# An Analysis of Total Factor Productivity with an Application to Australian National

## Report

This Report has two main goals. The first is to present the theoretical aspects of productivity measurement and its interpretation with particular emphasis on its role as a performance measure. The second is to provide, within the context of performance appraisal, an empirical analysis of productivity growth in the Australian National Railways Commission over the period 1979-80 to 1987-88.

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# An Analysis of Total Factor Productivity with an Application to Australian National

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## FOREWORD

Policy guidelines tabled in October 1987 by the then Minister for Finance detailed certain changes to the environment in which government business enterprises (GBEs) were to operate. These changes were designed to elicit more efficient production, in line with the wider micro-economic reform program announced by the Prime Minister at the outset of the Hawke Government's third term. Significant among these changes was the requirement for the GBEs to produce strategic corporate plans which would contain targets, in terms of rates of return and other performance measures.

This report has two main goals. The first is to present the theoretical aspects of productivity measurement and its interpretation with particular emphasis on its role as a performance measure. The second is to provide, within the context of performance appraisal, an empirical analysis of productivity growth in the Australian National Railways Commission over the period 1979–80 to 1987–88.

The report was prepared by Dr D. Brunker and Mr C. Gallagher, and was supervised at various stages by Mr A. Shaw and Mr M. Cronin.

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## ABSTRACT

In the current climate of micro-economic reform the role of performance indicators for government business enterprises has taken a high profile. Financial indicators have received most attention and, while these are important, so too are indicators more directly related to productive efficiency. In this respect, measures of productivity growth provide valuable additional information on performance. Total factor productivity measurement takes into account all the major factors of production and, where practicable, is the preferred measure of productive performance.

Traditional measures of total factor productivity growth capture rates of technological progress as well as changes in productive efficiency. These measures are applied to the Australian National Railways Commission — trading as Australian National (AN) — and indicate an average annual growth rate of 5.1 per cent between 1979–80 and 1987–88, assuming constant returns to scale. Reductions in surplus staff over the period have contributed significantly to efficiency gains. As the inefficiencies in AN production are reduced, total factor productivity growth is expected to decline towards a long term average of 1 to 2 per cent per year.

# SUMMARY

The role of performance indicators has a high profile in the current climate of micro-economic reform in government business enterprises. Financial indicators have received most attention, and while these are important, so too are indicators more directly related to productive efficiency. In this respect, measures of productivity growth provide valuable additional information on performance.

While rates of return can be directly influenced by pricing policy, productivity measures provide an indication of the efficiency with which inputs are converted into outputs, and are only indirectly related to prices. As such, they provide an important adjunct to rates of return in the overall assessment of performance.

The most commonly used measure of productivity is labour productivity, or the level of output obtained per unit of labour input employed. Its popularity stems largely from its relative ease of computation, as output and labour input data are usually readily available. However, it is only a partial measure in the sense that there are typically several other inputs used jointly with labour to produce the output in question, and as such can fail to represent correctly the full picture of productivity growth. Indeed, at the firm or industry level, an increase in labour productivity can be either a desirable or an undesirable outcome depending upon the cause of the increase. For example, if labour costs rise while other input factor costs remain unchanged, and if there is some scope for the substitution of other factors for labour, then output per unit of labour may rise as substitution occurs, while at the same time unit costs of production rise.

On the other hand, total factor productivity (TFP) takes into account all the major factors of production and, in complete and efficient markets, a rise in TFP is unambiguously a desirable outcome. Unlike labour productivity, and other partial measures of productivity, its precise measurement requires a good analytical knowledge of the structure of the production technology, as well as price and quantity data on all the important input factors and on all the outputs. In certain industries, therefore, its measurement may not be practicable. However, where it is practicable, TFP should be the preferred measure of productive performance.

The technique for measuring TFP growth, based on the assumption that firms were efficient in terms of cost minimisation, was developed to determine rates of technological progress. In the context of GBE reform, however, there is substantial evidence that cost minimisation has not always been the primary

objective, and that output has not therefore always been produced efficiently. As a result, traditional measures of TFP growth capture not only technological progress, but also changes in productive efficiency. While this is not an undesirable feature, in itself, there are reasons why it may be useful to identify the extent to which efficiency and technological factors contribute to measured TFP growth. In the context of targets for future TFP growth, it is important to consider the extent to which further gains in efficiency could be made, independent of technological progress. High achieved rates of measured TFP growth resulting from internal efficiency gains being made from an inefficient base may not be sustainable. Once the activity in question approaches 'best practice', potential TFP growth will be limited by the rate of technological progress.

An important aspect of the technology, in terms of the measurement of TFP growth, is the existence and extent of returns to scale. If constant returns to scale hold then changes in the level of inputs do not influence traditionally measured TFP growth. However, in the presence of, say, increasing returns to scale, traditional measures of TFP growth will overstate technological change if inputs are growing, and understate it if inputs are falling.

Overseas econometric evidence indicates that there probably are increasing returns to scale in rail. However, the degree of returns to scale is in general not large, and is statistically insignificant when average length of haul is held constant. Moreover, the estimates apply to North American rail networks at a point in time some five years prior to the beginning of the period relevant to this study of Australian National (AN) productivity. Also, the estimates of the magnitude of the returns to scale may be dependent upon the size of the average firm sampled, and upon its state of capacity utilisation. These factors indicate significant scope for error, if the same returns to scale parameter is assumed for AN. Consequently, constant returns to scale are assumed to hold in general for AN for the purposes of measuring TFP growth, and sensitivity analysis on the implications of non-constant returns is carried out using the North American estimates.

It may be argued that AN is not driven entirely by an economic profit motive. Indeed, over much of the 1980s, its objective has been to break even, in accounting terms, on its commercial operations. The major discrepancy between accounting costs and economic costs is in respect of capital. In addition to the usual issue of an historical versus replacement basis for measuring depreciation costs, AN's total interest paid falls far short of what might be generally accepted to represent the true opportunity cost of funds employed. TFP growth estimates have been made based on the accounting objective as explicitly identified by AN's Chairman in the 1987–88 annual report.

The traditional approach to the measurement of TFP growth indicates an average annual rate of growth of 5.1 per cent for AN between 1979–80 and 1987–88 (or 5.5 per cent taking into account the effect of returns to scale on the basis of United States estimates). This is far in excess of the corresponding figure for multi-factor productivity growth in the Australian market sector, which the Australian Bureau of Statistics has estimated at 1.2 per cent per year. However, TFP growth for AN has been achieved from a comparatively low base. Specifically, reductions in surplus staff over the period have reduced AN's total employment by about 30 per cent. In addition to the gains in efficiency resulting from surplus staff reductions, the general corporate restructuring in AN would also have given rise to efficiency gains.

The scope for reductions in surplus staff had largely been exhausted by the close of the 1987–88 financial year, and so too had that source of TFP growth. It is of interest in terms of setting productivity goals to endeavour to estimate what the trend in TFP growth would have been in the absence of initial overstaffing. Upper and lower estimates of TFP growth with surplus staff effects netted out indicate average annual growth rates in adjusted TFP of 4.8 and 3.5 per cent respectively. Even the lower estimate of 3.5 per cent is substantially higher than the 1.2 per cent in the Australian market sector as a whole. However, it must be recognised that the general restructuring in AN would have led to the elimination of other inefficiencies.

As the inefficiencies that existed in AN production at the outset of the 1980s are eliminated, the potential for TFP growth will approach the rate of technological progress. Unlike the surplus staff issue, the other sources of efficiency gain are not readily quantifiable. However, a similar restructuring exercise in Canadian National Railways during the 1960s provides data from which can be gained an idea of the general pattern of TFP growth resulting from a change to more commercial practices. Over the period 1960 to 1965 Canadian National Railways achieved an average annual rate of TFP growth of approximately 7 per cent. Between 1965 and 1970 the average rate was approximately 5 per cent, and between 1970 and 1980, approximately 2 per cent.

The efficiency gains resulting from the change in corporate philosophy in AN, as reflected in high rates of TFP growth are to be applauded. However, the evidence indicates that only some five to ten years of high TFP growth can be expected from the time AN's restructuring began. Thereafter, it would be expected that TFP growth would rapidly decline towards a long term average of probably 1 to 2 per cent per year. In addition to this decline, there is some evidence that the capital replacement program in AN has failed to keep pace with depreciation and obsolescence, and TFP growth could be expected to be further attenuated during periods where accumulated capital deficiencies were rectified. As the restructuring in AN began in the early 1980s, the decline in TFP growth indicated by the above discussion can be expected in the near future.

# CHAPTER 1 INTRODUCTION

In October 1987 the Minister for Finance tabled policy guidelines designed to implement major changes to the micro-economic environment in which government business enterprises (GBEs) were to operate. A significant area of change was that the corporate plan of each enterprise would be formalised and would include target rates of return, and, where possible, target levels for other performance measures.

In assessing performance it is useful to consider indicators other than purely financial ones directly related to output price. Measures of productivity provide information on the amount of output obtained from the physical inputs used in the productive process. Although not entirely independent of prices, they provide a valuable complement to financial measures. They may be used to set future targets for productivity growth and to assess past performance.

The purpose of this paper is twofold. First, it is to discuss the various methods of measuring productivity growth, and to present an analytical framework by which to measure and interpret total factor productivity (TFP). Second, it is to apply these theoretical considerations to the specific case of the government-owned Australian National Railways Commission, trading as Australian National (AN). AN provides, in many respects, a case study which illustrates the points made in the theoretical discussion.

## PRODUCTIVITY MEASUREMENT AND INTERPRETATION

Measures of productivity are used in a variety of applications extending from wage negotiations to industry and economy-wide performance assessment. The most common measure of productivity is output per unit of labour input employed, or labour productivity. There are, however, several other important factors of production such as capital and energy, and the exclusion of these from the measurement of productivity can result in some misleading (and frequently misused) figures, especially at the firm or industry level. Total factor productivity takes into account all the major inputs, and therefore can accommodate adjustments in the ratio of the input factors employed.

Total factor productivity may conveniently be thought of as the ratio of an index of aggregate output to an index of aggregate input, although the methods available for measuring the various outputs and inputs and for aggregating them are not without controversy.

Productivity measures over time and across firms (especially total factor productivity) provide valuable information on relative performance. Periods (or firms) exhibiting unusually high or low productivity growth may indicate, together with other data, the impact of important influences on economic growth. Over particular periods of time, productivity measures may provide an indication of the economic value of certain structural changes. Finally, they can be useful in setting performance targets that are largely independent of pricing policy.

The relationship between various types of (static) efficiency and technological growth are discussed in chapter 2. The distinction is important, and especially so in the case of AN where the influence of efficiency growth on measured productivity has been substantial, but is likely to be of declining significance in the future.

A discussion of the uses and pitfalls of various types of productivity measures as performance indicators is provided in chapter 3, and in chapter 4 the theoretical issues relating to the measurement of total factor productivity are discussed. Chapters 2, 3 and 4 are therefore of a theoretical nature. The practical application to the case of AN is presented in chapter 5.

## PRODUCTIVITY GROWTH IN AUSTRALIAN NATIONAL

Since the early 1980s AN has been involved in a major restructuring exercise designed to transform it into a modern commercial railway. These adjustments have included substantial reductions in staff levels, adjustments to the composition and relative pricing of outputs, and changes in management practices. It would therefore be expected that quite high levels of productivity growth would have been achieved, reflecting the gains made from what was arguably a low level of efficiency at the outset of the 1980s. However, recognition of the substantial gains to be made in efficiency suggests equal recognition of the limitations upon this source of productivity growth. When there is a large gap between current and best practice, relatively large gains can be made over a short period, but as best practice is approached, technological progress becomes the primary source of productivity improvement.

In chapter 5, partial and total factor productivity measures are derived for AN for the period 1979–80 to 1987–88. The results are compared with productivity measures for other Australian railways and railways in Canada and the United States.

The comparisons highlight the similar effects that structural reform in public rail systems have had on TFP growth in the Canadian railways during the 1960s, and in AN during the 1980s. Consistent with the temporary nature of large efficiency gains, mentioned above, the very high levels of productivity growth in the

Canadian railways during the 1960s slowed substantially through the first half of the 1970s.

Adjustments to 'net out' from TFP growth the temporary gains resulting from major reductions in the levels of surplus staff in AN have been made in order to estimate the growth in TFP which would have been obtained in the absence of surplus staff. While reductions in surplus staff are not the only source of efficiency growth in AN flowing from the restructuring, they are probably the most important single factor, and they are relatively easily identified. The adjusted series still represent, however, some other efficiency gains as well as gains of a purely technological nature. Nevertheless, in conjunction with the Canadian data they provide a good indication of the rates of TFP growth which might be expected for AN in the near future.

# CHAPTER 2 EFFICIENCY, TECHNOLOGY AND PRODUCTIVITY

Widespread public interest in the notions of efficiency and productivity has recently emerged. In an area of economics where the theoretical aspects were the concern mainly of academics, and the practical aspects the concern of entrepreneurs, there has arisen a ground swell of interest ranging from academia and business to the parliament and the public in general. A wider interest in such important economic issues is to be encouraged for its potential to generate more informed, objective public debate on questions fundamental to the future growth and prosperity of Australia.

For such debates to be useful, it is important that the relevant concepts and definitions be agreed upon, and it is the purpose of this chapter to define and discuss the various notions of efficiency and productivity.

## EFFICIENCY AND PRODUCTION TECHNOLOGY

It should be emphasised at the outset that the notion of efficiency is not the same as that of productivity, though changes in efficiency over time may be a factor contributing to measured productivity change. Efficiency in production is, generally speaking, a static notion, reflecting the extent to which a productive activity is best possible, or equivalently, cost minimising.

At the level of the firm, there are three main aspects of economic efficiency, and these are best expressed through the three questions: Are input factors being used in the correct (most efficient) proportions? Are input factors being employed parsimoniously for the level of output being produced? Is the appropriate level of output being produced? The notions expressed through these questions are referred to as *allocative*, *technical*, and *scale* efficiency respectively. To appreciate properly the relationships among these three concepts it is worth attending momentarily to the definitions of production function, cost function and profit function.

For convenience it is supposed that the productive process in question entails the use of two distinct homogeneous inputs, say capital and labour, to produce a single output. A *production function* in this context gives the maximum output which it is technically possible to produce from given combinations of the inputs. Similarly, a *cost function* gives the minimum level of cost at which it is technically possible to produce various levels of output, at given input prices. Finally, there is the *profit function* which gives the maximum profit that can be achieved at given output price and input prices.

In each of these definitions the optimality (maximality or minimality) is important, and the term 'frontier' is often applied to emphasise this optimality. Thus the functions are referred to as production, cost and profit frontiers respectively — production cannot exceed the production frontier, cost cannot lie under the cost frontier and profit cannot exceed the profit frontier. Each of these optimality conditions is one-sided, and the extent to which a firm lies below its production and profit frontiers or above its cost frontier provides a measure of inefficiency. These issues are discussed along with an exposition of the econometric methods of efficiency measurement in Forsund, Lovell and Schmidt (1980).

To illustrate the definitions of allocative and technical inefficiency it is convenient to assume a competitive environment and a production frontier that exhibits constant returns to scale, that is, a given proportionate increase in the input factors leads to the same proportionate increase in the maximum achievable output. In such a case, the technology is completely described by the unit isoquant (the locus of input combinations that just allows one unit of output to be produced) denoted by AB in figure 2.1. The slope of the line WC represents the (negative of the) ratio of capital to labour prices.

Optimisation leads to the conclusion that one unit of output is produced at minimum cost precisely when the inputs illustrated by $Z_0$ are used. If $Z_1$ is used then the wrong input proportions are being used, albeit in a parsimonious way. Thus $Z_1$ is a position of *allocative inefficiency* but of *technical efficiency*. On the other hand, $Z_3$ represents a wasteful use of resources (it is off the frontier) though capital and labour inputs are in the correct (optimal) proportion. $Z_3$ represents a position of *allocative efficiency* but *technical inefficiency*. A position like $Z_2$ entails both allocative and technical inefficiency. There is only one way of efficiently producing the unit of output and that is by employing labour and capital in the amounts indicated by $Z_0$.

If the technology exhibits locally increasing returns to scale followed by decreasing returns as in figure 2.2 (for illustrative purposes a single input, labour, is assumed) then there is a unique output level $Q^*$ at which a (price taking) profit maximising firm should be producing; output price is denoted by p and the price of labour by w. Any other level of output would be *scale inefficient*.

Notwithstanding the above discussion, there are considerations of a somewhat more philosophical nature which question the whole concept of efficiency. The notion was considered by Stigler (1976) who took the view that perceived inefficiency results from the failure of the observer to identify correctly what is being maximised (or minimised) and to measure correctly all relevant inputs (or prices and outputs). Taken to the extreme this view is unhelpful, and suffers from the danger of degenerating into the kind of tautology which can result from the application of extreme neoclassical ideas. However, there are some aspects which bear consideration.

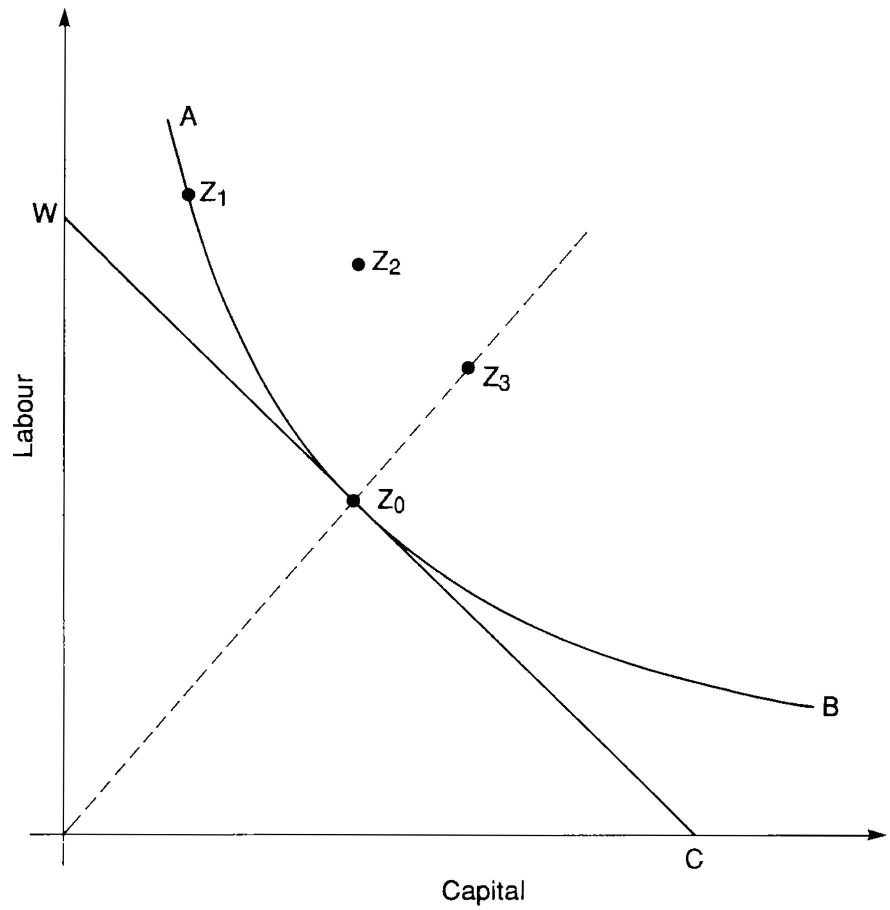



**Figure 2.1 Efficient and inefficient input combinations**

Consider for example a firm facing a 'putty-clay' technology, producing in an allocatively efficient fashion. (A technology employing capital and labour is said to be putty-clay if substitution possibilities exist but only ex ante. Once capital has been purchased and put in place, that capital requires a fixed amount of labour to operate it. Substitution possibilities exist at the time of purchase by way of a choice between types of capital exhibiting a variety of embedded labour requirements.) Suddenly there is a change in the relative price of capital and labour. Short of scrapping its entire capital stock, the firm will be seen to be operating in an allocatively inefficient way. The point is that the optimising problem is not as simple as portrayed in the standard texts. Indeed, the appropriate behaviour of the firm is to move gradually towards the new optimal capital to labour ratio as dictated by the vintage structure and depreciation rates

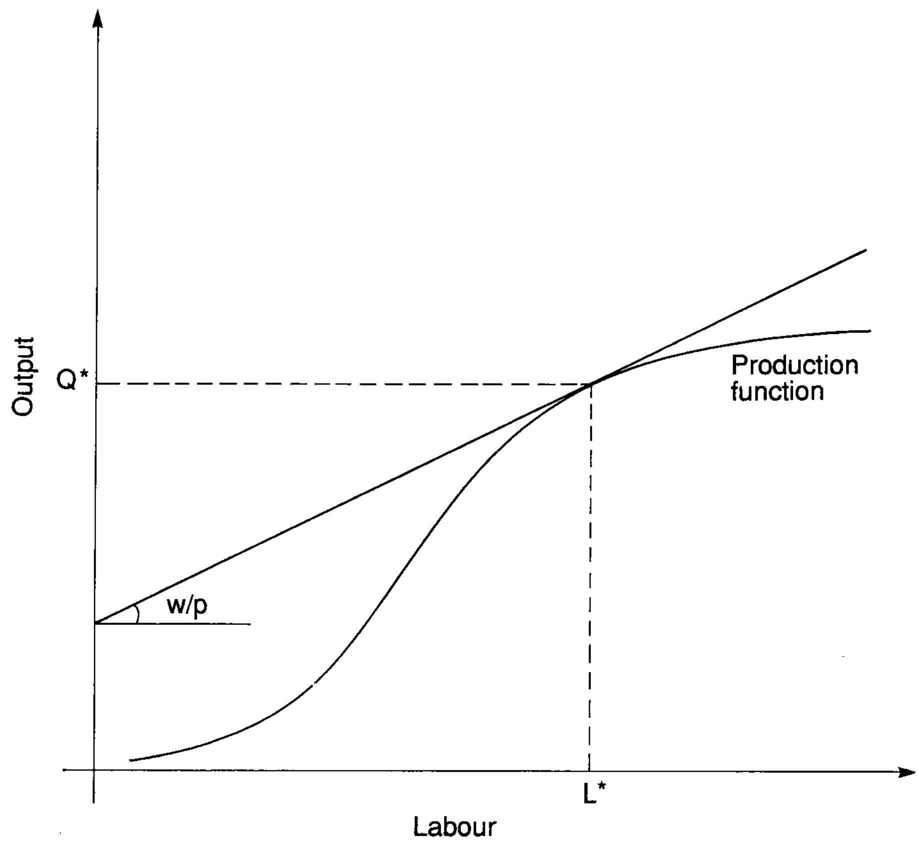



**Figure 2.2 Scale efficient production**

of its capital stock. Moreover, since prices change frequently, the optimising firm will typically never be observed at an allocatively efficient point. Similar considerations indicate the possible appropriateness of being off the frontier at any time, since the best possible technical practice would require a capital stock which is entirely state-of-the-art.

Although there are many reasons why firms may not be at the theoretical point of efficiency, it is necessary to determine which firms appear to be operating most efficiently, before reasons for divergence in efficiency can be considered.

Unfortunately, considerable cross-sectional data are necessary before an estimation of best practice production, and hence levels of efficiency, is possible. In many situations such data do not exist. However, changes in the level of efficiency of a firm over time will be picked up in traditional measures of productivity growth (but may not be identified separately from the effects of technological progress). These issues are addressed below.

## PRODUCTIVITY GROWTH

In general when business people, the media and others discuss productivity they are usually referring to labour productivity (output per person-hour) or some similar measure. In this context, productivity growth reflects the extent to which the rate of output growth exceeds the rate of growth of labour inputs.

There are many reasons why partial productivity measures such as labour productivity may rise, some of which are discussed in greater detail in chapter 3. However, it is worth noting one possible reason immediately in order to appreciate the potential limitations of the notion of labour productivity.

Suppose a technological change in machine efficiency takes place that enables a greater output to be produced using the same (or even fewer) labour resources. A good example of this is provided by the advances in computer technology. It is possible then that some labour shedding will occur and that output per person-hour (labour productivity) will rise as a consequence, though no inherent change in the nature or price of labour has occurred. Alternatively, the same rise in labour productivity could occur as the result of improvements in the skill of the workforce. Thus a given change in labour productivity may be the result of better capital or better labour, or some combination of the two.

To avoid the weakness inherent in partial productivity measures such as labour productivity, growth in each of the input factors must be taken into account. Total factor productivity (TFP) growth is usually defined as the difference between a weighted average of output growth rates and a weighted average of input growth rates. (The traditional measure of TFP growth usually applies revenue shares for output weights and cost shares for input weights. The problem is, however, more complicated than this — see appendix I).

In the sense of Solow (1957), TFP growth is the result of a change in the production technology (function) over time. It may be intuitively thought of as the rate at which the production frontier is expanding with time. This notion is represented graphically in figure 2.3, for the case of a constant returns to scale technology, subject to neutral technological change. Technological change is said to be neutral if inputs are used in the same proportions to produce a unit of output after the technological change as before, given no change in relative input prices.

The unit isoquant, AB, of figure 2.3 is seen to move back towards the origin with time, indicating a reduction in the quantities of inputs required to produce a unit of output. The optimal input combination is seen to move from $Z_0$, as in figure 2.1, to $Z_0'$ as the isoquant moves back to A′B′.

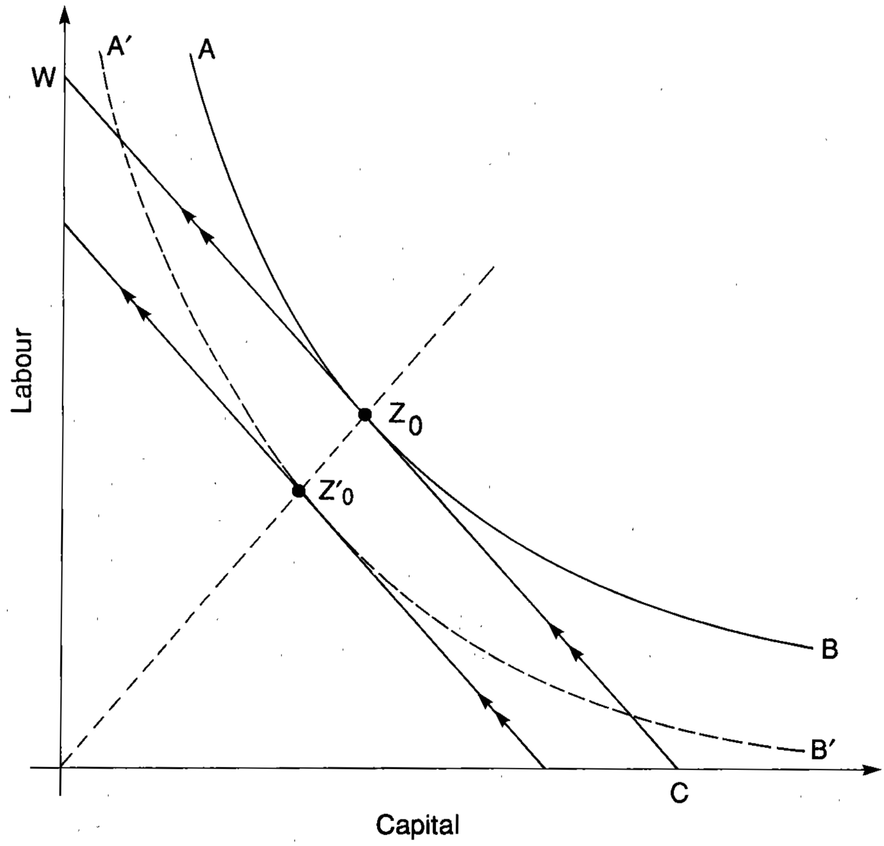



**Figure 2.3 Neutral technological progress**

The standard (non-econometric) approach to the measurement of TFP growth is

$$\hat{TFP} = \sum_{i=1}^{n} r_i \hat{y}_i - \sum_{j=i}^{m} s_j \hat{x}_j \tag{2.1}$$

where *TFP* is total factor productivity, $r_i$ is the *i* th revenue share, $s_j$ is the *j* th cost share, $y_i$ is the quantity of the *i* th output and $x_j$ is the quantity of the *j* th input, and ^ over a variable indicates growth rate.

In the case of a single output and a single input, say labour, equation 2.1 reduces to the difference between the rate of growth of output and the rate of growth of the input, that is, labour productivity. Generally speaking, however, there will be several inputs and each cost share $s_j$ will therefore be less than unity, reflecting the existence of other influential inputs.

In general, the production process may be economically inefficient in the sense discussed earlier in this chapter, and the degree of such inefficiencies may change from time to time. The above formulation of TFP growth relies on inputs and outputs only. There is no term isolating the effects of efficiency. Thus, even if it were the case that no change in the production frontier occurred, a firm could still register positive (or negative) TFP growth, as the result of changes in its levels of technical, allocative, or scale efficiency. The point is that the derivation of equation 2.1 (given in appendix I) relies on the assumption of profit maximising behaviour (and therefore cost minimising behaviour) and as such does not accommodate the possibility of inefficiency. As a result the traditional index of TFP growth will reflect changes in economic efficiency as well as technological change. Although this feature is not necessarily undesirable, there may be good reasons to make adjustments, where possible, to identify separately the effects of certain efficiency changes from other factors influencing the traditional measure of TFP growth.

## SUMMARY

Historically, measures of total factor productivity growth were intended to provide an indication of the rate at which the production function (frontier) was moving outward with time. The traditional measure of TFP growth achieves that goal only under special conditions which seldom, if ever, exist simultaneously in the real world. Specifically, these conditions entail cost minimising, competitive production under constant returns to scale, and a steady state economy. In the marketplace, firms are typically subject to exogenous shocks in demand, to institutional and technological rigidities and to input supply constraints in their choice of input factor quantities. Some may also operate in non-competitive markets and be subject to non-constant returns to scale. All these factors have an influence on traditional measures of TFP growth, compromising the original intent. Nevertheless, measured TFP growth at the micro-economic level can be a useful performance indicator, largely because of the influence of these other factors rather than despite them.

# CHAPTER 3 PRODUCTIVITY MEASURES AS PERFORMANCE INDICATORS

In order to monitor dynamic performance and to aid in the development of corporate planning, firms frequently produce a check list of performance indicators which they update at the end of each accounting period. In addition to financial indicators such as rates of return measures, which are directly influenced by pricing policy, valuable insights are provided by changes in productivity based indicators — that is, indicators which reveal changes in the ratio of outputs to inputs. Partial productivity measures of various kinds are frequently presented in firms' annual reports, and the most common among these are various forms of labour productivity. Labour productivity is typically easier to measure than other partial measures requiring the estimation of capital stocks. It must be said, however, that labour productivity figures can frequently be misleading since they are often expressed as output per employee, a measure which fails to take proper account of items such as variations in standard hours worked due to changes in award structures and, more importantly, variations in the amount of overtime worked.

As already mentioned, there are problems associated with the interpretation of partial measures of productivity. It is preferable to calculate a measure of total factor productivity in addition to various other performance indicators. Such a measure will be a weighted average of partial productivity measures, but requires additional information on cost shares and revenue shares as well as estimates of aggregates such as capital stocks. Its distinct advantage is that it provides an objective assessment of the influence of all the partial productivity measures, in contrast to the typically subjective assessment based upon the perusal of a usually incomplete set of partial measures.

In this chapter some of the difficulties associated with partial productivity measures as performance indicators are considered, and the roles of traditional and adjusted measures of total factor productivity are discussed, again within the context of performance indicators.

## PERFORMANCE INDICATORS

Performance indicators provide a means by which the performance of an enterprise can be assessed, both in terms of past performance, and in contemporaneous comparison with other similar enterprises. Any areas identified to be sources of strength or weakness can then be addressed within the corporate plan. Typically, there are a large number of theoretically available indicators. Some of these will indicate financial performance while others will concentrate more on measures of productivity. While productivity is a major driving force behind financial performance, output pricing policy and input factor costs impinge directly on financial performance and only indirectly on productivity.

Financial performance is usually monitored by reference to measures of rates of return. Such rates of return may be expressed before or after tax, and as a proportion of total funds employed or of some particular identifiable fraction of total assets such as equity, the appropriate measure depending upon the question in hand. For example, overall performance may be best measured by earnings (before or after tax) as a proportion of total funds employed, but at the same time shareholders are also likely to be interested in rates of return to equity.

There are two major types of influence upon financial performance indicators. One relates to changes in the costs of inputs, the price of the resulting outputs, and the price induced changes in demand. The other relates to the productivity of the enterprise. At fixed input and output prices, productivity improvements result in increased rates of return. Measures of productivity are therefore valuable additions to financial indicators. In 'complete and efficient' markets they reflect changes in the fundamentals of wealth generation, and are the appropriate choice for the internal input–output targets of firms operating in a competitive environment, and from a social welfare point of view they provide an indication of how well scarce resources are being used. However, complete and efficient markets do not exist in reality, and measured TFP may become less closely tied to welfare as the degree of market failure grows. These issues are discussed further in chapter 4.

The most commonly used measures of productivity relate the level of output (or a proxy thereof) to the level of labour input. For a single firm different measures of this type can result from the use of different output proxies or, in the case of several outputs, from the use of specific outputs. For example, in telecommunications, the number of main lines per employee is a widely used measure of labour productivity, the number of main lines being a proxy for output. In rail, passenger and freight outputs are usually distinguished, so partial productivity measures include passenger train kilometres per employee, and freight tonne-kilometres per employee.

Partial measures of productivity are of some value in their own right, but under various scenarios a given rate of productivity growth can be indicative of quite different phenomena. The example in chapter 2 showed how an innovation in capital inputs, such as computers, can give rise to an increase in labour productivity through labour shedding, but the same increase in labour productivity could also result from improvements in labour efficiency alone. The point of the example is to illustrate that a given change in labour productivity can be indicative of quite different phenomena and therefore warrant entirely different appropriate reactions. In the case of the capital innovation it may be appropriate to increase the capital to labour ratio, while in the case of improved labour efficiency alone, it may be appropriate to reduce the capital to labour ratio. Other considerations, such as a move to greater or lesser contracting out of labour intensive activities, can also have an effect on measured labour productivity even when no fundamental change in productive capabilities has occurred.

Not only might the measure of labour productivity on its own be of ambiguous use to the manager, but it may also be so to employees if their claims on wage policy were intended to reflect their contribution to production. (There is a considerable literature on the relationship between wages, productivity and technical progress — see for example Salter 1969; Eggleston 1983; Harris 1988.) If, in the case of increased labour productivity due to labour shedding after introduction of computers, claims for increased wages are made and granted, then the resulting change in relative input prices could lead to further capital for labour substitution, and hence to further associated increases in labour productivity. There may then arise the possibility of spiralling retrenchment as indicated in figure 3.1.

At time zero, the unit isoquant is depicted by AB, $Z_0$ represents the efficient use of resources, and $\omega_0$ is indicative of the slope of the input price line. The slope of the price lines as shown in the diagram is tan $(90 - \omega)$ so that the larger is $\omega$ the flatter the slope of the price line. Suppose that a technological change occurs to shift the unit isoquant to A′B′. At prevailing input prices the efficient use of resources occurs at $Z_1$. The amount of labour now required to produce a unit of output has fallen and hence labour productivity has risen. If the entire cost saving resulting from the improvement goes into wages then demand may not rise significantly, while the slope of the input price line changes to that indicated by $\omega_1$. As a result, $Z_2$ becomes the efficient point. Again, this gives rise to an increase in labour productivity, and so the process continues.

While the above analysis is of a somewhat simplistic and partial nature (in reality there would be other effects and feedbacks), it serves to indicate the possible short-run consequences of policies based on inadequate measures of productivity growth. In reality, managers are likely to be aware of any significant changes in the efficiency of different input factors, and to take these into account in their decision making. Nevertheless, the exact extent of labour-saving technological change, and the weight to attach to that change in assessing its aggregate impact on productivity, will be largely subjective in the absence of a comprehensive measure of productivity growth.

These considerations point to measures of multi-factor or total factor productivity as being more relevant indicators of overall productive efficiency than their partial counterparts. An increase in total factor productivity unambiguously implies greater average aggregate output (per unit of aggregate input) or equivalently the same output at a lower cost of production.

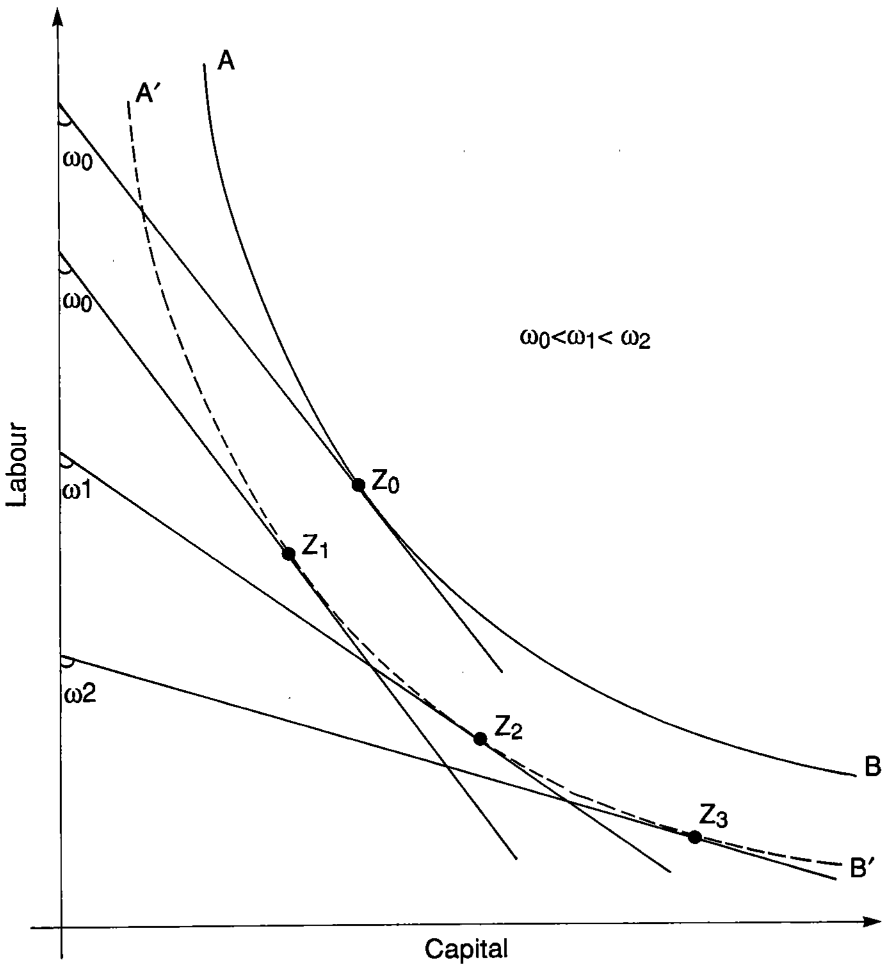



**Figure 3.1 Spiralling retrenchment**

## INTERPRETATION OF PRODUCTIVITY MEASURES

Recently there has been much public discussion, both in the media and in political debate, on the level of productivity growth in Australia, and on the associated implications for Australia's future prosperity. The empirical evidence has ranged from the micro-economic level of the firm, through industry and sector level, right up to measures of productivity for the economy as a whole (see for example Industries Assistance Commission 1989b; Bureau of Industry Economics 1985; Australian Bureau of Statistics 1989b; Economic Planning Advisory Council

1989). Whenever new results are released the media take up discussion of the causes and implications of these results. Such public debate is to be encouraged, but it is important that certain disarmingly common misconceptions should be corrected.

Some of the misinterpretations of productivity measures have been mentioned earlier, in the discussion of the limitations of partial measures of productivity. It is important to emphasise again that high levels of labour productivity growth do not necessarily imply that labour is operating efficiently, and low levels of capital productivity growth are not necessarily indicative of 'capital not pulling its weight' (Australian Financial Review 1989). The case in point relates to the Australian Bureau of Statistics (1989b) results on multi-factor productivity estimates for Australia from 1974–75 to 1987–88. The figures indicate an average annual rate of growth in multi-factor productivity of 1.5 per cent for the Australian market sector over the entire period. This is accounted for by a weighted aggregate of an average 2.0 per cent growth per year in labour productivity (output per hour worked) and –0.2 per cent per year growth in capital productivity (output per unit of capital). These figures alone cannot imply the extent to which each of these factors is 'pulling its weight'.

The Australian Bureau of Statistics paper also gives time series for output (gross product) and the capital to labour ratio. These series give information on the ratio of inputs used to produce a unit of output. If, in aggregate, output is being produced at minimum cost, then an increase in the effectiveness with which labour combines with a unit of capital will tend to exert downward pressure on the capital to labour ratio. However, the trend in this ratio over the period considered by the Australian Bureau of Statistics has been quite strongly upward, which may imply that capital has been in relatively greater demand. Certainly there are other considerations such as the relatively fixed supply of labour in the short run, although it must be said that the period in question has not been one of an excessively tight labour market.

The point of this short section has been to emphasise that rates of growth in partial productivity measures do not necessarily provide any indication of that factor's contribution to lower costs of production. In fact it is frequently the contrary that holds true.

## APPLICATION TO GOVERNMENT BUSINESS ENTERPRISES

In describing the agenda for the Government's third term, the Prime Minister put great emphasis on the need for micro-economic reform, and particularly so in the area of government business enterprises (GBEs). In line with this agenda the Government is investigating appropriate rate of return targets for the GBEs. The Industries Assistance Commission (1989b) has already published the results of some research on GBE performance. As discussed earlier, rates of return do not provide a complete picture of enterprise performance. It is important that productivity targets are included in corporate plans, and that these targets be sufficiently comprehensive to prevent the sort of misinterpretation of partial productivity measures cited above, or preferably, that they include target measures for total factor productivity growth.

The computation of total factor productivity indexes is likely to be easier for some GBEs than others. It is generally the estimation of capital stocks which causes the most difficulty, although this may be a considerably easier task in the case of some GBEs. For example, estimating capital stocks for Australian Airlines may be considerably easier than for Telecom Australia. On the other hand, the measurement of output for some GBEs may be the major source of difficulty in the estimation of total factor productivity. For example, Australia Post provides many different services. The major one of these entails the delivery of mail, both domestic and international, and it is doubtful whether information on exact numbers of items of each weight category, to and from each possible destination, is available. In addition it is difficult to apply boundaries to the extent of Australia Post's influence on the efficiency of the provision of international postal services since other countries' efficiency may impinge directly upon the domestic carrier. Similar problems apply to overseas telecommunications.

Notwithstanding the estimation difficulties in measuring quantities of both inputs and outputs, it is preferable that some form of operational estimation of year by year total factor productivity growth be developed for each of the GBEs.

In the Transport and Communications portfolio there are currently ten GBEs: Telecom Australia, OTC, Australia Post, Australian National, Australian Airlines, Qantas, Australian National Line, Federal Airports Corporation, Civil Aviation Authority, and Aussat. Some of these are already developing their own in-house measures of total factor productivity, and others are soon to embark upon the task. In chapter 5 indexes of total factor productivity for Australian National for the period 1979–80 to 1987–88 are developed and analysed.

## SUMMARY

Indexes of productivity growth provide a useful addition to the check list through which enterprises can set their corporate goals and by which governments can assess the performance of GBEs. The use of productivity measures in this respect is not new, but has typically been restricted to partial measures in the past, and although total factor (or multi-factor) productivity measures are now more common, there remain misconceptions regarding the interpretation of partial components of total factor productivity growth.

Measures of total factor productivity growth reflect the extent to which increased amounts of output are realisable from given inputs. As such, they provide a useful performance measure. However, in the case of Australian GBEs, their usefulness is largely restricted to an assessment of a given period's performance relative to some other. Higher rates of productivity growth in one enterprise compared with others are not necessarily a sign that one is 'performing better' than the others. For example, one may have previously been operating at a relatively inefficient level, thereby allowing greater scope for productivity (efficiency) improvements, and enterprises engaged in different productive activities are likely to be subject to different rates of technological progress.

The estimation of total factor productivity growth for the GBEs will facilitate both the development of corporate plans and the continued assessment of performance, both of which are fundamental to the implementation of the Government's micro-economic reform package.

# CHAPTER 4 MEASURING PRODUCTIVITY GROWTH

In chapter 2 the distinction was made between changes in efficiency and in technological progress. The original approach to measuring TFP was intended to capture technological progress, as it was assumed that the productive activities in question were being engaged in at minimum cost. However, there are likely to be changes in (static) efficiency from time to time, which cannot be distinguished from technological change in a traditional non-parametric approach to the estimation of TFP. In addition to the efficiency issues raised in chapter 2, temporary equilibrium, resulting from unforeseen changes in demand or from unforeseen changes in the relative price of input factors, may be an important issue in the use of past productivity growth as a basis for setting future targets. And finally, in the case of a non-marginal pricing policy it may also be appropriate to make certain changes to the traditional approach to the estimation of TFP growth.

In this chapter, the way in which the three issues raised above impinge upon the computation and interpretation of productivity growth are discussed in detail; the algebraic ramifications are presented in appendix I. Even when data restrictions prevent the full implementation of appropriate adjustments, it is important to be aware of the likely effect of these phenomena on the empirical results.

## TRADITIONAL MEASURES OF TOTAL FACTOR PRODUCTIVITY GROWTH

The difference between the notions of (static) efficiency and productivity were discussed in some detail in chapter 2. The formula presented in equation 2.1 derives, in the case of a single output, from the assumption of perfectly competitive markets and a profit maximising firm facing Hicks neutral technological progress. The assumptions of competition and profit maximisation give rise to two fundamental equalities. The first is that output price is set equal to marginal cost, and the second is that input factors are used in amounts which equalise their unit cost and the value of their product at the margin. In the presence of constant returns to scale, these assumptions give rise to equation 2.1 with just a single output. That is, TFP growth equals the difference between output growth and the cost-share weighted average of input growths.

Frequently, productive activities entail the production of several outputs jointly from several inputs, and a common approach to the multi-output case has been to replace growth in the single output with the revenue-share weighted average of the growths in the various outputs. This gives rise to equation 2.1. If this is done, TFP growth is implicitly defined to be the difference between the two averages of the output and input growth rates. (Under certain conditions, these weighted averages represent the growth rates in Divisia indexes of aggregate output and aggregate input. These issues are discussed in detail in appendix I.) However, in many circumstances it is not possible to interpret this difference as the rate of growth in some intuitively appealing index. This results from the problems associated with the Divisia index being a line integral and therefore possibly path dependent (see appendix I for further discussion).

In the single output, single input case, TFP growth is simply the growth rate in an index of the ratio of output to input. In the multi-output, multi-input case, TFP growth can be defined to be the maximum common rate at which all outputs could grow when all inputs are held constant, or alternatively the maximum common rate at which all inputs could decline when all outputs are held constant.[1]

Using the notation of Caves, Christensen and Swanson (1981), the former is denoted *PGY*, and the latter *PGX*. If constant returns to scale do not hold, the two definitions give different results. In general, *PGY* is equal to *PGY* times the returns to scale parameter as defined by Panzar and Willig (1977).

In chapter 5 empirical measures of TFP growth are estimated for AN using both the approach of equation 2.1 and the approach derived by Caves, Christensen and Swanson with certain other modifications to be discussed in general terms below. In this way, appropriate series can be chosen for making comparisons with other results and for setting targets.

## TEMPORARY EQUILIBRIUM

The theory of temporary equilibrium recognises the fact that from time to time firms may find themselves in a position where 'stocks' of input factors are not at static optimal levels. There are many reasons why such phenomena occur. For example, the accumulation or disposal of capital stock takes time and may exhibit indivisibilities giving rise to 'lumpiness' in investment. Unforeseen fluctuations in demand may give rise to periods of overcapacity or undercapacity, and not only in respect of capital. Since the traditional formulations for measuring TFP growth depend on the assumption that input factors are being used in their (static) optimal quantities, deviations from such due to temporary equilibrium will give rise to changes in measured TFP growth. To the extent that TFP measures are being interpreted as measuring the efficiency of production, it may be desirable in some

1. What is meant here by the common rate of growth in a vector $(y_1, \ldots, y_n)$ of, say, outputs with inputs held constant, is the number $r$ where $[(1 + r)\, y, \ldots, (1 + r)y_n]$ is feasible from the same input vector as previously produced $(y_1, \ldots, y_n)$, and that $r$ is maximal.

circumstances to be able to purge the effects of temporary equilibrium from the productivity measures.

The impact of temporary equilibrium on productivity has long been recognised, but has only recently been fully addressed in the literature (see Berndt & Fuss 1986; Hulten 1986; Morrison 1986). Generally speaking, either a subjective, informal adjustment would be made to productivity results to account for recession and the like, or the measures of capital stock may be adjusted by some capacity utilisation factor. Not only have such issues as labour market rigidities with their effects on adjustment of the firm's stock of labour been largely ignored, but, in addition, it has been shown by Berndt and Fuss that it is prices of input factors rather than quantities that should be adjusted for temporary equilibrium when measuring TFP growth.

It is worth spending a little time on two examples of temporary equilibrium in order to appreciate how they affect measures of TFP growth. The first example (figure 4.1) relates to the effects of an unforeseen shock in demand. At time zero, in long-run equilibrium the level of output produced by the industry, with the supply

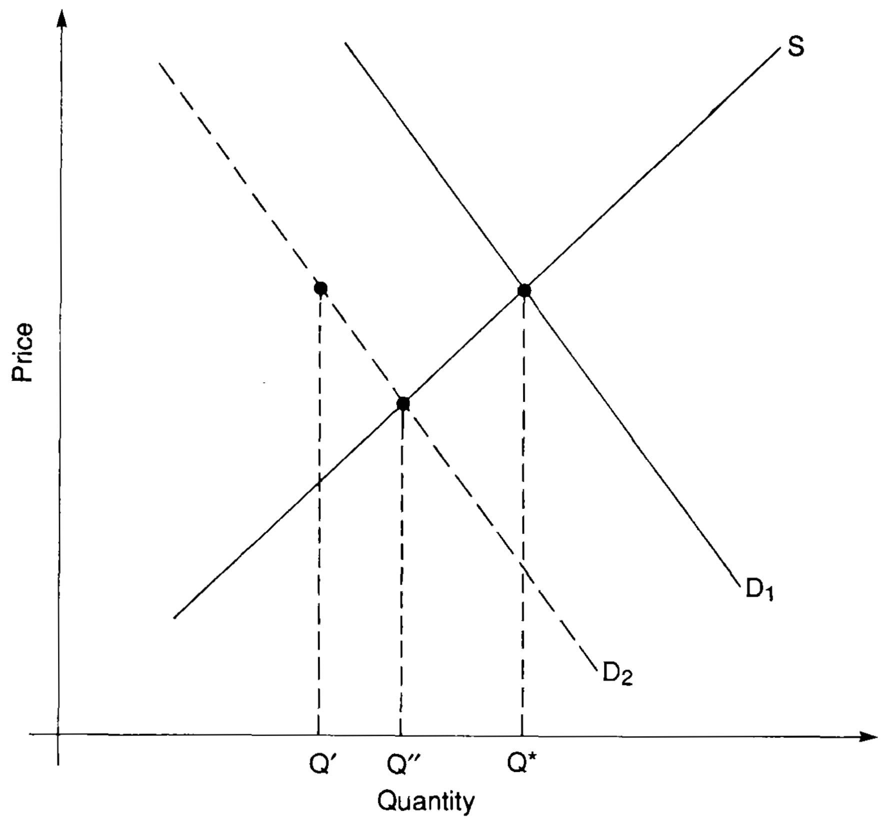



**Figure 4.1 Unanticipated shock in demand**

curve denoted by S, is Q*. An unanticipated fall in demand, from $D_1$ to $D_2$, gives rise to a reduction in output from Q* to Q′ (or to Q″ if prices fall in the short run). However, the industry holds a stock of capital (and probably labour too) capable of producing Q*. The shock may then give rise to a reduction in measured TFP since input factors may not have changed (notwithstanding that some of them are not being utilised) while output has fallen. These considerations are of consequence only to the extent that the industry or firm in question is facing a downward sloping demand curve, and as such are not relevant in the model of perfect competition, where a firm can always sell as much as it wishes. They are, however, of importance to many firms in the real world and, as will be evident in chapter 5, they are of significance in the case of AN.

The second example is best illustrated by reference to a situation which has faced AN. Employment policy in AN prior to about 1980 gave rise to a substantial excess of labour for the level of output produced. This meant that for marginal increases or decreases in the number of employees, the effect on output in value terms would have been somewhat less than the change in the wage bill. Indeed, some would argue that the 'surplus' staff contributed nothing to output. Since the traditional measures of TFP growth identify the wage with the incremental addition to the value of output from labour, there is a case for adjustment. It is the weight applied to the rate of growth in labour input that is derived from the relationship between the wage and the value of output, and as mentioned above, it is here that the wage should be replaced by an estimate of the shadow price of labour. If surplus labour contributes nothing to output then incremental changes in labour input carry a shadow price of zero, and for some purposes are entirely irrelevant to TFP growth (though not, of course, to productive efficiency in general). It may be argued that surplus labour does contribute something, in which case the appropriate shadow price is greater than zero but less than the wage, and the weight attached to labour change in the computation of TFP growth may be positive but less than would be the case at a position of optimal labour use.

These issues will be discussed more fully in relation to productivity growth in AN in chapter 5. However, it should be said that the adjustments to TFP growth measures described above do not imply that there is no efficiency gain to be had from reducing the amount of surplus labour. Rather, the technique is designed to compute estimates of TFP growth arising from sources other than the removal of surplus labour. As such, they can provide a more useful guide to expected TFP growth, and, in conjunction with the unadjusted estimates, can provide estimates of the relative role of labour reduction as a source of efficiency gain within the aggregate gains being realised from all sources.

## PRICING

One more area where the assumptions behind the traditional measures of TFP growth may be at variance with reality is the area of output prices. Traditional TFP estimation assumes marginal cost pricing, but in certain cases, such as monopoly, prices may not be related only to cost. For example, in a regulated public monopoly prices may be set at a uniform mark-up on marginal cost, or may entail a degree of discrimination based on demand elasticities (so-called Ramsey pricing). An alternative form of regulation is that of rate of return constraint. However, while this has been relatively common in the United States, it is not used in Australia.

It can be shown that in the case of uniform mark-up of output prices over marginal cost, there is no adjustment necessary to the traditional formula for TFP growth. However in the case of non-uniform mark-up, certain adjustments to the traditional formula are necessary to remove the effect of non-marginal cost pricing on measured TFP growth. Details on these adjustments are provided in Denny, Fuss and Waverman (1981).

## TOTAL FACTOR PRODUCTIVITY GROWTH AND NATIONAL WELFARE

TFP growth for a multi-output, multi-input production activity was defined earlier to be the common rate at which all outputs could grow with all inputs held constant (*PGY*), or alternatively the common rate at which all inputs could decline with all outputs held constant (*PGX*). It was also noted that the relationship between these two definitions of productivity growth is given by

$$PGY = RTS \, . \, PGX$$

where *RTS* is the returns to scale parameter as defined by Panzar and Willig (1977). Thus, under constant returns to scale, *PGY* and *PGX* are identical.

It is not difficult to show that in complete and efficient markets exhibiting constant returns to scale, productivity growth of *x* per cent leads to a gain in welfare approximately equal to *x* per cent of current revenue (the error in approximation is of second order and depends upon the elasticity of demand for the output in question). It may be worth pointing out, however, that *x* per cent productivity growth does not lead to an increase in welfare of *x* per cent (except in the highly theoretical case where demand is infinitely elastic at all output levels below that being produced).

Under ideal market conditions, then, the relationship between the rate of total factor productivity growth and changes in the level of welfare is given by

$$\Delta W = \widehat{TFP} \, . \, Rev$$

where $\Delta W$ is the change in the level of welfare, $\widehat{TFP}$ is the rate of growth in total factor productivity, and *Rev* is the level of current revenue.

In reality neither complete nor efficient markets exist, and in many cases the extent of the departure from this ideal is sufficient to significantly distort the above relationship between TFP growth and welfare gain. There are many possible reasons why this relationship may be obfuscated. They include the effects of taxation, externalities in input and markets, and policies which result in (relative) prices which do not reflect (relative) marginal costs. Positive externalities associated with the production of output, for example, will lead to the underestimation of welfare gain using the above relationship, and negative externalities to its overestimation, and similarly in the case of input usage. In short, all the complexities associated with the social evaluation of benefits and costs bear upon that relationship.

Despite the difficulties of interpreting the implications of TFP growth for economic welfare, the definitions of *PGY* and *PGX*, and the associated analytic expressions, equations I.4 and I.5 in appendix I, are unambiguous (although their empirical measurement does rely on assumptions, usually of particular specified private objectives being maximised). Even in the absence of ideal markets, measured TFP growth may still be a useful indicator of performance in an engineering sense, that is, the rate of growth in the efficiency with which inputs are transformed into outputs.

It is important to keep in mind that unless private shadow prices at the level of the firm (reflected in the partial derivatives of the production transformation with respect to outputs and inputs) are equal to social shadow prices, the implications of measured productivity growth for welfare are ambiguous. The general comments on the role of TFP growth as a performance measure for GBEs, and the interpretation of the results of measuring *PGY* for AN, are therefore all subject to the caveats raised above.

## SUMMARY

Traditional non-parametric measures of TFP growth are derived from a general production transformation under the assumptions of profit maximisation in an economic environment where prices are given and input factors can be adjusted instantaneously. However, in reality the factors of production cannot be adjusted instantaneously, and output prices may not be exogenously determined. If the intention is to measure the potential rate of growth of output from given inputs, then adjustments to traditional measures of TFP growth may be necessary to compensate for the effects of temporary equilibrium and of non-marginal cost pricing. These issues are likely to be relevant in the area of productivity growth in GBEs, and perhaps even more so in the future in the light of the effects on pricing policy resulting from the Government's commitment to cost recovery.

# CHAPTER 5 PRODUCTIVITY GROWTH IN AUSTRALIAN NATIONAL

In chapter 3 the role for measures of total factor productivity growth as indicators of performance was discussed in some detail. It was recognised that TFP growth provides a measure of productive performance which is largely independent of pricing policy (although, as indicated in chapter 4, not necessarily entirely so). As such it provides a useful complement to financial measures of performance, and wherever practically possible it should be included within the basket of indicators used to assess past performance and to set future corporate targets. Traditional measures of TFP growth may require adjustment to account for scale, temporary equilibrium, and pricing effects, depending on the use to which the measures are put.

This chapter first gives a brief history and describes the main characteristics of AN, as these have some bearing on the outcome of measures of TFP growth. The next section provides some partial productivity measures for AN and a comparison with similar measures for other rail systems in Australia. The results from six different approaches to measuring TFP growth are then presented and analysed. These results are compared with TFP results in other Australian industries and in the economy as a whole, as well as with results for railways in the United States and Canada.

## HISTORY AND CHARACTERISTICS OF AUSTRALIAN NATIONAL

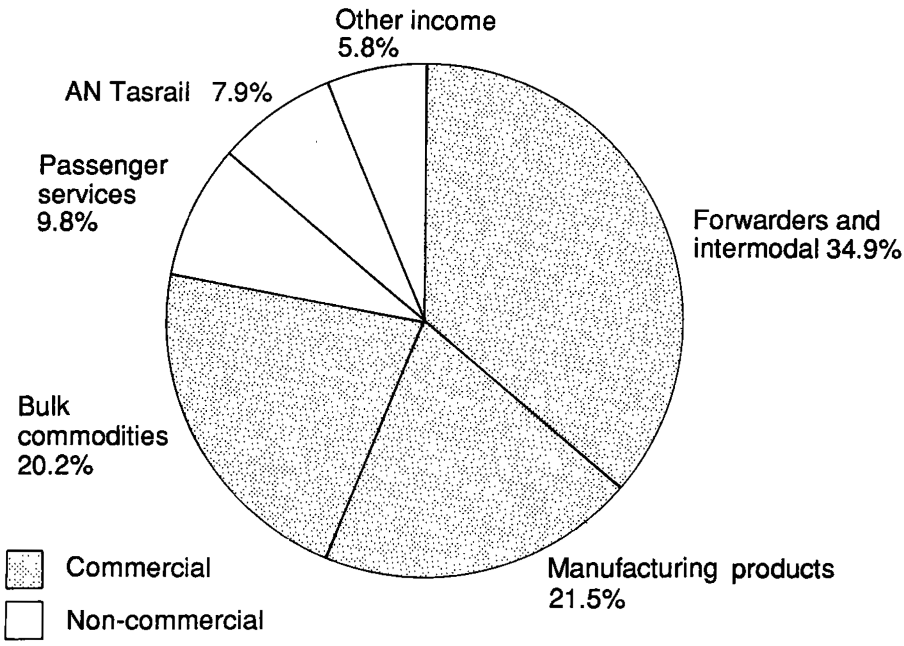
The Australian National Railways Commission (operating as Australian National or AN) is a statutory authority under the *Australian National Railways Commission Act 1983*, and is responsible for the management and operation of railways owned by the Commonwealth government.

AN was established in 1975 to take over the former Commonwealth, South Australian (non-metropolitan lines only) and Tasmanian rail systems, with full responsibility for all operations assumed in March 1978.

As a result of large deficits incurred in AN early years a parliamentary inquiry was held. The report recommended substantial changes to AN objectives (Australia, House of Representatives Standing Committee on Expenditure 1982). The Committee emphasised the need for commercial objectives and the clear separation of these from community service obligations. This led to the new legislation of 1983, designed to provide a legal environment conducive to commercial operations.

AN operations are now divided into 'commercial' and 'non-commercial' activities. 'Commercial business comprises all wagonload freight on the Mainland and accounts for over three-quarters of total AN revenue' (AN News 1987). AN's 'commercial' activities are divided into three major groups: forwarders and intermodal, manufacturing products, and bulk commodities. The first of these includes freight forwarders traffic (containers and wagonloads), piggyback, shipping containers and other commercial wagonloads. The second includes iron and steel, lead and zinc, chemicals, explosives, timber and timber products, paper, motor vehicles, machinery, cement and fly ash, soda ash and oil products. The third includes grain, fertiliser, coal, gypsum, salt, mineral concentrates and limestone.

AN's 'non-commercial' business comprises mainly passenger services and Tasrail business. There are some additional 'non-commercial' activities such as less-than-carload (LCL) freight. Of the 'commercial' activities the forwarders and intermodal group accounts for the largest revenue share and of the 'non-commercial' activities, passenger services account for the largest share of revenue (figure 5.1).




*Source* AN News 1987.

**Figure 5.1 Revenue from AN business groups 1986-87**

## SOME PARTIAL MEASURES OF PRODUCTIVITY GROWTH

In chapter 3, some of the problems associated with the use of partial measures of productivity for the purpose of measuring performance were discussed. It was recognised that where only partial measures are available they may be of use, both in their own right and in order to allow for comparison, albeit qualified, with other activities. In this section some partial productivity measures for AN are presented and discussed.

### Labour productivity

The most popular partial measure of productivity is labour productivity, or output per unit of labour input. Ideally, this measure would be computed by taking the ratio of total output to total hours of labour input used in the production of that output. Unfortunately, data on hours worked is not available for AN, and it is therefore necessary to make do with the less accurate measure of output per employee. Due to a lack of detailed information on sources of revenue in AN, output could be disaggregated only as far as passenger, mainland freight and Tasmanian freight. There are therefore three indexes of output: passenger train kilometres, and net tonne-kilometres of freight for mainland and for Tasmanian operations. It would be preferable to disaggregate the measure of freight into bulk and non-bulk, or even into a greater number of different categories reflecting the diversity of input needs required to transport various types of freight over varying lengths of haul. Unfortunately, data necessary for such disaggregation were not available.

Initial considerations may suggest that the measure of passenger output is even more inappropriate. However, AN is required by legislation to provide certain passenger services. As such, it may be viewed as having entered into a contractual agreement with the Commonwealth government to provide a given level of passenger services. Whether or not that level constitutes an overprovision is of importance from a national welfare viewpoint, but is not relevant to the question of how efficiently that contractual arrangement is fulfilled. These considerations, together with a lack of origin–destination data or even data on passenger kilometres in aggregate, provide some justification for the measure. Further details regarding AN data are discussed in appendix II.

Labour productivity data for AN are provided in table 5.1. Table 5.2 provides comparable indexes of labour productivity for four other Australian rail systems. In all cases, output has been computed from a Divisia index approach to output growth. Specifically, passenger and freight output growths have been weighted by their respective revenue shares to provide series for annual growth in aggregate output. The series are then used to construct indexes of output to be used in the computation of labour productivity.

The only period of negative growth in labour productivity was the financial year 1982–83, which was a year of recession in the economy as a whole, and also a drought year. In the early 1980s a significant component of AN's freight task was

TABLE 5.1 OUTPUT, LABOUR INPUT AND LABOUR PRODUCTIVITY FOR AN

| *Year* | *Output index* | *Number of employees index* | *Labour productivity index* | *Labour productivity growth (per cent)* |
|---|---|---|---|---|
| 1979–80 | 100.0 | 100.0 | 100.0 | .. |
| 1980–81 | 102.7 | 96.1 | 106.9 | 6.9 |
| 1981–82 | 102.0 | 94.8 | 107.6 | 0.7 |
| 1982–83 | 91.9 | 91.4 | 100.5 | –6.6 |
| 1983–84 | 99.0 | 88.3 | 112.1 | 11.5 |
| 1984–85 | 102.4 | 84.0 | 121.9 | 8.7 |
| 1985–86 | 115.0 | 77.5 | 148.4 | 21.7 |
| 1986–87 | 111.3 | 74.8 | 148.8 | 0.3 |
| 1987–88 | 121.6 | 68.7 | 177.0 | 19.0 |

.. Not applicable.

*Sources* AN annual reports; BTCE estimates.

made up of haulage of grain and other items related to production levels in the agricultural sector. As a result, the impact of the recession on AN's output was exacerbated by the drought. The decline in output in 1982–83 compared with 1981–82 was some 10 per cent, while the decline in real gross product in the Australian market sector was approximately 16 per cent. Since the increase in AN's output over the entire period, 1979–80 to 1987–88, is comparable with the increase in real gross product over the same period, the relatively large difference between the two in the year 1982–83 indicates the magnitude of the impact of the drought on AN Rail's output (figure 5.2).

Other rail systems also had negative labour productivity growth in the year 1982–83. Over the period 1979–80 to 1985–86, Queensland Rail registered total labour productivity growth of 71 per cent, V/Line 44 per cent, AN 48 per cent and Westrail 21 per cent. It is likely that a significant amount of the growth in labour productivity in Queensland Rail is the result of greater concentration on freight operations, particularly since 1983–84.

It is worth repeating that comparisons between different rail systems on the basis of partial productivity figures should be made with extreme caution. Many factors that are not taken into account, such as variation in passenger and freight mix, may cause labour productivity measures to be poor indicators of performance.

## Capital productivity

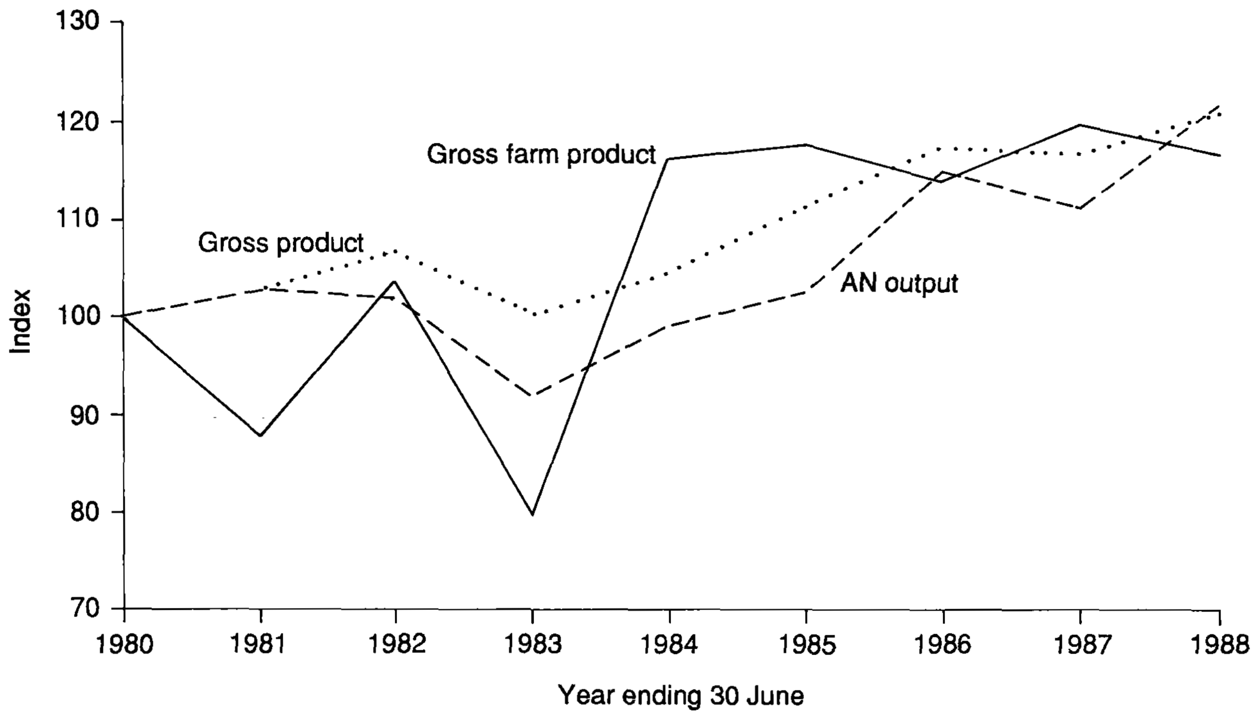
There are several partial measures of capital productivity corresponding to the various types of capital employed, such as locomotives, wagons, permanent way

TABLE 5.2 LABOUR PRODUCTIVITY FOR AUSTRALIAN RAIL AUTHORITIES

| | *Westrail* | | *State Rail Authority of NSW* | | *V/Line* | | *Queensland Railways* | |
|---|---|---|---|---|---|---|---|---|
| *Year* | *Index* | *Growth (per cent)* | *Index* | *Growth (per cent)* | *Index* | *Growth (per cent)* | *Index* | *Growth (per cent)* |
| 1979–80 | 100.0 | .. | 100.0 | .. | 100.0 | .. | 100.0 | .. |
| 1980–81 | 98.9 | –1.1 | 99.7 | –0.3 | 99.7 | –0.3 | 104.6 | 4.6 |
| 1981–82 | 101.4 | 2.5 | 104.3 | 4.6 | 97.5 | –2.2 | 112.9 | 7.9 |
| 1982–83 | 107.3 | 5.8 | 94.1 | –9.6 | 78.1 | –19.9 | 110.7 | –1.9 |
| 1983–84 | 100.4 | –6.4 | 106.6 | 13.2 | 111.0 | 42.1 | 130.9 | 18.3 |
| 1984–85 | 120.7 | 20.2 | na | na | 151.1 | 36.1 | 155.1 | 18.4 |
| 1985–86 | 121.1 | 0.3 | na | na | 144.2 | –4.5 | 171.1 | 10.3 |

.. Not applicable.
na Not available.

*Source* Industries Assistance Commission (1989a).




*Sources* Australian Bureau of Statistics (1989); BTCE estimates.

**Figure 5.2 Gross product (market sector), gross farm product, and AN output**

and so on. It should be noted, however, that, in addition to the difficulties of interpreting partial measures which have already been discussed, the variation in type and vintage of locomotive further complicates interpretation and comparison of measures such as output per locomotive.

A more complete measure of capital productivity is obtained by aggregating the capital stock into an index through the use of appropriate deflators and a perpetual inventory method, and considering output per unit of aggregate capital input (figure 5.3).

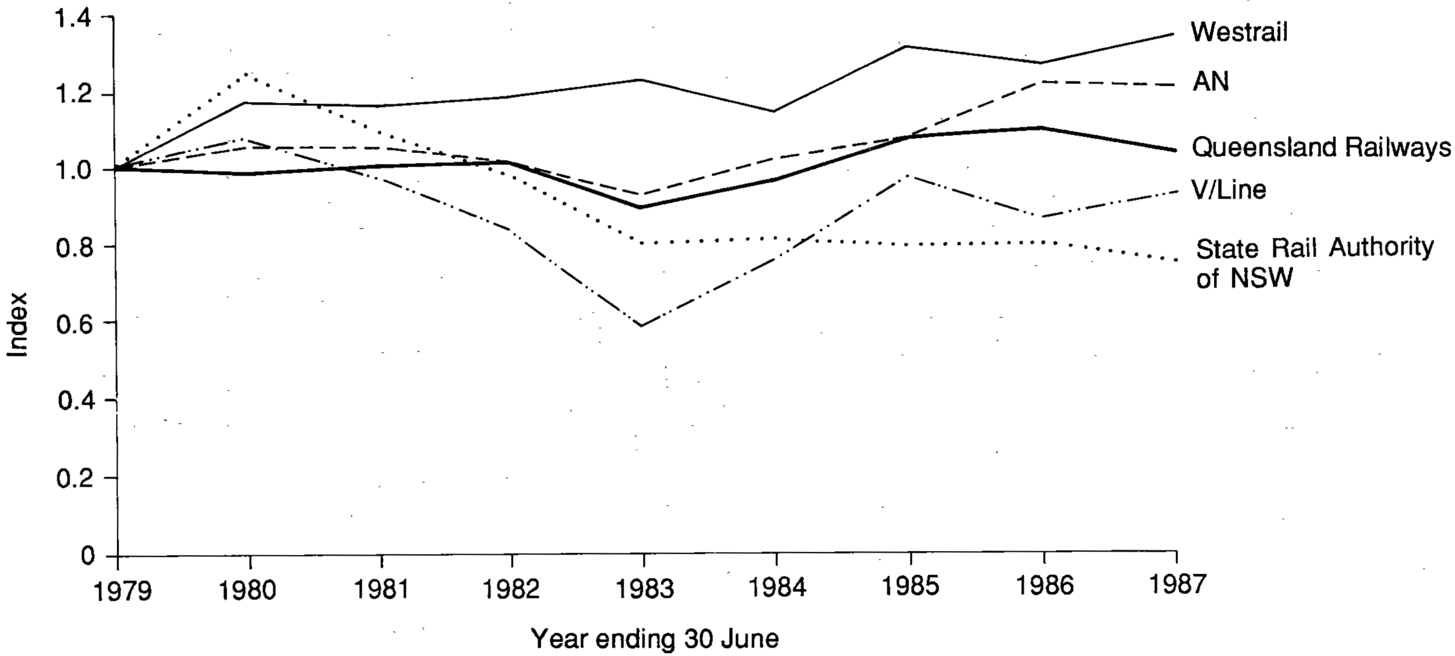
## TOTAL FACTOR PRODUCTIVITY GROWTH

In this section, six different estimates of TFP growth for AN are presented. These estimates result from two different assumptions regarding the objective being pursued by AN. Under each of these two assumptions, three measures are computed, one based on the traditional approach described in equation 2.1, and two additional measures resulting from the 'netting out' of the effects of surplus staff reduction under different assumptions regarding the marginal product of surplus labour. The first of these sets the marginal product of surplus labour equal to the average product of labour and is likely to be an overestimate, while the second sets the marginal product of surplus labour equal to zero, and is likely to be an underestimate. Analytical details of the six measures are provided in appendix III.

On the input side there are six categories: labour, fuel, materials, capital equipment, locomotives and rolling stock, and permanent way, land and buildings. In each of the series for TFP growth described above, the quantities of the three outputs, described in the preceding section, and the six inputs listed above are used to produce annual rates of growth, and it is only the treatment of the weights attached to these growth rates that varies over the different TFP estimates. A more detailed description of the sources and derivation of input and output data is presented in appendix II, together with annual quantities of these items, and the revenue and cost data from which the weights are computed.

The levels of passenger and freight related outputs are presented in figures 5.4 and 5.5 respectively. The trend in passenger train kilometres has generally been in slight decline over the period while that of net tonne-kilometres of freight, with a couple of exceptions, has exhibited strong growth. The two obvious declines in freight output occurred in 1982–83 and in 1986–87, at the same time as the index of gross product in the Australian market sector and the aggregate index of AN output also fell (see figure 5.2). As a result of the recession and drought in 1982–83 AN's freight task, of which a significant proportion came from the transportation of grain and other farm related products, was substantially reduced in 1982–83. This reduction occurred in an otherwise strongly rising trend, unlike the corresponding fall in passenger train kilometres.

Figure 5.6 shows the movement in the number of staff employed (excluding staff made available to the State Transport Authority of South Australia, and the State




*Source* Industries Assistance Commission (1989b).

**Figure 5.3 Capital productivity for rail authorities**

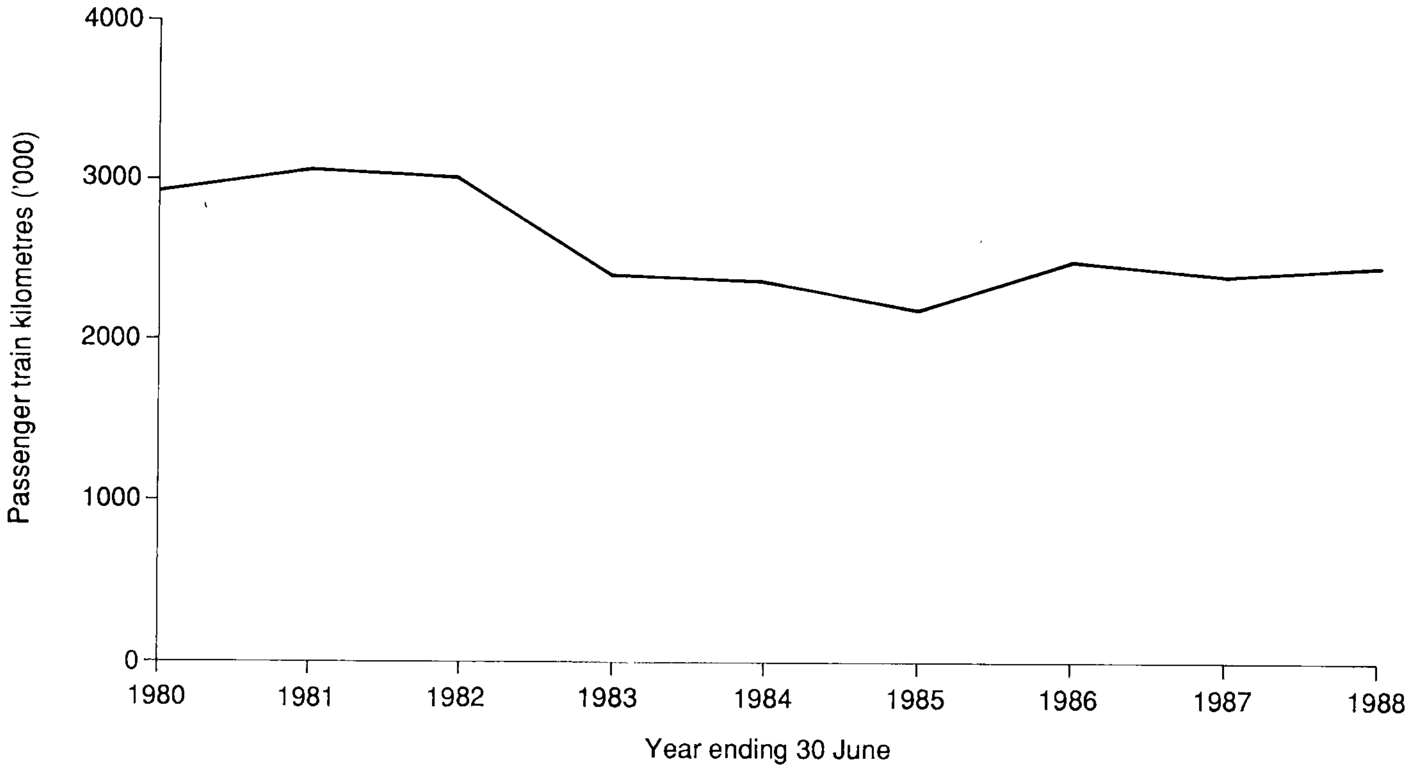



**Figure 5.4 AN passenger output**

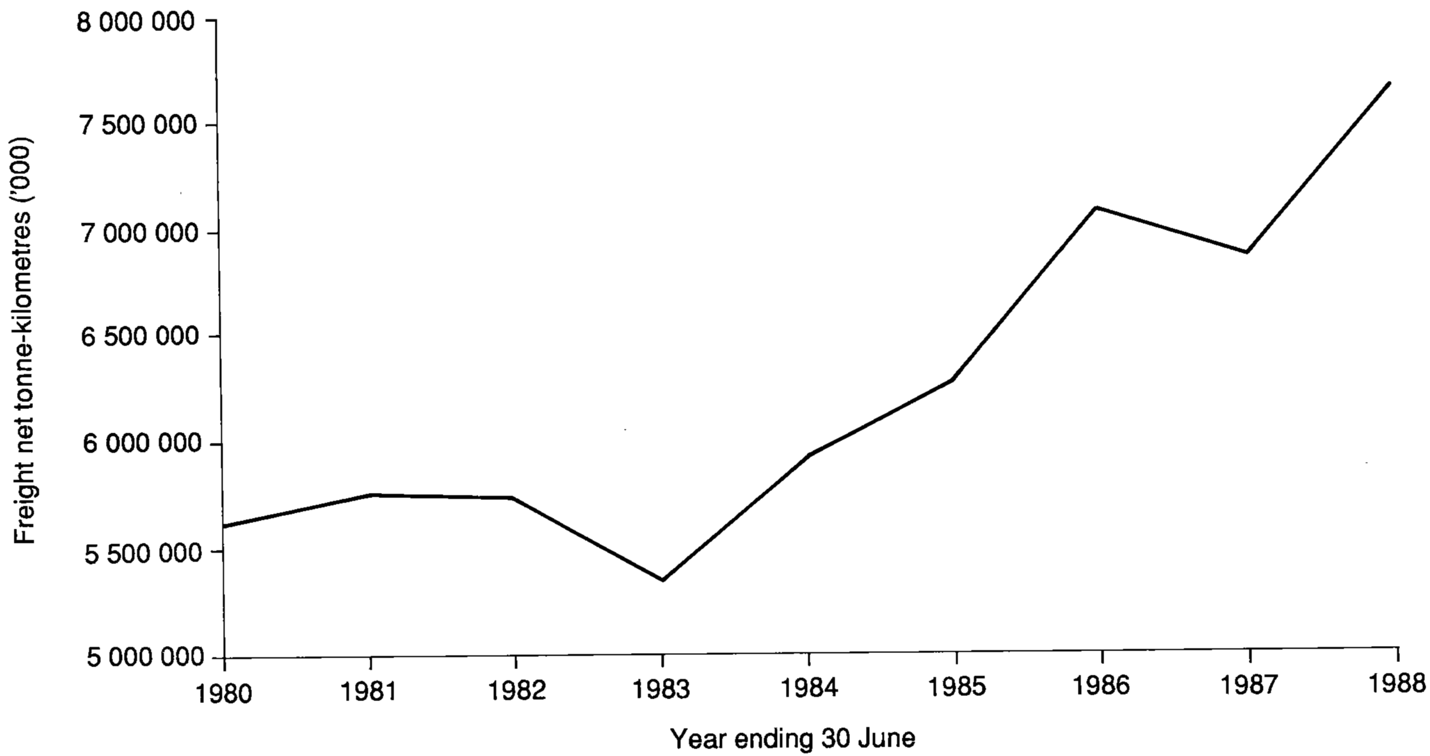
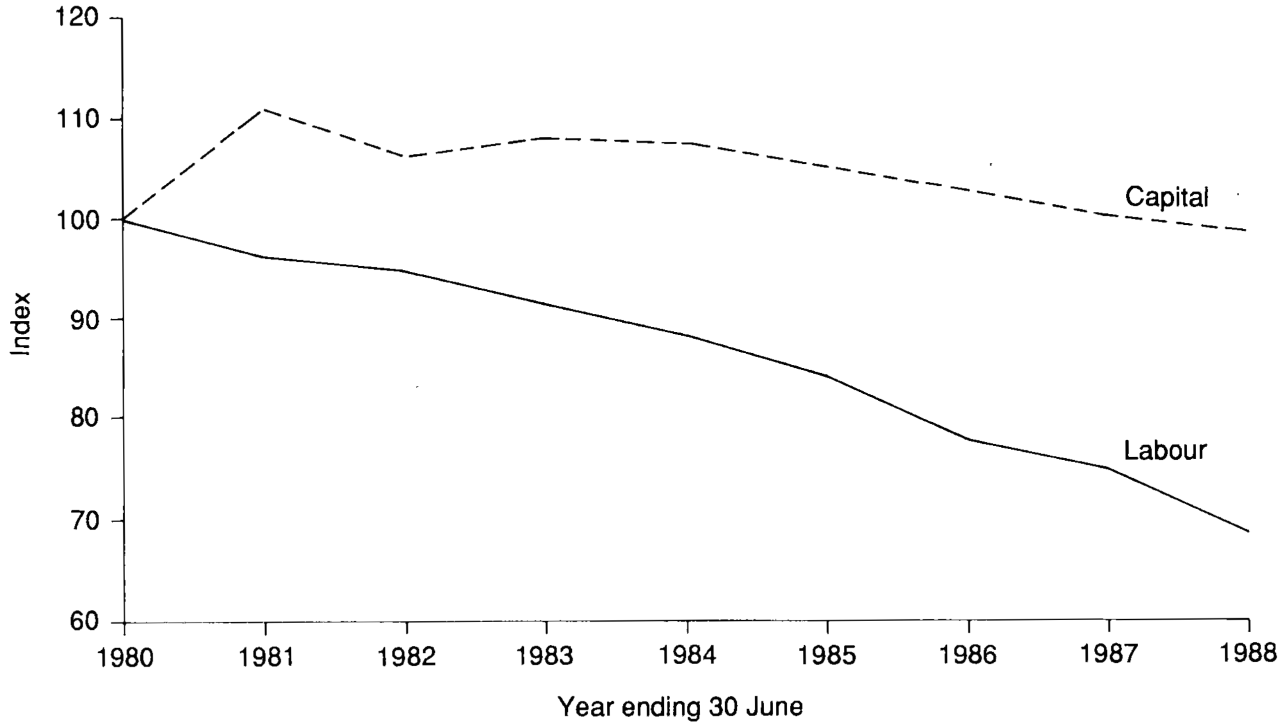



**Figure 5.5 AN freight output**




*Source* BTCE estimates.

**Figure 5.6 AN labour and capital stock**

Rail Authority of New South Wales) and in an index of the stock of capital (based on a perpetual inventory method, detailed in appendix II). The general rationalisation of AN activities is apparent in the decline in both these indexes, and the extent of labour shedding is quite dramatic. The adjustment to a more appropriate capital to labour ratio is displayed in figure 5.7. Once the problem of surplus staff is resolved, it may be expected that the growth in the capital to labour ratio will slow.

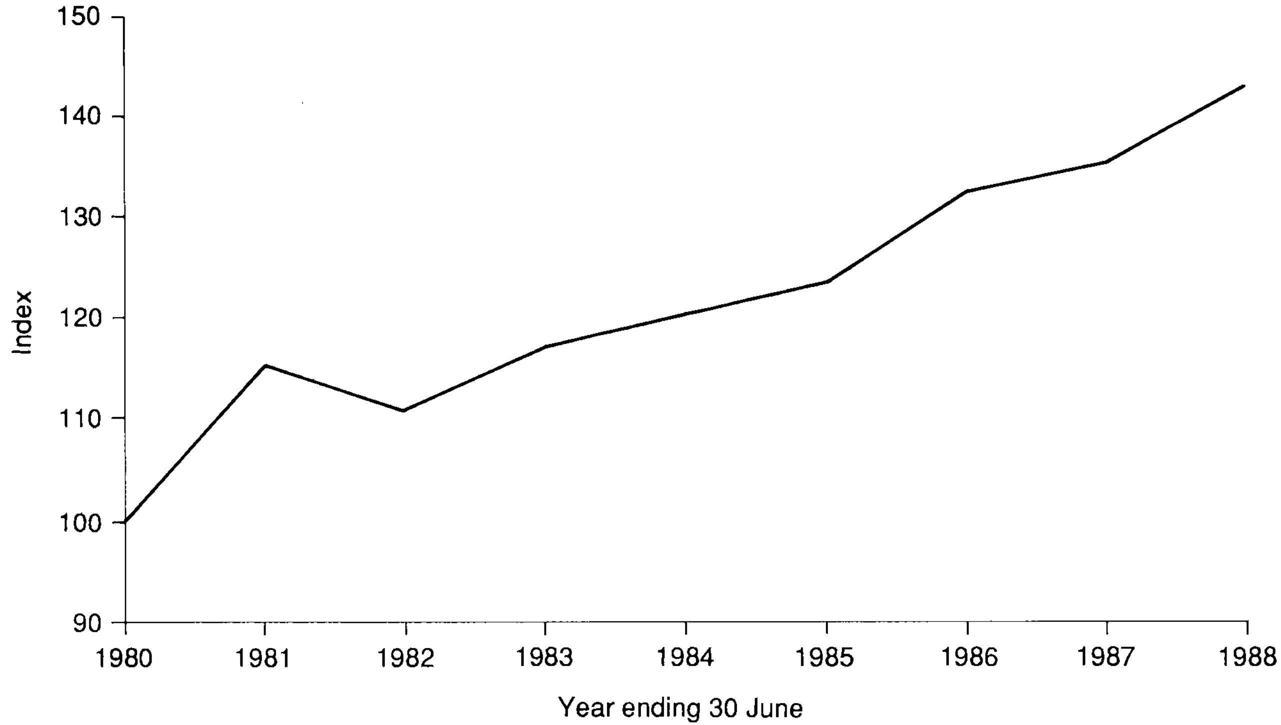
The other two inputs are materials and fuel. The decline in materials usage over the whole period (figure 5.8) has been similar to the decline in staff employed, while fuel usage has increased substantially (figure 5.9). The pattern of fuel usage has followed that of AN output quite closely, as would be expected.

The effect of the reduction in surplus staff on TFP growth and labour productivity growth has been mentioned several times. This effect is the manifestation of an improvement over time in the level of (static) efficiency, as discussed in chapter 2. It is of interest, in terms of setting targets for continued productivity growth, to be able to isolate the extent of this effect and so produce an adjusted series which better reflects how TFP growth would have progressed had there been no surplus staff. The techniques for making such adjustments have been based on the work of Berndt and Fuss (1986). A lack of information on the precise nature of the technology facing AN makes an accurate adjustment impossible. It is, however, possible to produce two adjusted series between which the true series almost certainly lies.

As mentioned earlier and discussed in detail in appendix III, three measures of TFP growth are estimated under each of two more general assumptions regarding AN's objective. The first of these assumptions is that AN minimises economic cost, while the second is that AN maximises accounting profits. In each case, the first of the three measures is based on Solow's original formulation (Solow 1957). Then the two adjusted series are computed.

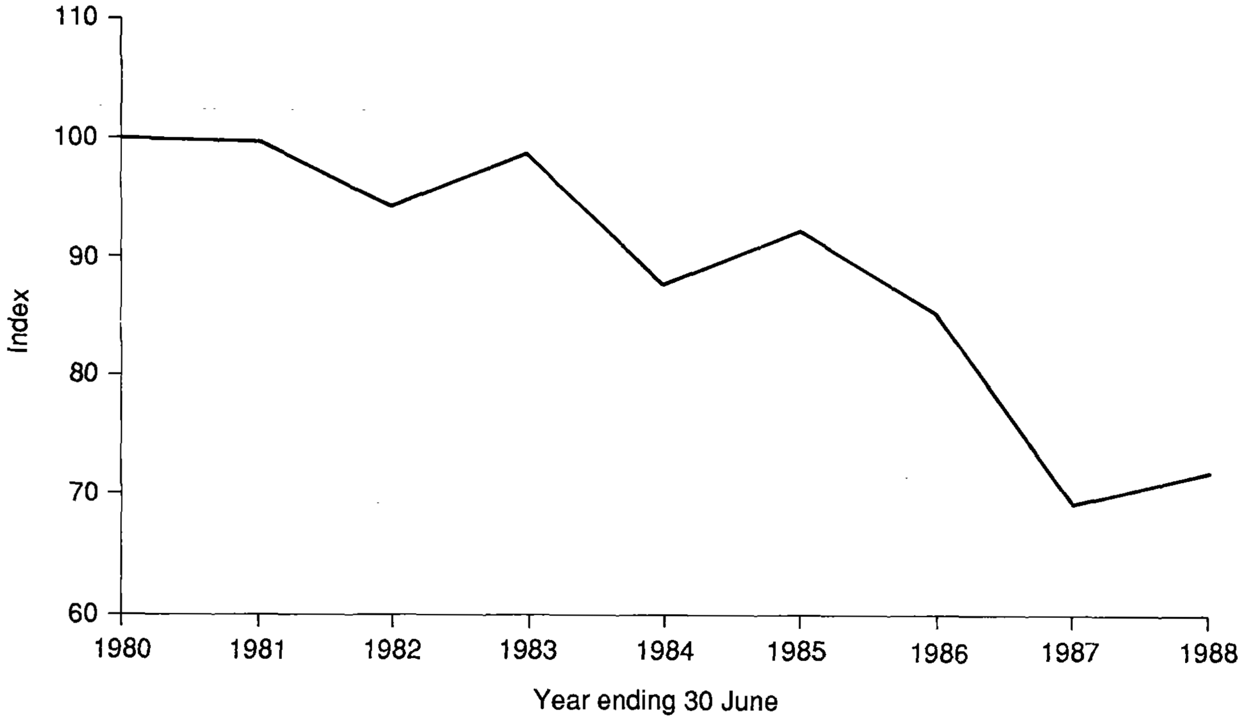
The first form of adjustment to exclude the effect of the elimination of surplus labour attributes to each surplus labour unit a product equal in value to the average value per unit of labour, based upon the residual of revenue after non-labour accounting costs. Thus, if $R$ is revenue and $A$ is non-labour accounting costs, then a surplus unit of labour is assumed to contribute to the value of output an amount $(R - A)/L$ where $L$ is the total number of units of labour used. This assumption is equivalent to attributing to each unit of surplus labour the average return on a unit of labour, and therefore provides what is likely to be an upper bound to the true value of the product of surplus labour. (The statement applies to any production technology exhibiting non-increasing returns to labour alone.) The TFP index resulting from the implementation of this assumption is identified in tables 5.3 and 5.4 by the condition $Z = \tilde{Z}$.

The second and simpler of the two series is obtained by assuming that the product of any surplus unit of labour is zero. This is equivalent to the assumption that there would be no effect on the level of output were all surplus staff removed.



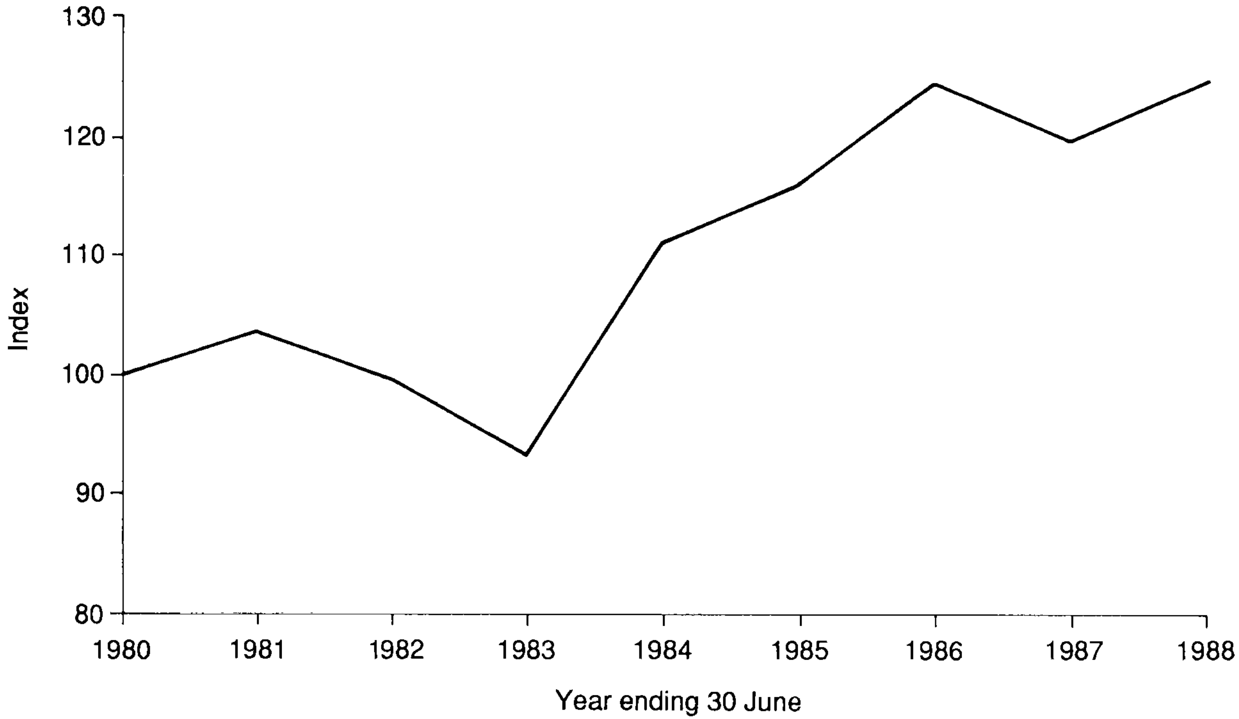

*Source* BTCE estimates.

**Figure 5.7 AN capital to labour ratio**




*Source* AN (pers. comm.).

**Figure 5.8 AN materials usage**




*Source* AN (1988).

**Figure 5.9 AN fuel usage**

TABLE 5.3 INDEXES OF TOTAL FACTOR PRODUCTIVITY GROWTH FOR AN BASED ON ECONOMIC COST MINIMISATION

| Year | TFP traditional | TFP $Z=\bar{Z}$ | TFP $Z=0$ |
|---|---|---|---|
| 1979–80 | 100.0 | 100.0 | 100.0 |
| 1980–81 | 101.4 | 100.6 | 97.2 |
| 1981–82 | 104.2 | 103.6 | 101.4 |
| 1982–83 | 94.8 | 93.8 | 90.1 |
| 1983–84 | 104.3 | 103.1 | 98.4 |
| 1984–85 | 110.0 | 108.3 | 101.5 |
| 1985–86 | 128.9 | 126.4 | 116.6 |
| 1986–87 | 132.1 | 129.8 | 121.2 |
| 1987–88 | 148.5 | 145.4 | 131.9 |
| Average compound rate of growth (per cent) | 5.1 | 4.8 | 3.5 |

TABLE 5.4 INDEXES OF TOTAL FACTOR PRODUCTIVITY GROWTH FOR AN BASED ON ACCOUNTING PROFIT MAXIMISATION

| Year | TFP traditional | TFP $Z=\bar{Z}$ | TFP $Z=0$ |
|---|---|---|---|
| 1979–80 | 100.0 | 100.0 | 100.0 |
| 1980–81 | 104.7 | 104.3 | 101.5 |
| 1981–82 | 107.0 | 106.9 | 106.3 |
| 1982–83 | 98.4 | 97.7 | 94.4 |
| 1983–84 | 108.9 | 108.0 | 103.9 |
| 1984–85 | 114.7 | 113.1 | 104.7 |
| 1985–86 | 135.4 | 133.1 | 120.6 |
| 1986–87 | 140.3 | 138.5 | 130.3 |
| 1987–88 | 158.6 | 155.9 | 138.9 |
| Average compound rate of growth (per cent) | 5.9 | 5.7 | 4.2 |

This assumption gives rise to the TFP index identified in tables 5.3 and 5.4 by the condition $Z = 0$ (in the absence of surplus staff $Z = w$, the going wage rate).

Over the full nine-year period, traditionally measured TFP growth averaged 5.1 per cent per year under the assumption that AN minimises economic cost and 5.9 per cent under the assumption that AN maximises accounting profits. The adjusted estimates of TFP growth averaged 4.8 per cent and 3.5 per cent per year, under the first behavioural assumption, and 5.7 and 4.2 per cent per year under the second, according to whether the value of the product of a surplus unit of labour was assumed to equal $\bar{Z}$ or zero respectively. It is therefore, likely that the correctly adjusted annual TFP growth rate would have been about 4 or 5 per cent, on average, depending upon AN's objective. Thus, between 5 and 30 per cent of the average unadjusted rates of TFP growth may be due to the efficiency gains resulting from corrections to the stock of labour resources. In addition to these labour-based allocative efficiency gains, the change in the overall corporate philosophy within AN since the late 1970s has given rise to various forms of restructuring in respect of the use of inputs, the structure of output and techniques of management. These changes will have contributed to TFP growth through increases in technical efficiency, but it is not possible with existing data to indicate the extent of such contributions.

The indexes of TFP are graphed in figures 5.10 and 5.11.

For class I United States railroads, econometric estimation of cost functions by Caves, Christensen and Swanson (1981) indicates that at their sample average, returns to scale from increasing only the average length of haul equal 1.2 and from increasing only the tonnage carried equal 1.05. Data for AN indicate that increases in net tonne-kilometres of freight were due to increases in average length of haul and in tonnage carried in a ratio of approximately 3:1. On this basis, a return to scale parameter of 1.16 was applied, to estimate how sensitive the estimates of (traditional) TFP growth in tables 5.3 and 5.4 were to this change from the constant returns to scale assumption. The average rates of growth in TFP (not adjusted to remove the efficiency gains from surplus staff reduction) rose from 5.1 and 5.9 to 5.5 and 6.5 respectively. Even smaller proportional increases apply to the rates adjusted to remove efficiency gains from surplus staff reduction. The general pattern in productivity growth, and the conclusions to be drawn would therefore be similar.

## COMPARISONS WITH OTHER FINDINGS

In the Industries Assistance Commission's report (1989b), TFP estimates, based on traditional methodology, were computed for V/Line, AN, Queensland Railways, Westrail and the State Rail Authority of New South Wales (figure 5.12). The results for AN are very similar to those computed here by the traditional method. They indicate that along with V/Line and Queensland Railways, AN has been one of the better performers (notwithstanding that there may have been significant efficiency differences among the railways in the base year). In addition to these results some qualified comparisons can be made with results obtained for other sectors of the Australian economy and for the economy as a whole. There are also some estimates available of TFP growth in United States and Canadian railways, which are of considerable comparative interest.

Estimates of multi-factor productivity (MFP) growth in the Australian market sector have been made by the Australian Bureau of Statistics for the period 1974–75 to 1987–88. The corresponding index of TFP growth, over the period 1979–80 to 1987–88 is illustrated in figures 5.13 and 5.14 along with the three different indexes of TFP for AN presented earlier in tables 5.3 and 5.4. The index of MFP

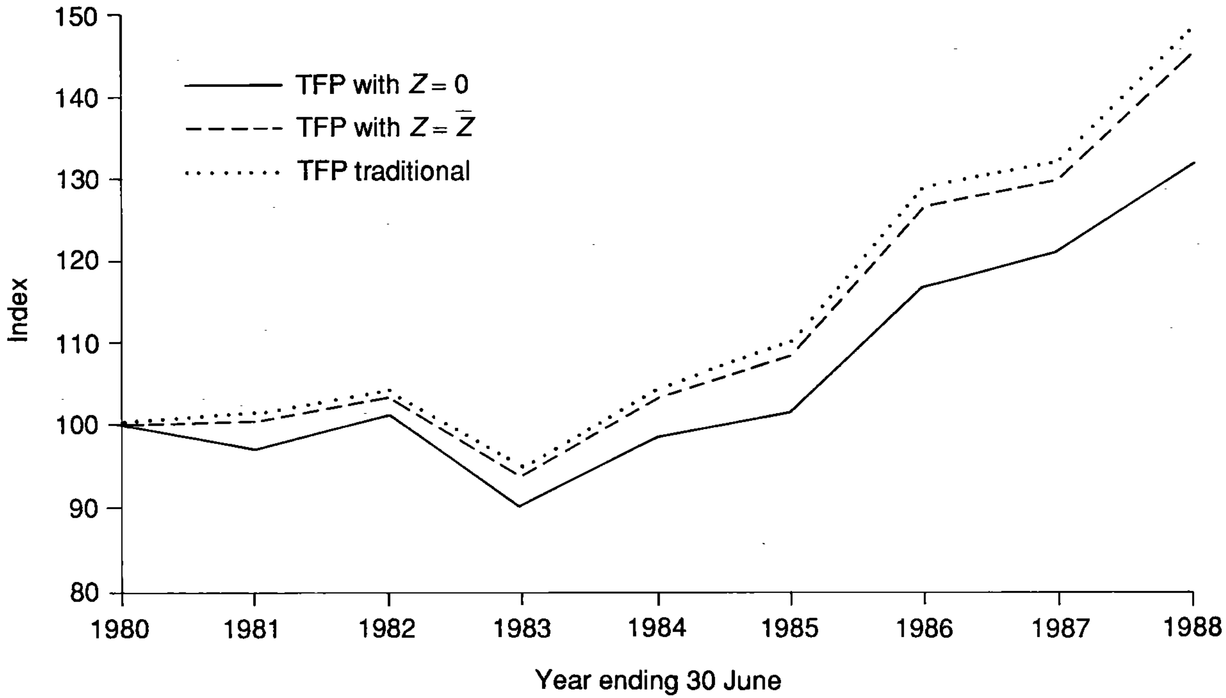



**Figure 5.10 Total factor productivity for AN based on economic cost minimisation**

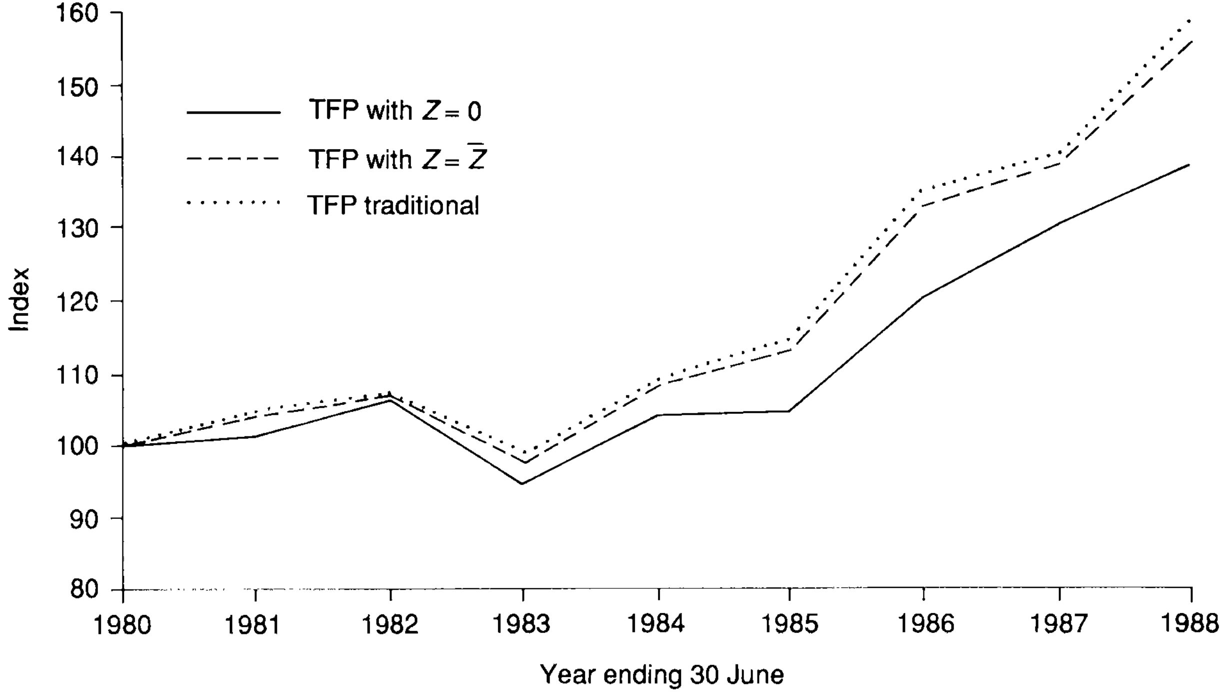
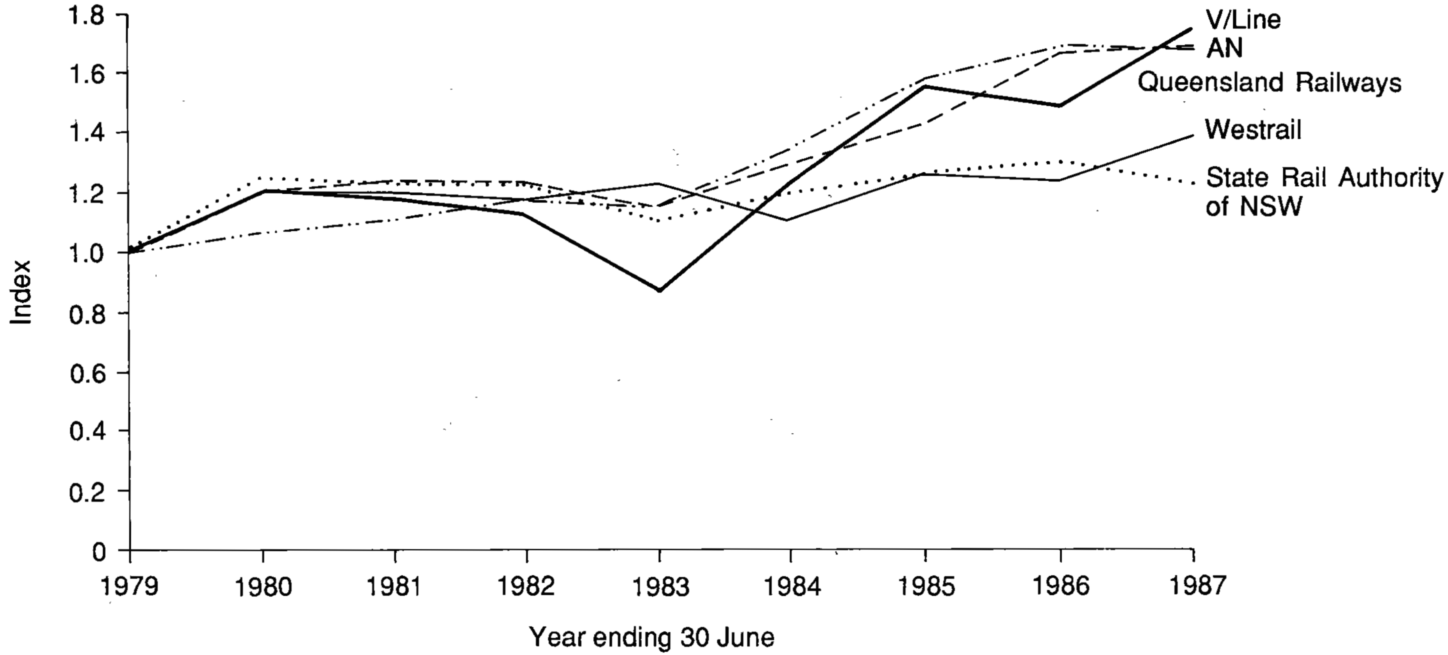



**Figure 5.11 Total factor productivity for AN based on accounting profit maximisation**




*Source* Industries Assistance Commission (1989b).

**Figure 5.12 Total factor productivity in rail authorities**

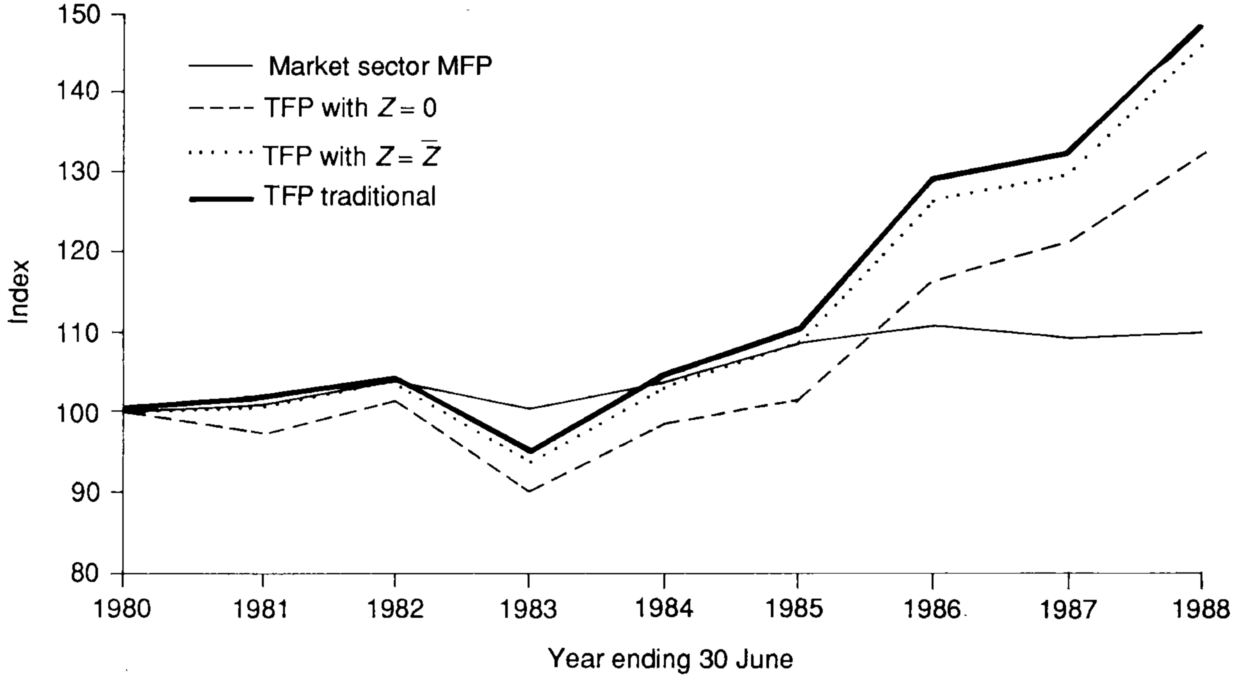



**Figure 5.13 AN and Australian market sector productivity indexes based on economic cost minimisation**

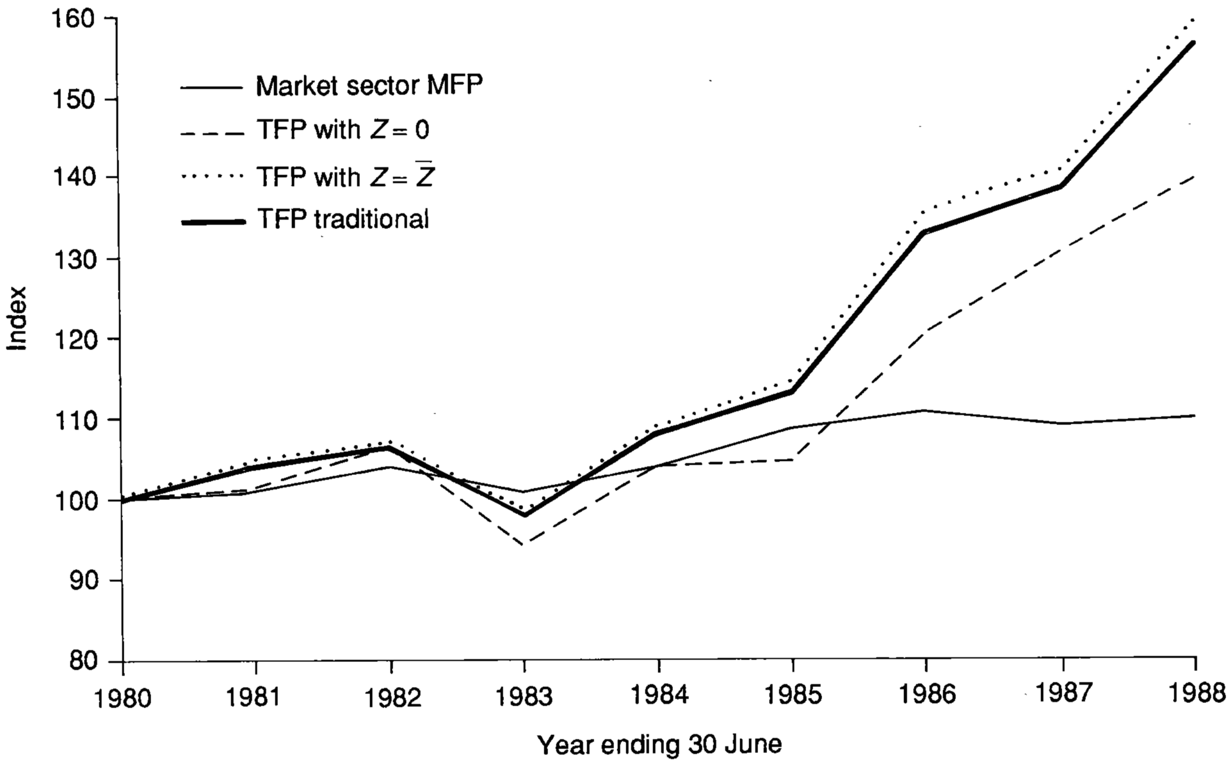



**Figure 5.14 AN and Australian market sector productivity indexes based on accounting profit maximisation**

for the Australian market sector is very close to the traditional TFP index for AN up to 1981–82. The drought of 1982–83 pulled the AN index substantially below that of the whole market sector, although the effect of the recession in that year is still clearly visible in the whole market index. After 1982–83, TFP growth in AN was significantly higher than in the economy as a whole, with the index for AN being far above that for the market sector in 1987–88, even when the contribution of AN labour is set to zero at the margin. Average annual growth rates in MFP for the market sector, and other TFP indexes, are presented in table 5.5.

TABLE 5.5 ESTIMATES OF AVERAGE ANNUAL RATES OF TOTAL FACTOR PRODUCTIVITY GROWTH

| *Industry* | *TFP growth (per cent)* |
|---|---|
| Canadian Pacific Railways | |
| 1960–65[a] | 4.9 |
| 1965–70[a] | 2.0 |
| 1970–79[a] | 1.8 |
| 1975–81[b] | 1.5 |
| Canadian National Railways | |
| 1960–65[a] | 6.9 |
| 1965–70[a] | 4.6 |
| 1970–79[a] | 1.8 |
| 1975–81[b] | 1.4 |
| United States class I railroads | |
| 1955–63[c] | 3.9 |
| 1963–74[c] | 0.7 |
| Australian manufacturing | |
| 1979–85[d] | 1.7 |
| Australian market sector | |
| 1980–88[e] | 1.2 |
| AN | |
| 1980–88[f] | 5.1[g] |
| | 5.9[h] |

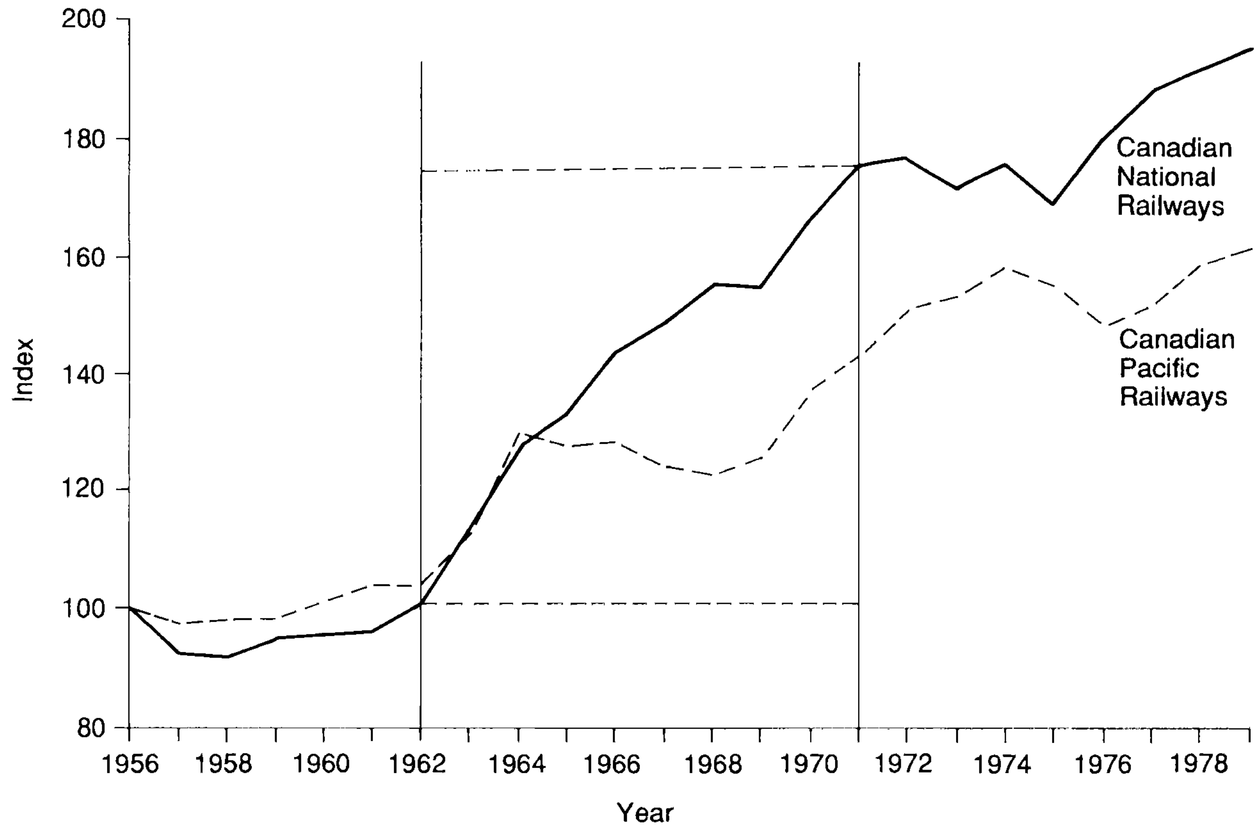
a. *Source* Caves, Christensen, Swanson and Tretheway (1982).
b. *Source* Freeman, Oum, Tretheway and Waters (1985).
c. *Source* Caves, Christensen and Swanson (1981).
d. *Source* Economic Planning Advisory Council (1989).
e. *Source* Australian Bureau of Statistics (1989b).
f. *Source* BTCE estimates.
g. Average annual TFP growth rate for AN without adjustment for reductions in excess labour, and under the assumption of economic cost minimisation.
h. Average annual TFP growth rate for AN without adjustment for reductions in excess labour, and under the assumption of accounting profit maximisation.

The average annual growth rates in TFP for some overseas railways presented in table 5.5 provide some interesting comparisons. In the late 1950s and throughout most of the 1960s the Canadian railways were gradually deregulated. By the early 1960s they were investigating ways and means of competing with other transport modes, especially trucking, through improved service and differentiated pricing techniques. These changes are reflected in the high average rates of annual TFP growth achieved over the period 1960–65, 6.9 per cent for Canadian National Railways and 4.9 per cent for Canadian Pacific Railways. It is also noticeable how much these rates declined towards the end of the 1960s and even more so through the 1970s, once the short-run benefits available through static gains following deregulation had been largely exploited.

The same extent of regulatory change was not forthcoming in the United States rail industry despite official recommendations that the US national transportation policy should encourage and promote full competition between modes of transportation and reduce economic regulation of transportation to the minimum consistent with the public interest. 'Although a transportation act was passed in 1958, by the mid 1960s a number of ICC and court decisions made it clear that the Weeks committee and the act had failed to produce any significant changes in US regulatory practice' (Caves, Christensen, Swanson & Tretheway 1982). In spite of the apparent failure of the Weeks report to effect significant deregulation, the figures in table 5.5 relating to United States railroads indicate much higher TFP growth between 1955 and 1963 than between 1963 and 1974.

The important point to be drawn from these observations relates to the extent to which TFP growth can be expected to remain high following regulatory (or similar) changes which may bring about short-run gains in static efficiency. The combined effect of the reductions in surplus labour and new commercially oriented approaches to the provision of rail services by AN over the 1980s might be expected to produce the sort of deviation from long-run trend rates of growth in TFP evident in Canadian railways through the 1960s. To aid in comparison of TFP in Canadian railways over the period 1956 to 1979, an index (implied by the growth rates estimated by Caves, Christensen, Swanson and Tretheway) for Canadian National Railways and Canadian Pacific Railways is graphed in figure 5.15.

It is apparent that there was little change in TFP in Canadian railways from 1956 to 1962. From 1962 to 1964 both Canadian railways experienced rapid TFP growth, a phenomenon which continued in the case of Canadian National until about 1971, but which ended abruptly for Canadian Pacific in 1964, before picking up again in 1969. The differential rate of TFP growth between the two railways through the mid 1960s was a manifestation of the closure of the productivity gap that existed between the government-owned Canadian National and Canadian Pacific in the early 1960s. Caves, Christensen, Swanson and Tretheway (1982) estimated that TFP in Canadian National Railways was approximately 0.82 times that in Canadian Pacific Railways in 1961. This gap had closed by 1966. Evidently, the deregulatory impetus gave rise to additional efficiency gains in the national railway by way of a 'catching up process'.




*Source* Caves, Christensen, Swanson and Tretheway (1982).

**Figure 5.15 Total factor productivity for Canadian National Railways and Canadian Pacific Railways**

These considerations point to the TFP growth of Canadian National Railways over the 1960s as the most appropriate for comparison with TFP growth in AN since 1983. If the effect of the drought and the recession in 1983 is smoothed over, then unadjusted TFP growth in AN has averaged somewhat in excess of 8 per cent per year since 1983. This covers a period of five years of exceptionally high growth, similar to that achieved by Canadian National Railways over the period 1962 to 1971. If the analogy is taken a little further, it may be supposed that in a few years TFP growth in AN will be likely to decline quite quickly towards more modest long-run levels of between 1.0 and 2.0 per cent per year.

There is another important consideration in respect of the rates of TFP growth in AN. It is apparent from figure 5.6 that the capital stock has been gradually falling since 1983. Personal communication with AN suggests that this must be a relatively short-run phenomenon if output levels are to continue to grow. Indeed, it has been suggested that the decline in the capital stock must be reversed soon. These considerations indicate that the high rates of TFP growth over the past five years would be reduced in the face of more appropriate levels of capital expenditure.

## SUMMARY

Since the early 1980s AN has progressively moved towards a more commercially oriented approach to the provision of rail services. It has reduced surplus staff dramatically, reorganised the composition of its freight output, identified the financial extent of its community service obligations in respect of mainland passenger services and Tasmanian freight operations, and made substantial changes to its management techniques. These changes have brought with them substantial gains in static efficiency to supplement purely technological gains. The estimates of TFP growth in AN over the period reflect the extent of these gains. The average annual rate of TFP growth in AN between 1979–80 and 1987–88 was 5.1 or 5.9 per cent depending upon the objective assumed for AN. That of the Australian market sector over the same period was only 1.2 per cent. When adjustments are made to account for the reductions in surplus labour in AN, average annual rates are still at least 3.5 per cent, which is substantially higher than TFP growth in the Australian market sector.

In addition to the gains made through the elimination of surplus staff, further efficiency gains are likely to have resulted from a more commercially determined mix of outputs. The extent to which these show up in the estimates of productivity growth depends, at least partially, upon how well relative output prices reflect relative marginal social benefits. In any event, the new output mix is likely to have added to national welfare.

Another issue which influences estimated TFP growth relates to economies of fill. These economies accrue as a result of excess capacity in certain types of capital (they may also be viewed as another example of the manifestation of temporary equilibrium). Certain types of capital, such as track, are lumpy in respect of output capacity — one new route in a network may not reach capacity constraints for many years after it first becomes an economically justifiable investment. These highly discrete items of capital can be responsible for high volatility in year-on-year measures of productivity growth near the time when such investments occur, and for sustained productivity growth over periods when output is growing and existing capital capacity is being filled, but not yet congested. The increase in net tonne-kilometres of freight carried by AN over the 1980s provides an example of economies of fill with respect to permanent way.

While the efficiency gains resulting from the change in corporate philosophy in AN are to be applauded, some care must be exercised not to extrapolate such growth too far into the future. In addition to the obviously limited nature of static efficiency gains, it appears that AN may have run down its capital stock over the period in question in a manner which may be incompatible with sustained output growth. The implications of this situation are not unlike the consequence of lumpiness in certain capital, inasmuch as it gives rise to distorted year-on-year estimates of TFP growth. Thus, in addition to an inevitable fall in AN's TFP growth rate relative to the rest of the Australian economy as static efficiency gains are exhausted, the remaining sources of TFP growth are likely to be attenuated as the issue of replacement of worn out and obsolete capital stock is addressed.

Some hint of the pattern in TFP growth that might be expected is provided by the estimates of TFP growth in Canadian railways displayed in table 5.5 and figure 5.15. After some five to ten years of strong TFP growth, average rates declined quickly back to the more typical levels of 1.5 to 2.0 per cent per year. Similar results can be expected in the case of AN, perhaps with a period of additional attenuation while the issue of possible undercapitalisation is addressed.

# CHAPTER 6 CONCLUSIONS

The general level of interest in productivity growth at both economy-wide and less aggregated levels has increased considerably over the past ten years. The interpretation and application of more traditional partial measures of productivity and more recently of total factor productivity have been widely debated.

The purpose of this paper has been to attempt to set right some of the more popular misconceptions associated with partial measures of productivity growth, to indicate the value, and possible shortcomings, of total (or multi) factor productivity measures, and finally to analyse productivity growth in AN, over the period 1979–80 to 1987–88. The analysis of AN productivity was undertaken primarily in the context of performance measurement and its application to corporate planning within the wider context of the micro-economic reform package applying to government business enterprises.

## TOTAL FACTOR PRODUCTIVITY — A MEASURE OF PERFORMANCE

Labour productivity and some other partial productivity measures have been used in support of various arguments ranging from wage determination cases to annual reports to shareholders. Collectively, their multiplicity of form and of interpretation has allowed for virtually any case to be argued through judicious selection of indicators. Total factor productivity measures, insofar as measurement constraints permit, take account of the variation in all the significant inputs and outputs simultaneously and in an objective way, although that is not to say that partial productivity measures and other performance indicators are superfluous.

The recent policy initiatives associated with micro-economic reform of the GBEs have necessitated adjustments to the associated regulatory environment. These adjustments included, for example, redefined regulatory boundaries, price control arrangements, and formal arrangements in respect of corporate plans. The more formal role of the corporate plan extends to all the GBEs, and it is largely in this context that performance indicators such as productivity measures play an important role. While financial indicators such as rates of return will be foremost in the setting of targets for the GBEs, one of the advantages of TFP measures is that they provide a measure of performance which is only indirectly related to output prices. Since it may be undesirable for GBEs to meet their rate of return targets through the manipulation of output prices, measures of achievement in terms of TFP growth will provide a valuable adjunct to financial measures of performance.

## TOTAL FACTOR PRODUCTIVITY GROWTH IN AUSTRALIAN NATIONAL

Estimated TFP growth in AN, over the period 1979–80 to 1987–88, has averaged somewhere between 5 and 6 per cent per year. A significant proportion of this growth has resulted from the rapid reduction in surplus staff throughout the period. This adjustment to staff levels is reflected in an average annual rate of growth in labour productivity of some 7.0 per cent over the period.

For the purpose of corporate planning, it is important to be able to make reasonable forecasts of achievable productivity growth. To the extent that past productivity performance bears upon such forecasts, it may be necessary to estimate the amount of current (and recently past) productivity growth which has resulted from phenomena which are not expected to be of importance over the forecast period. In the case of AN, the effects of the implementation of the new corporate philosophy have resulted in unsustainably high rates of TFP growth since 1982–83. These gains, reflecting the relatively inefficient production of the past, may now have been largely realised, and it must be recognised that once the inefficiencies have been removed, measured productivity growth will decline.

The most obvious, and perhaps most significant, source of TFP growth in AN has derived from the reductions in the level of excess staff. When TFP estimates are adjusted to remove the effects of staff reductions the average annual growth rate in TFP falls by up to 30 per cent depending upon the method of adjustment employed. An annual average growth rate of even 3.5 per cent (the lowest adjusted estimate) is still high when compared with more general rates in the Australian economy, and this reflects, in part, the effects of the other aspects of restructuring in AN's activities.

It would be desirable to adjust these results further, to obtain figures that are indicative of likely TFP growth in the absence of all static inefficiencies — that is, to obtain estimates of the underlying rate of TFP growth due to effects other than those resulting from AN's restructuring. However, without a more comprehensive data set, it is not possible to make such estimates in an objective way. Fortunately though, there is a precedent for such restructuring in the Canadian railways, spanning much of the 1960s. Partial deregulation together with a switch in corporate philosophy in Canadian National Railways gave rise to between five and ten years of high TFP growth — averaging some 6.5 per cent per year. Thereafter, however, average annual TFP growth rates fell dramatically to approximately 1.5 per cent over the 1970s. These data give a good indication of the extent to which the TFP growth obtained by AN over the 1970s is directly due to the structural change and corporate reorientation that have taken place, and therefore give some indication of what might be expected of longer-term trend rates. After a period of high growth, there is likely to be a rapid decline to low levels of annual growth in productivity.

There is also likely to be a short-run decline in the near future due to capital adjustments. The gradual decline in the capital stock, resulting from a replacement program which has failed to keep pace with depreciation and obsolescence, has left AN in need of substantial recapitalisation. When recapitalisation occurs, measured TFP growth will decline, albeit temporarily.

The efficiency gains resulting from the change in corporate philosophy in AN, as reflected in the high growth rates in TFP, are to be applauded. However, the evidence suggests that such high growth rates cannot be sustained for long, and that after some five to ten years of strong growth, six of which have already passed, average annual growth rates can be expected to decline quickly back to more typical levels of between 1.0 and 2.0 per cent per year.

# APPENDIX I MEASURING TOTAL FACTOR PRODUCTIVITY GROWTH

In many total factor productivity growth studies of multi-output firms, the starting point is the traditional formula described by

$$\hat{TFP} = \sum_{i=1}^{n} r_i \hat{y}_i - \sum_{j=1}^{m} s_j \hat{x}_j \tag{I.1}$$

where $y_i$ are outputs, $x_j$ inputs, $r_i$ are revenue shares, and the $s_j$ cost shares, and ^ indicates instantaneous growth rates. It is unfortunate that this formula has taken on such a life of its own that it is frequently viewed as defining total factor productivity (TFP) growth, though on occasions some passing comments are made in respect of returns to scale. As a result, TFP growth defined in this way means different things in different contexts — an unsatisfactory state of affairs.

The purpose of this appendix is twofold. First, it is to define TFP growth in terms of a notion rather than a formula, and to derive the associated generalisation of equation I.1. Second, it is to note the relationship between certain terms in the generalised formula and shadow prices.

The definitions of TFP growth are due to Caves, Christensen and Swanson (1981), as is most of the derivation of the generalisation of equation I.1. The inclusion of shadow prices into the measurement of TFP growth extends slightly the ideas in Berndt and Fuss (1986) and Hulten (1986), and places them within the multi-output setting of Caves, Christensen and Swanson.

Following Caves, Christensen and Swanson we consider a multi-output firm whose technology is fully described by the production transformation

$$F(y_1, \ldots, y_n; x_1, \ldots, x_m; t) = 0 \tag{I.2}$$

where the $y_i$ are outputs, the $x_j$ are inputs, and $t$ is an index of time. (Caves, Christensen and Swanson express the production transformation in terms of the logarithms of the inputs and outputs, thereby deriving slightly different looking, but logically identical, formulae to those derived here.) Before defining productivity growth, we observe that totally differentiating equation I.2 with respect to time yields

$$\sum_{i=1}^{n} \frac{\partial F}{\partial y_i} \frac{dy_i}{dt} + \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} \frac{dx_j}{dt} = -\frac{\partial F}{\partial t} \tag{I.3}$$

Now define productivity growth to be the common rate at which all outputs could grow over time with inputs held fixed (*PGY*). Thus, $PGY = \frac{d \ln y_i}{dt} = \frac{d \ln y_j}{dt}$ for $i, j = 1, ..., n$ and $\frac{d \ln x_j}{dt} = 0$ for $j = 1, ..., m$.

Substituting these conditions into equation I.3 yields

$$PGY. \sum_{i=1}^{n} \frac{\partial F}{\partial y_i} y_i = -\frac{\partial F}{\partial t}$$

In fact, both outputs and inputs will be changing over time, and

$$-\frac{\partial F}{\partial t} = \sum_{i=1}^{n} \frac{\partial F}{\partial y_i} \frac{dy_i}{dt} + \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} \frac{dx_j}{dt}$$

Thus

$$PGY = \left( \sum_{i=1}^{n} \frac{\partial F}{\partial y_i} y_i \hat{y}_i + \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} x_j \hat{x}_j \right) / \sum_{i=1}^{n} \frac{\partial F}{\partial y_i} y_i \tag{I.4}$$

where $\hat{y}_i = \frac{d \ln y_i}{dt}$ and $\hat{x}_j = \frac{d \ln x_j}{dt}$ are the growth rates in the outputs and inputs respectively. (To estimate the value of *PGY* certain behavioural, and possibly other, assumptions need to be made.)

As remarked by Caves, Christenson and Swanson, it is just as reasonable to define productivity growth to be the common rate at which all inputs could be *reduced* over time with all outputs held fixed (*PGX*). In this case $PGX = \frac{-d \ln x_j}{dt}$ for $j = 1, ..., m$ and $\frac{d \ln y_i}{dt} = 0$ for $i = 1, ..., n$. Then equation I.3 implies

$$PGX. \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} x_j = \frac{\partial F}{\partial t} = -\left( \sum_{i=1}^{n} \frac{\partial F}{\partial y_i} \frac{dy_i}{dt} + \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} \frac{dx_j}{dt} \right)$$

and therefore

$$PGX = -\left(\sum_{i=1}^{n} \frac{\partial F}{\partial y_i} y_i \hat{y}_i + \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} x_j \hat{x}_j\right) / \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} x_j \qquad \text{(I.5)}$$

The relationship between *PGY* and *PGX* lies in the returns to scale parameter *RTS*. Following Panzar and Willig (1977), *RTS* is defined to be the proportional increase in all outputs, $\alpha$, resulting from a proportional increase in all inputs, $\beta$. In order to derive a general expression for *RTS* consider the total (static) differential of equation I.2 expressed in terms of growth rates, namely

$$\sum_{i=1}^{n} \frac{\partial F}{\partial y_i} y_i \hat{y}_i + \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} x_j \hat{x}_j = 0$$

or

$$\alpha \sum_{i=1}^{n} \frac{\partial F}{\partial y_i} y_i = -\beta \sum_{j=1}^{m} \frac{\partial F}{\partial x_j} x_j$$

and

$$RTS = \frac{\alpha}{\beta} = -\left(\sum_{j=1}^{m} \frac{\partial F}{\partial x_j} x_j\right) / \sum_{i=1}^{n} \frac{\partial F}{\partial y_i} y_i \qquad \text{(I.6)}$$

It is now clear from equations I.4, I.5 and I.6 that

$$PGY = RTS \,.\, PGX$$

This is the relatively well-known relationship between proportional shifts in the cost and production functions as derived in Ohta (1974) and in Denny, Fuss and Waverman (1981). Thus, under constant returns to scale ($RTS = 1$), the two definitions of productivity growth coincide.

It is worth spending a little time reconciling equation I.4 with the more traditional method of measuring productivity growth by use of the formula given in equation I.1.

Equation I.1 has its origins in the work of Solow (1957) where it is derived in the case of a single output, constant returns to scale, neutral technology. The multi-output version expressed by equation I.1 has typically been justified by appealing to the Divisia index as an appropriate aggregation of the various outputs. The growth rate in the Divisia index is then the revenue weighted average of the individual growth rates, and equation I.1 results. However, the Divisia index is a line integral and this approach is therefore satisfactory only under conditions which guarantee path independence. Hulten (1973) showed that constant returns to scale are necessary for the existence of the Divisia index, and it therefore follows that the output growth sum in equation I.1 may be of unknown theoretical meaning in the absence of constant returns to scale, as indeed may be the input growth sum. Although Hulten indicates some instances where these problems can be overcome, we show here that the problem results only from the desire to fit a multi-output activity into the single-output context, or to identify certain sums with growth rates in an index, something which is entirely unnecessary if equation I.4 is used.

Consider now a firm facing a technology described by equation I.2. Suppose also that the firm is a price taker in both input and output markets, and that it is a static profit maximiser. Its objective in period t is then

$$\text{Max} \sum_{i=1}^{n} p_i y_i - \sum_{j=1}^{m} w_j x_j \quad s.t.\ F[y_1, \ldots, y_n; x_1, \ldots, x_m; t] = 0$$

where the $p_i$ are output prices and the $w_j$ are input prices. The associated first order conditions are then obtained by setting the partial derivatives of the Lagrangian, $L$, equal to zero.

$$L = \sum_{i=1}^{n} p_i \ y_i - \sum_{j=1}^{m} w_j x_j + \lambda_o[F(y_1, \ldots, y_n; x_1, \ldots, x_m; t)\ ]$$

$$\frac{\partial L}{\partial y_i} = p_i + \lambda_o \frac{\partial F}{\partial y_i} = 0 \quad (i = 1, \ldots, n)$$

$$\frac{\partial L}{\partial x_j} = -w_j + \lambda_o \frac{\partial F}{\partial x_j} = 0 \quad (j = 1, \ldots, m)$$

and the first order conditions are then $\frac{\partial F}{\partial y_i} = -\frac{p_i}{\lambda_o}$ and $\frac{\partial F}{\partial x_j} = \frac{w_j}{\lambda_o}$ for $i = 1, \ldots, n$ and $j = 1, \ldots, m$.

These conditions can now be substituted into equation I.4 to obtain (noting that the multiplier, $\lambda_o$, cancels out):

$$PGY = \sum_{i=1}^{n} r_i \hat{y}_i - \sum_{j=1}^{m} s_j^* \hat{x}_j \qquad (I.7)$$

where $s_j^* = \frac{w_j x_j}{R}$ and $R = \sum_{i=1}^{n} p_i y_i$ = total revenue.

Equation I.7 differs from equation I.1 only in the coefficients $s_j^*$. However, in the case of constant returns to scale ($RTS = 1$) and the same first order conditions derived above, equation I.6 implies that total cost equals total revenue and therefore that $s_j^* = s_j$ for each $j$, and equations I.7 and I.1 agree. An analogous derivation to that above yields

$$PGX = \sum_{i=1}^{n} r_i^* \hat{y}_i - \sum_{j=1}^{m} s_j \hat{x}_j \tag{I.8}$$

where $r_i^* = \frac{p_i y_i}{C}$ and C = total cost.

Equations I.7 and I.8 make no appeal to index numbers, and are quite general in that sense. The only caveat associated with their interpretation is that it may be incorrect to identify any particular part of the formula with the growth rate in an index of outputs (inputs).

## SHADOW PRICES AND TOTAL FACTOR PRODUCTIVITY GROWTH

Equation I.4 or I.5 is the appropriate starting place for the measurement of productivity growth. Under certain additional assumptions the more familiar forms of I.7 and I.8 are appropriate. However, there is a notationally and intuitively preferable way of expressing equations I.4 and I.5, which follows essentially Berndt and Fuss (1986) and also Hulten (1986), but in the more general multi-output case.

For various reasons, from regulation to temporary equilibrium, the first order conditions used in deriving equation I.7 may fail to hold. Specific cases where the first order conditions differ from those above are described below. However, it is intuitively valuable to make some definitions and some observations regarding equation I.4 before considering specific cases.

Assume now that the firm faces the technology of equation I.2, and is a price taker, and that it maximises profits subject to some additional constraints $g_k(y_1, \ldots, y_n; x_1, \ldots, x_m; t) = 0$, $k = 1, \ldots, K$. Assume that the resulting feasible set is non-empty. The Lagrangian associated with the problem is

$$L = \sum_{i=1}^{n} p_i y_i - \sum_{j=1}^{m} w_j x_j + \lambda_o F(y_1, \ldots, y_n; x_1, \ldots, x_m; t)$$

$$+ \sum_{k=1}^{K} \lambda_k g_k(y_1, \ldots, y_n; x_1, \ldots, x_m; t)$$

and the associated first order conditions are

$$\frac{\partial L}{\partial y_i} = p_i + \lambda_o \frac{\partial F}{\partial y_i} + \sum_{k=1}^{K} \lambda_k \frac{\partial g_k}{\partial y_i} = 0 \quad (i = 1, \ldots, n)$$

and

$$\frac{\partial L}{\partial x_j} = -w_j + \lambda_o \frac{\partial F}{\partial x_j} + \sum_{k=1}^{K} \lambda_k \frac{\partial g_k}{\partial x_j} = 0 \quad (j = 1, \ldots, m)$$

or

$$\lambda_o \frac{\partial F}{\partial y_i} = -\left(p_i + \sum_{k=1}^{K} \lambda_k \frac{\partial g_k}{\partial y_i}\right) \quad (i = 1, \ldots, n)$$

and

$$\lambda_o \frac{\partial F}{\partial x_j} = w_j - \sum_{k=1}^{K} \lambda_k \frac{\partial g_k}{\partial x_j} \quad (j = 1, \ldots, m)$$

Now define the ex-ante shadow price of the $i$th output to be

$$\tilde{p}_i = -\lambda_o \frac{\partial F}{\partial y_i} \tag{I.9}$$

and the ex-ante shadow price of the $j$th input to be

$$\tilde{w}_j = \lambda_o \frac{\partial F}{\partial x_j} \tag{I.10}$$

We can now express equation I.4 in a way reminiscent of I.1 by first defining total ex-ante shadow revenue to be

$$\tilde{R} = \sum_{i=1}^{n} \tilde{p}_i y_i$$

and then observing that equation 1.4 is precisely

$$PGY = \sum_{i=1}^{n} \tilde{r}_i \hat{y}_i - \sum_{j=1}^{m} \tilde{s}_j^* x_j \tag{I.11}$$

where $\tilde{r}_i = \frac{\tilde{p}_i y_i}{\tilde{R}}$ and $\tilde{s}_j^* = \frac{\tilde{w}_j x_j}{\tilde{R}}$ once again making the observation that both numerator and denominator may be multiplied by $-\lambda_o$.

Equation I.11 is now appropriate to any constrained optimising firm which is a price taker in all markets, whether the constraints apply to inputs, outputs, or inputs and outputs jointly.

A similar expression for *PGX* is obtained by defining total ex-ante shadow cost to be

$$\tilde{C} = \sum_{j=1}^{m} \tilde{w}_j x_j$$

Then equation 1.5 becomes

$$PGX = \sum_{i=1}^{n} \tilde{r}_i^* \hat{y}_i - \sum_{j=1}^{m} \tilde{s}_j \hat{x}_j \qquad (I.12)$$

where $\tilde{r}_i^* = \frac{\tilde{p}_i y_i}{\tilde{C}}$ and $\tilde{s}_j = \frac{\tilde{w}_j x_j}{\tilde{C}}$

# APPENDIX II DATA FOR AUSTRALIAN NATIONAL

In its present form, Australian National (AN) is the amalgamation of three railways that operated independently prior to 1 March 1978. These were the former Commonwealth Railways, South Australian Railways (freight and non-urban passenger operations), and Tasmanian Government Railways. AN provides transportation of freight and passengers, using a range of inputs which can be broadly categorised into labour, capital, fuel and materials.

In appendix I, formulae were derived for the measurement of total factor productivity (TFP) growth. The implementation of these requires data on input and output quantities, as well as on costs and revenues. This appendix details the data used in the measurement of AN TFP growth, describing its sources and its limitations.

## OUTPUTS

Three different outputs are identified. These are mainland freight services, passenger services, and Tasmanian freight services. The level of each of the freight services is measured in net tonne-kilometres, while that of passenger services is measured in passenger train kilometres.

It would be preferable to disaggregate the measure of freight into bulk and non-bulk, or even into a greater number of different categories reflecting the diversity of input needs required to transport the various types of freight. Unfortunately, data necessary for such disaggregation were not available.

Initial considerations may suggest that the measure of passenger output is even more inappropriate. However, AN is required by legislation to provide certain passenger services regardless of the level of passenger demand. As such, it may be viewed as having entered into a contractual agreement with the Commonwealth government to provide a given level of passenger services. Whether or not that level constitutes an overprovision is of importance from a national welfare viewpoint, but is not relevant to the question of how efficiently that contractual arrangement is fulfilled. These considerations, together with a lack of origin–destination data, provide some justification for the measure.

The output data were obtained from AN annual reports, together with corresponding revenue data and revenue community service obligation (CSO) supplements for the provision of passenger services and Tasrail freight services.

The CSO payments have been explicitly agreed to by AN and the Government, and identified in AN annual reports for the years 1985–86, 1986–87, and 1987–88. Prior to these years the Government made payments to AN that included implicit CSO payments. The size of the implicit CSO payments for the years 1979–80 to 1984–85 were imputed by multiplying the unsupplemented revenue (from Tasrail services and from passenger services respectively) for that year by the ratio of CSO payment to revenue (unsupplemented) for the relevant service in the year 1985–86. This method imposes the assumption that the ratio of CSO payment to unsupplemented revenue remains constant for all years prior to and including 1985–86.

## INPUTS

As mentioned above, the inputs into the production of AN services have been disaggregated into the four categories of labour, capital, fuel and materials.

### Labour

Over the period of investigation, the number of AN employees fell by just over 30 per cent, from 10 481 in 1979–80 to 7198 in 1987–88. This reflects AN's policy of gradually removing surplus staff through attrition and retirement or redundancy packages. These numbers exclude staff 'made available' to other authorities, mostly to the State Transport Authority of South Australia.

Total staff number is not an appropriate labour input measure when staff are used in varying intensity over time, as can be expected to be the case in AN. Such variations in intensity would normally be reflected in the amount of overtime worked. However, overtime data were not available, and therefore the inferior measure of employee numbers formed the basis for the measure of labour input (although as discussed later, the issue of excess labour is addressed through the use of shadow pricing). The use of employee numbers also fails to recognise the differing nature of various categories of employee such as management and non-management staff, but, again, data at this level of disaggregation were unavailable.

Total labour costs, and therefore average labour price, were available, together with employee numbers, from AN annual reports.

### Capital

For the purposes of this study, capital was disaggregated into three categories, according to approximate depreciation profiles. The first consists of permanent way, land and buildings, the second of rolling stock, and the third of plant and equipment. Their depreciation profiles are based on assumed lifetimes of 50, 20 and 10 years respectively.

The value of capital stocks published in AN annual reports is based on historical cost accounting, which distorts the true economic value and quantity of capital. It is therefore necessary to compute capital stocks at replacement values, and a perpetual inventory method (PIM) was used to do so. Implementation of the method requires starting values for each category of capital, capital expenditure data, and disposals data in addition to depreciation rates. The basic algorithm is given by

$$K_t = [K_{t-1}.(1-\delta) - DISP_t] \;.\; [1 + \pi_t] + [INV_t]$$

where $K_t$ is replacement value of capital at the end of period $t$; $\delta$ is the geometric rate of depreciation; $DISP_t$ is disposals during period $t$; $INV_t$ is the investment expenditure during period $t$; and $\pi_t$ is the rate of capital price inflation over period $t$.

Since the PIM requires knowledge of the replacement value of capital in the previous period it is necessary to find an approximation for the replacement values of capital at the end of 1979–80. In order to use the values of $K_t$ throughout the period 1979–80 to 1987–88, the estimated starting value of capital in 1979–80 must be of acceptable accuracy. To ensure this, it is desirable to begin the application of the PIM some years prior to the first year in which one needs an accurate measure of the value of capital, since for a given starting value and rate of depreciation, the accuracy of a given iteration of the PIM depends on the number of iterations already performed.

In the years 1978–79 and 1979–80, capital expenditure data were not available explicitly in the annual reports. Capital expenditures were therefore imputed by taking the difference in total undepreciated capital stocks at historical cost for consecutive years. Prior to 1978–79, balance sheets were published for each of the three individual railways. However, not all of the State Transport Authority (STA) of South Australia's operations were transferred to AN. Comparisons of capital stocks before and after amalgamation indicate a reduction in STA capital expenditure of some 22 per cent for permanent way, land and buildings, and plant and equipment, and some 13 per cent for rolling stock. The starting (1970–71) values of the various categories of capital were adjusted to reflect these ratios.

A further problem was that the capital expenditure data for both the STA and Tasmanian Railways were not available in the disaggregated form required — permanent way, land and buildings, and plant and equipment were aggregated. Investment expenditures in this category were attributed to permanent way, and land and buildings and to plant and equipment in the ratio of investment expenditures on these categories by Commonwealth Railways.

Starting values for the year 1969–70 were obtained by inflating capital stock values based on historical cost accounting by multiplying by 1.1 for equipment, 1.2 for rolling stock, and 1.5 for permanent way, land and buildings. These multipliers were derived by computing the ratio of replacement to historical capital values under the assumption of constant real investment and observed variable rates of inflation. While the assumption of constant real investment cannot be expected to reflect reality it is employed simply to provide rough starting values for the perpetual inventory method in 1969–70, in order to improve the capital value estimates for the first year (1979–80) of implementation of the TFP algorithm.

An index of the economic rental price of capital was computed as the product of the relevant capital deflator times the sum of the real opportunity cost of funds (taken to be 8 per cent) and the relevant declining balance depreciation rate.

### Fuel

The only data relating to fuel published in AN annual reports are expenditure data. No data on quantities are provided. AN were able to provide some price data upon request, but these were in the form of prices paid by AN Rail at various locations each month, and only over the period 1983–84 to 1987–88. The mean of these prices was computed to obtain a series of average annual prices for this period.

The Australian Railway Research and Development Organisation (1986) published an energy consumption (quantity) and expenditure series for AN covering the period 1971–72 to 1982–83. However, when the quantity series was joined to that implied by the AN price and expenditure series from 1983–84 to 1987–88, the sum of quantities consumed between 1978–79 and 1987–88 was slightly in excess of 938 megalitres compared with 918 megalitres reported in consultation with AN (pers. comm.). To adjust for this discrepancy, the Australian Railway Research and Development Organisation fuel quantity series for the four years 1979–80 to 1983–84 was uniformly deflated in such a way as to ensure that the sum over the nine years would equal 918 megalitres.

### Materials

Expenditure on materials is defined to be the residual of operating expenses after labour and related expenses and fuel expenses have been removed. As such it consists of many different items, but by far the most significant are ballast and wooden sleepers. In order to obtain an index of material quantities used, materials expenditure was deflated using the implicit price deflator for non-farm product.

TABLE II.1 AN OUTPUT QUANTITIES

| *Year* | *Mainland freight ('000 net tonne-kilometres)* | *Tasmanian freight ('000 net tonne-kilometres)* | *Passenger movements ('000 passenger train kilometres)* |
|---|---|---|---|
| 1979–80 | 5 235 208 | 383 000 | 2 924 |
| 1980–81 | 5 330 930 | 420 000 | 3 057 |
| 1981–82 | 5 357 283 | 374 000 | 2 992 |
| 1982–83 | 4 966 757 | 381 000 | 2 395 |
| 1983–84 | 5 511 947 | 400 000 | 2 355 |
| 1984–85 | 5 866 920 | 403 000 | 2 187 |
| 1985–86 | 6 678 816 | 402 000 | 2 486 |
| 1986–87 | 6 443 719 | 429 000 | 2 381 |
| 1987–88 | 7 192 000 | 455 000 | 2 439 |

*Source* AN annual reports.

TABLE II.2 AN OUTPUT REVENUES

*($'000)*

| *Year* | *Mainland freight* | *Tasmanian freight* | *Passenger movements* |
|---|---|---|---|
| 1979–80 | 119 014 | 12 500 | 14 517 |
| 1980–81 | 136 005 | 14 200 | 17 669 |
| 1981–82 | 151 214 | 14 000 | 19 400 |
| 1982–83 | 144 273 | 15 000 | 20 733 |
| 1983–84 | 174 798 | 15 600 | 22 460 |
| 1984–85 | 196 798 | 16 900 | 22 940 |
| 1985–86 | 219 045 | 18 300 | 27 456 |
| 1986–87 | 215 697 | 22 400 | 27 812 |
| 1987–88 | 236 882 | 26 118 | 29 100 |

*Note* In current dollars.

*Source* AN annual reports.

TABLE II.3 AN COMMUNITY SERVICE OBLIGATION SUPPLEMENTS
*($'000)*

| *Year* | *Tasmanian freight* | *Passenger movements* |
|---|---|---|
| 1979–80 | 12 700 | 16 100 |
| 1980–81 | 14 300 | 19 600 |
| 1981–82 | 14 200 | 21 500 |
| 1982–83 | 15 200 | 23 000 |
| 1983–84 | 15 800 | 25 000 |
| 1984–85 | 17 100 | 25 500 |
| 1985–86 | 18 400 | 30 500 |
| 1986–87 | 17 800 | 27 100 |
| 1987–88 | 16 200 | 27 000 |

*Note* In current dollars.

*Sources* AN annual reports and BTCE estimates. Prior to 1985–86 community service obligation supplements were not identified in the annual reports, and have been imputed.

TABLE II.4 AN LABOUR AND FUEL INPUT QUANTITIES

| *Year* | *Labour (number)* | *Fuel (litres)* |
|---|---|---|
| 1979–80 | 10 481 | 77 379 559 |
| 1980–81 | 10 071 | 80 147 704 |
| 1981–82 | 9 941 | 77 104 899 |
| 1982–83 | 9 575 | 72 128 702 |
| 1983–84 | 9 252 | 85 868 260 |
| 1984–85 | 8 799 | 89 706 335 |
| 1985–86 | 8 127 | 96 311 990 |
| 1986–87 | 7 838 | 92 519 336 |
| 1987–88 | 7 198 | 96 435 020 |

*Source* AN annual reports.

TABLE II.5 AN NON-CAPITAL EXPENDITURE
($'000)

| Year | Materials | Fuel | Labour |
|---|---|---|---|
| 1979–80 | 49 254 | 13 975 | 137 300 |
| 1980–81 | 53 427 | 20 748 | 148 300 |
| 1981–82 | 54 586 | 21 727 | 165 900 |
| 1982–83 | 63 702 | 26 490 | 178 600 |
| 1983–84 | 60 049 | 32 186 | 186 600 |
| 1984–85 | 66 033 | 34 946 | 187 500 |
| 1985–86 | 69 652 | 39 094 | 203 500 |
| 1986–87 | 64 266 | 38 637 | 206 900 |
| 1987–88 | 67 492 | 41 658 | 205 600 |

*Note* In current dollars.

*Sources* AN annual reports; Australian Railway Research and Development Organisation (1986); BTCE estimates.

TABLE II.6 AN CAPITAL INPUTS AT REPLACEMENT COST
($'000)

| Year | Permanent way, land, buildings | Plant and equipment | Rolling stock |
|---|---|---|---|
| 1979–80 | 543 406 | 19 933 | 239 173 |
| 1980–81 | 728 127 | 22 928 | 239 937 |
| 1981–82 | 800 274 | 23 029 | 235 586 |
| 1982–83 | 947 299 | 28 403 | 242 800 |
| 1983–84 | 1 008 000 | 28 094 | 255 769 |
| 1984–85 | 1 055 000 | 29 144 | 250 709 |
| 1985–86 | 1 153 000 | 30 485 | 272 011 |
| 1986–87 | 1 216 000 | 36 354 | 291 918 |
| 1987–88 | 1 291 000 | 39 683 | 286 098 |

*Note* In current dollars.

*Source* BTCE estimates.

TABLE II.7 AN RAIL INTEREST PAID PLUS DEPRECIATION (HISTORICAL COST)
*($'000)*

| *Year* | *Permanent way, land, buildings* | *Plant and equipment* | *Rolling stock* |
|---|---|---|---|
| 1979–80 | 5 836 | 3 025 | 8 836 |
| 1980–81 | 7 374 | 2 860 | 8 309 |
| 1981–82 | 8 467 | 3 877 | 8 206 |
| 1982–83 | 14 050 | 4 666 | 9 298 |
| 1983–94 | 18 585 | 5 464 | 10 931 |
| 1984–85 | 22 868 | 4 662 | 11 702 |
| 1985–86 | 22 899 | 6 049 | 11 717 |
| 1986–87 | 22 776 | 7 249 | 11 781 |
| 1987–88 | 27 720 | 7 957 | 12 046 |

*Notes* 1. In current dollars.
2. Total interest has been allocated in the same proportions as the (historical) values of the different types of capital.

*Source* AN annual reports.

TABLE II.8 DEFLATORS FOR AN EXPENDITURES

| *Year* | *Permanent way, land, buildings*[a] | *Rolling stock, plant, equipment*[b] | *Materials*[c] |
|---|---|---|---|
| 1979–80 | 100.0 | 100.0 | 100.0 |
| 1980–81 | 112.2 | 108.8 | 110.1 |
| 1981–82 | 126.6 | 117.6 | 122.9 |
| 1982–83 | 143.8 | 131.0 | 136.8 |
| 1983–84 | 153.5 | 139.1 | 146.4 |
| 1984–85 | 162.4 | 145.6 | 155.0 |
| 1985–86 | 180.0 | 166.2 | 165.6 |
| 1986–87 | 193.8 | 189.5 | 178.1 |
| 1987–88 | 208.6 | 191.6 | 191.8 |

a. Implicit price deflator non-dwelling.
b. Implicit price deflator equipment.
c. Implicit price deflator non-farm gross domestic product.

*Source* Australian Bureau of Statistics (1989a).

# APPENDIX III MEASURING TOTAL FACTOR PRODUCTIVITY GROWTH IN AUSTRALIAN NATIONAL

The purpose of this appendix is to derive appropriate methodologies for measuring total factor productivity (TFP) growth in AN, based upon the development in appendix I. As discussed in appendix I, the traditional formulation for TFP growth due to Solow (1957) agrees with equation I.4 in the case of competitive profit maximisation under constant returns to scale (CRTS).

Profit maximisation under exogenous input and output prices and CRTS implies revenue equal to cost. In reality, various unanticipated shocks would typically lead revenue to differ from cost on a year by year basis even when the above assumptions hold on average. However, in the case of AN, revenue (plus community service obligation (CSO) supplements) falls substantially and consistently short of economic cost even when account is taken of surplus labour. This phenomenon may result from the CRTS assumption being incorrect, or it may be that the standard profit maximisation assumption fails to hold. Econometric evidence presented by Caves, Christensen and Swanson (1981) indicates the existence of some scale economies. However, they are small and not statistically significant when average haul and trip length are assumed not to change. In the absence of further empirical evidence, it is assumed here that AN production has been subject to CRTS over the period in question. There is therefore a need to review the objective of AN, in order to avoid revenue being different from cost in the presence of CRTS.

Two different behavioural assumptions consistent with the data and the CRTS assumption are discussed, and corresponding TFP measures are derived. Under each of the two behavioural assumptions, three TFP measures are presented, one corresponding to the 'traditional' approach following Solow, and two more which adjust for the efficiency gains from reductions in surplus staff under two different assumptions regarding its marginal product.

The traditional (continuous) expression for TFP growth, due to Solow, is

$$\hat{TFP} = \sum_{i=1}^{n} r_i \hat{y}_i - \sum_{j=1}^{m} s_j \hat{x}_j \qquad \text{(III.1)}$$

as derived in appendix I.

As mentioned above, the derivation of equation III.1 entails assumptions which imply equality between revenue and cost, a situation which does not obtain for AN. However, one set of assumptions which is consistent with equation III.1 is as follows.

Assume that however AN's output is determined, it is produced at minimum cost. With the notation of appendix I, cost minimisation implies

$$\frac{\partial F}{\partial x_j}=\frac{w_j}{\lambda_0} \qquad (\text{for } j=1, \ldots, m)$$

Under the assumption of constant returns to scale

$$\sum_{j=1}^{m}\frac{\partial F}{\partial x_j}x_j=-\sum_{i=1}^{n}\frac{\partial F}{\partial y_i}y_i$$

and therefore

$$\sum_{j=1}^{m}w_jx_j=-\lambda_0\sum_{i=1}^{n}\frac{\partial F}{\partial y_i}y_i \qquad \text{(III.2)}$$

In the absence of any further information regarding AN's objective function, if it is assumed that the partials, $\frac{\partial F}{\partial y_i}$ are in profit maximising (relative) proportions,

then for some constant, $\theta$,

$$-\lambda_0\frac{\partial F}{\partial y_i}=\theta p_i$$

where the $p_i$ are implied output prices (in the case of mainland freight, the implied price is AN's quoted price; in the case of passenger services and Tasmanian freight services it is taken to be actual revenue from that service plus the relevant CSO supplement, divided by the relevant quantity of service provided).

Equation III.2 then determines $\theta$ according to

$$\theta = \text{Cost}/(\text{Revenue} + \text{Supplements})$$

and equation III.1 follows from equation I.4.

The inclusion of CSO revenue supplements in the revenues derived from passenger services and Tasmanian freight services is consistent with the view that the supplements represent the cost, borne by the government, of the CSO component of those services. The implied output price discussed above therefore represents the average price paid for a unit of output.

Thus, equation III.1 provides the underlying formula for the first approach to measuring TFP growth in AN. The only adjustment that remains to be effected is that necessary to make the formula applicable to discrete data. The adjustment used in this, and all ensuing cases, is made through the application of the Tornqvist approximation, namely:

$$\hat{TFP}_t(1) = \frac{1}{2}\sum_{i=1}^{3}[r_i(t) + r_i(t+1)]\,[\ln y_i(t+1) - \ln y_i(t)]$$

$$-\frac{1}{2}\sum_{j=1}^{6}[s_j(t) + s_j(t+1)]\,[\ln x_j(t+1) - \ln x_j(t) \qquad \text{(III.3)}$$

where ln represents the natural logarithm and $\hat{TFP}_t(1)$ represents measured TFP growth over the period from $t$ to $t+1$. The six inputs, including three types of capital, and the three outputs, are described in appendix II.

The application of equation III.3 to AN data will result in a measure which captures both technological progress and (static) efficiency improvements. Probably most significant in terms of efficiency is the gradual reduction in surplus staff, and it is of some interest to ascertain the amount of TFP growth implied by equation III.3 which can be attributed to factors other than reductions in excess staff.

The developments presented in appendix I indicate that the appropriate adjustment to equation III.3 necessary to 'net out' the effects of surplus staff reductions is effected by adjusting the weights applying to changes in labour input, by using the shadow price of labour rather than the market price in determining these weights. The task is then to estimate, in each period, the shadow price of labour as defined in appendix I. However, without detailed knowledge of the production transformation it is not possible to compute this value. As a result, two values postulated as extremes are derived below, in order to provide upper and lower bounds for the likely values of TFP growth based on equation III.3 but adjusted to 'net out' the effects of surplus staff reduction.

Discussions with AN concerning estimates of the number of surplus staff in the year 1987–88 indicate that in that year, revenue plus supplements (approximately) covered all accounting costs excepting the cost of surplus staff.

(Accounting costs are the sum of material, fuel, and labour costs, plus interest and depreciation, based on book values.) Assuming this relationship to hold throughout the data set implies the condition

$$CL^* = R - \text{(non-labour accounting costs)}$$

The shadow price of labour, $Z$, may now be defined by

$$Z = \frac{CL^*}{L} = \frac{R - \text{(non–labour accounting costs)}}{L}$$

This estimate is, subject to the various assumptions made explicit, likely to be an overestimate of the shadow price of labour since the residual value product, after non-labour accounting costs, is averaged over all units of labour, whereas in reality it is likely that marginal value product declines as surplus labour grows.

The application of equation III.3 with the $s_j(t)$ adjusted as above is denoted by $\hat{TFP}_t(2)$.

It should be noted that as the level of labour held, $L$, tends to the optimal level, $L^*$, the shadow price, $Z$, as defined above, tends continuously to the wage rate, $w$.

A likely lower bound for the shadow price of labour is zero. With the shadow price of labour equal to zero whenever there are surplus staff, any changes in the amount of labour held have no effect on measured TFP as long as those changes fail to remove excess staff entirely. AN Rail has indicated that over the entire period in question there existed a positive number of surplus staff, and therefore, with this 'extreme' assumption regarding the form of the production transformation, the weight applied to changes in labour input in the computation of TFP growth is zero.

It should be noted that while labour is held in excess amounts, a small proportionate increase in *all other* input factors will have the same effect on output as would that same proportionate increase in *all* input factors were labour not in excess. Therefore, if it is assumed that constant returns to scale holds along the optimal inputs path, the weights applied to the non-labour inputs in the computation of TFP growth should sum to unity. If they are in proportion to their costs, then the weights, $s_j(t)$, in equation III.3 will satisfy

$$S_1(t) = 0$$

$$S_j(t) = \frac{w_j x_j}{\sum_{j=2}^{6} w_j x_j} \qquad (\text{for } j > 1)$$

where $x_1, \ldots, x_6$ are the inputs identified in the AN production process, the first representing the number of staff employed by AN.

This method of calculation of TFP growth is denoted by $\hat{TFP}(3)$.

The two adjustments to equation III.3 described above have been derived in an intuitive setting. Moreover, the development of the parameter θ, necessary to the logical compatibility of the constant returns to scale assumption and the revenue and cost data, is somewhat arbitrary. In the discussion below, an explicit objective for AN Rail is postulated, the optimisation of which leads to conditions which render the data and the constant returns to scale assumption compatible without the need for any additional parameters. This approach may be logically preferable for computing TFP growth in the purely technical sense, but is likely to deviate more than the previous method from a good representation of the direction of national welfare change.

In the 1987–88 AN annual report, the Chairman wrote, 'Corporate Plan No 1 proclaimed the goal of achieving break even from commercial operations by 1988. This has now been achieved'. More precisely, the goal, or objective, was to cover *accounting* costs. Indeed, the Chairman also wrote, 'AN's commercial business earned a surplus after all expenses (including interest and depreciation) of $0.7 million during 1987/88...'.

Using essentially the same notation as in appendix I, and inputs and outputs as described in appendix II, AN's objective, as described by the Chairman's comments, was

$$Max \sum_{i=1}^{3} p_i y_i - \sum_{j=1}^{6} w_j x_j$$

subject to (i) $F(y_1, y_1, y_3; x_1, ..., x_6; t) = 0$; (ii) $y_1 \geq a_1$; (iii) $y_2 \geq a_2$; and (iv) $x_1 \geq b_1$;

where $y_1$ is level of (mainland) passenger service; $y_2$ is level of Tasmanian freight service; $y_3$ is level of mainland freight service; $a_1$ is minimum allowable level of passenger service; $a_2$ is minimum allowable level of Tasmanian freight service; and $b_1$ is minimum allowable amount of labour employed.

The parameters $a_1$, $a_2$, and $b_1$ are set implicitly by AN's CSOs, and by the labour adjustment policy operating within AN (although largely exogenously determined). It is assumed that constraints (ii), (iii) and (iv) are binding.

The only major deviation in notation from that already established is that the cost of the capital inputs, $w_2x_2$, $w_3x_3$, $w_4x_4$, are taken to be the sum of interest and depreciation (based on book values). It is further assumed that AN is implicitly aware of the replacement value of its capital, and of appropriate capital deflators. It therefore implicitly views the rental price of a unit of capital as

$$w_j = \frac{I_j + D_j}{x_j} \qquad (j = 2, 3, 4)$$

where $I_j$ is interest paid on capital $x_j$; $D_j$ is depreciation (book value) on capital $x_j$; and $x_j$ is appropriately deflated replacement value of capital.

These assumptions are equivalent to attributing entirely to the implicit rental price all of the difference between capital costs based on (replacement) opportunity cost and (replacement) depreciation cost, and capital costs given by interest plus depreciation (historical cost).

The Lagrangian associated with the optimisation problem is

$$L = \sum_{i=1}^{3} p_i y_i - \sum_{j=1}^{6} w_j x_j + \lambda_0 F + \lambda_1 (y_1 - a_1) + \lambda_2 (y_2 - a_2) + \mu (x_1 - b_1)$$

The first order conditions, as derived in appendix I, are

$$\lambda_0 \frac{\partial F}{\partial Y_i} = -(p_i + \lambda_1) \qquad (i = 1, 2)$$

$$\lambda_0 \frac{\partial F}{\partial y_3} = -p_3$$

$$\lambda_0 \frac{\partial F}{\partial x_1} = (w_1 - \mu)$$

$$\lambda_0 \frac{\partial F}{\partial x_j} = w_j \qquad (j = 2, ..., 6)$$

In the traditional (Solow) approach the constraints are ignored, and equation III.3, or *TFP*(1), is applied in the same way as before except that the weights applied to changes in the three types of capital are much smaller than previously. This results from depreciation being on an historical basis and interest paid being less than the true opportunity cost of funds employed. With these lesser weights applied to changes in capital, traditionally measured TFP growth based on equation III.3, is

$$\hat{TFP}_t(4) = \frac{1}{2} \sum_{i=1}^{3} [r_i(t) + r_i(t+1)] [\ln y_i(t+1) - \ln y_i(t)]$$

$$- \frac{1}{2} \sum_{j=1}^{6} [s_j(t) + s_j(t+1)] [\ln x_j(t+1) - \ln x_j(t)] \qquad \text{(III.4)}$$

In equation III.4, the weights $r_i(t)$ are the same as in $TFP_t(1)$; however, all of the $s_j(t)$ are affected by the capital weights being smaller than in equation III.3 — they are accounting cost shares.

Returning to the first order conditions described above, the Lagrange multipliers associated with the outputs can be conveniently interpreted within the following context.

If it is assumed that in the region of current output levels CRTS hold, at least approximately, and that at very low levels of output increasing returns to scale hold, then it may be the case that unconstrained outputs fall short of that considered desirable by the Government. For illustrative purposes, these assumptions are depicted in a single output case in figure III.1, where unconstrained output would be zero. If the authorities believe that the area of consumer surplus under the demand curve and above the line $P_1$ is larger than the amount by which revenue falls short of cost, that is, $(P_1 + \lambda_1)BAP_1$, then it may be desirable to require AN to produce $Q^*$ and to pay it a supplement equal to $\lambda_1 Q^*$ in order that it can cover costs. Under the assumption of local CRTS, and in the absence of any constraints on inputs

$$\sum_{j=1}^{m} w_j x_j = (p_1 + \lambda_1)\, y$$

Thus, as hinted at in the notation in figure III.1, the multiplier $\lambda_1$ may be interpreted as the mark-up on nominal price necessary to cover the cost of producing $y$, and $\lambda_1 y$ as the supplement paid to AN in respect of the production of that output.

This discussion can be extended to apply in the case of input constraints, simply by replacing $w_j$ by its corresponding shadow price, and assuming that the supplement is designed to allow the difference between true costs and shadow costs, as defined in appendix I, to be covered.

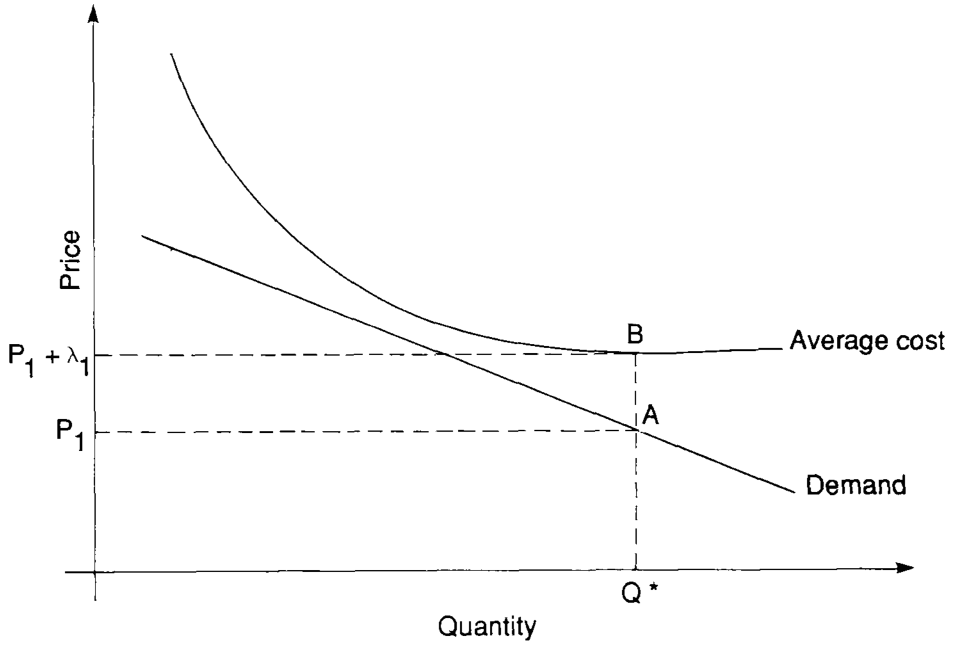



**Figure III.1 Hypothetical average cost and demand schedules**

Recalling that the price of capital in the objective function is AN's implicit accounting price, constant returns to scale now implies that the shadow price of labour is

$$Z = \lambda_0 \frac{\partial F}{\partial x_1} = \frac{R - (\text{non-labour accounting cost})}{x_1}$$

This is the same shadow price as used in *TFP*(2), but in this instance it is derived from the constant returns to scale assumption and the form of AN's objective alone. However, the (shadow) weight applied to labour is now much higher due to the relatively small contribution of capital to accounting cost.

$T\hat{F}P(5)$ is thus obtained from equation III.4 by setting

$$s_1 = \frac{Zx_1}{R}$$

$$s_j = \frac{w_j x_j}{R}$$

where $Z$ is the shadow price of labour as defined above, and $w_j x_j$ is the *accounting* cost of the $j$th input.

Notice that $Z$ has been defined so that $\sum_{j=1}^{6} s_j(t) = 1$.

As before, the extreme case where the shadow price of labour is assumed to be zero is obtained from equation III.4 by setting

$$s_1 = 0 \qquad s_j = \frac{w_j x_j}{\sum_{j=2}^{6} w_j x_j} \qquad (j = 2, ..., 6)$$

In summary, six different approaches to measuring TFP growth in AN have been described. These six consist of three measures within each of two more general categories. The first of the more general categories is based upon the assumption that AN minimises economic costs, and produces outputs at levels which result in the partial derivatives of the production transformation (with respect to the outputs) being in the same ratios as the profit maximising ratios. However, the assumption of CRTS implies, together with revenue and cost data, that they are not equal to the profit maximising partials.

Within the first general category, three measures of TFP growth are derived. The first is the traditional measure, following Solow, which makes no adjustment for the temporary equilibrium effects resulting from surplus staff. It therefore includes the efficiency effects of reductions in surplus staff.

Two further estimates of TFP growth, designed to 'net out' the efficiency effects of surplus staff reductions, are then made. The first is based upon the assumption that the marginal product of (surplus) labour is equal to the average product of labour, and is considered likely to be an overestimate of the true marginal product. The second is based on the assumption that the marginal product of (surplus) labour is zero, and is considered likely to be an underestimate of the true marginal product.

The second general category is based upon the assumption that AN's objective is to maximise its accounting profit. This objective is explicitly identified as having been a major goal for AN by the Chairman's Report in AN's 1987–88 annual report. Again, three measures are estimated, one traditional and two making what are considered to be upper and lower bound adjustments to 'net out' the efficiency effects of surplus labour reductions, as with the first general category.

The six methods of estimation are represented schematically in figure III.2. The estimates are compared and discussed in chapter 5.

| | *TFP growth based on economic cost minimisation* |
|---|---|
| $\hat{TFP}(1)$ | Traditional |
| $\hat{TFP}(2)$ | Efficiency effect of reduction in surplus staff 'netted out'; marginal product of labour set at average |
| $\hat{TFP}(3)$ | Efficiency effect of reduction in surplus staff 'netted out'; marginal product of labour set at zero |

| | *TFP growth based on maximisation of accounting profit* |
|---|---|
| $\hat{TFP}(4)$ | Traditional |
| $\hat{TFP}(5)$ | Efficiency effect of reduction in surplus staff 'netted out'; marginal product of labour set at average |
| $\hat{TFP}(6)$ | Efficiency effect of reduction in surplus staff 'netted out'; marginal product of labour set at zero |

**Figure III.2 Schematic representation of estimation methodologies**

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## ABBREVIATIONS

| | |
|---|---|
| AN | Australian National |
| CRTS | Constant returns to scale |
| CSO | Community service obligation |
| GBE | Government business enterprise |
| LCL | Less-than-carload |
| MFP | Multi-factor productivity |
| PIM | Perpetual inventory method |
| SRA | State Rail Authority of New South Wales |
| STA | State Transport Authority of South Australia |
| TFP | Total factor productivity |