

MEASURING PRODUCTIVITY IN TRANSPORT:
SOME LESSONS FROM STUDIES IN THE U.S.A.

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ABSTRACT:

Improving productivity is a major issue in many, if not all, transport industries in Australia. In this regard, it is common to refer to performance measures as indicators of relative efficiency. These are usually in the form of a ratio between some measure of output or cost, and one type of input. However, these performance measures provide little in the way of rigour, lacking, as they do, a strong theoretical foundation. It will be claimed in this paper that a more satisfactory account of productivity differences can be derived from the economic theory of production. To date, though, there is very little evidence of applied work in this country which has proceeded on this basis.

This is in contrast to the situation in the U.S.A. where there is a well-developed body of economic theory which has been applied to the analysis of production. Of particular interest, there have been a number of studies of the railway industry which have demonstrated some of the pitfalls which can be encountered in using simple measures of productivity change.

The present paper draws attention to these studies and examines some of the important implications which should be borne in mind in any future analyses of the subject. In particular, the lack of adequate data, especially in the case of capital, is noted. This situation severely limits the possibilities of carrying out applied work in productivity measurement.

INTRODUCTION

Given the adverse conditions which have been experienced by most, if not all, transport industries in Australia in recent times, the theme 'productivity and performance' has been raised on many occasions. In the case of several key sectors, the concern about lack of efficiency has been more of a long-standing one, so that the study of productivity is certainly worthy of the attention of transport researchers.

Perhaps a useful place to start in exemplifying the situation is with the case of ports. It has been said on many occasions that Australian ports are not as efficient as their overseas counterparts. For example, an investigation into the adequacy of Australia's ports found that:

'Concerning the overall adequacy of Australia's ports and their future needs, the strongest, most serious and most widely held view expressed was one of concern over the low labour productivity in some Australian ports and very high costs in all Australian ports.'

[Commission Of Inquiry (1976), p. 21]

That report found that port facilities, in themselves, were generally adequate but that labour productivity was very low. This view also tended to be supported by several speakers at a recent conference on shore-based shipping costs. Indeed, the views of the Chairman of the Australian National Line (ANL), Captain Bolitho, are particularly worthy of note. He stated that:

'Productivity then does matter to us all. It matters to ANL in that we have \$62 million tied up in non performing assets, a crippling burden at this critical stage of our existence. It matters to the workers in the shipping and stevedoring industries in that work available and hence job opportunities depend upon productivity to a substantial extent. And it matters to all Australian's in that to some extent, however slight, our standard of living depends upon the productivity of the waterfront.'

[Bureau of Transport Economics (1984), page 71.]

The situation was highlighted by pointing out that there were significant disparities between the productivity of ANL's terminals. For example, the rather large investment of \$42 million invested by ANL in its Port Botany terminal was not reflected in higher throughput per man. In comparison, there were assets valued at \$54,000 per man at Webb Dock to achieve a throughput of 324 TEU's per man in 1983⁽¹⁾. The Newstead terminal in Brisbane achieved a similar rate of cargo handling, but with only \$20,000 of assets per man. In contrast, each worker at Port Botany was matched by assets valued at \$91,000 and only achieved a throughput of 305 TEU's!

1. The TEU is a 'twenty-foot equivalent unit', the twenty-foot ISO container being the most common size (6.1 metres in length, 2.44 metres wide, and 2.6 metres high).

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Even with an array of statistics on output per unit of labour input and capital to output ratios, Captain Bolitho was unable to attribute responsibility for the apparent lack of productivity at Port Botany to any particular factor. Partly, at least, it is suspected that the reason for this stemmed from the lack a satisfactory way of examining productivity, for nowhere in his account was there an explanation of what he meant by productivity, except in terms of throughput per man. This, of course does not diminish in any way the importance of the situation he was describing.

It is appropriate to also consider the case of the railway industry. ARRO (1981) pointed out that, if railway managers had any freedom to move in reducing deficits, it had to be in the achievement of higher productivity levels from the factors of production employed. Although no detailed account of what was meant by this was given, the report did point out that the industry was particularly labour intensive and that higher labour productivity was essential to improved financial performance.

Thus, in both the case of the railways and ports, at least, there has been a preoccupation with improving labour productivity. What this paper argues is that statistics which purport to measure labour productivity, such as output per unit of labour input can be misleading. There is a need, therefore, to handle them with the utmost care. This will be demonstrated by reference to the relevant economic theory, and by examining the experience gained from a number of studies carried out in the U.S.A.. Hopefully, by bringing this work to the attention of a wide audience of transport researchers, more rigour can be achieved in productivity and performance studies. Furthermore, the need to improve data collection procedures will be emphasised.

PERFORMANCE MEASURES

Performance measures can simply take the form of a single variable, such as 'number of tonnes handled'. In some situations, comparisons of performance according to this measure might reveal differences in the level of productivity from period to period, or from one operation to another. The performance measure could also be expressed as in relative terms. For example, it might be important to monitor changes in market shares. However, the most common type of performance measure reflects the principles of constrained optimization. This is achieved by examining the amount of output that is produced for a given amount of input. Alternatively, the amount of an input for a given amount of output might be minimized.

Thus, performance measures are often found in the form of ratios. A good example can be found in the widely-used statistic, output per man-hour, or its companion, output per employee. It is also common to find comparisons between output and capital inputs, although it is usual to focus on particular types of assets. For example, it might be useful to compare the number of tonne-kilometres hauled per locomotive, or number of passengers per bus.

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The performance measure can be made to reflect operational characteristics, or it can be designed to place the attention on financial matters. What can be said in general about them, though, is that they are only capable of treating one or two variables at a single time. For this reason, it is possible to refer to them as 'partial productivity measures'. At best, they simply reflect the contribution of one factor to output. At worst, partial productivity measures could give a misleading account of the underlying causes of differences or of change. It has long been accepted that when, say, output per unit of labour varies, very little of substance is revealed by the fact alone.

Nowhere would this be more apparent than in the case of ports where the number of registered waterside workers has fallen from over 17,000 at the commencement of the previous decade to slightly more than 7,000 in 1982/83, a reduction of 60 per cent in the interval of 14 years. At the same time, the number of tonnes handled by waterside workers increased from 42 million to 58 million, a rise of around 40 per cent. Thus, a simple analysis of the statistics reveals that the number of thousand tonnes stevedored increased from 2.4 per man in 1969/70 to 8.2 per man in 1982/83. When it is acknowledged that hours worked per waterside worker have decreased over the period, the apparent improvement in productivity is even more dramatic. These statistics are set out in more detail in Table 1.

Table 1
Labour Productivity In Australian Ports:
1969/70-1982/83

YEAR	NO. OF WW	MAN-HOURS (thousand)	TONNES STV/DORED (thousand)	TONNES PER WW (thousand)	TONNES PER MAN-HOUR (thousand)
69/70	17688	28100	42200	2.4	1.5
70/71	16853	25100	46600	2.8	1.9
71/72	14592	20000	44700	3.1	2.2
72/73	13591	17900	41700	3.1	2.3
73/74	13375	19100	49300	3.7	2.6
74/75	13351	17800	51100	3.8	2.9
75/76	11860	12300	47700	4.0	3.9
76/77	10386	11600	50400	4.9	4.3
77/78	9823	10400	51900	5.3	5.0
78/79	9311	9900	58400	6.3	5.9
79/80	8816	9600	66800	7.6	7.0
80/81	8314	9200	65200	7.8	7.1
81/82	7944	8900	64400	8.1	7.2
82/83	7126	7700	58600	8.2	7.6

Source: Department of Transport, Sea Transport Statistics.

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Of course, the explanation of the statistics presented in the table must lie largely in the substitution of capital for labour, the change in the composition of throughput, and in productivity change as such. One way to improve this type of analysis is to report statistics on a more disaggregated basis. For example, the Bureau of Transport Economics (1984) distinguished between cargoes that were stevedored in terminals and those which were not⁽¹⁾. In the period 1977/78 to 1982/83, it was found that the number of tonnes handled per man-hour in terminals decreased from 4.3 to 3.9, whereas there was an increase overall from 5.0 to 7.6. The situation in the non-terminal, bulk area clearly had a major impact on this, as, for example, the number of tonnes loaded for overseas destinations increased from 62.8 per man-hour in 1977/78 to 129.9 in 1982/83.

ARRDO (1981) also appreciated the importance of reporting disaggregated figures, and favoured analysis at the market segment level. This view is apparent in references such as the Centre for Transportation Studies, Tomazinis (1975), Kneafsey (1975), and Rippin (1984). These studies advocated the use of a wide variety of performance statistics in a number of different contexts.

However, it is usually the case that discussions of performance measures produce lengthy lists of statistics, the Centre for Transportation Studies, for example, produced over 70 possible measures for use in railways without being comprehensive. However useful these statistics might be for managers at various levels of an organisation, they can provide little guidance in the overall analysis of productivity. A characteristic of these lists of performance measures is that they lack a rigorous theoretical foundation. Because of this, they are unable to deal with a number of well-known phenomena in production. An important example of this is that it is often the case that an improvement in one performance measure has to be assessed against a detrimental change in another related statistic. Unfortunately, there is little in the performance measures themselves which would indicate how the conflict should be resolved.

For example, cost per bus kilometre can simply be reduced by diverting buses to freeways where free running conditions lead to lower costs. But this would probably conflict with another performance measure such as revenue per bus hour. The dilemma arises because the problem of management is one of constrained optimisation. A full account of the management problem would have to comprehend what it is that the managers of the undertaking are attempting to maximize, and to also appreciate what constraints are being faced.

One problem in practice is that a large number of transport undertakings are operated by government agencies, and it is not always clear what objectives have been set. In a private firm, it is usually a good working hypothesis to assume that the managers act to maximize profits. In gov-

1 'Terminal' in this context is according to the definition to be found in the Department of Transport's Sea Transport Statistics, and refers to container and other specialized berths (eg Ro-Ro) where the terminal operator employs the waterside labour.

ernment enterprises, it might be more appropriate to assume that output is maximized subject to a budget constraint. Alternatively, the managers of the government enterprise might try to minimize the cost to the taxpayer of providing a given level of output. Whatever the case, it is normally possible to analyse the management problem in terms of the principles of constrained optimization.

The principal constraints are then those that exist in the market (demand and supply), those imposed by government, and those which limit the technological possibilities. The main interest in this paper lies in the technological constraints because of the importance of phenomena such as substitution, scale and technical change is to be emphasized in demonstrating the deficiencies in partial productivity analyses. It is argued that there is value in understanding the relationships between inputs and outputs when considered simultaneously, and this is appropriately done by appealing to economic theory which analyses total factor productivity.

TOTAL FACTOR PRODUCTIVITY

It is beyond the scope of this paper to explain the details of production theory, but the interested reader is referred to Layard and Walters (1978) as a basic text, with more advanced works being found in Varian (1984), Fuss and McFadden (1978), and in survey articles by Nadiri (1971,1978). The aim here is simply to give the reader who is not familiar with the theory a basic understanding of the subject. Later in the paper, some knowledge of the theory is necessary in order to understand developments in applied research. Specifically, it will be shown that analyses of productivity change based upon partial productivity (performance) measures gave misleading conclusions about the rate of productivity growth in the rail sector in the U.S.A..

The economic theory of production properly has its basis in the study of the firm. As noted above, it is normally taken to be a safe assumption that the managers of the firm attempt to maximize profits, although it is also possible that they might try to maximize something else, sales, for example. The firm is also constrained by conditions in the market and by conditions established by governments. In what follows, the simplest of these types of constraints will be assumed so that attention can be focused on the technological constraints.

The starting point for production theory is to assume that, somewhere, there is a set of 'blueprints' which establishes all of the possible ways of transforming inputs into outputs. Now, this set of production possibilities includes efficient and inefficient plans for any given scale of operation. Taking the sub-set of efficient plans, it is possible to summarise the relationship between the inputs and outputs in a 'transformation function'. For the sake of simplicity, though, the special case of a single output (Y), and two inputs, labour (L) and capital (K) will be examined. It is then possible to write the 'production function' as:

$$Y = f(K,L) \tag{1}$$

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That is, Equation (1) says that there is a relationship between the amounts of capital and labour inputs and the amount of output. By specifying the relationship in this way, it should be possible in theory to explore all the meaningful economic relationships such as scale, substitution and productivity change. For example, scale effects can be examined by increasing all input quantities, and then by observing the effect on output. If all inputs were to be increased by a given proportion and output increased by a greater proportion, it could be said that economies of scale exist. Substitution and complementarity relationships can also be observed by examining the effects on output when input proportions vary⁽¹⁾.

The concepts of scale and substitution are therefore very useful in examining the effects upon output when the quantities of inputs and their relative combinations are varied. However, over time, improvements are made to production processes which permit greater output for fewer inputs. This increase in productive capability has often been called 'technical progress' or 'productivity change'.

To investigate this effect, it is necessary to add another term to the expression. Now, output is dependent upon the factor inputs, but remains fixed for a given state of application of technology (t). Thus Equation (1) becomes:

$$Y = f(K, L; t) \quad (2)$$

Now the change in productivity can be observed by examining the growth in output from one period to another after taking account of any changes in the level of inputs. That is, any increase in output that cannot be attributed directly to the growth in inputs can be considered to be evidence of productivity improvement. There is considerable debate in the economic literature about how the process of productivity change occurs, a useful review reference being Nelson (1981). However, three concepts which need to be appreciated are:

- (1) neutrality
- (2) factor augmentation
- (3) embodiment

When technological advances are made, they can possibly be embodied in the factors of production. Thus, the quality of inputs such as labour can be improved through education and training. Similarly, capital inputs can embody new technology. Alternatively, the type of technical advance could be equivalent to a specific increase in a factor of production. In that case, the change would be said to be 'factor augmenting'. Productivity change

¹ It is worth noting that production theory has recently been employed by a number of researchers to investigate modal competition in freight transport. In more detail, transport services have been treated as a derived demand, and the modes can be substituted for each other to give various combinations of service and cost. A useful example can be found in the work of Oum (1979).

therefore need not affect factors in a neutral way. Indeed, it can affect scale and substitution relationships as well. It thus becomes necessary to specify what type of technical change is expected.

Neutrality of technical progress can be measured by the effects of change on certain economic variables such as the ratios between outputs and inputs and between the inputs themselves. For example, capital to output ratios or capital to labour ratios could be examined. Neutral technical progress would leave these ratios unchanged. However, several definitions of neutrality are widely used. For the sake of brevity, only the simplest case, Hicks neutrality, will be discussed here.

In this case, productivity change increases output without affecting the relationship between inputs. For example, the production function for period t becomes:

$$Y = A(t) \cdot f(K_t, L_t) \quad (3)$$

(where $A(t) =$ "efficiency parameter")

By differentiating Equation (3) with respect to time, the following result is obtained:

$$\dot{Y}/Y = f(K_t, L_t) \cdot \dot{A}/A + A \cdot f_K(K/Y, \dot{K}/K) + A \cdot f_L(L/Y, \dot{L}/L) \quad (4)$$

(where the period over the variable indicates the derivative with respect to time, and f_K and f_L are partial derivatives with respect to capital and labour, respectively)

More simply, Equation (4) becomes:

$$\dot{Y}/Y = \dot{A}/A + Y (K/Y, \dot{K}/K) + Y (L/Y, \dot{L}/L) \quad (5)$$

Thus, in estimating the relationship between output and inputs, the residual term, \dot{A}/A , is simply the rate of growth of the efficiency parameter over time. In this specification, then, productivity change does not affect the relationship between the factors.

TOWARDS A MORE GENERAL MODEL

The simple model of a single output and two homogeneous classes of inputs presents difficulties in practice. Jara Diaz (1982), for example, has pointed out the difficulties in defining output in transport as a single measure. The basic problem being that there are many dimensions involved, weight, volume and distance being obvious ones in the case of freight. Very often, recourse is made to the composite measure of tonne-kilometres. However, it can be readily appreciated that this measure could be the same for many different combinations of tonnes and kilometres. If, as is often the case in transport, there are economies associated with increasing length of haul, productivity would appear to change simply by varying the output mix. This suggests that the output should be measured by a vector.

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In the case of inputs, it is also desirable to expand the list of inputs beyond capital and labour and to admit that even within those classes, there is often heterogeneity. For example, locomotives and rolling stock have very different characteristics to track investment in the railways case. Labour of different types would have different abilities to contribute to output, and substitution and complementary relationships would exist. Thus, the input side of the equation should be expressed as a vector of dimension greater than two.

It is no longer possible to deal with the simple production function and we now turn to the transformation function. In general we have to acknowledge that the distinction between what is an output and what is an input is essentially an arbitrary accounting one. Thus, in general terms, the transformation function is represented as follows:

$$f(y_1, y_2, \dots, y_m; v_1, v_2, \dots, v_n; t) = 0 \quad (6)$$

where y = a vector of outputs, $i = 1, 2, \dots, m$
 v = a vector of inputs, $j = 1, 2, \dots, n$

Of course all this attention to detail comes at the price of complexity and difficulty of measurement. It is perhaps time to turn to the methods used to estimate these functions in practice.

ESTIMATION

The choice of a form for the estimating function is a non-trivial step because the chosen form should be capable of capturing the important economic relationships. Early attempts to estimate production relations were limited in their techniques and it was necessary to accept some simplification in order to proceed. The result was that the functions implied some prior assumptions about the nature of the technology. This was justified to the extent that there were higher order effects which were of interest. It was common, for example, for the main focus to be on scale effects, and the Cobb-Douglas function proved to be the most tractable model. This can be characterized as a power function of the following type:

$$y = A \cdot v_1^a \cdot v_2^a \dots v_n^a \quad (7)$$

Scale effects can be observed by reference to the exponents; specifically, if the sum of the exponents equalled unity this means that constant returns to scale existed, while a sum exceeding unity implies increasing returns (economies of scale). However, it is also the case that the elasticity of substitution has to remain constant and equal to unity no matter what the level and proportion of the inputs. Notwithstanding this drawback, the Cobb-Douglas function received widespread use, a particular feature being its ease of estimation.

In general, it is not desirable to impose any a priori restrictions on the technology. The contribution by Fuss, et al (1978) indicates how to proceed on this basis. These authors list all the important economic effects and then identify the relevant parameters which would be necessary to completely describe the technology. The useful finding is that these effects can be summarised in the value of the function itself and its first and second derivatives. Thus, a Taylor's expansion to the second-order is capable of approximating any true underlying technology at a point.

It turns out that the Cobb-Douglas can be interpreted as a first-order expansion in logarithms. The second-order expansion is the Translog function, the one which has been used most widely in empirical work, particularly in transport applications. However, the Translog can be seen as only one example of a family of linear-in-parameters expansions which approximate any arbitrary function⁽¹⁾. The general form of the Translog can be expressed as:

$$\ln y = a_0 + \sum a_i \ln v_i + \sum \sum a_{ij} (\ln v_i)(\ln v_j) \quad (8)$$

This, then represents the state-of-the-art in the methods being used to investigate production relationships in transport, but especially including substitution between transport modes, economies of scale and productivity change. One final point needs to be made before turning to the empirical evidence. As a practical matter, it is often preferable to deal with information on prices, rather than to deal with data on quantities.

Varian (1984) provides further details, but it will suffice here to mention that the cost function is often preferred as an empirical tool rather than the production function. This begs the question about the relationship between cost functions and production functions. The relevant theory establishes that there is a duality relationship between the two classes of functions provided that a number of generally acceptable assumptions are made. This is an important result because it establishes the cost function as a sufficient statistic for analysing the nature of production.

EMPIRICAL STUDIES OF PRODUCTIVITY

Perhaps the most comprehensive study of its kind was the Deakin and Seward (1969) work on the broad transport sector in the U.K.. This study covered railways, road passenger transport, road haulage contracting, sea transport, port and inland water transport, and air transport. The overall aim was to estimate total factor productivity change in the industry as a whole using a Cobb-Douglas production function. This work has been reviewed elsewhere and its interest here lies in its historical value⁽²⁾.

1. Other linear-in-parameter expansions include: Generalised Leontief, Generalised Cobb-Douglas, Quadratic, and others.

2. See, for example, Hooper (1984) or the review of Deakin and Seward by Martin Rudd in The Journal Of Transport Economics, Vol. 4 (1), 1970, pp.115-117.

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There is little evidence in the published literature of further empirical work in the U.K. at the transport sector level. More interest can be seen in the U.S.A. where evidence on economies of scale and productivity change had some influence in official attitudes to rate change proposals and mergers in regulated industries. It might also be noted that the prospects for econometric work have been greater in the U.S.A. given the large number of transport operators of varying sizes, and given statutory requirements to publish detailed statistics in standard ways.

The Bureau of Labor Statistics (BLS), for example, has reported data on productivity in a number of key sectors of the U.S.A. economy over a period of time, including the transport sector. Mainly these have been in the form of output per unit of labour input or, in the case of transport, as ton-miles and passenger-miles per man-hour. From time to time, the BLS has also estimated Cobb-Douglas production functions on railway data.

The eminent economist, Kendrick (1966,1973), has also published the results of productivity studies in transport, including rail, air, pipeline, waterway, local passenger transport, intercity bus, and intercity motor trucking. Many of these earlier studies have been reviewed by Sceppach and Woehlicke (1975) and by Meyer and Gomez-Ibanez (1980).

The studies mentioned to this point typically employed partial productivity measures or they relied upon the use of restrictive production models, particularly the Cobb-Douglas. However, in the latter part of the 1970's, developments in applying the so-called 'flexible functional forms' such as the Translog were beginning to find their way in to the transport literature. In this regard, the articles by Caves, et al (1980,1981) on productivity in rail transport represent the state-of-the-art.

The more advanced functional forms employed by the latter authors enabled them to specify production relationships in a theoretically more plausible way, making it possible to simultaneously examine scale effects and productivity change. The practical implications of this work were that previous estimates of productivity growth in the rail sector had to be revised downward.

However, this result only confirmed and extended the findings of a series of studies which examined the rail sector. Early studies by the BLS found that the rail sector had been experiencing productivity growth at a rate well in excess of the overall economy, despite the general state of decline in rail transport. Since then, economists have been concerned to solve the puzzle. The solution appears to have been found both in the method and in the data. In the remainder of this section, this series of studies will be examined in more detail because of the important lessons that can be derived from it.

The BLS, as has been pointed out, regularly reported statistics on the increase in rail output, measured in ton-miles and passenger-miles, per man-hour in the railway industry. Over the period 1948-1966, these data suggested an average annual increase in rail productivity of 5.8 per cent.

In comparison, intercity trucking's increase was 3.1 per cent, water transport was 0.7 per cent, and the economy as a whole had an increase of only 3 per cent. Given the general state of decline in the rail industry, many were inclined to ask, as did Meyer and Morton (1975), "...how have the railroads seemingly violated the usual rule relating good productivity performance to general industry growth and prosperity?".

However, another study by Kendrick (1973) appeared to confirm this finding. Kendrick estimated total factor productivity by using an index of total input, weighting the quantities of labour and capital by their shares in national income originating in the railway industry.

Nevertheless, Meyer and Morton remained sceptical. Further analysis began to suggest some explanations to the paradox. In the first place, it was pointed out that the BLS statistics completely ignored the fact that capital was being substituted for labour. Although this was also true for the other industries with which rail had been compared, the rate at which this change was occurring in the railway industry exceeded rates in many other industries.

For example, the capital-labour ratio in the private domestic economy had been rising by 2.6 per cent per annum. In contrast, this ratio had been increasing by 4.7 per cent in the case of rail. Furthermore, there was a tendency for the ownership of rail's assets to fall outside the industry. This was particularly evident with leased equipment. Thus, the published statistics on capital employed by the railways were increasingly understating the situation. Furthermore, materials and services were declining at a slower rate than labour, particularly since the railways were turning to outside suppliers for services which had hitherto been provided by the industry's own workforce. Thus, any statement about productivity change had to encompass more than a relationship between labour and output.

More concern was expressed when output, as defined by the BLS, was placed under scrutiny. Meyer and Morton noted some of the changes in the composition of rail's output. In the first place, passenger services had been declining. The import of this was that the BLS had been weighting ton-miles of freight and passenger-miles by their revenue shares to obtain an overall index of output, the ratio being one is to two. The problem with this is that revenue shares bore no direct relationship to costs. Meyer and Morton felt that the ratio of costs was more likely to be between five to one and nine to one, passenger services being far more resource consumptive than freight operations.

The troubles with the output index did not stop there. The average length of haul in freight had been increasing, giving rise to an increase in ton-miles. It is a well-known feature of the cost structure of railways that unit costs decline with distance, establishing that the marginal costs of increasing ton-miles in this way should have been below average costs. This factor should also have been reinforced by the increased importance of bulk traffics.

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Thus, Meyer and Morton saw good reason to make a downwards adjustment to the estimates of productivity growth in rail transport. The National Commission on Productivity (1973) had made adjustment for some of the factors cited by Meyer and Morton and had estimated that productivity growth was more likely to have been in the range of one or two per cent. However, this was still above the average for all industries when calculating productivity on an equivalent basis.

In respect of Kendrick's results, Meyer and Morton noted that the index of inputs was constructed by giving capital a weighting of 10 per cent and labour 90 per cent. Apart from the neglect of other inputs, it was suggested that these weights understated the importance of capital. As an alternative explanation, Meyer and Morton calculated their own estimates of productivity change using an index number procedure.

Essentially, their method involved the construction of two indices, one for the rate of input growth, and one for the rate of output growth. The difference between the two was taken to be a crude estimate of the rate of growth of productivity. The output index was obtained by combining measures of freight and passenger output in each period, weighted by their base period shares of costs. That is, the index was recognisable as a Laspeyre's quantity index. Some difficulty was found in deciding how to weight the various inputs. In the end result, a Laspeyre's and a Paasche's index were calculated.

The results of this analysis suggested that overall rail productivity had grown at an average rate of 1.5 per cent per annum between 1947 and 1970. Although this was lower than the comparable figure for the economy in general of 2.5 per cent, Meyer and Morton considered that this was not a particularly adverse finding for rail considering the industry's declining market. The growth in previous studies of labour productivity merely reflected the shift from labour to capital.

The validity of using index numbers to represent production processes has been established by Samuelson and Swamy (1974) and Diewert (1976). However, the choice of a particular indexing procedure implies particular assumptions about the nature of the underlying technology. Importantly, the method used by Meyer and Morton required that rail transport exhibit constant returns to scale, that freight and passenger transport are produced in fixed proportions, and that the elasticity of substitution between any pair of inputs is equal to unity. Caves et al (1980) rejected these assumptions and suggested that results obtained by using index procedures would be inadequate.

Instead, they employed a flexible functional form and simultaneously investigated scale effects and productivity change. By invoking duality relationships which establish the cost function as a sufficient statistic for describing all the technically relevant features of a production relationship, Caves et al were free to work with the more convenient cost function. The function chosen was the Generalised Translog (multiproduct) cost function. This type of function has basically the same form as the Translog except that it permits the inclusion of firms with no passenger output in the

sample⁽¹⁾. To estimate this type of function, it was necessary to have time series for a cross-section of firms.

These authors found that scale economies did exist, invalidating Meyer and Morton's results. Caves et al estimated an average rate of productivity growth of 1.5 per cent per annum over the period 1951-1974. Using similar methods to those employed in previous studies, growth rates of around 3.6 per cent were obtained. Approximately half this difference was attributed to the inappropriate use of revenue shares as weights in aggregating inputs; the correct weights being output cost elasticities. These elasticities, it should be noted, were obtained from cross-section analyses. The remainder of the discrepancy was attributed to inappropriate input weights, Caves et al rejecting shares of labour and capital in national income in favour of using the type of corrections suggested by Meyer and Morton with the difference that fixed base weights were rejected.

In a subsequent paper, Caves et al (1981) modified their method to take account of the fixity of a large part of rail's costs. Thus, their cost function in this case was a short-run relationship. Strong evidence of economies of scale were again found, particularly as trip lengths increased. The revised model indicated that there had been rapid productivity growth in the period 1955-1963, but that the rate slowed to less than one per cent per annum in the period from 1963 to 1974 and it is interesting to note their explanation:

...the primary reason for this difference is that, in our previous paper, we used industry totals rather than firm data. The estimated total cost function implied a shift in the production structure, but scale economies. Much of the effect of scale economies on cost is hidden in the industry aggregate data. This is because industry totals show little output growth and hence little effect on scale; whereas output of the average firm has grown substantially through mergers and consolidations. The scale effects associated with this growth of firm size show up as productivity growth at the industry aggregate level.

[Caves et al (1981), pp. 1000-1001.]

POTENTIAL APPLICATIONS IN AUSTRALIA

Perhaps the most likely place to consider application of the types of analyses discussed above in an Australian context would be with the railway industry. Given the wealth of research on this particular industry in the U.S.A., researchers would be able to commence with a reasonable understanding of the nature of the technology, how it can be represented, and what types of data are required. Indeed, the only previous research which has been published in Australia on productivity in transport has been Winn's (1983) attempt to fit an aggregate production function for Australian railways.

1. The Generalised Translog substitutes the Box-Cox metric for the natural log metric for the output levels.

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Winn found the data to be generally inadequate. In the first place, there was an insufficient number of railways to provide a useful cross-section. This necessitated the pooling of time series and cross-section data, with all the problems that this practice raises. Winn would have preferred to use tonne-kilometres as an output measure, but then was forced to compromise because of the difficulty in converting passenger kilometres into equivalent tonne-kilometres, particularly when some of the railway systems only reported the number of passengers. In the event the variable, 'revenue train kilometres', was used.

It can be noted that the practice of combining passenger-kilometres and tonne-kilometres in the U.S.A. studies is to weight each according to their revenue shares. More correctly, output cost elasticities are to be preferred as weights where they are available. Caves et al (1980,1981) derived their elasticity measures from cross-section data, a possibility not open to Winn. The use of revenue train kilometres as a measure of output still does not overcome the problems inherent in using a single measure of output. Any change in the composition of traffic or of the size of train loads would affect the estimates of productivity. Apart from that, the problems of combining passenger statistics with freight statistics are overcome only by ignoring them.

The problems in obtaining data on capital expenditure in the railways raised even more difficulties. Apart from the inconsistencies in accounting practices, it was invariably the case that data on capital were reported in historic cost values, and depreciation charges, if made at all, bore no necessary relationship to true economic depreciation. From the author's knowledge of the type of information maintained by the railways, it would be a difficult matter to construct a time series of capital input. The main obstacle is that assets inventories have generally not been maintained, so that data on vintages and scrappings cannot be constructed on a comprehensive basis.

The only other variable considered by Winn was labour input, and that was measured as man-hours. Unfortunately, series on this variable had to be arrived at indirectly by multiplying the number of workers by average hours worked. In order that the changing composition of the workforce could be accounted for, an aggregate was obtained by multiplying hours of salaried staff and hours of wage staff by their respective earnings in the base period. Now this procedure raises a number of problems, involving the application of a Laspeyre's index. The difficulties associated with forming aggregates by index number procedures have already been noted. However, it will suffice to note that any change in the relative earnings of the two groups from period to period would raise questions as to whether the Laspeyre's index was introducing a source of bias into the estimate of the quantity of labour. Scope therefore exists for improving on this specification of the variable.

The overall conclusion that can be gained from Winn's work is that the state of the data and the limited number of observations on which to work will prove to be disappointing to researchers. The prospects for advancing the state-of-the-art in measuring productivity in the rail transport sector in this country are therefore limited at this stage. Nevertheless, Winn has

provided a useful starting point, and the challenge is there for researchers to improve on that contribution. It is worth noting that ARRDO's work programme includes work on the establishment of assets inventories. Another field that ARRDO appears to be working on is on the relationship between maintenance and capital expenditure in the form of renewals. Work on these subjects can only enhance the state of the data.

Turning attention to another field, the author has been considering the possibilities of measuring productivity change in the port sector. One of the problems confronted by Winn might not be so severe in this case. Namely, there is a larger number of units if it is intended that a cross-section study should be mounted. There are 41 major ports to choose from, plus a number of smaller facilities. It might be objected, though, that there is wide variation between types of trades served even within this group, so that the size of the cross-section of comparable ports is much smaller. However, this remains a matter for investigation. In any event, there are possibilities for carrying out time series studies on single ports.

Regarding the availability and quality of the data, there are some positive comments to be made. Although there are problems in treating all tonnes as though they are the same, there would appear to be fewer problems in specifying output here in comparison to the problems in using tonne-kilometres in the railway case. Certainly, the practical difficulties faced by Winn in even obtaining data are not present; both the Australian Bureau of Statistics (ABS) and the Department of Transport (DOT) report series on trade through ports. Several sources are used in collecting these statistics, so it is possible to check for accuracy. Detailed breakdowns by commodity are also available.

Similarly, data are available on waterside labour input in the form of hours worked and earnings. Unfortunately, it is not as easy to establish what amount of labour is employed by port authorities in administrative tasks. Annual reports published by the ports generally do not contain sufficient information on this matter. It is also worth noting that there are a number of organisations involved in providing services in ports, not the least of which being the services of the stevedoring companies or terminal operators. This division of responsibilities raises obvious practical problems in attempting to measure productivity. Of course, one way to overcome the problem is to measure productivity at the level of the individual terminal or berth, but then the data are not as readily available in this disaggregated form.

As with the railways, the major practical difficulty is in obtaining data on capital input. Unlike the throughput statistics and labour input data, information on capital input is not reported by any central agency. Recourse to annual reports of the port authorities does not suggest any real possibility of deriving the necessary data from that source. It would appear that the only real prospects lie in the internal accounts of the port authorities. From preliminary investigations by the author, it appears that port authorities records of assets are no better than those maintained by the railways.

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The conclusion from this is that, for the port sector, the lack of data on capital input is the main obstacle to empirical work on productivity measurement. It is entirely appropriate that researchers should concentrate their efforts on ways to improve the state of the data. It is to be noted that the Victorian Ministry of Transport has been active in this area. Hopefully, this will establish prospects for empirical work on productivity measurement in the not too distant future.

CONCLUSIONS

What this paper has set out to demonstrate is that productivity is important, and that reliable analyses of the subject will enhance debate on problems facing key transport industries. It is furthermore contended that a firm foundation for such analyses can be found in the economic theory of production.

Experience in the application of this theory in the U.S.A. suggests the need to be careful about the use of partial measures of productivity change. Moreover, the evidence is that the technique used can seriously bias the results by imposing prior assumptions about the nature of the technology.

Notwithstanding this, it is unlikely that state-of-the-art techniques, as evident in the works of Caves et al (1981), will find extensive application in Australia in the near future, even if only because of data limitations; it is difficult to find situations where there is a cross-section of firms of varying sizes and where there are published time series with information of the required type. From the discussion in the previous section, it should be apparent that researchers in this country will have to remain satisfied with much cruder types of analyses.

This suggests two types of priorities in further research in the area. In the first place, attention should be devoted to ways of improving the state of the data, especially in the construction of capital series. The second priority should be to find suitable proxies for the important variables and to investigate production relationships on some expedient basis. In this regard, it would be advisable for researchers to heed the results of recent work coming from the U.S.A., even if it only serves to indicate the likely direction and extent of bias in the results of work carried out using more restricted methods and data.

However, to abandon the field altogether is not regarded as a desirable state of affairs. Partial productivity measures, such as labour-output ratios, will invariably be calculated. Transport researchers ought to be aiming to illustrate the shortcomings of such statistics and to be improving upon the state of knowledge of the subject.

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