

TOTAL FACTOR PRODUCTIVITY IN BUS TRANSPORT

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1. INTRODUCTION

Efficiency of economic activity has been one of the main objectives of public policy. This efficiency objective has also been the prime focus of researchers analysing the bus transport sector. Most of the research so far done in this sector has concentrated on the question of scale economy, and a recent paper published in this journal investigated cost elasticities, factor demand and factor substitution (Berechman, 1983). The important question of productivity (or efficiency) growth (level) in the provision of bus service has, however, been largely neglected.

Though our understanding of the numerous factors contributing to productivity differentials has greatly improved, it is widely appreciated that reliable measures of transport sector productivity must be further developed.

Several improvements in the analytical aspects of productivity measurement have thrown light on 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 these recent improvements, however, much more work has to be done to enable researchers to understand the productivity "black box".

The purpose of this paper is to present a unified body of knowledge pertaining to productivity measurement and apply it to the bus transport sector. More specifically, we measure intertemporal efficiency differentials¹ in the bus transport sector, and in addition we calculate average cost differentials through time. These average cost differentials are then decomposed into the responsible factors, such as factor inputs, scale economy and efficiency.

The paper consists of a methodological section (section 2), followed by the implementation of the methodology (section 3). Empirical results are presented in section 4.

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¹ This is the dual problem of total factor productivity.

2. MEASUREMENT OF TOTAL FACTOR PRODUCTIVITY IN THE TRANSPORT SECTOR

The measurement of productivity is an attempt 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 analysing 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,² 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 the function specifying the minimum costs of producing a given level of output with a given vector of input prices. Formally, the cost function is

$$C = g(w, y) \quad (1)$$

which solves

$$\min_x [x \cdot w | F(x, y) = 0] \quad (2)$$

where x is a vector of input quantities, w is a vector of corresponding input prices, y is output, F is the production function and C represents minimum cost. The expression

$$x \cdot w \equiv \sum_i^n w_i x_i$$

is the inner product of x and w .

The above cost function dressed with some functional form, such as the translog, is what researchers have recently been estimating.³

Following Denny, Fuss and May (1981), consider the production process at time d as represented by the cost function (1) as

$$C_d = g_d(w_d, y_d, T_d) \quad (3)$$

where T_d is an index of technology at time d .

The logarithm of the cost function g_d can be approximated by a quadratic function in the logarithms of w_d , y_d , and T_d in the following manner (Denny, Fuss and May, 1981):

² See Fuss, McFadden and Mundlak (1978) for a very useful and clear elaboration of this point.

³ The use of the translog function has become popular in recent years because it does not impose restrictions on the elasticities of substitution, and allows for a U-shaped average cost curve. For a comparison of the performance of the translog and other (flexible) functional forms see Guilkey, Knox Lovell and Sickles (1983). For the empirical application of the translog in studies related to transport see, for example, Harmatuck (1981), Kim (1984), Spady and Friedlaender (1978), Wang Chiang and Friedlaender (1984), and Brown, Caves and Christensen (1979).

$$\log C_d = g(\log w_d, \log y_d, \log T_d) \quad (4)$$

where g is specified as a quadratic function.⁴

The differences in costs producing output y at time d instead of time o are defined by the application of Diewert's (1976) quadratic lemma to the logarithmic quadratic cost function (4) as follows:⁵

$$\begin{aligned} \Delta \log C &= \log C_d - \log C_o & (5) \\ &= \frac{1}{2} \sum_i \left[\frac{\partial g}{\partial \log w_i} \Big|_{w_i = w_{id}} + \frac{\partial g}{\partial \log w_i} \Big|_{w_i = w_{io}} \right] \cdot [\log w_{id} - \log w_{io}] \\ &\quad + \frac{1}{2} \left[\frac{\partial g}{\partial \log y} \Big|_{y = y_d} + \frac{\partial g}{\partial \log y} \Big|_{y = y_o} \right] \cdot [\log y_d - \log y_o] \\ &\quad + \frac{1}{2} \left[\frac{\partial g}{\partial \log T} \Big|_{T = T_d} + \frac{\partial g}{\partial \log T} \Big|_{T = T_o} \right] \cdot [\log T_d - \log T_o] \end{aligned}$$

Let

$$\mu_{do} = \frac{1}{2} \left[\frac{\partial g}{\partial \log T} \Big|_{T = T_d} + \frac{\partial g}{\partial \log T} \Big|_{T = T_o} \right] \cdot [\log T_d - \log T_o] \quad (6)$$

represent the intertemporal effect,

$$\frac{\partial g}{\partial \log y} = \frac{\partial \log C}{\partial \log y} \equiv \epsilon_{cyk} \quad k = d, o \quad (7)$$

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

$$\frac{\partial g}{\partial \log w_i} = \frac{\partial \log C}{\partial \log w_i} \equiv S_i \quad (8)$$

represent the i th factor share in total cost. Then

⁴ The approximation assumes the cost functions in all time periods to have common elements, since g_d in (3) is replaced by g in (4).

⁵ The efficiency formula used in this paper is based on application of the quadratic lemma, which shows that if a function is quadratic, say

$$f(z) = a_o + \sum_i a_i z_i + \sum_i \sum_j a_{ij} z_i z_j$$

where the a_i , a_{ij} are constants, then

$$f(z^1) - f(z^0) = \frac{1}{2} [\nabla f(z^1) + \nabla f(z^0)] \cdot (z^1 - z^0)$$

where $\nabla f(z^r)$ is the vector of first-order partial derivatives of f evaluated at z^r .

$$\begin{aligned} \Delta \log C = & \frac{1}{2} \sum_i [S_{id} + S_{io}] \cdot [\log w_{id} - \log w_{io}] \\ & + \frac{1}{2} [\epsilon_{cy_d} + \epsilon_{cy_o}] \cdot [\log y_d - \log y_o] + \mu_{do} \end{aligned} \quad (9)$$

which upon rearrangement becomes

$$\begin{aligned} \mu_{do} = & [\log C_d - \log C_o] - \frac{1}{2} [\epsilon_{cy_d} + \epsilon_{cy_o}] \cdot [\log y_d - \log y_o] \\ & - \frac{1}{2} \sum_i [S_{id} + S_{io}] \cdot [\log w_{id} - \log w_{io}] \end{aligned} \quad (10)$$

The value represented by μ_{do} is the Tornqvist approximation to the negative of the dual rate of intertemporal cost efficiency growth (see Denny, Fuss and May, 1981).

Note that "simple technologies", the ones characterised by (for example) constant returns to scale, are just a special case of (10); that is, $\frac{1}{2}[\epsilon_{cy_d} + \epsilon_{cy_o}]$ in (10) would equal unity in the case of constant returns to scale. Cost efficiency differentials between time periods would then be explained only by factor price effects and levels of output.

This method is very useful, not only in comparing cost efficiency but also in comparing average costs between time periods. In order to do this we rearrange (10) as follows:

$$\begin{aligned} \log(C_d/y_d) - \log(C_o/y_o) = & \frac{1}{2} \sum_i [S_{id} + S_{io}] \cdot [\log w_{id} - \log w_{io}] \\ & + \left\{ \frac{1}{2} [\epsilon_{cy_d} + \epsilon_{cy_o}] \cdot [\log y_d - \log y_o] \right. \\ & \left. - [\log y_d - \log y_o] \right\} + \mu_{do} \end{aligned} \quad (11)$$

The LHS of (11) represents average cost differential between time periods d and o . This average cost differential is the result of: (i) factor inputs effect, the first term on the RHS of (11); (ii) non-constant returns to scale, the terms in braces; and (iii) pure efficiency differential μ_{do} .

The usefulness of equation (11) is that it enables us to decompose the average cost differential (growth) into effects such as factor inputs and pure efficiency, both resulting in the displacement of the average cost curve, as well as the effect of scale economies resulting in a movement along an average cost curve. For the sake of brevity we demonstrate such an example in Figure 1.

Suppose we observe an industry in two time periods o and d . Further, suppose this industry is observed at points A and B, which are assumed to be located on the industry's respective unit cost curves ($C'_o C''_o$ and $C'_d C''_d$); this implies that production is behaviourally efficient (see Denny and Fuss, 1982). It is apparent that the industry at time period o has a scale advantage, producing $OA^* > OB^*$ units of output. However, despite the scale advantage at time o , its unit cost exceeds that of time d by an amount $C_A C_B$. Two forces are at work here, scale effect and (for example) efficiency effect. If the levels of efficiency in both time periods were the same and equal to the level of d , then the unit costs at time o would be $OC'_A < OC'_B$. However, since the level of efficiency at time d is superior to that at time o (at any level of output) and by a substantial magnitude, the net effect is a lower unit cost in time d .

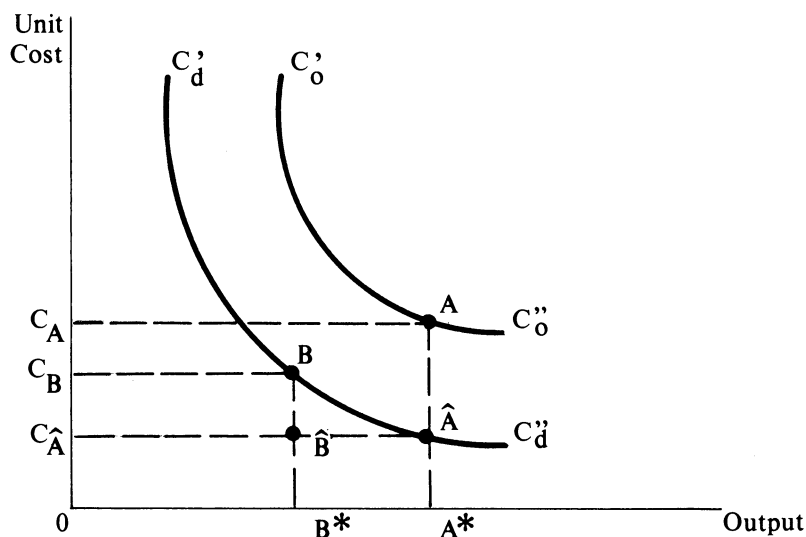


FIGURE 1

3. IMPLEMENTATION OF THE METHODOLOGY

The proposed methodology as presented in the previous section is applied to the intercity bus transport sector. In a recent article published in this journal, Berechman (1983) estimates costs, economies of scale and factor demand in bus transport. In this study we make use of his data set in order to complement his study by calculating cost efficiency and average cost differentials.

The data necessary for our study are taken directly from Berechman, where they are described in detail (see appendix). Specifically, we employ his data on output (y), the price of labour (w), the price of capital (r), the share of labour in total costs (S_L), the share of capital in total costs (S_K) and total costs (C).⁶

Berechman's paper shows that he found significant economies of scale in the Israeli bus sector. Consequently, there is a need to estimate the degree of scale economy for each of the time periods included in the sample in order to utilise equations (10) and (11).

Using the translog cost function of the form

⁶ We note at this stage that output is measured in terms of revenue in the absence of a reliable physical measure. This may give an upward bias to the resulting cost efficiency growth because of subsidies. For more elaboration see section 4.

$$\log C = A + \alpha \log y + \sum_i^n \beta_i \log w_i + \frac{1}{2} \delta (\log y)^2 + \frac{1}{2} \sum_i^n \sum_j^n \gamma_{ij} \log w_i \log w_j + \sum_i^n \rho_i \log y \log w_i, \quad (12)$$

one of the cost share equations of the form

$$\frac{\partial \log C}{\partial \log w_i} \equiv S_i = \beta_i + \sum_j \gamma_{ij} \log w_j + \rho_i \log y \quad (13)$$

and the parametric restrictions ensuring linear homogeneity and symmetry, $\sum \beta_i = 1$, $\sum \rho_i = 0$, $\sum \gamma_{ij} = 0$, $\gamma_{ij} = \gamma_{ji}$ we can estimate the degree of cost elasticity (of output) ϵ_{cy_k} (which is a measure of scale economy) as follows:

$$\epsilon_{cy_k} = \frac{\partial \log C}{\partial \log y} = \alpha + \delta \log y + \rho_j \log w_j \quad (14)$$

Since the ρ_j parameters in (14) were not significantly different from zero, ϵ_{cy_k} was set to equal $\alpha + \delta \log y$.

The data described above, and the parameter estimates of the cost elasticity of output derived from the joint estimation of equations (12) and (13), were used to derive the cost efficiency and the average cost differentials in equations (10) and (11).⁷ We note at this stage that the efficiency measure in (10), that is, the μ_{do} , is interpreted as the logarithmic difference in total costs from producing output (y) at time period d instead of time period o . In the presentation of the results we define efficiency = $\exp(\mu_{do})$ and normalise the base (reference) period (the first quarter of 1972) to equal 100. This standardisation has the result that an efficiency measure greater than 100 for any period has the meaning of lower efficiency, and vice versa.

The resulting efficiency differentials are presented in Table 1. For clarity and ease of interpretation, the figures used in Table 1 are the annual average efficiency levels; that is, they represent the average of the efficiency levels of the quarters in each year.

Table 1 shows that all years investigated have higher levels of efficiency than the first quarter of 1972 – the base period. The average increase in efficiency from 1972 to 1979 is 9.44 %, which is quite a favourable result. There is a general trend of increase in efficiency, but the last year (1979) investigated in this study has a lower level of efficiency than all previous years in the sample (excluding the base period).

To see whether this decline in efficiency is a beginning of a down trend for the industry, further research using more recent data is needed. However, it is interesting to note that the ratio of the price of capital to the price of labour has

⁷ The estimates (t -values) of α and δ are 0.859 (4.531) and -0.551 (-2.371) respectively. Using these parameter estimates, we calculated the cost elasticity ϵ_{cy_k} .

TABLE 1

Efficiency Differentials – Annual Averages

<i>Year</i>	<i>Efficiency exp (μ_{do})</i>	<i>Rank</i> ^a
1972	94.44	7
1973	93.92	6
1974	90.53	4
1975	86.11	3
1976	90.67	5
1977	85.71	2
1978	84.27	1
1979	98.85	8

^a The ranking is in descending order of efficiency; i.e. rank 1 is more efficient than rank 2.

markedly increased in 1979 (by an average of about 50% over previous years). This increase in the price ratio may have caused temporary adjustment costs of optimisation, and may not necessarily imply a down trend in operating efficiency.⁸

In order to gain further knowledge of the efficiency of bus transport we use equation (11) to find the intertemporal differentials of average cost levels. Moreover, we decompose the average cost differentials into the contributing sources.⁹ Specifically, we present the relative importance of labour, capital, non-constant returns to scale and the pure efficiency parameter in the average cost differentials. This information is presented in Table 2.

It is clear from Table 2 that there is a general trend of decline in average cost over the sample period, with the exception of the last year (1979). Throughout the sample period average cost is below 100 (the level of average cost in the base period). In 1979 average cost was 12.7% higher than in the base period. The

⁸ We note that this increase in the price ratio was due partly to a decline in the real wage and partly to an increase in the price of capital caused by the introduction of new, more efficient buses. If this trend is to be continued we can expect future increases in cost efficiency, after the initial adjustment period is over.

⁹ A similar approach, though using different methodology, is presented in Denny, Fuss and Waverman (1981) for the Canadian telecommunications industry.

TABLE 2

Average Cost (AC) Differentials – Annual Averages

Year	AC	Rank ^b	AC explained by: ^a				
			Labour	Capital	Non-constant Returns to Scale	Efficiency	Residual from Estimation ^c
1972	94.8	5	3.03	1.07	-3.41	-5.56	4.87
1973	96.3	7	3.15	0.13	-0.57	-6.08	3.37
1974	95.6	6	8.58	-2.18	-0.35	-9.47	3.42
1975	93.7	4	11.35	-1.82	-0.37	-13.89	4.73
1976	90.2	2	5.02	-4.04	-1.38	-9.33	9.73
1977	89.6	1	17.08	-4.87	-6.42	-14.29	8.50
1978	93.4	3	27.36	-6.79	-6.62	-15.73	1.78
1979	112.7	8	17.78	3.44	-6.07	-1.15	-14.00

^a Percentages.

^b The ranking is in a decreasing order of performance, i.e. rank 1 has the interpretation that AC in 1977 was the lowest.

^c This is the residual caused by the fact that the scale elasticity contained in equation (11) is based on estimated parameters from the translog [equation (14)].

average annual cost is 95.8, meaning that the average cost of the sample period was 4.2 percentage points below the average cost of the base period. The decomposition of average cost differential into the various factors indicates that labour has caused an upward shift of average cost of about 11.7%; capital has caused a downshift of 1.9%; scale has caused a reduction of about 3.1%, and the pure efficiency effect has contributed to a downshift of 9.4% of the average cost. We note also that the unexplained portion of the average cost differential amounts to about 2.7%.¹⁰ The most important factor affecting average cost has been labour,

¹⁰ The residual from estimation can be viewed as an accounting discrepancy resulting from the need to estimate cost elasticities. It is positive in some periods and negative in others. However, it averages out over the whole period, as expected, since its source is regression error. On this point see Denny, Fuss and Waverman (1981).

which had its largest effect in 1978 (27.36%). However, the effects of pure efficiency, scale and capital outweigh that of labour, and the result is an overall decline in average cost throughout the sample period. In 1979, the worst year in terms of average cost, the large upward effects of labour and capital outweigh the strong effect of scale and the small effect of efficiency, with a resulting increase in average cost. This is consistent with our previous discussion, which highlighted the fact that in 1979 the ratio of the price of capital to the price of labour was at its highest. This higher factor price ratio may reflect both the introduction of new, more efficient, expensive buses and the decline in real wages. The results for that year should therefore not be taken as indicating the start of a downtrend in bus operating efficiency. When adjustment has taken place we may see increased efficiency. But a conclusion on this point awaits further research using more recent data.

4. CONCLUSIONS

In this paper we have applied a new technique to measure total factor productivity. The dual to total factor productivity, namely, cost efficiency, has been presented and applied to the bus transport sector. According to our results, average cost has been declining and efficiency has been rising in bus transport. This contrasts with experiences in other transport sectors (see Gallop and Jorgenson, 1980, Table 36). However, our results should be interpreted with caution, since output has been measured in terms of revenue (in the absence of a measure of reliable physical output). If government subsidies to this sector are high, then output (as it is measured here) may be upward biased, and this may account for the trend of increased efficiency and decrease in average cost. Nevertheless, the methodology used in this paper may prove useful for future students of transport efficiency and productivity.

APPENDIX

Data

The data used in this study are taken from Berechman (1983), who collected data on input prices and quantities as well as on output from the Israeli bus transport sector. Since the data and their sources are described in detail in Berechman's study, I will only sketch the main variables here.

Output is measured in terms of revenue in fixed prices (IL million). The price of labour w includes wages, taxes and social benefits, and is measured per actual man-day. The price of capital r is arrived at by deflating total expenditure on buses by the number of buses and then deflating by the industrial price index. Costs are arrived at by summing up the expenditures on labour and capital. These variables and their quarterly data are presented on page 17 in Berechman (1983).

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