TOTAL FACTOR PRODUCTIVITY MEASUREMENT IN TRANSPORT INDUSTRIES

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1. INTRODUCTION

Issues regarding productivity of economic activity have been the focus of many recent studies. The efforts to assess productivity levels and rates of growth have been of particular interest in regulated industries. This is so because productivity growth appears to have declined sharply in the last decades. The apparent decline in productivity is particularly alarming given pressures currently induced by inflation and resource shortages.

Although our understanding of the numerous factors contributing to productivity differentials has greatly improved, the necessity of further developing reliable measures of regulated sector productivity is vastly realized. This is particularly true at the firm level.

Total factor productivity in the transportation sector has been steadily declining during the past decade with the most apparent decline realized in the trucking industry. Table 1 summarizes the rates of growth for the (U.S.) regulated sector as estimated by Gollop and Jorgenson (1980). Immediately obvious is that the trucking industry exhibits the worst performance in terms of productivity growth among the transport modes. This gloomy picture might have led many of the researchers to focus on the production side of the industry rather than on the traditional market structure and rate analysis.

Table 1

AVERAGE ANNUAL RATES OF TOTAL FACTOR PRODUCTIVITY GROWTH (U.S.)

Industry	1948-1966 (%)	1966-1973 (%)
Trucking	3.6	-0.3
Railroads	5.1	1.7
Airlines	9.7	3.5
Pipelines	8.1	6.5
Gas Utilities	3.2	0.4
Electric Utilities	5.6	-0.4
Telephone	3.4	1.2

SOURCE: Gollop and Jorgenson (1980), Table 36.

Several improvements in the analytical aspects of productivity measurement have helped us to gain insights into previously insurmountable problems. In particular, developments in and application of duality theory have helped to resolve problems related to econometric estimation of the structure of technology; improvements in aggregation methodology and functional forms have contributed to a more precise specification and measurement of the production technology. Despite, however, these recent improvements, much more work has to be done in order for researchers to be able to understand the productivity "black box".

The purpose of the present paper is to present a unified body of knowledge pertaining to productivity measurement in regulated transport industries. In addition, we provide an extension to the existing methodology. Such extension allows investigators to directly account for the specific characteristics of regulated transport industries.

2. GENERAL CHARACTERISTICS OF REGULATED TRANSPORT INDUSTRIES

Regulated transport industries feature several important characteristics which, if ignored, may contribute to serious misspecifications of the estimated underlying technology and thus, wrong conclusions as to the resulting productivity differentials will be claimed.

The specific characteristics common to transport industries can be broadly categorized as (i) economies of scale, (ii) technical change, (iii) capacity utilization, (iv) joint and/or common costs, (v) heterogeneous output, (vi) non-marginal cost pricing and (vii) regulatory constraints (rate of return, operating authorities, etc.). Cowing and Stevenson (1981) discuss several of these aspects characteristics and it will suffice for the present purpose to briefly sketch them here.

The majority of transport industries are subject to economies of scale. This is particularly true with respect to railroads, pipelines, marine and possibly trucking.[1] The failure to consider this characteristic will lead to biased productivity measures. Similarly, embodied technical change which is not taken in consideration leads to biased productivity estimates. This is particularly important, e.g., in the trucking industry where substantial technological improvements have been introduced in order to conserve energy.

Capacity utilization is of prime importance, particularly so in the regulated sectors of the transport industry. Regulatory constraints often put a wedge between the available stocks (capital, e.g.) and the flows of services generated from such. The assumption, often made, of the proportionality of flows to stocks and hence maximum rates of utilization cause serious misspecifications of technology. Moreover, the neglect of sub-optimal levels of factor utilization may bring us to derive the wrong policy implications. For instance, one may conclude (based on some structural estimation of the production structure) that since small firms are disadvantaged with respect to scale economies they cannot successfully compete with large firms benefitting from large scale economies.[2] If, however, small firms exhibit higher levels of capacity utilization, *at every output level*, then they may provide services at lower unit cost (at every output level).[3] Whether this is true is an empirical question, of course; however, the point to be emphasized is that the theoretical construct should enable the empirical application to detect such problems and *decompose* productivity differentials into the various sources.

In industries where problems of joint output or costs are present, the marginal-cost pricing does not usually exist (price discrimination). This phenomenon induces allocative distortions that should directly be accounted for if productivity measures are to be meaningful.[4]

Finally, the fact that transport firms produce heterogeneous outputs, though generically identical (e.g., ten-mile), and the fact that the various output characteristics may directly be affected by regulatory constraints (back haul, route and commodity restrictions in the case of trucking) should directly be accounted for. This is particularly important at the firm level. This is so because regulatory tightness may substantially vary across firms.

Thus, several modifications and extensions are to be made before we can use empirical tools to derive policy sensitive and sensible results. In the ensuing sections we present methodology capable of dealing with the problems discussed earlier.

3. MEASUREMENT OF TOTAL FACTOR PRODUCTIVITY IN THE TRANSPORT SECTOR

The measurement of productivity attempts to assess the performance of industries and/or individual firms in using real resources to produce goods and services. There are two basic constructs for analyzing the structure of technology; one is the production function and the other is the cost function. Since the direct estimation of production functions is problematic,[5] and since recent advances in duality theory enable us to use the cost function without loss of information, productivity analysis can be carried out through its analogue -- cost efficiency. The cost efficiency concept is defined as real production cost per unit of output and is directly linked to the cost function. The cost function is defined as that function specifying the minimum costs of producting a given level of output and a vector of input prices. Formally, the cost function is

$$C = g(\underline{w},\underline{y}) \tag{1}$$

which solves

$$\min_{x}\{\underline{x} \cdot \underline{w} \mid F(\underline{x},\underline{y}) = 0\} \tag{2}$$

where $\underline{x}$ is a vector of input quantities, $\underline{w}$ is a vector of corresponding input prices, $\underline{y}$ is a vector of outputs, F is the production function and C represents minimum cost. The expression $\underline{w} \cdot \underline{x} \equiv \sum_{i}^{n} w_i x_i$ is the inner product of $\underline{x}$ and $\underline{w}$.

The above cost function dressed with some functional form, say the translog, is what researchers of transport technologies have been estimating. However, this cost function does not (explicitly) allow the decomposition of cost (efficiency) into the various characteristics alluded to earlier. Let us include these characteristics in a vector called T, and represent (following McFaden (1978)) the cost function as,

$$C = g(\underline{w},\underline{y},\underline{T}) \tag{3}$$

which solves

$$\min\{\underline{x} \cdot \underline{w} \mid F(\underline{x},\underline{y},\underline{T}) = 0\}$$

where all variables are as defined earlier.

Following Jorgenson and Nishimizu (1978) and Denny and Fuss (1980), consider the production process in region (firm) d as represented by the cost function (3) as[6]

$$C_d = g_d(\underline{w}_d, Y_d, \underline{T}_d) \tag{5}$$

The logarithm of the cost function g_d can be approximated by a quadratic function in the logarithms of $\underline{w}_d$, Y_d, $\underline{T}_d$ and D. D is a vector of dummy variables, one for each region (or firm size) other than the reference region. The approximation is presented in the following manner,

$$\log C_d = g(\log \underline{w}_d, \log Y_d, \log \underline{T}_d, \underline{D}) \tag{6}$$

where g specified as a quadratic function.[7] Differences in regional (type of firm) cost functions are achieved by the introduction of D in (6) which allows the constant and linear terms in the quadratic approximation to differ across regions (or firm sizes).

The differences in costs of producing output y in region (firm) d vs. region o are characterized by the application of Diewert's (1976) Quadratic Lemma to the logarithmic quadratic cost function (6) as follows,

$$\begin{aligned}\Delta\log C &= \log C_d - \log C_o \\ &= 1/2\left[\frac{\partial g}{\partial D_d}\Big|_d + \frac{\partial g}{\partial D_d}\Big|_o\right] \cdot [D_d - D_o] \\ &+ 1/2\sum_i\left[\frac{\partial g}{\partial \log w_i}\Big|_{w_i = w_{id}} + \frac{\partial g}{\partial \log w_i}\Big|_{w_i = w_{io}}\right] \\ &\cdot [\log w_{id} - \log w_{io}] \\ &+ 1/2\left[\frac{\partial g}{\partial \log Y}\Big|_{Y=Y_d} + \frac{\partial g}{\partial \log Y}\Big|_{Y=Y_o}\right] \cdot [\log Y_d - \log Y_o] \\ &+ 1/2\sum_j\left[\frac{\partial g}{\partial \log T_j}\Big|_{T_j=T_{jd}} + \frac{\partial g}{\partial \log T_j}\Big|_{T_j=T_{jo}}\right] \\ &\cdot [\log T_{jd} - \log T_{jo}]\end{aligned} \tag{7}$$

Letting

$$\frac{\partial g}{\partial \log T_j} = \frac{\partial \log C}{\partial \log T_j} \equiv \mu_{jk} \qquad k = d,o \tag{8}$$

represent the cost elasticity of the arguments contained in the T vector (i.e., capacity utilization, shipment characteristics, etc.)

$$\frac{\partial g}{\partial \log Y} = \frac{\partial \log C}{\partial \log Y} \equiv \varepsilon_{cy_k} \qquad k = d,o \tag{9}$$

represent the cost elasticity of output (= the inverse of the measure of scale economy),

$$1/2[\frac{\partial g}{\partial D_d}|_d + \frac{\partial g}{\partial D_d}|_o] \cdot [D_d - D_o] \equiv \Theta_{do} \tag{10}$$

represent regional (or firm size) effect, and

$$\frac{\partial g}{\partial \log w_i} = \frac{\partial \log C}{\partial \log w_i} \equiv S_i \tag{11}$$

represent the $i^{\underline{th}}$ factor share in total cost. Then

$$\begin{aligned} \log C = {} & 1/2 \sum_i [S_{id} + S_{io}]\cdot[\log w_{id} - \log w_{io}] \\ & + 1/2[\varepsilon_{cy_d} + \varepsilon_{cy_o}] [\log Y_d - \log Y_o] \\ & + 1/2\sum_j[\mu_{jd} + \mu_{jo}] [\log T_{jd} - \log T_{jo}] \\ & + \Theta_{do} \end{aligned} \tag{12}$$

which upon rearrangement becomes,[8]

$$\begin{aligned} \Theta_{do} = {} & [\log C_d - \log C_o] - 1/2[\varepsilon_{cy_d} + \varepsilon_{cy_o}]\cdot[\log Y_d - \log Y_o] \\ & - 1/2\sum_i[S_{id} + S_{io}]\cdot[\log w_{id} - \log w_{io}] \\ & - 1/2\sum_j[\mu_{jd} + \mu_{jo}]\cdot[\log T_{jd} - \log T_{jo}] \end{aligned} \tag{13}$$

The value represented by Θ_{do} is the efficiency differential between regions (or firms) d and o after accounting for differences in factor prices, scale economies and a host of variables (indexed j) such as levels of capacity utilization, average length of haul, average shipment size, percent shipments carried in LTL lots, technical change, etc.

Note that "simple technologies" characterized by constant returns to scale, uniform levels of capacity utilization, etc., are just a special case of (13), i.e., $1/2[\varepsilon_{cy_d} + \varepsilon_{cy_o}]$, in (13) would equal unity in the case of constant returns to scale, and the characteristics included in the last term of (13) would equal zero if utilization rates, e.g., would be ignored. In such a case cost efficiency differentials across firms would be explained only by factor price effects and levels of output.

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The above method is very useful not only in comparing cost efficiency across firms but also in comparing average costs across these firms. In order to do this we rearrange (13) as follows,

$$\log(\frac{C_d}{Y_d}) - \log(\frac{C_o}{Y_o}) = 1/2\sum_i[S_{id} + S_{io}]\cdot[\log w_{id} - \log w_{io}]$$

$$+ \{1/2[\varepsilon_{cy_d} + \varepsilon_{cy_o}]\cdot[\log Y_d - \log Y_o]$$

$$- [\log Y_d - \log Y_o]\}$$

$$+ 1/2\sum_j[\mu_{jd} + \mu_{jo}]\cdot[\log T_{jd} - \log T_{jo}]$$

$$+ \Theta_{do} \tag{14}$$

The LHS of (14) represent average cost differential between firms (regions) d and o. This average cost differential is the result of: (i) factor price effect, the first term on the RHS of (14); (ii) non-constant economies of scale, the terms in braces: (iii) the effects of factors such as levels of capacity utilization (etc.), the third term; and (iv) pure efficiency differential Θ_{do}.

The importance of (14) is that it enables us to measure the "true" efficiency differentials across firms or relative differences in average costs. It may be the case, e.g., that some firms although disadvantaged with respect to scale, have the advantage in unit costs. For the sake of brevity we demonstrate such an example using Figure 1.

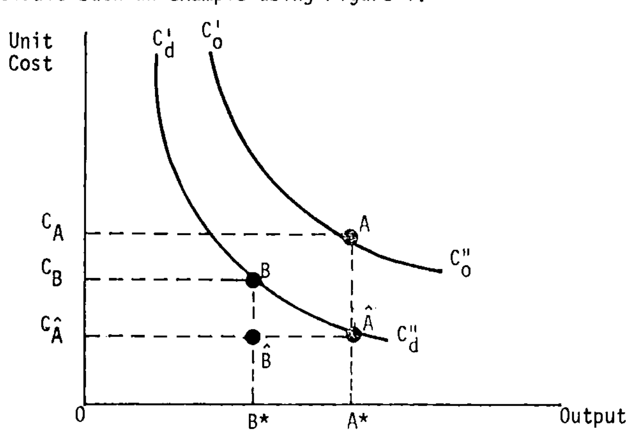

Figure 1

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Suppose we observe two firms o and d in a specific point in time. Further, suppose these firms are observed at points A and B respectively, which are assumed to be located on their respective unit cost curves ($C_o'C_o''$ and $C_d'C_d''$, respectively), implying that production is behaviorally efficient (see Denny and Fuss (1982)). It is apparent that firm o has a scale advantage producing 0 A* > 0 B* units of output. However, despite firm o's scale advantage, its unit cost exceeds that of firm d by an amount $C_A C_B$. Two forces are at work here, scale effect and capacity utilization effect. If it were the case that both firms' levels of capacity utilization were the same and equal to firm d's level, then firm o's unit costs would be $OC_{\hat{A}} < OC_B$. However, since firm d's level of capacity utilization is superior to that of firm o's (at any level of output) and by a substantial magnitude, the net effect is lower unit cost for firm d.

Thus, to conclude (as does Harmatuck (1981)) that small firms cannot compete with large firms due to disadvantageous scale may not be correct. We have shown that there are a host of factors contributing to the performance of transport firms. These factors should be taken into consideration when measuring productivity and cost efficiency. The decomposition method as applied and extended in this paper should be a useful tool for those attempting to unveil the productivity mystery.

4. CONCLUSIONS

A brief survey of the existing techniques for measuring total factor productivity in transport industry was provided. The existing techniques were modified and extended in order to be able to account for characteristics specific to transport industries, such as scale economies, levels of capacity utilization and other variables which may be affected by regulatory constraints. It is hoped that future research, by utilizing such techniques, will be able to better explain the productivity slowdown in the transport sector so evident in the last decade.

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FOOTNOTES

1. Whether trucking is subject to economies of scale has not been resolved as yet. Though, several studies that have appeared recently do find scale economies. See Cairns and Kirk (1980), Chow (1980) and Kim (1982) in the Canadian context and Harmatuck (1981) in the U.S. context.

2. See, e.g., Harmatuck's (1981) conclusion.

3. Kim (1982) found that even though larger carriers had the advantage of large scale, they exhibited higher unit costs than small carriers, mainly due to inferior levels of truck utilization (at every output level).

4. See Denny, Fuss and Waverman (1981).

5. See Fuss, McFadden and Mundlak (1978) for a very useful and clear elaboration regarding this point.

6. For the sake of expositional brevity, we treat output as homogeneous and hence suppress the bar underlying it. This does not affect either the analysis or the results. The extension to the multi-output case is straightforward.

7. The approximation assumes the cost function in each region (firm size) to have common elements since g_d in (5) is replaced by g in (6). Denny and Fuss (1980) indicate that "any method of measuring productivity without econometric estimation of the production technology implies that the underlying technology has common elements" (p. 27).

8. Note that if $\varepsilon_{cy_k} \neq 1$ and $\mu_{jk} \neq 1$ then the values for these elasticities should be structurally estimated and an error term should be added to (13).

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