assume that there is substitutability among modes for the shipment of any given commodity, but no substitutability among commodities, which leads to these inverse demand functions:

$$q_{ij} = q_{ij}(X_{1j},\ldots,X_{mj}) \qquad \begin{array}{l} i = 1,\ldots,m \\ j = 1,\ldots,n \end{array} \tag{1}$$

where q_{ij} represents the price paid by the shipper. By definition, $q_{ij} \equiv p_{ij} + u_{ij}$ where p_{ij} represents the producer price and u_{ij} represents the user charge for commodity j on mode i. The net revenue obtained by mode i is therefore

$$R_i = \sum_j (q_{ij} - u_{ij})X_{ij} \qquad i = 1,\ldots,m \tag{2}$$

To highlight the problem of the optimal provision of infrastructure, we divide costs into variable costs and infrastructure costs. For each mode a conventional cost function relates total variable costs to the vector of outputs, the vector of input prices, and the level of infrastructure. Since all factor prices remain constant by assumption, we suppress this vector in the cost function. However, we introduce fuel taxes as an explicit argument in the cost function:

$$C_i = C_i(X_{i1},\ldots,X_{in};\ t_i,\ I_i) \qquad i = 1,\ldots,m \tag{3}$$

where C_i is the total variable cost, t_i is the fuel tax and I_i is the level of infrastructure for mode i, which is assumed to be provided by the government. The infrastructure costs are given by $w_i I_i$, where w_i is the unit cost of infrastructure.

Each transport mode is assumed to control its own level of output. Hence profit maximization yields the following first-order conditions.

$$\frac{\partial \pi_i}{\partial X_{ij}} = [q_{ij}(X_{1j},\ldots,X_{mj}) - u_{ij}] + X_{ij} \frac{\partial q_{ij}(X_{1j},\ldots,X_{mj})}{\partial X_{ij}} - \frac{\partial C_i(X_{i1},\ldots,X_{in};\, t_i,\, I_i)}{\partial X_{ij}} = 0 \qquad \begin{array}{l} i = 1,\ldots,m \\ j = 1,\ldots,n \end{array} \tag{4}$$

Thus in maximizing its own profits, each mode will treat the outputs of the other modes as given. However, a full solution of the problem requires the simultaneous solution of the above $m \times n$ first-order conditions. We assume this yields the following reduced-form equations for each of the outputs:

$$X_{ij} = X_{ij}(u_{ij},\, t_i,\, I_i) \qquad \begin{array}{l} i = 1,\ldots,m \\ j = 1,\ldots,n \end{array} \tag{5}$$

2.2. Welfare Maximization

The problem facing the government is to maximize the sum of consumers' surplus, producers' surplus and the government's surplus, subject to the existing price distortions and/or financing constraints, given the reduced-form behavior of output embodied in eq. (5). The benefits can be expressed equivalently as the sum of the willingness-to-pay in each mode and fuel tax revenues, less the total costs of production.[4/] Hence,

$$B = \sum_j \left[\int_0^{X_{1j}} q_{1j}(h_{1j}, 0, \ldots, 0)\, dh_{1j} + \cdot \cdot \cdot \cdot + \int_0^{X_{mj}} q_{mj}(X_{1j}, \ldots, X_{m-1,j}, \; h_{mj})\, dh_{mj} \right]$$

$$+ \sum_i t_i V_i(X_{i1}, \ldots, X_{in}, \; t_i, \; I_i)$$

$$- \sum_i C_i(X_{i1}, \ldots, X_{in}, \; t_i, \; I_i) - \sum_i w_i I_i \tag{6}$$

where X_{ij} is the equilibrium output and q_{ij} is the shipper price of commodity j in mode i; h_{ij} is a dummy of integration; t_i is the fuel tax and V_i is the conditional demand for fuel on mode i, derived from the cost function by Shepherd's Lemma; I_i is the infrastructure; and w_i is its unit cost for mode i.

Since the relationship between investment rules and price distortions can be seen most clearly in the case where no financing constraints exist, we first consider this case and then analyze the implications of the imposition of financing constraints.

The government has three policy instruments available: an output tax u_{ij} on each commodity in each mode, a fuel tax t_i on each mode,[5/] and the level of infrastructure I_i in each mode, giving a total of $m(n+2)$

control variables. Maximization of the net benefit function with respect to these control variables yields these first-order conditions:

$$\frac{\partial B}{\partial u_{rs}} = \sum_i \sum_j (q_{ij} - C_{ij}) \frac{\partial X_{ij}}{\partial u_{rs}} + \sum_i t_i \sum_j \frac{\partial V_i}{\partial X_{ij}} \cdot \frac{\partial X_{ij}}{\partial u_{rs}} = 0 \tag{7a}$$

$$r = 1,\ldots,m$$

$$s = 1,\ldots,n$$

$$\frac{\partial B}{\partial t_r} = \sum_i \sum_j (q_{ij} - C_{ij}) \frac{\partial X_{ij}}{\partial t_r} + \sum_i t_i (\sum_j \frac{\partial V_i}{\partial X_{ij}} \cdot \frac{\partial X_{ij}}{\partial t_r} + \frac{\partial V_i}{\partial t_r}) = 0 \tag{7b}$$

$$r = 1,\ldots,m$$

$$\frac{\partial B}{\partial I_r} = \sum_i \sum_j (q_{ij} - C_{ij}) \frac{\partial X_{ij}}{\partial I_r} + \sum_i t_i (\sum_j \frac{\partial V_i}{\partial X_{ij}} \cdot \frac{\partial X_{ij}}{\partial I_r} + \frac{\partial V}{\partial I_r}]$$

$$- \frac{\partial C_i}{\partial I_i} - w_i = 0 \qquad r = 1,\ldots,m \tag{7c}$$

where $C_{ij} \equiv \partial C_i/\partial X_{ij}$ represents the marginal cost of the ith mode with respect to the jth output, and the meaning of the other variables should be clear.

Note that $q_{ij} - C_{ij}$ is the deviation bewteen price and marginal cost. This can differ from zero if user taxes are imposed or if noncompetitive pricing elements exist. Hence $q_{ij} - C_{ij} \equiv u_{ij} + d_{ij}$ where u_{ij} represents the user charge and d_{ij} represents the noncompetitive price distortion. Making this substitution and rewriting eqs. (7a) — (7c) in matrix form yields the following:

$$[X_u](u + [V_X]t) = - [X_u]d \tag{8a}$$

$$[X_t](u + [V_X]t) + [V_t]t = - [X_t]d \tag{8b}$$

$$[X_I](u + [V_X]t) + [V_I]t + \delta = - [X_I]d \tag{8c}$$

where $[X_u]$ = $(m \times n) \times (m \times n)$ matrix of reduced form output derivatives with respect to the output taxes, i.e., $\partial X_{ij}/\partial u_{rs}$

u = $(m \times n) \times 1$ vector of output taxes

$[V_x]$ = $(m \times n) \times m$ matrix of derivatives of fuel usage with respect to output, i.e., $\partial V_i/\partial X_{ij}$

t = $m \times 1$ vector of fuel taxes

d = $(m \times n) \times 1$ vector of noncompetitive price distortions

$[X_t]$ = $m \times (m \times n)$ matrix of reduced form output derivatives with respect to the fuel tax, i.e., $\partial X_{ij}/\partial t_r$

$[V_t]$ = $(m \times m)$ diagonal matrix of derivatives of fuel usage with respect to the fuel tax, i.e., $\partial V_i/\partial t_i$

$[X_I]$ = $m \times (m \times n)$ matrix of reduced form output derivatives with respect to infrastructure, i.e., $\partial X_{ij}/\partial I_r$

$[V_I]$ = $(m \times m)$ diagonal matrix of derivatives of fuel usage with respect to infrastructure, i.e., $\partial V_i/\partial I_i$

δ = $m \times 1$ vector of deviation between marginal cost savings and infrastructure costs, i.e., $\delta_i \equiv -\partial C_i/\partial I_i - w$.

As long as X_u and V_t are not singular, in the absence of noncompetitive price distortions, i.e., $d \equiv 0$, eqs. (8a) and (8b) require $u = 0$ and $t = 0$. However, this implies that $\delta = 0$ in eq. (8c). Thus in the absence of noncompetitive price distortions and financing constraints, first-best pricing and investment rates should be followed: price equals marginal cost; no user taxes; and investments should be carried to the point where the marginal cost savings $(-\partial C_i/\partial I_i)$ equal the marginal cost of infrastructure (w_i). Conversely, eqs. (8a) — (8c) also indicate that in the presence of arbitrary price distortions $(d \neq 0)$, second-best welfare maximization will generally require nonzero user charges, fuel taxes, and deviations from first-best investment rules. However, inspection of eqs. (8a) — (8c) should also indicate that while explicit solutions of u, t and δ are possible (if d is treated as exogenous), without knowing the specific functional forms involved it is not possible to obtain much information concerning the sign or magnitude of the relevant policy instruments.

Because of the complexity of the multi-modal, multi-commodity framework, it is useful to consider a single-mode, single-output example. In this case, the government has three policy instruments at its disposal (u, t and I), and the above system of equations reduces to:

$$B_u = (q - C_X)X_u + t\,V_X X_u = 0 \tag{9a}$$

$$B_t = (q - C_X)X_t + t\,V_X X_t + t\,V_t = 0 \tag{9b}$$

$$B_I = (q - C_X)X_I + t\,V_X X_I + t\,V_I - C_I - w = 0 \tag{9c}$$

where the subscripts denote differentiation with respect to the relevant argument, and the variables are now scalars. Note that $q - C_X \equiv u + d$.

We first determine the effects of the government's policy instruments on the endogenous variables by implicitly differentiating the profit-maximizing conditions for the (single-output, single-mode) firm, eq. (4)[6/] to obtain:

$$X_u = -\Pi_{xu}/\Pi_{xx} = 1/\Pi_{xx} \qquad < 0 \qquad (10a)$$

$$X_t = -\Pi_{xt}/\Pi_{xx} = C_{xt}/\Pi_{xx} = C_{tx}/\Pi_{xx} = V_x X_u < 0 \qquad (10b)$$

$$X_I = -\Pi_{xI}/\Pi_{xx} = C_{xI}/\Pi_{XX} \qquad > 0 \qquad (10c)$$

Note that $\Pi_{xx} < 0$ from the second-order condition for profit maximization and $C_{tx} = V_x$ from Shepherd's Lemma. Finally, it seems reasonable to assume that $C_{XI} < 0$, that is, an increase in infrastructure reduces marginal costs.

We examine the relationship between price distortions, user charges, and investment rules in the case where an arbitrary fuel tax is employed, but there is no direct link between investment levels and user tax revenues. This situation is roughly comparable to the case of the waterways. Here the government's problem is to determine the optimal output taxes (if any) and the optimal investment levels.

Eq. (9a) indicates that with an arbitrary fuel tax the optimal output tax is equal to the negative of the exogenous price distortion plus the marginal change in fuel tax revenues with respect to output, that is

$$u = -(d + tV_X) \qquad (11a)$$

Thus the output tax should correct not only for any price distortions that may exist in the transport industries, but also for the revenue effect of the input price distortion. If u can be set in this quasi-optimal fashion, then eq. (9c) indicates that investment should be carried to the point where the difference between the marginal investment benefits and costs is equal to the negative of the marginal change in fuel tax revenues due to the change in investment, that is,

$$\delta = -tV_I \tag{11b}$$

Since we expect an increase in infrastructure to reduce the amount of the variable factors utilized, we assume $V_I < 0$. Thus eq. (11b) indicates that for an arbitrary fuel tax $t > 0$ and the quasi-optimal output tax policy in eq. (11a), we have $\delta > 0$, i.e., investment should be curtailed relative to its first-best levels. The distortion caused by a fuel tax and monopolistic pricing should be countered by an output subsidy; but this causes equilibrium output to increase. In response to this effect, the level of infrastructure should be curtailed.

However, if institutional constraints prevent a subsidy (as they apparently do), infrastructure should be expanded relative to its quasi-optimal levels. In this case, the divergence between marginal investment benefits and costs should equal the value of the disallowed subsidy less the loss in fuel tax revenues arising from the change in the infrastructure, that is,

$$\delta = -dX_I - t(V_X X_I + V_I) \ . \tag{12}$$

The first term of this expression is unambiguously negative, while the second term reflects two conflicting pressures: the revenue loss due to the substitution against fuel (tV_I), which we call the substitution effect;

and the revenue increase due to the increase in capacity and usage ($tV_X X_I$), which we call the output effect. If the output effect is greater than the substitution effect, the second term is also unambiguously negative. Hence $\delta < 0$, indicating that infrastructure should be expanded relative to its first-best levels. If, however, the substitution effect is greater than the output effect, the sign of the second term is ambiguous, indicating that $\delta \lesseqgtr 0$. Hence whether the infrastructure should be greater or less than its first-best levels cannot be determined a priori, and depends upon the relative magnitudes of the price distortions and the net revenue loss in fuel taxes arising from the investment. Nevertheless, a comparison of eq. (12) and eq. (11b) clearly indicates that in the absence of a quasi-optimal output subsidy, investment should be expanded relative to the levels that would exist with such a subsidy. This makes intuitive sense, since the increase in capacity operates in the same fashion as a subsidy.

Although the single-output, single-mode case sheds some intuition on the problem, it clearly represents a major oversimplification. Thus while it is possible to determine analytically the nature of the second-best pricing and investment rules in this simplified case, it is not generally possible to do so in the multi-modal, multi-commodity case.

2.3. Financing Constraints

The imposition of financing constraints raises two interesting questions: (1) What is the optimal structure of output and fuel taxes in the presence of a financing constraint; and (2) What are the appropriate investment rules to follow in the presence of a financing constraint?

The problem can be formally analyzed by adding this financing constraint:

$$\sum_{j=1}^{n} u_{ij}X_{ij} + t_iV_i = \gamma_i w_i I_i \qquad i = 1,\ldots,m \tag{13}$$

where γ_i represents a parameter reflecting the stringency of the financing constraint, $\gamma_i \leq 1$. If $\gamma_i = 1$, all of the investment must be financed by user charges, $\gamma_i = 0$ means no net tax collection, and $\gamma_i < 0$ permits net subsidies.

Thus the government's problem is to choose u_{ij}, t_i and I_i to maximize

$$L = B + \sum_i \lambda_i(\Sigma u_{ij}X_{ij} + t_iV_i - \gamma_i w_i I_i) \tag{14}$$

where B is the net benefit function defined in eq. (6) above. The resulting first-order conditions are:

$$\frac{\partial L}{\partial u_{rs}} = \frac{\partial B}{\partial u_{rs}} + \sum_i \lambda_i[\sum_j u_{ij}\frac{\partial X_{ij}}{\partial u_{rs}} + t_i \sum_j \frac{\partial V_{ij}}{\partial X_{ij}} \cdot \frac{\partial X_{ij}}{\partial u_{rs}} + X_{rs}] = 0$$

$$r = 1,\ldots,m \qquad s = 1,\ldots,n \tag{15a}$$

$$\frac{\partial L}{\partial t_r} = \frac{\partial B}{\partial t_r} + \sum_i \lambda_i[\sum_j u_{ij}\frac{\partial X_{ij}}{\partial t_r} + V_r + t_i(\sum_j \frac{\partial V_i}{\partial X_{ij}} \cdot \frac{\partial X_{ij}}{\partial t_r} + \frac{\partial V_i}{\partial t_r})] = 0 \tag{15b}$$

$$r = 1,\ldots,m$$

$$\frac{\partial L}{\partial I_r} = \frac{\partial B}{\partial I_r} + \sum_i \lambda_i[\sum_i u_{ij}\frac{\partial X_{ij}}{\partial I_r} + t_i(\sum_j \frac{\partial V_i}{\partial X_{ij}} \cdot \frac{\partial X_{ij}}{\partial I_r} + \frac{\partial V_i}{\partial I_r}) - \gamma_r w_r] = 0 \tag{15c}$$

$$\frac{\partial L}{\partial \lambda_i} = \sum_j u_{ij}X_{ij} + t_iV_i - \gamma_i w_i I_i = 0 \tag{15d}$$

where the variables have their previous meanings.

A solution to this system can be characterized by using eq. (15b) to solve for the λ_i and substituting the resulting expressions into eqs. (15a) and (15c). Eqs. (15a) and (15d) then form m(n+1) equations to solve for the (m × n) output taxes (u_{ij}) and the m fuel taxes (t_i). These can then be substituted into eq. (15c) to solve for the second-best investment rules (δ_i) or the second-best levels of infrastucture (I_i). However, while the system is determined, it is clear that little intuition concerning the signs or the magnitudes of these second-best taxes or investment levels can be obtained from this analysis.

Again, a highly simplified single-mode, single-output example is useful in focusing on some of the issues involved. In this case the first-order conditions are:

$$R_X X_u + \lambda R_u + d\,X_u = 0 \tag{16a}$$

$$R_X X_t + tV_t + \lambda R_t + d\,X_t = 0 \tag{16b}$$

$$R_I + \delta + \lambda(R_I - \gamma w) + d\,X_I = 0 \tag{16c}$$

$$uX + tV - \gamma w I = 0 \tag{16d}$$

where $R \equiv uX(u,t,I) + tV[X(u,t,I),t,I]$ and the subscripts denote differentiation with respect to the appropriate variable. To characterize the quasi-otpimal user taxes we first solve eq. (16a) for the Lagrangian multiplier λ and substitute this into eq. (16b). We then use eqs. (16b) and (16d) to obtain these expressions for u and t:

$$t = -(1 - E_{VX})VX_u(\gamma wI + dX)/D \tag{17a}$$

$$u = \{\gamma wI[VX_T(1 - E_{VX}) - XV_t] + dX_u[V^2(1 - E_{VX}) - \gamma wIV_t]\}/D \tag{17b}$$

where $$D \equiv -[V^2X_u(1 - E_{VX})^2 + X^2V_t] + dXX_u \tag{17c}$$

X_u is the change in equilibrium output with respect to an output tax and was shown to be negative in eq. (10a). E_{VX} represents the partial elasticity of fuel usage with respect to output and is positive since $V_X > 0$. V_t represents the own-price derivative of fuel and is negative. Thus in the absence of exogenously determined price distortions ($d = 0$), a necessary and sufficient condition for the fuel tax to be positive, i.e., $t > 0$, is that $E_{VX} < 1$.

For $u > 0$, an additional condition is needed, namely that

$$[E_{VX} + \frac{V_t/V}{X_t/X}] < 1 . \tag{18}$$

The first term of this expression denotes the direct elasticity of fuel usage with respect to output, while the second term denotes the indirect elasticity of fuel usage with respect to output that is induced by a change in the fuel tax. Thus expression (18) indicates that for $u > 0$, the sum of direct and indirect elasticity of fuel usage with respect to output must be less than unity. Since expression (18) also implies $E_{VX} < 1$, a sufficient condition for both $t > 0$ and $u > 0$ is that expression (18) holds and that there are no exogenous price distortions in the economy ($d = 0$).

Alternatively, expression (18) can be written as

$$\left(\frac{\partial V}{\partial X} \cdot \frac{\partial X}{\partial t} + \frac{\partial V}{\partial t}\right)\frac{t}{V} < \frac{\partial X}{\partial t} \cdot \frac{t}{X} \quad . \tag{18a}$$

This states that for u and t to be positive, the sum of the direct and indirect elasticity of fuel usage with respect to the fuel tax must be less than the elasticity of output with respect to the fuel tax. This conclusion is consistent with the usual Ramsey pricing criteria. A positive fuel tax will cause distortions in both input and output markets. For $t > 0$, the direct elasticity of output with respect to the fuel tax must be smaller in absolute value than the indirect elasticity of fuel usage with respect to the fuel tax, i.e., the direct output distortion must be less than the indirect input distortion. However, for $u > 0$, the output elasticity with respect to the fuel tax must be smaller in absolute value than the sum of the direct and indirect fuel elasticities. Otherwise, output should be subsidized rather than taxed. In this latter case, output should be expanded to counteract the distortions caused by the fuel tax.

Finally, if there are exogenous price distortions ($d > 0$), eqs. (17a) — (17c) indicate that one cannot determine the sign of t and u a priori. If d is sufficiently great, $D < 0$ and then the opposite conclusions may hold. Thus the appropriate signs and magnitudes of the quasi-optimal fuel and output taxes crucially depend upon the relevant input and output elasticities and the nature of the existing price distortion. Nevertheless, it will usually be the case that second-best pricing will require a combination of fuel and output taxes. Since transport investments are typically financed by revenues from fuel taxes alone, this indicates that the use of output taxes should be considered.

We consider next the second-best investment rule. Using eq. (16a) to solve for λ and then solving expression (16c) for δ yields:

$$\delta = \frac{-\gamma w[X(E_{RI} - 1) + R_u]}{R_u} \tag{19}$$

where E_{RI} represents the elasticity of revenue with respect to infrastructure and R_u denotes the derivative of user tax revenues with respect to the output tax. The second-best difference between marginal investment benefits and costs depends upon the strength of the financing constraint (γ) and the sensitivity of revenue to the level of infrastructure and output taxes.

While it is impossible to sign δ a priori, it is possible to obtain some inferences concerning its sign. First, if $\gamma = 0$, i.e., no net subsidy is allowed, then $\delta = 0$ as long as the output tax and the fuel tax are set at their optimal levels, i.e., $u = t = 0$. Second, if $R_u > 0$ and $E_{RI} \geq 1$, $\delta < 0$ and investment should be increased relative to its first-best level. Finally, if $E_{RI} < 1$, while $R_u > 0$, it is possible that δ could be zero or negative. More generally, however, since the values of X, R_u, and E_{RI} depend upon the values of u and t, a determination of the value of δ requires that the second-best values of u and t, given in eqs. (17a) — (17b) be substituted into these expressions and all of the relevant variables be simultaneously determined.

Basically, expression (19) indicates that if revenues are sufficiently elastic with respect to investment, it is desirable to expand investment relative to its first-best levels. If, however, revenues (and usage) are not very elastic with respect to investment, then distortions caused by the user charges needed to finance the investment generate a sufficient deadweight burden to make curtailment of investment relative to its first-best levels desirable. Finally, if exogenous price distortions exist, then it may be necessary to employ offsetting distortions through user charges and investment levels. However, without specific knowledge of the magnitude of the distortion, and the magnitude of the relevant derivatives, it is not possible to make a priori statements in terms of the nature of the second-best user taxes and investment rules. Thus exogenous price distortions introduce a fundamental complexity, making second-best generalizations difficult.

Again, it is important to stress that in the multi-commodity, multi-mode case, it is virtually impossible to determine the signs of u_{ij}, t_i, and δ_i analytically. However, given the underlying cost and demand functions, it should be possible to solve for the optimal user charges and investment levels under a range of price distortions and/or financing constraints. In this way, it should be possible to determine the social costs of price distortions and imperfect investment rules.

3. A Simulation Analysis

To analyze the quantitative impact of price distortions and financing constraints, we utilize the cost and demand functions estimated by Friedlaender and Spady (1981) for the rail and trucking industries for bulk and manufactured goods. While this two-commodity, two-mode case is still highly simplified, this empirical analysis is considerably more realistic than the one presented analytically in the single-commodity, single-mode case.

A full description of the cost and demand functions used in this analysis is given in Friedlaender and Spady (1981). The demand function for each mode assumes that output depends on rates and service qualities of both modes and exogenous factors such as income and employment. Thus

$$X_{Tj} = X_{Tj}(q_{Tj}, q_{Rj}, Q_{Tj}, Q_{Rj}, A_j) \qquad j = M,B \qquad (20a)$$

$$X_{Rj} = X_{Rj}(q_{Tj}, q_{Rj}, Q_{Tj}, Q_{Rj}, B_j) \qquad j = M,B \qquad (20b)$$

where X_{Tj}, X_{Rj} are the outputs; q_{Tj}, q_{Rj} are the rates; Q_{Tj}, Q_{Rj} are the modal and shipment characteristics of commodity j on truck and rail, respectively; A_j and B_j represent other factors affecting the demand for commodity j.

The marginal cost function for railroads includes the output of passengers and of bulk and manufactured goods explicitly and incorporates the role of infrastructure as well as a number of other technological variables; it takes the following general form:

$$MC_{Rj} = MC_{Rj}(X_{RP}, X_{RM}, X_{RB}, w_R, \tau_{Rj}, X_{RM}/X_{RB}, I_R) \quad j = M,B \qquad (21a)$$

where X_{RP}, X_{RM}, and R_{XB} respectively are passenger, manufactured, and bulk output by rail; w_R is a vector of factor prices facing railroads (including fuel); τ_{Rj} is a vector of technological characteristics (length of haul, track, average load, etc.); X_{RM}/X_{RB} is a traffic mix variable; and I_R is the railroad infrastructure. Thus MC_{Rj} represents a short-run marginal cost function.

The trucking marginal cost functions incorporate the role of operating characteristics for each commodity type but do not take the underlying highway infrastructure into consideration or consider bulk and manufactures as separate outputs. Thus they take the following general form:

$$MC_{Tj} = MC_{Tj}(X_{TM} + X_{TB}, w_T, \tau_{Tj}) \qquad j = R,M \tag{21b}$$

where the variables have the same definitions as they did in the case of the rail cost function.

These marginal cost and demand functions were estimated for rail and trucking firms for a geographic area defined by the Interstate Commerce Commission as the Official Territory for the year 1972. The year 1972 was chosen because it represents the most recent year for which data were available to estimate compatible cost and demand functions; the Official Territory was chosen because it encompasses the area of New England, the Middle Atlantic States, and the North Central and Central States, and thus incorporates the industrial heartland of the country.[7/]

Given our assumption that the only input which can be taxed is fuel, a full simulation analysis of the two-mode, two-commodity case requires optimization with respect to eight variables: two output taxes in each mode, the fuel tax in each mode, and the infrastructure in each mode. However, data on highway infrastructure and trucking fuel taxes were not incorporated into the trucking cost functions, necessitating these variables to be taken exogenously.[8/] Hence this analysis focuses on taxes and infrastructure levels in the railroads under a number of different assumptions about distortions in the trucking industry.

We present detailed results for the following scenarios:

1. Historical price distortions and fuel taxes and infrastructure.

2. Status quo "competitive" equilibrium in which p = MC, but input taxes and trucking infrastructure are exogenously determined.

3. Historical price distortions and fuel taxes: solve for optimal railroad infrastructure.

4. Historical trucking price distortions and fuel taxes: solve for optimal rail taxes and infrastructure.

5. No trucking price distortions, but historical fuel taxes and infrastructure: solve for optimal rail taxes and infrastructure.

These last two scenarios are analyzed in two cases: no financing constraint ($\gamma \geq -\infty$); and a binding financing constraint ($\gamma = 1$).

Table 1 summarizes the benefits, second-best levels of railroad infrastructure and taxes, and a number of other variables reflecting traffic allocations under each of these scenarios.[9/]

Case 1 provides the historical status quo, with the rates and traffic allocation that existed in 1972. This is marked by wide deviation between prices and marginal costs with rail rates on manufactured goods being significantly below marginal costs and those on bulk commodities being somewhat above marginal costs, while truck rates are above marginal costs on both commodities. At this time railroad investment was \$17.990 billion and the total net benefits were measured to be \$5.742 billion.

Case 2 provides a competitive equilibrium in the rail and trucking markets in conjunction with the determination of the optimal railroad infrastructure. However, although this solution approaches a long-run competitive equilibrium, it does not represent a full competitive equilibrium, since highway infrastructure and fuel taxes are taken to be at their historical levels. Nevertheless, a movement from the historical equilibrium to this quasi-competitive equilibrium increases net benefits to $6.934 billion, indicating that the status quo is quite inefficient. Note that in this solution railroad investment falls by approximately 50 percent and that rail traffic on manufactures is reduced drastically. Thus this solution leads to a substantial diversion of activity from rail to truck.

It is interesting to compare this competitive equilibrium with Case 3, which assumes historical price distortions in the output markets (denominated in percentage terms) and finds the optimal railroad infrastructure. Since there is more rail traffic in this case, there is also more infrastructure, but benefits are substantially lower than those associated with the competitive equilibrium, again indicating the inefficiencies associated with existing pricing policies.

Since neither highway infrastructure nor highway fuel taxes are set in an optimal fashion, it is likely that competitive pricing will not yield a full second-best optimum. Indeed one of the major conclusions of this paper is that if distortions exist in one market, offsetting distortions are needed in all markets. This is illustrated in Cases 4 and 5, which solve for the optimal level of railroad taxes and infrastructure, given historical pricing distortions in the trucks (4) and competitive pricing in trucks (5). In both cases, the second-best optimum calls for output taxes on bulk and manufactured goods, but a fuel subsidy. While price distortions are needed in the output market to reflect trucking distortions, input subsidies are needed to reduce overall rail costs and expand output relative to trucks. While inferential, this solution would be consistent with a scenario in which there was overinvestment in highway infrastructure. It is also interesting to note that although truck prices equal marginal costs in Case 5, the second-best pricing still includes output taxes for the railroads.

Cases 6 and 7 provide a similar analysis when a financing constraint is imposed and railroads are required to pay for their infrastructure. In this case, rail output taxes rise, and output and infrastructure are reduced accordingly. Since less rail traffic is carried because of the need to finance the infrastructure and the smaller capital stock, benefits are also reduced. However, it is interesting to note that under a financing constraint, benefits are somewhat higher under the imposition of historical trucking distortions. Apparently, since considerable rail distortions are needed to satisfy the financing constraint, society is better off with similar trucking distortions.

From Table 1 we infer that there is substantial social payoff in moving from the existing pricing distortions to ones that either reflect competitive pricing or second-best pricing. However, once the historical pricing distortions are abandoned, the benefit function appears to be relatively flat. Moreover, it is also interesting to note that the main social cost appears to come from inefficient pricing policies rather than from nonoptimal infrastructure levels, since there is a relatively modest rise in benefits from changing railroad infrastructure alone (Case 1 as opposed to Case 3).

Finally, even though the benefit function may be rather flat, it is worth noting that the allocation of these benefits among the various transport users is not. In particular, shippers of manufactured goods by rail are the clear beneficiaries of the historical pricing policies and would suffer a major loss in any policy that moved away from historical rail price distortions. Similarly, truck users would clearly benefit from policies that led truck prices toward their competitive levels as opposed to the existing distortions.

In conclusion, this simulation exercise shows that the interrelationships both within and between modes make it necessary to have an integrated policy for the rail and trucking modes. However, it also suggests that once the gross inefficiencies have been corrected, the benefits from further fine-tuning of the rate structure or infrastructure may be relatively small. This suggests that a full optimization may not be necessary and that the problem may be more tractable than the theoretical analysis of this paper would indicate.

TABLE 1. Net Benefits, Railroad Infrastructure, Railroad Taxes, and Related Variables, by Different Scenarios, Official Region, 1972

	NO BUDGET CONSTRAINT					BUDGET CONSTRAINT	
	NO RAIL FUEL TAX			RAIL FUEL TAX ALLOWED			
Description of Conditions Defining the Simulations	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7
Variable Name	Historical Status Quo	Perfect Competition $p = MC$	Historical Percentage Distortions $p \neq MC$	Historical Distortions in Trucks	Competition in Trucks	Historical Distortions in Trucks	Competition in Trucks
I. Policy Variables	None	I_R	I_R	I_R, u_R, t_R	I_R, u_R, t_R	I_R, u_R, t_R	I_R, u_R, t_R
II. Net Benefits ($bil.)	5.742	6.934	6.036	7.026	7.114	6.823	6.791
1) Consumers' Surplus	9.155	8.738	8.572	7.820	8.842	6.892	7.810
2) Producers' Surplus	-1.220	-0.730	-1.390	0.112	-0.690	-0.074	-1.019
3) Government Surplus	-2.195	-1.074	-1.147	-0.907	-1.038	0.005	0.0
II. Optimal/Assumed (*) Values							
1) Railroad Investment ($bil.)	17.990*	8.800	9.400	8.800	8.600	5.900	4.600
2) Rail Manu. Tax/ Distortion (¢)	-2.487*	0.0*	-3.062	0.875	0.492	3.360	3.131
3) Rail Manu. Tax/ Distortion (%)	-103.410*	0.0*	-103.410*	13.790	8.260	33.330	27.540
4) Rail Bulk Tax/ Distortion (¢)	0.194*	0.0*	0.234	0.253	0.157	1.234	1.319
5) Rail Bulk Tax/ Distortion (%)	9.130*	0.0*	9.130*	13.790	9.090	45.650	47.590

Table 1, continued

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7
6) Rail Fuel Tax (¢/gal)	0.0*	0.0*	0.0*	-5.814	-5.924	-5.814	-5.595
7) Rail Fuel Tax (%)	0.0*	0.0*	0.0*	-53.00	-54.00	-53.00	-51.00
IV. Assumed Values of Exogenous Variables							
1) Truck Manu. Distortion (%)	18.870	0.0	18.870	18.870	0.0	18.870	0.0
2) Truck Bulk Distortion (%)	29.350	0.0	29.350	29.350	0.0	29.350	0.0
V. Equilibrium Values of Endogenous Variables							
1) Truck Manu. Output (bil. ton-miles)	27.516	54.526	30.091	38.685	53.294	44.576	63.761
2) Truck Manu. Rate (¢/ton-mile)	6.067	4.442	5.978	5.829	4.455	5.692	4.336
3) Truck Bulk Output (bil. ton-miles)	13.348	24.162	14.658	13.624	23.900	16.336	29.081
4) Truck Bulk Rate (¢/ton-mile)	5.908	3.620	5.789	5.593	3.635	5.410	3.499
5) Rail Manu. Output (bil. ton-miles)	83.071	18.010	62.617	21.233	20.404	10.258	6.868
6) Rail Manu. Price (¢/ton-mile)	2.405	6.451	2.961	6.345	5.955	10.079	11.372
7) Rail Bulk Output (bil. ton-miles)	57.142	62.986	44.424	68.097	64.507	40.403	33.199
8) Rail Bulk Rate (¢/ton-mile)	2.125	1.752	2.560	1.834	1.723	2.702	2.772

Table 1, continued

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7
VI. Composition of Producers' Surplus ($ billion)							
1) Net Rail Manu. Revenues	1.998	1.162	1.854	1.162	1.115	0.689	0.566
2) Net Rail Bulk Revenues	1.214	1.104	1.137	1.077	1.010	0.593	0.482
3) Rail Variable Costs	4.542	2.351	4.510	2.263	2.178	1.535	1.358
4) Rail Surplus	-1.330	-0.085	-1.518	-0.025	-0.053	-0.252	-0.310
5) Truck Manu. Revenues	1.669	2.422	1.799	2.255	2.374	2.537	2.765
6) Truck Bulk Revenues	0.788	0.875	0.849	0.762	0.869	0.884	1.017
7) Truck Variable Costs	2.348	3.942	2.519	2.880	3.880	3.243	4.491
8) Truck Surplus	0.110	-0.645	0.128	0.137	-0.637	0.178	-0.709
VII. Composition of Consumers' Surplus ($ billion)							
1) In Truck Manu.	3.044	3.975	3.087	3.160	3.967	3.230	4.049
2) In Truck Bulk	1.538	2.278	1.568	1.618	2.271	1.666	2.332
3) In Rail Manu.	2.787	0.902	2.367	1.122	0.999	0.557	0.338
4) In Rail Bulk	1.786	1.583	1.551	1.920	1.605	1.439	1.091

Table 1, continued

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7
VIII. Composition of Government Surplus ($ billion)							
1) Rail Manu. Tax Revenues	0.0	0.0	0.0	0.186	0.100	0.345	0.215
2) Rail Bulk Tax Revenues	0.0	0.0	0.0	0.172	0.101	0.499	0.438
3) Rail Fuel Tax Revenues	0.0	0.0	0.0	-0.191	-0.190	-0.119	-0.092
4) Total Tax Revenues	0.0	0.0	0.0	0.167	0.011	0.724	0.561
5) Fixed Cost	2.195	1.074	1.147	1.074	1.049	0.719	0.561

NOTES to Table 1

1. The highway infrastructure and the truck fuel tax are fixed at their historical (1972) values in all the cases. The policy variables are the railroad infrastructure I_R, the two railroad output taxes for manufactured and bulk goods u_R, and the railroad fuel tax t_R.

2. The budget constraint requires total railroad tax revenues to be equal to the fixed costs of the railroad infrastructure, which are taken to be 12.2% of the values of the infrastructure.

3. If taxes/subsidies are levied, the producers' revenues and costs shown are those after taxes have been paid and subsidies received. Where there is only a distortion and no taxes are collected, the producers' revenues have been evaluated at the market prices.

4. The percentage tax/distortion is given by 100 * (Price - Marginal Cost)/ Price. For the rail fuel tax, the price used is the 1972 value of 10.97¢/gallon for diesel.

NOTES

1. Friedlaender and Spady (1981) have recently argued that bulk commodities are priced substantially in excess of marginal cost in the rail and trucking industries and that manufactured goods are priced somewhat below marginal cost in the rail industry. Unfortunately, data are lacking to perform similar anlayses for the barge industry, but the Corps of Engineers appears to assume that prices equal marginal cost for the purposes of evaluating waterway investments.

2. For related work see Wheaton (1978), Wilson (1980), and Borins (1978).

3. Thus the analytics of the problem are quite similar to those of optimal commodity taxation or optimal income taxation, e.g., Atkinson and Stiglitz (1980, Chs. 12 and 13). We are implicitly assuming that there are no distortions in the rest of the economy.

4. Note that the sum of consumers' surplus, producers' surplus, and govenrment surplus can be written as

$$B = \sum_i \sum_j \left[\int_0^{X_{ij}} q_{ij}(z_{ij})dz_{ij} - q_{ij}X_{ij} \right] + \left[\sum_i \sum_j p_{ij}X_{ij} - \sum_i C_i(X_{i1},\ldots,X_{in},t_i,I_i) \right]$$

$$+ \left[\sum_i \sum_j u_{ij}X_{ij} + \sum_i t_iV_i - \sum_i w_iI_i \right]$$

where the first bracketed term represents the consumers' surplus, the second bracketed term represents producers' surplus, and the third bracketed term represents the government surplus. Noting that $q_{ij} = u_{ij} + p_{ij}$ and collecting terms yields eq. (6).

5. In principle, the government can levy a tax on all the inputs used by each mode. For simplicity we allow a tax on only one input, and call it fuel because this has been the traditional source of revenues.

6. Note that we provide this analysis for the case of a price-taking regulated transportation firm. Hence d is treated as being exogenously determined by regulatory policy rather than endogenously determined through monopolistic pricing practices. To analyze an endogenous price distortion would complicate the analysis considerably, without changing its fundamental nature.

7. The Census of Transportation contains the data needed to perform the analysis. Although a 1977 edition is now available, this was not available when the cost and demand analysis was undertaken.

8. The problem with incorporating highway infrastructure variables into the analysis is that there are many other highway users than the trucks utilized in this analysis. Hence a satisfactory quantitative analysis of the impact of the highway infrastructure upon trucking costs was not possible. Although fuel was incorporated as an explicit factor price in the trucking cost functions, the tax component of these prices was not available.

9. The optimal values of the policy variables have been found by evaluating alternative combinations of their values over a wide range. For each combination considered, the equilibrium values of the endogenous variables were generated by solving the eight nonlinear supply and demand equations by an iterative technique. The consumers' surpluses were calculated by integrating the area under the demand curves with an upper cut-off point of 20¢. In view of the various approximations required to find the optimal values, it is clear that the precision of the reported figures is somewhat overstated.

In addition, it is worth noting that the rail revenues exclude $1.06 billion of exogenous revenues derived from passengers, grain, and coal traffic which were assumed to be constant throughout the analysis. Moreover, the negative trucking surplus reflects the fact that the trucking costs were estimated to be subject to diminishing returns and hence will yield a deficit at a competitive equilibrium.

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