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Freight Service Quality and Carrier Economics[1]

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ABSTRACT

This paper is concerned with the economic implications of freight service quality, particularly as it affects the individual carrier. The model development allows carrier economics to be properly examined as part of a larger logistics process.

Optimal service quality is framed as a technical efficiency criterion which minimizes the full cost of transportation (a sum of carrier and shipper costs). This criterion, termed quality efficiency (QE), is shown to be profit-maximizing with the full cost-full price formulation of carrier profit, where full price is the sum of freight rate and an average shipper cost expression.

A quality policy is a rule, such as QE, which specifies the implemented quality level as a function of volume. The quality policy construct permits a simplification of the carrier profit model. Alternative quality policies, such as carrier cost minimization, are examined and compared with QE.

The relationship between service quality and economic analysis of the carrier is then explored with respect to perfect competition and returns-to-scale. The paper closes by examining the potential impact of freight rate regulation on service quality.

INTRODUCTION

Freight service quality is economically significant because of its impact on the consumption of both carrier and shipper resources in the larger logistics process. Technical efficiency is concerned with minimizing resource consumption (cost) by the firm at a given output level. In the next section, optimal freight service quality—termed "quality efficiency"—is defined as a technical efficiency criterion with respect to the full cost of transportation, a sum of carrier and shipper costs.

In the remaining sections, service quality in general, quality efficiency in particular, and the full cost of transportation are examined with respect to several topics. These include carrier profit, alternative quality policies, economic analysis of the carrier, and freight rate regulation. (A quality policy is a rule, such as quality efficiency, which specifies the implemented quality level as a function of volume.) While each of these issues may be examined separately at some length, their joint examination permits a broad overview of freight service quality economics, which underscores the importance of quality efficiency and the fundamental role of the full cost of transportation.

QUALITY EFFICIENCY AND THE FULL COST OF TRANSPORTATION

Freight transportation is a logistical service which is fully integrated by the shipper into his logistics system.[2] The economic implications of changes in transportation service can be properly analyzed only within this larger logistical environment. Variations in transportation service quality affect the resources required by other elements of the shipper's logistics apparatus (particularly the inventory system). The consumption of these shipper resources is as integral to the provision of transportation service as are the resources consumed by the carrier. The quality of freight service impacts the amounts, and hence costs, of both resource sets.

General production efficiency requires that a firm minimize resource consumption at any given output volume level. This technical efficiency is defined by minimizing the total cost of inputs subject to an output constraint. The cost minimization defines a social efficiency criterion, which is also a necessary prerequisite for firm profit-maximization.

Consequently, efficient freight transportation requires that the sum of carrier and relevant shipper costs be minimized at any given volume level with respect to freight service quality. Henceforth, the term "quality efficiency" (QE) is used to refer to this "full cost" minimizing efficiency criterion:

$$\min_{z} T(v,z) \quad (1)$$

where
- $T(v,z)$: Full cost of transportation $= C(v,z) + S(v,z)$ (2)
- $C(v,z)$: Carrier cost function (per unit time)
- $S(v,z)$: Shipper cost function (per unit time)
- v : Freight volume (quantity per unit time)
- z : Freight service quality variable

A quality variable is an observable characteristic of the freight service, which affects both the carrier's cost and the shipper's cost. In addition to average transit-time, other possible service quality variables include transit-time variability, loss and damage, shipment size, and transportation equipment availability. These variables are distinguished from related carrier operating variables, such as speed and frequency, which are not always observable by the shipper. In this model, freight rate is not a quality variable; a transportation service is a product for which freight rate is the price and not a measure of product quality. To simplify the presentation, the model includes a single continuous service quality variable.

QE is a technical efficiency criterion which specifies a socially optimal service quality level as a function of volume:

$$z = Z(v) \tag{3}$$

where Z(v) solves problem (1). Volume level is left to be determined by market considerations. Technical efficiency is usually only concerned with the producing firm's cost function. However, QE is defined with respect to the cost functions of both producer (carrier) and customer (shipper).

The carrier cost formulation, C(v,z), explicitly acknowledges the functional relationship between carrier cost and the service quality provided to the shipper. For example, on a railroad a lower average transit-time may require some combination of faster and more frequent train service. This will necessitate increased investment in locomotives, higher fuel consumption, and more crew sets. Decreased transit-time variability (greater reliability) may require increased investment in fixed facilities in order to reduce congestion-related delays.

A shipper is an economic agent which uses freight transportation service. S(v,z) includes all opportunity costs of the shipper which vary with the freight service quality variable; these are typically inventory costs. For example, longer average transit-time will increase the shipper investment devoted to goods-in-transit. Also, transit-time variability may affect the required safety stock level, and hence inventory holding cost. Shipper cost does not include the freight cost paid to the carrier.

A numeric example is used throughout this paper for illustration. The example is based on these cost functions:

$$C(v,z) = 2v^2 - 2vz + z^2 + 10$$
$$S(v,z) = vz + z^2$$

The consequent average full cost function is depicted in Figure 1, along with QE. This and the other notation in the figure are discussed below.

CARRIER PROFIT

A microeconomic model of carrier profit is developed here to examine the effects of freight service quality. To simplify the presentation, only a single shipper is explicitly considered throughout most of the presentation. However, this single shipper can be interpreted as representing an entire class of homogeneous shippers. Futhermore, most of the results and conclusions remain valid when the carrier serves multiple heterogeneous shippers.[3]

The carrier profit model includes a carrier profit equation and a demand function which eliminates volume as an independent variable:

$$\pi = rv - C(v,z) \tag{4}$$
$$\text{where } v = D(r,z) \tag{5}$$

π : Profit of carrier (per unit time)
r : Freight rate (price)

The demand function represents the simple idea that carrier freight volume will generally go up if the carrier charges a lower freight rate and/or provides better service (and conversely go down with a higher rate and/or poorer service), everything else remaining the same. The carrier and shipper(s) are the only economic agents explicitly considered within the model. In that context, this demand function must implicitly reflect the appropriate reactions of all other relevant economic forces, such as commodity markets and any competing carriers.

Shippers are generally opportunity-cost-minimizing firms. As discussed above, they are sensitive to freight service quality because it affects their internal logistics costs. Shipper cost may be used therefore to specify amore detailed demand function:

$$v = f(\, r + U(v,z)\,) \tag{6}$$

where $f(\cdot)$: Strictly decreasing function
U(v,z) : Shipper unit cost function

$$= \frac{S(v,s)}{v} \tag{7}$$

Equation (6) replaces equation (5) as the demand function in the carrier profit model.

Equation (6) defines v as an implicit function of r and z (the multiple occurrences of v cannot be combined). For the numeric example, this relationship is depicted in Figure 2 [using $f(x) = 5 - 0.2x$].[4] A tacit assumption of the new demand function is that the shipper does not make any distinction, on a dollar-per-dollar basis, between the freight charge, rv, and the internally generated cost S(v,z). To the shipper, both r and U(v,z) are simple per-unit-volume prices. Because S(v,z) may be defined as the shipper's perceived cost, this assumption is not very restrictive.

The shipper unit cost function, U(v,z), specifies how the shipper values different service quality levels. Thus at any given volume level, the function defines what constitutes better versus poorer service. The volume argument in U(v,z) and S(v,z) may be viewed as a parameter which allows the structure of the functional relationship between service quality and shipper cost to change from one volume level to another. For example in Figure 3, the shipper unit cost surface is much steeper on the left than on the right. These general shipper cost functions are in contrast to the more common simple linear approach where for some constant "k" it is assumed that:

$$U(z) = kz \text{ and } S(v,z) = kvz \tag{8}$$

In most applications, the service quality variable is (average) transit-time, and the constant k is the product of a commodity unit cost and an interest rate specifying the opportunity cost of capital.

Equations (4) and (6) together constitute a carrier profit formulation with independent variables r and z. Carrier profit as function of these two variables is depicted in Figure 4. The dashed contour curves on the left side of Figure 4 represent negative profit (loss). Analysis of carrier profit can be significantly simplified by an interesting reformulation in which shipper cost is both added to and subtracted from equation (4):

$$\pi = P(r,z,v)v - T(v,z) \quad (9)$$

$$\text{where} \quad v = f[\,P(r,z,v)\,] \quad (10)$$

$$P(r,z,v): \text{Full price of transportation}$$
$$= r + U(v,z) \quad (11)$$

Equations (9) and (10) together constitute the full cost-full price formulation of carrier profit. This is in contrast to the more typical carrier cost-freight rate formulation developed previously.

Equilibrium conditions obtained from the first order conditions of carrier profit maximization are:

$$\frac{\partial T}{\partial v} = v\frac{1}{f'[P(r,z,v)]} + P(r,z,v) \quad (12)$$

$$\frac{\partial T}{\partial z} = 0 \quad (13)$$

[where $f'(\cdot)$ is the derivative of $f(\cdot)$]. The derivation of these two conditions is presented in the appendix.[5] The second condition is of special interest; it is also the first order condition for minimizing full cost with respect to service quality, i.e. problem (1), the QE definition. Hence, likeother technical efficiency criteria, QE is also a prerequisite for (carrier) profit maximization. This result should not be too surprising after a brief examination of the full cost-full price formulation.

QUALITY POLICIES

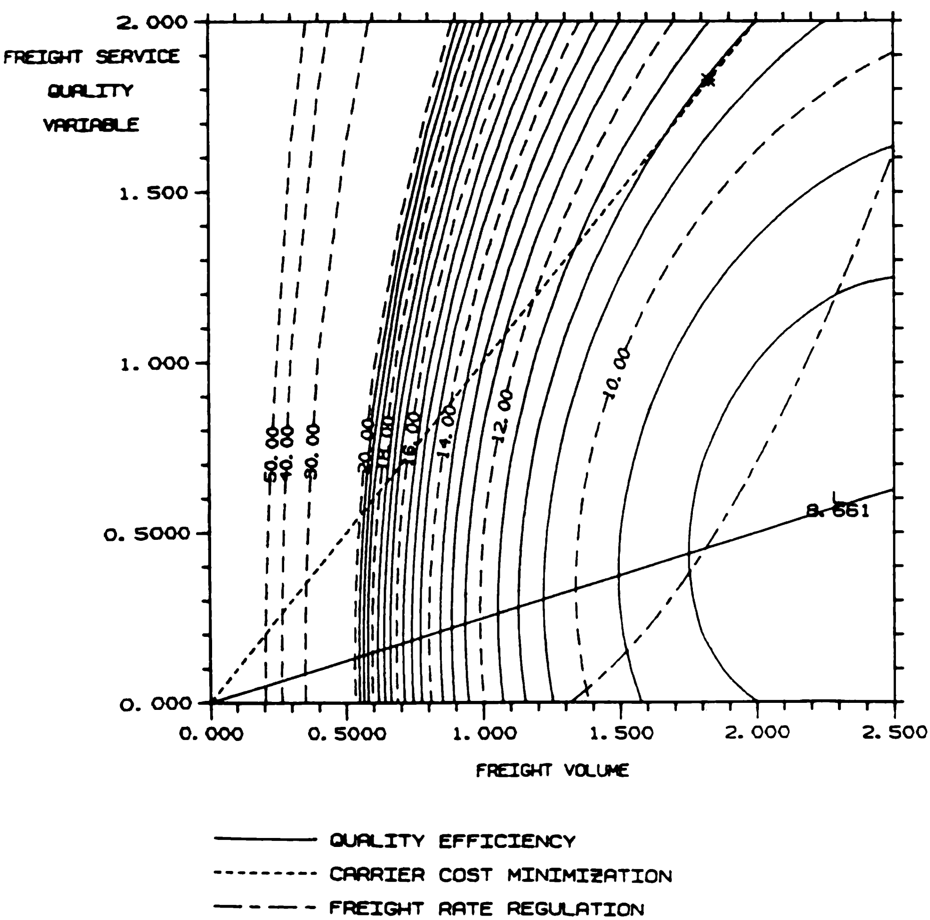
A quality policy is a rule which specifies the quality level implemented by the carrier as a function of volume level. QE is an example of a quality policy, represented by equation (3). For the numeric example:

$$Z(v) = v/4$$

This quality policy is indicated by the solid line through Figures 1, 2, 3 and 4.[6] Note that in Figure 1 this line includes the point of minimum average full cost, and in Figure 4, the point of maximum profit.

FIGURE 1

Average Full Cost of Transportation



The fact that QE is uniquely profit-maximizing should provide the carrier with sufficient motivation for implementing this quality policy. However, successful implementation will require, first, a management structure sufficiently fine-tuned to discern and fully exploit all quality-related profit opportunities, and second, a regulatory environment which will permit this exploitation. No management is perfect, and historically, carriers have often failed to explore these opportunities. Therefore it is worthwhile to examine alternative quality policies such as minimizing the carrier cost alone with respect to quality, or treating quality as a fixed constraint.

Carrier cost minimization (CCM) is the quality policy defined by minimizing the carrier cost alone with respect to quality. For the numeric example, the CCM quality policy is:

$$Z^c(v) = v$$

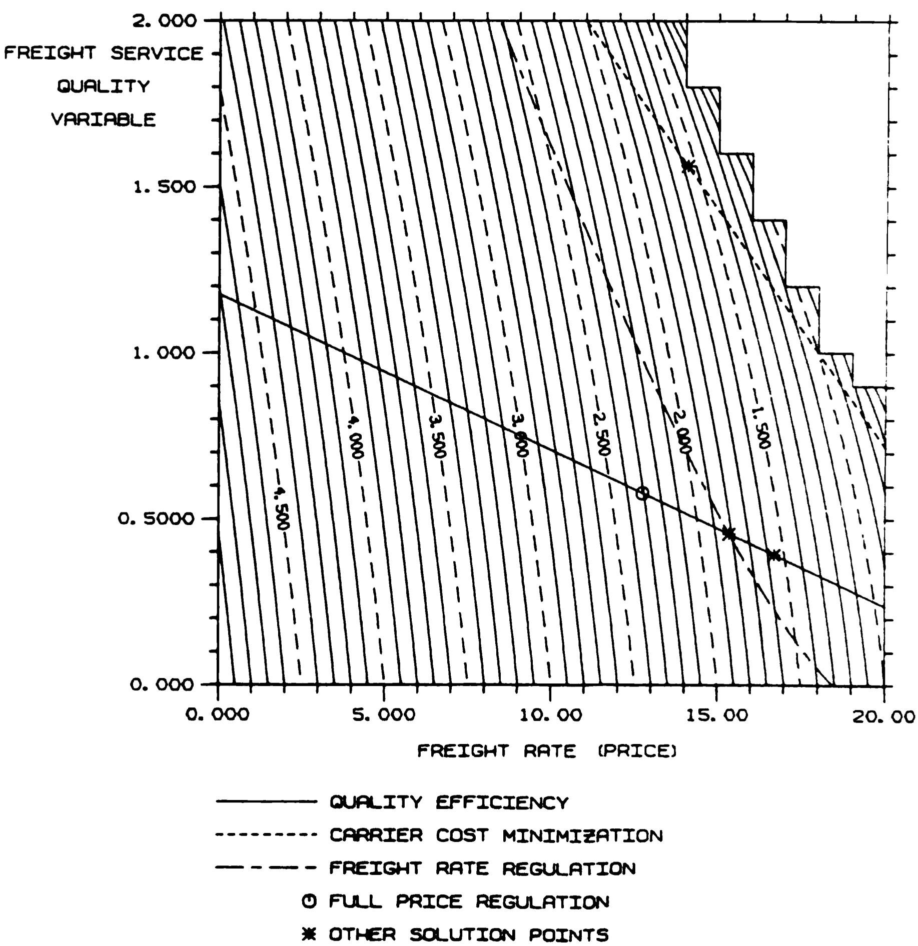
It is represented in Figures 1, 2, 3 and 4 by the simple dashed line.[7] In Figure 1, an asterisk is placed on this line to indicate the smallest possible average full cost with this quality policy; similarly, in Figure 4, an asterisk indicates the largest possible carrier profit.

Since CCM is not equivalent to QE, it is generally not profit-maximizing, and therefore not optimal to the carrier. However, a carrier will tend toward CCM if it is overly concerned with internal cost control and relatively insensitive to shipper satisfaction. For example, this is a likely outcome with the classical railroad management structure, where the viewpoint of the operations department is completely dominant relative to the input of the marketing department.[8]

Fixed quality is a quality policy defined by fixing quality equal to some preset design value z°. Thus, fixed quality is actually a family of quality policies parameterized by z°. Any horizontal line in Figures 1, 2, 3 and 4 corresponds to a member of this family. A carrier which recog-

FIGURE 2

Volume (Demand) as a Function of Freight Rate and Service Quality



nizes the importance of service quality and the debilitating effects of unrestrained (carrier) cost minimization, might implement a fixed quality policy. If the value z° is chosen separately for each shipper (or homogeneous shipper class) and reevaluated with changes in volume, then the quality policy may tend toward QE. However, if the same z° is applied to all shippers (thus ignoring their individual cost characteristics) and/or is held constant over significant volume changes, then the fixed quality policy will tend away from QE and profit-maximization. An overemphasis on monitoring and controlling service quality, without sufficient consideration of shipper cost, will probably lead to a non-optimal fixed quality policy.

Quality policies may be used to restructure and further simplify the model of carrier profit. To facilitate this development, the general quality policy is introduced:

$$z = Z^g(v) \tag{14}$$

Any quality policy may be used to eliminate the quality variable from the cost functions. For example, with the general policy:

$$C^g(v) = C(v, Z^g(v)) \tag{15}$$
$$S^g(v) = S(v, Z^g(v)) \tag{16}$$

The functions $T^g(v)$, $U^g(v)$ and $P^g(r,v)$ are similarly defined with respect to equation (14).

These new cost functions have only one independent variable (volume), and hence have simple derivatives, i.e. marginal cost functions:

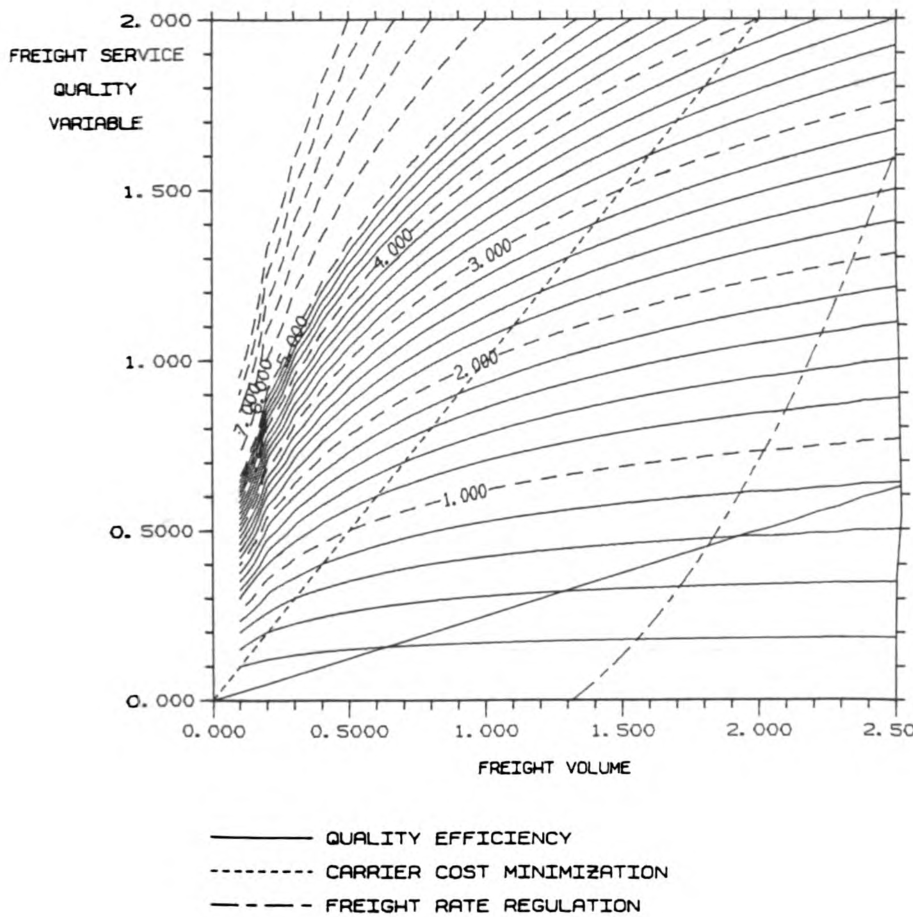
$$\frac{dC^g}{dv} = \frac{\partial C}{\partial v} + \frac{\partial C}{\partial z}\frac{dZ^g}{dv} \tag{17}$$

$$\frac{dS^g}{dv} = \frac{\partial S}{\partial v} + \frac{\partial S}{\partial z}\frac{dZ^g}{dv} \tag{18}$$

The full derivative of carrier cost on the left side of equation (17) shall be referred to as the "complete carrier marginal cost"; as distinguished from the "simple carrier marginal cost," which is a partial derivative and the first term on the right hand side of the equation. Complete and simple shipper marginal cost are similarly defined with

FIGURE 3

Shipper Unit Cost Function



respect to equation (18). While the simple marginal costs of carrier and shipper play an important algebraic role in this model, it must be emphasized that the complete marginal costs are the true marginal costs and hence have greater economic significance. The simple marginal costs may have implications for empirical applications of the model.

Other quality policies may be used to develop more specific cost functions and marginal cost functions. For the numeric example, the cost functions associated with the QE and CCM quality policies are presented in Table 1.

Using the general quality policy cost and price functions, the full cost-full price formulation of carrier profit is:

$$\pi = p^g(r,v)v - T^g(v) \qquad (19)$$

$$\text{where } v = f[P^g(r,v)] \qquad (20)$$

With the inverse demand function, carrier profit can now be stated as a closed function on volume:

$$\pi^g(v) = vf^{-1}(v) - T^g(v) \qquad (21)$$

The first order condition of profit-maximization is then:

$$\frac{dT^g}{dv} = v\,\frac{1}{f'[P^g(r,v)]} + f^{-1}(v) \qquad (22)$$

If QE is implemented, this condition is equivalent to equation (12).[9]

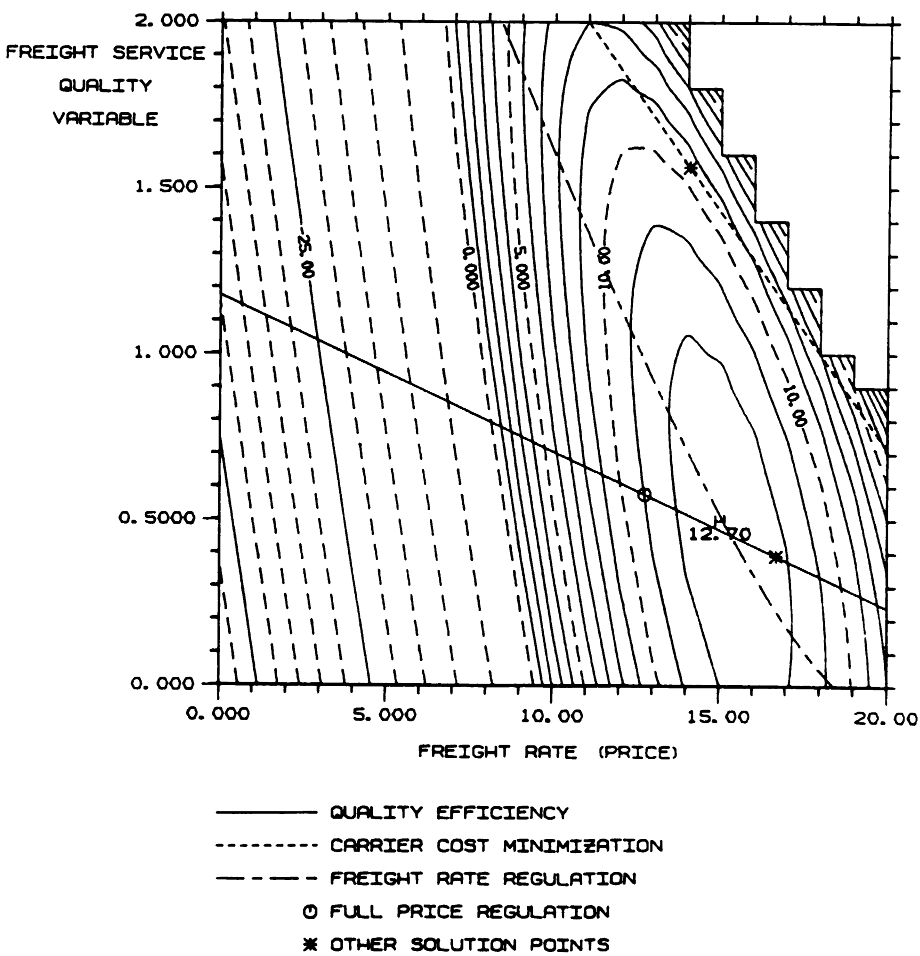
Equation (21) implies that the difference in profit between two quality policies is equal to the difference in full cost:

$$\pi^a(v) - \pi^b(v) = T^b(v) - T^a(v) \qquad (23)$$

(Where "a" and "b" represent any two quality policies.) For QE and CCM, this relationship is illustrated in Figure 5. The asterisks identify the profit maximization points of the two quality policies and a transition point. (These points are also identified in Figures 2 and 4.) Economic

FIGURE 4

Carrier Profit as a Function of Freight Rate and Service Quality



values associated with the three points are presented in Table 2.

Within the freight industry, service quality is usually viewed as a marketing tool for increasing demand (volume). However, equation (23) indicates how service quality may impact carrier profit directly, without any volume change. The change is profit is obtained by adjusting freight rate to exactly offset the difference in shipper unit cost:

$$r^a - r^b = U^b(v) - U^a(v) \qquad (24)$$

Full price is thus held constant, along with volume and the inverse demand function in equation (21). Equation (24) reinforces the role of U(•) in specifying the market value of freight service quality. The direct relationship between profit and service quality is illustrated by comparing columns 2 and 3 of Table 2. There, profit (line h) is increased by reducing full cost (line c), and trading off between freight rate and shipper unit cost within a constant full price (lines d, e and f).

TRANSPORTATION ECONOMIC ANALYSIS

There has been much empirical economic analysis of the transportation industry, particularly railroads and LTL (Less than Truck Load) trucking. These studies have inevitably used only carrier cost and freight rate to examine such things as returns-to-scale and the relationship between marginal cost and price, and have usually ignored any impact of service quality.

The preceding presentation suggests that economic analysis of the transportation industry ideally should be based on full cost and full price. In this section, returns-to-scale and the conditions of perfect competition are examined with respect to that conclusion. The examination of perfect competition reinforces the propriety of the full cost-full price paradigm, and indicates the potential error associated with using the traditionalcarrier cost-freight rate model. This error is then further illustrated with returns-to-scale.

The long-run conditions of perfect competition specify that the firm is a price taker with zero economic profits. For a price taker, f(•) is essentially a vertical line (yielding a horizontal demand curve), and:

$$\frac{1}{f'(\cdot)} = 0 \qquad (25)$$

The carrier would then face a fixed full price, but may be able to trade off between rate and unit shipper cost within that full price [see equation (11)].

Assume that the carrier is a full price taker at P^o. Then from equations (22) and (25):

$$\frac{dT^g}{dv} = P^o \qquad (26)$$

This is a classic result, equating price and mar-

TABLE 1

Cost Functions of Numeric Example

Quality Policy			(1) Quality Efficiency $Z^*(v) = v/4$	(2) Carrier Cost Minimization $Z^c(v) = v$
a)	Carrier Cost Function	$C^g(v)$	$C(v) = \frac{25}{16}v^2 = 10$	$C^c(v) = v^2 + 10$
b)	Shipper Cost Function	$S^g(v)$	$S(v) = \frac{5}{16}v^2$	$S^c(v) = 2v^2$
c)	Shipper Unit Cost Function	$U^g(v)$	$U(v) = \frac{5}{16}v$	$U^c(v) = 2v$
d)	Full Cost of Transportation	$T^g(v)$	$T(v) = \frac{15}{8}v^2 + 10$	$T^c(v) = 3v^2 + 10$
e)	Complete Carrier Marginal Cost	$\frac{dC^g}{dv}$	$\frac{dC}{dv} = \frac{25}{8}v$	$\frac{dC^c}{dv} = 2v$
f)	Complete Shipper Marginal Cost	$\frac{dS^g}{dv}$	$\frac{dS}{dv} = \frac{5}{8}v$	$\frac{dS^c}{dv} = 4v$
g)	Full Marginal Cost	$\frac{dT^g}{dv}$	$\frac{dT}{dv} = \frac{15}{4}v$	$\frac{dT^c}{dv} = 6v$
h)	Simple Carrier Marginal Cost (= 4v–2z)	$\frac{\partial C}{\partial v}$	$\frac{\partial C}{\partial v} = \frac{7}{2}v$	$\frac{\partial C}{\partial v} = 2v$
i)	Simple Shipper Marginal Cost (= z)	$\frac{\partial S}{\partial v}$	$\frac{\partial S}{\partial v} = \frac{1}{4}v$	$\frac{\partial S}{\partial v} = v$
j)	Degree of Scale Economies	$E(v)$	$E(v) = \frac{1}{2} + \frac{8}{3}\frac{1}{v^2}$	$E(v) = \frac{1}{2} + \frac{5}{3}\frac{1}{v^2}$
k)	Carrier-Cost Economies of Scale	$E_c(v)$	$E(v) = \frac{1}{2} + \frac{16}{5}\frac{1}{v^2}$	$E_c(v) = \frac{1}{2} + 5\frac{1}{v^2}$
l)	Shipper-Cost Economies of Scale	$E_s(v)$	$E_s(v) = \frac{1}{2}$	$E_s(v) = \frac{1}{2}$

ginal cost. However, it does not follow that carrier marginal cost is equal to freight rate. Specifically, the carrier marginal cost will equal rate if and only if the shipper marginal cost equals the shipper unit cost:

$$\frac{dC^s}{dv} = r \longleftrightarrow \frac{dS^s}{dv} = U^s(v) \tag{27}$$

This set of equations describes special, limited situations. An example is if the carrier implements a fixed quality policy with a linear shipper cost function [see equations (8)].

Zero economic profit, the second condition of perfect competition, implies that both full price and simple price (freight rate) are equal to average cost formulations:

$$\frac{T^s(v)}{v} = p^s(r,v) \tag{28}$$

$$\frac{C^s(v)}{v} = r \tag{29}$$

The only implication of assuming both full price taking and zero economic profits is that marginal full cost is equal to average full cost:

$$\frac{dT^s}{dv} = \frac{T^s(v)}{v} \tag{30}$$

Marginal carrier cost will equal average carrier cost if and only if equations (27) are valid.

In Table 3 perfect competition is illustrated for the two featured quality policies. The volume values correspond to the two average cost minimizing points previously identified with Figure 1. Note that for both QE and CCM, carrier marginal cost (line d) does not equal freight rate (or average carrier cost, line b). Interestingly, the deviation is much greater under CCM. With both quality policies in this example, an analyst may easily improperly conclude that the carrier is not a perfect competitor.

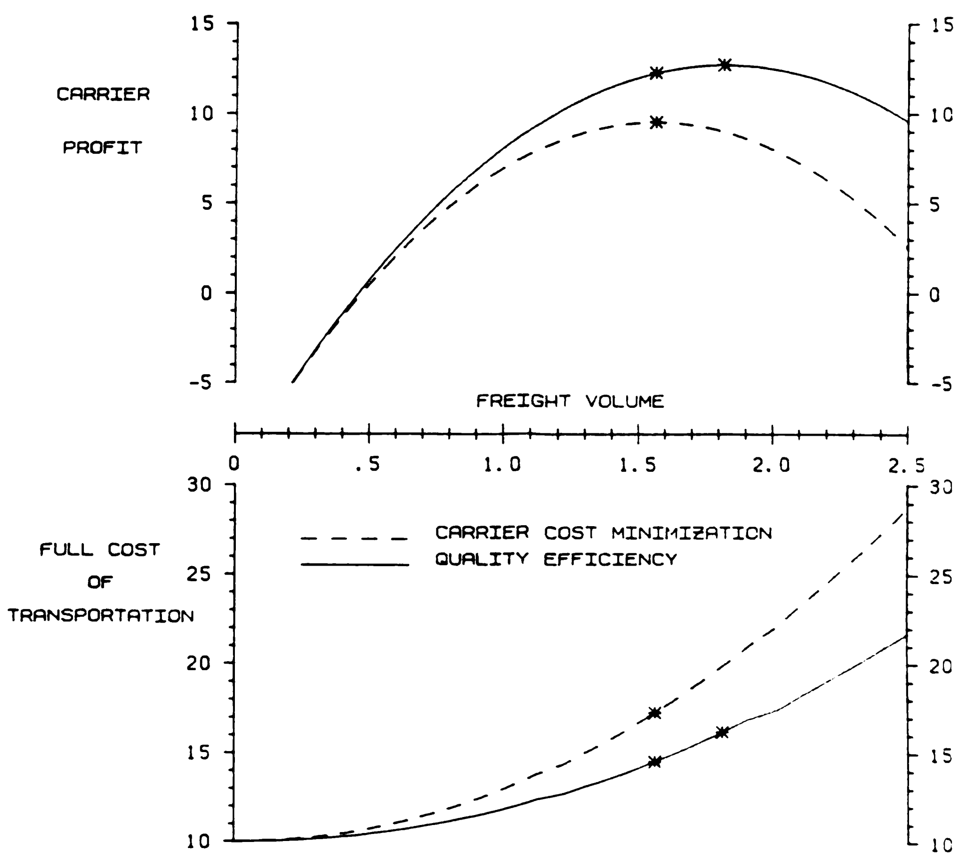
Potential errors such as this can be further illustrated with economies of scale. Using the full cost of transportation, the degree of scale economies is defined as:[10]

$$E(v) = \frac{T^s(v)}{v\,\frac{dT^s}{dv}} \tag{31}$$

This is the elasticity of output (volume) with respect to full cost, as well as the ratio of average

FIGURE 5

Carrier Profit and Full Cost with Quality Efficiency and Carrier Cost Minimization



full cost to marginal full cost. Returns to scale are increasing, constant or decreasing as E(v) is greater than, equal to, or less than unity. Note that the conditions of perfect competition imply constant returns to scale.

This measure of economies can be written as a weighted average of carrier-cost-only and shipper-cost-only economies of scale:

$$E(v) = \frac{\frac{dC^g}{dv}E_c(v) = \frac{dS^g}{dv}E_s(v)}{\frac{dC^g}{dv} + \frac{dS^g}{dv}} \tag{32}$$

$$\text{where: } E_c(v) = \frac{C^g(v)}{v \cdot \frac{dC^g}{dv}} \tag{33}$$

$$E_s(v) = \frac{S^g(v)}{v\,\frac{dS^g}{dv}} \tag{34}$$

Returns-to-scale functions for the numeric example are presented at bottom of Table 1; values for these functions are given at the bottom of Tables 2 and 3.

Equation (32) indicates that when $E_c(v)$ is greater than (less than) $E_s(v)$, an empirical examination using only carrier costs will overestimate (underestimate) the actual returns to scale. This effect may be illustrated with the numeric example; E(v), E(v) and $E_s(v)$ are plotted in Figures 6 and 7 for QE and CCM, respectively. Note that the difference between (full) returns to scale and carrier-cost-only returns is greater under CCM than it is under QE. Thus, again with this example, the error associated with using carrier cost rather than full cost to analyze industry cost structure is greater if CCM is implemented instead of QE. In particular, with CCM (see Figure 7) this error will cause the analyst to conclude, over a significant volume range, that carrier returns to scale are increasing when in fact theyare decreasing. It is ironic that when the carrier ignores the effects of service quality (by implementing CCM), it becomes even more important for the outside analyst to consider these effects.

Because of theoretical concerns, full cost and full price have been advocated in this section as the proper bases for economic analysis of the carrier. However, an empirical application of the full cost-full price model may prove difficult due to lack of access to sufficiently detailed service quality and shipper cost data. It is also quite possible that the results of such an empirical study may not differ significantly from traditional studies. These questions deserve investigation.

TABLE 2

Imperfect Competition with Numeric Example

Quality Policy Volume	(1) QE $Z(v)$ 1.82	(2) QE $Z(v)$ 1.56	(3) CCM $Z^c(v)$ 1.56
a) $C^g(v)$	15.17	13.81	12.44
b) $S^g(v)$	1.03	.76	4.88
c) $T^g(v)$	16.20	14.58	17.32
d) r	15.34	16.70	14.06
e) $U^g(v)$	.57	.49	3.13
f) $P^g(r,v)$	15.91	17.19	17.19
g) r•v	27.89	26.09	21.79
h) π	12.73	12.28	9.53
i) $\frac{dC^G}{dv}$	5.68	4.88	3.13
j) $\frac{dS^g}{dv}$	1.14	.98	6.25
k) $\frac{dT^g}{dv}$	6.82	5.86	9.38
l) $\frac{\partial C}{\partial v}$	6.36	5.47	3.13
m) $\frac{\partial S}{\partial v}$	.46	.39	1.56
o) $\frac{C^g(v)}{v}$	8.34	8.84	7.96
p) $\frac{T^g(v)}{v}$	8.91	9.33	11.09
q) E(v)	1.31	1.59	1.18
r) $E_c(v)$	1.47	1.81	2.55
s) $E_s(v)$	0.50	0.50	0.50

FREIGHT RATE REGULATION

A regulatory structure, such as that administered by the Interstate Commerce Commission, has an impact on freight service quality. The effect of rate regulation is examined in this section.

If freight rate is fixed at r by some outside regulatory authority, then z is only remaining

TABLE 3

Perfect Competition with Numeric Example

Quality Policy Volume	(1) QE $Z(v)$ 2.31	(2) CCM $Z^c(v)$ 1.83
a) $\frac{T^g(v)}{v} = \frac{dT}{dv} = p^g(r,v)$	8.66	10.95
b) $\frac{C^g(v)}{v} = r$	7.94	7.30
c) $U^g(v)$	.72	3.65
d) $\frac{dC^g}{dv}$	7.22	3.65
e) $\frac{dS^g}{dv}$	1.44	7.30
f) $\frac{\partial C}{\partial v}$	8.08	3.65
g) $\frac{\partial S}{\partial v}$	.58	1.83
h) E(v)	1.00	1.00
i) $E_c(v)$	1.10	2.00
j) $E_s(v)$	0.50	0.50

independent variable, and the single first order condition of profit maximization is:[11]

$$0 = \frac{\partial P}{\partial z} \cdot v + \left[P(r^{\circ},z,v) - \frac{\partial T}{\partial v}\right] f'(\cdot) \frac{\partial T}{\partial z}\left[1 - f'(\cdot)\frac{\partial P}{\partial v}\right] \qquad (35)$$

The impact of freight rate regulation is depicted in Figures 1, 2, 3 and 4 by the alternating short/long dashed line.[12] Note that this line crosses the iso-profit curves (Figure 4) at their vertical tangent.

Under rate regulation, a carrier may still implement a non-profit-maximizing quality policy such as CCM (or QE). The foregone profit associated with these policies may be illustrated with Figure 4. In this situation, any quality policy will determine all remaining variables (quality and volume).

If both QE and profit-maximization are assumed [equations (13) and (35)], then the last term of equation (35) drops off and the equation becomes equivalent to equation (12). This would require that r° be set at:

$$r^{\circ} = \frac{\partial T}{\partial v} - \frac{v}{f'[P(r^{\circ},z,v)]} - U(v,z) \qquad (36)$$

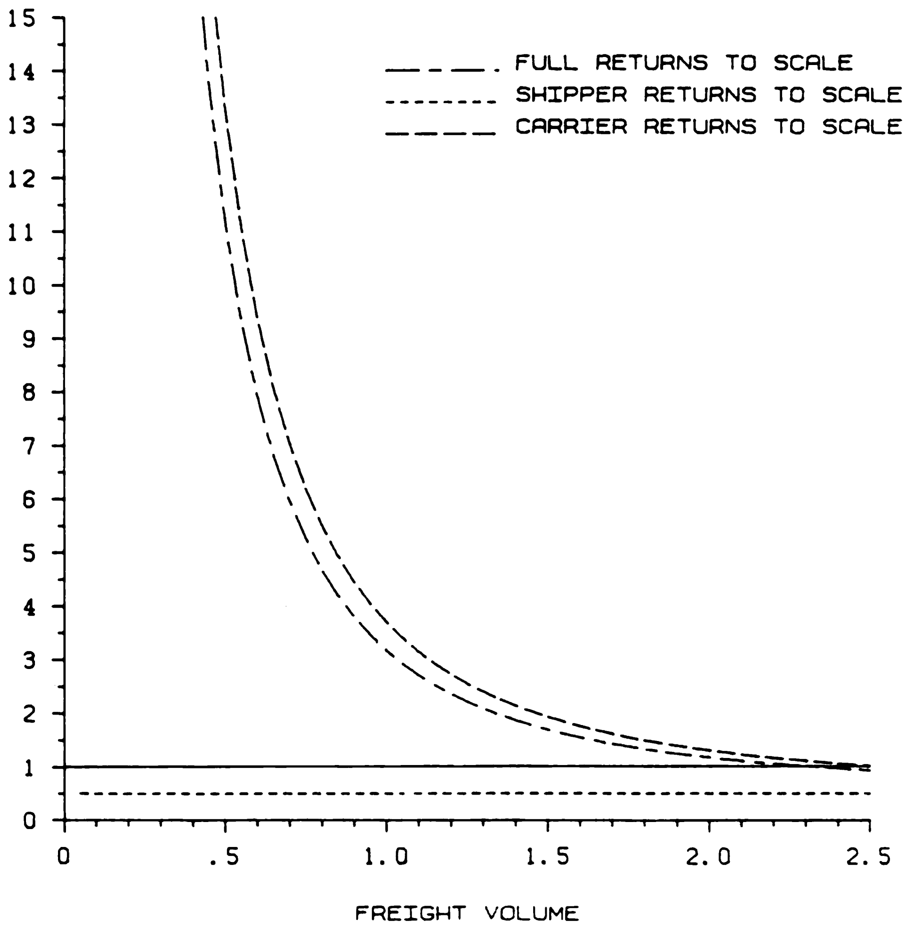
This rate value is identified by the intersection of the quality efficiency and rate regulation curves in Figures 2 and 4, the point of overall profit maximization. If r° is set at any other value, the profit-maximizing carrier will not implement QE.

For several reasons, it is unlikely that a regulatory agency would fix freight rate (except coincidentally) at the value described by equation (36). One reason is that knowledge of the shipper's cost function would be required, but is probably not available to the regulator. A second reason relates to the underlying logic of rate regulation. In order to have any impact, the regulated rate must be different from what the carrier would implement on its own without regulation. Because the r° defined by equation (36) is overall profit-maximizing, it can be argued that the (well managed) carrier is likely to implement this freight rate in the absence of regulation.

Thus, without specific evidence to the contrary, it is reasonable to assume that freight rate regulation will impose a non-optimal service quality and an associated welfare loss. This welfare

FIGURE 6

Degree of Scale Economies with Quality Efficiency



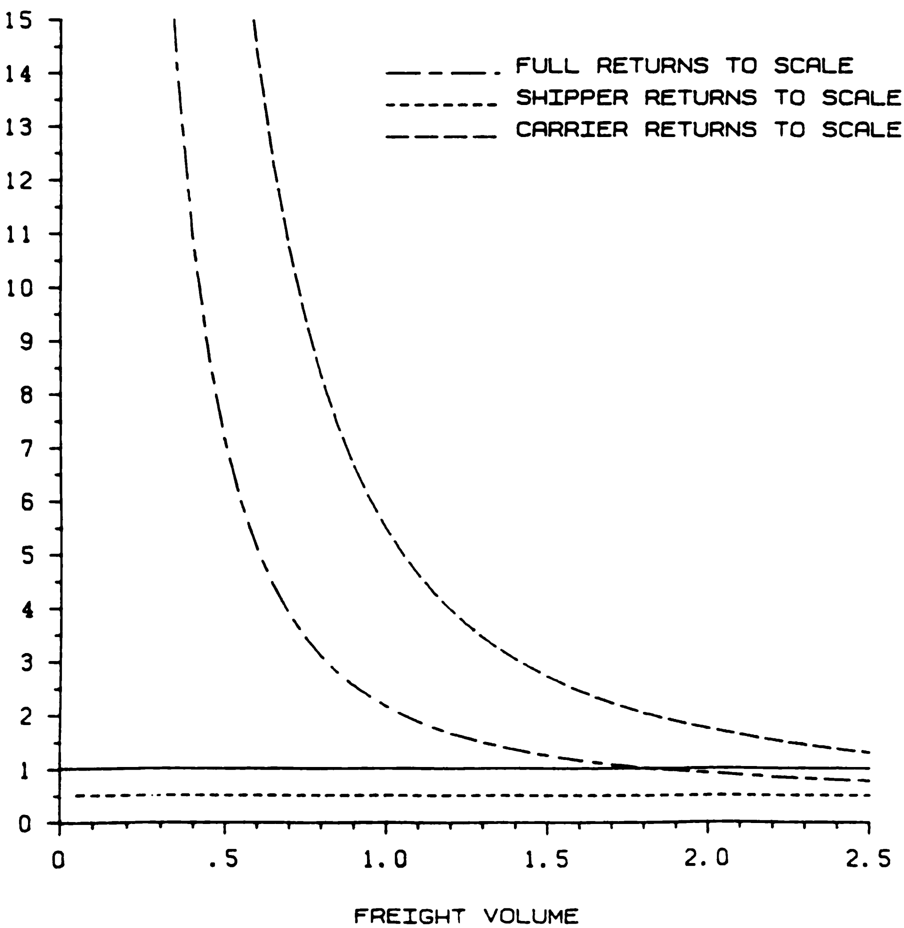
loss is a cost of regulation which must be considered with other costs and benefits, in any policy evaluation of freight rate regulation.

It is often concluded that carriers under rate regulation will engage in "service competition." This does not necessarily mean that the carrier will offer a higher quality service (as valued by the shipper) than it would otherwise. Service competition simply means that service quality is the sole (or dominant) basis of competition within full price. In the numeric example, if the regulated rate is less than the overall profit-maximizing rate (r = 15.34), the profit-maximizing carrier will have a higher volume (Figure 2) and offer poorer service quality (Figure 3) than it would otherwise.[13] The opposite is true if the prescribed rate is greater than the profit-maximizing rate. Thus, quality is adjusted in a manner which mitigates against the direct impact of rate regulation within full price [equation (11)].[14]

Rate regulation is often advocated as a technique for increasing the economic efficiency of the industry. However, in Figure 1 the rate regulation curve does not even include the point of minimum average full cost (nor the point of minimum average carrier cost). Within the full cost-full price framework, when price regulation is warranted, the theoretically proper regulatory policy is full price regulation. However, such a regulatory policy would probably be impossible to implement. The "O" in Figures 2 and 4 corresponds to a policy of setting full price equal to the minimum average full cost.

FIGURE 7

Degree of Scale Economies with Carrier Cost Minimization



CONCLUSION

As shippers become more concerned with the total cost of logistics, the economics of freight service quality are certain to have a large impact in the transportation market. The simple model developed in this paper provides a structure for understanding this impact, particularly as it applies to the individual carrier. Quality efficiency, the optimal service quality level,and the full cost-full price formulation of carrier profit are the most important concepts presented. The conclusions and observations of this paper are germane both for those inside the transportation industry, who must exploit service quality opportunities, and for outside analysts and regulators. Many of these concepts, conclusions and observations are relatively embryonic and await further development.

APPENDIX

Equations (12) and (13) are derived by first taking the total differential of equation (10):

$$dv = f'[P(r,z,v)]\left[\frac{\partial P}{\partial r}dr + \frac{\partial P}{\partial z}dz + \frac{\partial P}{\partial v}dv\right] \quad \text{(A1)}$$

When terms are combined:

$$dv = a\left[\frac{\partial P}{\partial r}dr + \frac{\partial P}{\partial z}dz\right] \quad \text{(A2)}$$

$$\text{where} \quad a = \frac{f'[P(r,z,v)]}{1 - f'[P(r,z,v)]\frac{\partial P}{\partial v}} \quad \text{(A3)}$$

Then by implicit differentiation:

$$\frac{\partial v}{\partial r} = a\frac{\partial P}{\partial r} \text{ and } \frac{\partial v}{\partial z} = a\frac{\partial P}{\partial Z} \quad \text{(A4)}$$

The partial derivatives of profit with respect to freight rate and service quality are obtained from equation (9):

$$\frac{\partial \pi}{\partial r} = \left(\frac{\partial P}{\partial r} + \frac{\partial P}{\partial v}\frac{\partial v}{\partial r}\right)v + P(r,r,v)\frac{\partial T}{\partial r} - \frac{\partial T}{\partial v}\frac{\partial v}{\partial r} \quad \text{(A5)}$$

$$\frac{\partial \pi}{\partial z} = \left(\frac{\partial p}{\partial z} + \frac{\partial P}{\partial v}\frac{\partial v}{\partial z}\right)v + P(r,z,v)\frac{\partial v}{\partial z} - \frac{\partial T}{\partial v}\frac{\partial v}{\partial z} - \frac{\partial T}{\partial z} \quad \text{(A6)}$$

The first order conditions of profit maximization are derived by setting equations (A5) and (A6) equal to zero, substituting in equations (A4), and combining terms:

$$0 = \left[\left(\frac{\partial P}{\partial v}v + P(r,z,v) - \frac{\partial T}{\partial v}\right)a + v\right]\frac{\partial P}{\partial r} \quad \text{(A7)}$$

$$0 = \left[\left(\frac{\partial P}{\partial v}v + P(r,z,v) - \frac{\partial TT}{\partial v}\right)a + v\right]\frac{\partial P}{\partial z} - \frac{\partial T}{\partial z} \quad \text{(A8)}$$

From equation (11):

$$\partial P/\partial r = 1 \quad \text{(A9)}$$

Substituting equation (A9) into equation (A7) forces the entire left hand factor of equation (A7) to zero:

$$0 = \left(\frac{\partial P}{\partial v}v + P(r,z,v) - \frac{\partial T}{\partial v}\right)a + v \quad \text{(A10)}$$

Equation (12) is equivalent to equation (A10); equation (13) is obtained by substituting equation (A10) into equation (A8).

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END NOTES

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1. This paper is largely based on material presented in the author's Ph.D. dissertation, Brown (1988).
2. See Shapiro (1984), particularly Exhibit III.
3. An explicitly multi-shipper model is developed in Brown (1988).
4. Figure 2 was obtained by applying the quadratic equation to the numeric example counterpart of equation (6).
5. A more complicated analysis of carrier profit maximization based on equations (4) and (6) is presented in Brown (1988).
6. The QE (and CCM) curves in Figures 2 and 4 were obtained with the numeric counterpart of equation (6) and the quality policy functions.
7. See note 6.
8. See Wyckoff (1976).
9. This equivalency is demonstrated by deriving dT^q/dv with equations (17) and (18), and substituting in equation (13).
10. This measure of scale economies is taken from Baumol, Panzar and Willig (1982). Its reciprocal is also a common measure of returns-to-scale.
11. Equation (35) is based on the full cost-full price formulation. A simpler equivalent, based on the carrier cost-freight rate formulation, is presented in Brown (1988).
12. These curves were obtained by numerically solving equation (6) and the carrier cost-freight rate equivalent of equation (35) over a range of z.
13. These comparisons are along the rate regulation curves.
14. Douglas and Miller (1974) describe a similar tradeoff between regulated airfares and schedule service quality.