

Productivity measurement: Alternative approaches and estimates

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Abstract

This paper provides a review of conceptual and methodological issues in measuring productivity. Attention is given to the concept of productivity and the relationship between productivity and technological change. Different approaches to measuring productivity are surveyed and the results from a number of NZ productivity studies are summarised. The availability of appropriate input and output data is essential for the accurate measurement of productivity and therefore this paper also discusses some important data issues that influence productivity measurement.

JEL CLASSIFICATION O30 – Technological change: General
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KEYWORDS Productivity; measurement issues; New Zealand; technological change

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Productivity measurement: Alternative approaches and estimates

1 Introduction

This paper provides a review of conceptual and methodological issues in measuring productivity. Attention is given to the concept of productivity and the relationship between productivity and technological change. The paper also surveys four approaches to measuring productivity growth and reports productivity estimates for the New Zealand economy. The availability of appropriate input and output data is essential for the accurate measurement of productivity and therefore this paper also discusses some important data issues that influence productivity measurement.

Economists and policy makers are interested in productivity measurement for several reasons. First, although TFP does not measure technological change, it is related to technological change to the extent that it measures free lunches associated with technological progress.¹ Second, even though productivity measures may imperfectly measure the free lunches associated with technological change, they still exhibit persistent and systematic time series properties. These properties point to relationships that are not yet independently measured in the growth accounting methodology and therefore suggest that current understanding of what drives economic growth requires refinement. Third, productivity numbers provide information about how much measured output is being produced in an economy relative to measured inputs. This is an indication of how the economy is performing in terms of its productive efficiency with respect to available resources. Fourth, growth accounting, growth theory and productivity measures form an intellectual paradigm that has engaged a vast number of researchers who are trying understand the growth process (Hulten, 2000). Productivity analysis has been a core of this research agenda and discovering what it does not measure has been as important as determining what it does measure.

Taken together with other indicators of economic activity (including independent measures on R&D and technological investment and diffusion), economists and policy makers can use productivity measures to develop an idea of how well or poorly an economy is doing in terms of the return it is obtaining on its investments. Uniform measures taken across

¹ However, as a number of authors have argued, TFP appears to be an imperfect measure of these free lunches (see for example, Carlaw and Lipsey (2003) Lipsey and Carlaw (2002), Hulten (2000), Basu and Fernald (1997), Hall (1988), and Jorgenson, Gallop and Fraumeni (1987)).

time, and to the extent possible across production units, can be used to examine whether productivity is rising or falling. These numbers can then be compared with other measures of economic performance, including per capita output growth, and direct measures of technological change to determine what are the correlations between measured productivity, output growth and technological change.

What is probably of most importance in terms of the research agenda on productivity is an answer to Prescott's (1998) call for a theory of productivity. Working out the causal linkages from fundamentals such as technological change through to measures such as GDP per capita growth and productivity change will provide economists and policy makers with a clearer picture of how productivity measures relate to underlying economic change and growth. To this end, research into productivity and its measurement are essential.

The paper is organised as follows. Section 2 discusses the concept of productivity and its relationship to technological change. Section 3 surveys four different approaches to productivity measurement. Historical productivity estimates for the New Zealand economy are reported in Section 4. Given data issues that complicate the construction of accurate productivity series, Section 5 discusses data issues in productivity measurement and research. Section 6 concludes.

2 The concept of productivity

This section discusses conceptual issues surrounding productivity. Subsection 2.1 outlines the concept of productivity, including the distinction between partial productivity measures, such as labour and capital productivity, and total factor productivity (TFP). Because TFP is often (erroneously) seen as a measure of technological change, Section 2.2 outlines several reasons why TFP cannot be equated with technological progress.

2.1 What is meant by “Productivity”?

When economists refer to productivity, at the broadest level they are referring to an economy's ability to convert inputs into outputs. Productivity is a relative concept with comparisons either being made across time or between different production units.² For example, if it is possible to produce more output in period 2, when using the same amount of inputs that were used in period 1, then productivity is said to have improved. In other words, productivity is higher in the second period compared to the first.

Different types of input measure give rise to different productivity measures. For example, labour productivity measures involve dividing total output by some measure that reflects the amount of labour used in production. The total number of worker hours is one such measure, although some studies have used total numbers employed.³ Capital productivity is measured by dividing total output by a measure reflecting the total amount of physical capital used in the production process.

Productivity measures, such as labour productivity and capital productivity, that only relate to one class of inputs are known as partial productivity measures. Caution needs to be

² For example, a comparison of productivity between two firms in an industry, between two industries within or between countries, or between countries.

³ Section 5.2 discusses issues associated with the measurement of the labour input.

applied when using partial productivity measures as changes in input proportions can influence these measures.

A simple substitution of capital for labour within the input mix of a firm or industry can also raise average labour productivity. This means that movements in the average labour productivity statistics do not always represent true changes in the underlying productivity of labour....

Dixon, 1990: 6

The level of TFP can be measured by dividing total output by total inputs. Total inputs are often an aggregation of only physical capital and labour, and may overlook inputs such as land.⁴ When all inputs in the production process are accounted for, TFP growth can be thought of as the amount of growth in real output that is not explained by the growth in inputs. This is why Abramovitz (1956) described the TFP residual as a 'measure of our ignorance'.

As TFP levels are sensitive to the units of measurement of inputs and outputs, they are rarely of primary interest. Rather, the measurement of TFP growth is of primary interest. Hence, it is common to use the notation "TFP" to refer to growth rather than levels, and this is the convention adopted in this paper.

2.2 The relationship between TFP and technology

Lipsey and Carlaw (2002) stated that there are three main views as to what TFP measures in the economics literature. The first is that TFP measures the rate of technological change.⁵ The second is that TFP measures the "free lunches" associated with technological change, which it is argued are mainly associated with externalities and scale effects.⁶ The third view is that TFP does not really measure anything useful at all.⁷

Lipsey and Carlaw argue that TFP does *not* measure technological change.⁸ Rather, it is an imperfect measure of the "super-normal" gains that are associated with growth-creating technological change. These gains are similar, although not identical, to Jorgensen and Griliches's (1967) concept of free lunches. They provide the following six reasons why TFP is an imperfect measure of these gains.⁹

The first is that different timings of the arrival of technological advances cause differences in measured TFP changes. Importantly these differences are more than just a different TFP time profile. When considering two different timings of a technological advance that both result in an identical final change in technology, costs and outputs, overall TFP growth may differ considerably between the two cases.

⁴ Consequently some authors prefer to define the resulting productivity measure as multifactor productivity (MFP) due to it including multiple inputs but not all possible (ie, total) inputs.

⁵ Lipsey and Carlaw (2002) argued that Krugman (1996), Young (1992), Law (2000) and Barro (1999) reflect the view that TFP measures the rate of technological change.

⁶ This view is reflected in Jorgenson and Griliches (1967) and Hulten (2000).

⁷ This view is reflected in Metcalf (1987) and Abramovitz (1956).

⁸ Solow (1957: 312) also noted that the term 'technical change' is a "shorthand expression for any kind of shift in the production function. Thus slowdowns, speedups, improvements in education of the labour force and all sorts of things will appear as 'technical change'."

⁹ For an overview of the issues raised by Lipsey and Carlaw see Carlaw and Lipsey (2003).

The second reason why TFP is an imperfect measure of the supernormal profits associated with technological change is due to the treatment of research and development (R&D) investment in the national accounts of some countries. In some countries R&D is recorded on the input side of the accounts as a current cost with no direct increase being made to current output. Offsetting output only appears when R&D results in reduced costs or increased final output. Such treatment means that increased R&D activity may reduce measured TFP even though there is no technological regression and even when potential technological advancement may be occurring. Their essential point is that “[i]f the patents produced are sold abroad, the transactions are recorded as capital transfers and no income is ever recorded. Hence there is no TFP gain at any point in the process.” (Carlaw and Lipsey, 2003: 19-20)

The third reason is that the omission of certain inputs, particularly natural resources, can bias measured TFP. When the quantity of the omitted variable used in the production process is growing slower than the measured inputs, TFP will be biased downwards. That is, the measured value of TFP growth will be lower than would result from a “true” measure that included accurate values for all inputs used in the production process. Conversely, if the quantity of omitted inputs is growing faster than the measured inputs, the bias will be upwards.

The fourth reason is that the use of an aggregate production function to describe disaggregated activity causes TFP growth to under-measure the free lunches associated with technological change. The reason is that if the free lunch component of the productivity advance occurs at a lower level of disaggregation than is being employed in the measurement of productivity, the free lunch will be measured as increases in inputs rather than a free increase in output for a given level of inputs.

The fifth reason is associated with the expenditure weights used to calculate the TFP index when markets are not in full equilibrium. If a technological change that confers a free lunch occurs in one sector of the economy but it takes several periods for the inputs in the economy to adjust, moving out of the relatively less productive sector into the more productive sector, then during this period of transition TFP calculated using an aggregating index such as the Divisia index will bias the measure of the free lunch depending on the returns to scale in the production function in each sector.

The sixth reason is that TFP measures the difference between contemporary changes in costs and output and consequently misses spillovers that freely provide profitable opportunities that spread across the economy as well as over long periods of time. This is yet another reason why TFP growth and technological change are not the same thing.

To illustrate the point that technological change does not necessarily show up as a change in TFP, Lipsey and Carlaw (2002) provided the following example where an upstream producer develops a piece of machinery that will allow a downstream producer to produce more output than did a previous machine. Assuming a development cost of w for the upstream firm, v representing the value of the marginal product for the downstream firm, and an initial TFP level of 1 (ie $TFP_0 = \frac{Y_0}{I_0}$, where the output index, Y_0 , equals the input index, I_0), then TFP after the machine is developed is:

$$TFP_1 = \frac{Y_1}{I_1} = \frac{Y_0 + v}{I_0 + w} \quad (1)$$

and thus (as $Y_0 = I_0$)

$$\Delta TFP = TFP_1 - TFP_0 = \frac{v - w}{Y_0 + w} \quad (2)$$

This leads to the following three cases depending on the relative sizes of v and w .

1. If $w > v$ then $\Delta TFP < 0$
2. If $w = v$ then $\Delta TFP = 0$
3. If $w < v$ then $\Delta TFP > 0$

Although in all three cases technological change occurs, measured TFP growth can be positive, negative or zero.

While it is true that there is no one-to-one mapping between TFP and technological change, TFP measures are still widely produced and used.¹⁰ TFP and the partial productivity measures do provide useful information on an economy's ability to convert a given level of input into valuable outputs. Given scarcity of resources, we are interested in whether an economy can produce more output from a given level of input than was the case in an earlier period and if so by how much more.

There are several different interpretations of TFP, only one of which can be correct. For example, Bannock (1998) stated that “[i]n the long run productivity advance is the main cause of increases in real per capita income” But a number of economists would argue that productivity is actually a measured observation of the fact that increases in real per capita income have occurred. Therefore, it is not a cause but rather an observation of economic growth. This must be the case for all productivity *measures*. Of course if one takes productivity advance to be synonymous with technological advance then the statement makes sense. But productivity must be measured directly in this case as changes in technology, not as labour or total factor productivity.

The neoclassical growth model (Solow, 1956) points to technological progress (and by implication productivity growth) as determining long run growth in output per worker. However, it has been noted that there is good reason to believe that measured productivity does not capture technological change, and so much of technological advance that could be leading to increases in per capita output will not show up in TFP growth.¹¹ Thus, economists and policy makers need to clarify what productivity measures are in order to ensure that they give the correct advice about if and how to intervene in a production system in order to try to produce higher rates of sustainable economic growth.

¹⁰ For, example see Black, Guy and McLellan (2003) for up-to-date measures of New Zealand's productivity performance since 1988.

¹¹ For an example of this Young (1995) showed that in spite of impressive real per capita income growth in Singapore, Taiwan and South Korea, the TFP numbers were not exceptional and in some cases even lower than the OECD average.

3 Approaches to measuring productivity

This section summarises four prominent approaches to productivity measurement: the growth accounting approach; the index number approach; a distance function approach; and the econometric approach.

3.1 Growth accounting

Growth accounting enables output growth to be decomposed into the growth of different inputs (typically capital and labour) and changes in total factor productivity. Growth accounting requires the specification of a production function that defines what level of output can be produced at some particular time given the availability of a certain level of different inputs and total factor productivity.

The production function is written as:

$$Y_t = A_t f(K_t, L_t) \quad (3)$$

where Y_t is output at time t , A_t represents total factor productivity at time t , K_t is the capital stock at time t , and L_t is a measure of the labour available at time t .

The growth accounting approach is based on several important assumptions. The first is that the technology or total factor productivity term, A_t , is separable as in (3). The second is that the production function exhibits constant returns to scale. Third, it is assumed that producers behave efficiently in that they attempt to maximise profits. Finally, it is assumed that markets are perfectly competitive with all participants being price-takers who can only adjust quantities while having no individual impact on prices.

Differentiating (3) with respect to t gives¹²:

$$\dot{Y} = \dot{A}f(K, L) + \frac{\partial f}{\partial K} \dot{K}A + \frac{\partial f}{\partial L} \dot{L}A \quad (4)$$

where the dots indicate a first partial derivative with respect to time. Dividing (4) by Y gives:

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + A \frac{\partial f}{\partial K} \frac{\dot{K}}{Y} + A \frac{\partial f}{\partial L} \frac{\dot{L}}{Y} \quad (5)$$

The elasticity of output with respect to labour (w_L) and the elasticity of output with respect to capital (w_K) can be written as:

$$w_L = \frac{\partial Y}{\partial L} \frac{L}{Y} = A \frac{\partial f}{\partial L} \frac{L}{Y}$$
$$w_K = \frac{\partial Y}{\partial K} \frac{K}{Y} = A \frac{\partial f}{\partial K} \frac{K}{Y}$$

and therefore (5) can be rewritten as:

¹² The subscript t 's have been dropped for simplicity.

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + w_K \frac{\dot{K}}{K} + w_L \frac{\dot{L}}{L} \quad (6)$$

Solving (6) for $(\frac{\dot{A}}{A})$, the growth rate of TFP, gives:

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - w_K \frac{\dot{K}}{K} - w_L \frac{\dot{L}}{L} \quad (7)$$

Thus TFP growth is a residual, in that it represents that part of the total growth of real output that cannot be explained by growth in labour or capital inputs alone.

To apply (7), estimates of w_L and w_K (the output elasticities) are required. These are typically not readily available. However, if it is assumed that the production function takes a Cobb-Douglas form with constant returns to scale:

$$Y = AK^\alpha L^{(1-\alpha)} \quad (8)$$

and that the factors of production are paid their marginal products, then w_K , is equal to the share of income paid to capital and w_L equals the share of income paid to labour.

From equation (7) it is apparent that if we have data on the growth rate of real output $(\frac{\dot{Y}}{Y})$, the growth rate of the capital stock $(\frac{\dot{K}}{K})$, the growth rate of labour inputs $(\frac{\dot{L}}{L})$ and capital and labour's share of income (which correspond to w_K and w_L) then we have enough information to obtain an estimate of TFP growth $(\frac{\dot{A}}{A})$.

The use of an underlying production function other than a Cobb-Douglas function will often mean that it is not appropriate to equate output elasticities with factor income shares. Consequently the use of a different production function yields different results compared with TFP estimates based on a Cobb-Douglas production function.

3.2 Index number approaches to measuring productivity

The majority of statistical agencies that produce regular productivity statistics use the index number approach. For example, the Australian Bureau of Statistics calculates market sector multifactor productivity using the index number approach based on a Törnqvist index, as does the US Bureau of Labor Statistics.

The index number approach to calculating productivity involves dividing an output quantity index by an input quantity index to give a productivity index. Therefore:

$$A_t = \frac{Y_t}{I_t} \quad (9)$$

Where A_t is TFP, Y_t is an index of output quantities (a real output index) and I_t is an index of input quantities. The subscript t indicates the time period. Equation (9) can be viewed as a re-arrangement of (3), but in (9) no production function has been specified

meaning that the TFP level (measured by A_t) and subsequent growth rates may not be the same as that which would result from using the growth accounting procedure.

After obtaining an output and input quantity indexes the calculation of a TFP index is straightforward. From this TFP index productivity growth rates can be easily calculated. The difficulty is in determining what type of index to use and then obtaining the necessary price and quantity data to construct them.

To construct an output (input) quantity index it is necessary to determine an appropriate way to aggregate the different outputs (inputs) produced in an economy. For example, it would not make sense to add the number of car tyres produced to the number of woollen jerseys. There are a number of different index formulations that try to overcome this problem by using prices (or output shares) to weight the various different kinds of outputs.

With vectors of prices $\underline{p}^t = (p_1^t, p_2^t, \dots, p_m^t)$ and quantities $\underline{y}^t = (y_1^t, y_2^t, \dots, y_m^t)$ for the m different outputs produced in an economy at time $t = 0, 1, \dots, T$, a Laspeyres index is calculated as:

$$Y_L(\underline{p}^0, \underline{p}^1, \underline{y}^0, \underline{y}^1) = \frac{\underline{p}^0 \cdot \underline{y}^1}{\underline{p}^0 \cdot \underline{y}^0} = \frac{\sum_{i=1}^m p_i^0 y_i^1}{\sum_{i=1}^m p_i^0 y_i^0} \quad (10)$$

$$Y_L(\underline{p}^0, \underline{p}^1, \underline{y}^0, \underline{y}^1) = \sum_{i=1}^m s_i^0 \left(\frac{y_i^1}{y_i^0} \right)$$

where $s_i^t = \frac{p_i^t y_i^t}{\sum_{i=1}^m p_i^t y_i^t}$ is quantity i 's nominal output share. Equation (10) shows that the

Laspeyres index is a nominal share-weighted sum of quantity ratios.

The Paasche quantity index is obtained by using period 0 prices rather period 1 prices:

$$Y_P(\underline{p}^0, \underline{p}^1, \underline{y}^0, \underline{y}^1) = \frac{\underline{p}^1 \cdot \underline{y}^1}{\underline{p}^1 \cdot \underline{y}^0} = \frac{\sum_{i=1}^m p_i^1 y_i^1}{\sum_{i=1}^m p_i^1 y_i^0} = \left[\sum_{i=1}^m s_i^1 \left(\frac{y_i^1}{y_i^0} \right)^{-1} \right]^{-1} \quad (11)$$

The geometric average of the Laspeyres and Paasche indexes is known as a Fisher index.

Finally, the Törnqvist output index is defined as follows:

$$Y_T(\underline{p}^0, \underline{p}^1, \underline{y}^0, \underline{y}^1) = \prod_{i=1}^m \left(\frac{y_i^1}{y_i^0} \right)^{0.5(s_i^0 + s_i^1)} \quad (12)$$

Similarly, input indexes are defined when using data on input quantities and prices.

Calculating a TFP index using the index number approach requires a decision regarding the type of index formulation to be used in constructing the output quantity and input

quantity indexes. Two approaches to choosing between different index number formulations are the economic and axiomatic approaches.

Diewert and Lawrence stated:

The economic approach selects index number formulations on the basis of an assumed underlying production function and assuming price taking, profit maximising behaviour on the part of producers. For example, the Törnqvist index used extensively in past TFP studies can be derived assuming the underlying production function has the translog form and assuming producers are price taking revenue maximisers and price taking cost minimisers.

Diewert and Lawrence, 1999: 9

The axiomatic approach involves comparing the properties of the different index number formulations with a number of desirable mathematical properties. The index that passes the most tests is the “preferred” index formulation. Diewert and Lawrence (1999) used this axiomatic approach in determining which index number formulation to use. The axioms (or desirable properties) were:

1. *Constant quantities test*: If quantities are the same in two periods, then the output index should be the same in both periods irrespective of the price of the goods in both periods;
2. *Constant basket test*: If prices are constant over two periods, then the level of output in period 1 compared to period 0 is equal to the value of output in period 1 divided by the value of output in period 0;
3. *Proportional increase in quantity test*: If all quantities in period t are multiplied by a common factor, λ , then the quantity index in period t compared to period 0 should increase by λ also; and
4. *Time reversal test*: If the prices and quantities in period 0 and t are interchanged, then the resulting output index should be the reciprocal of the original index.

Diewert and Lawrence note that of the four index formulations defined above, only the Fisher index has all four desirable properties. Both the Laspeyres and Paasche indexes are inconsistent with time reversal test and the Törnqvist does not pass the constant basket test. For this reason Diewert and Lawrence use a chained Fisher index for constructing output and input quantity indices in their construction of a TFP index. They also note that when a more extensive list of axiomatic tests is used, the Fisher index continues to satisfy more tests than other index formulations.

3.3 A distance function based approach

The distance function based approach to measuring TFP seeks to separate TFP into two components.¹³ This is done using an output distance function that measures the distance

¹³ More generally, the distance function (which is the dual of the cost function) is discussed in the consumer and production literature where duality concepts are used. An example of the use of the distance function in a demand context is Deaton (1979).

of an economy from its production function. In principle, this technique enables a change in TFP to be decomposed into changes resulting from a movement towards the production frontier and shifts in the frontier. The output distance function measures how close a particular level of output is to the maximum attainable level of output that could be obtained from the same level of inputs if production is technically efficient. In other words, it represents how close a particular output vector is to the production frontier given a particular input vector. Fare, Grosskopf, Norris and Zhang (1994) define an output distance function at time t as

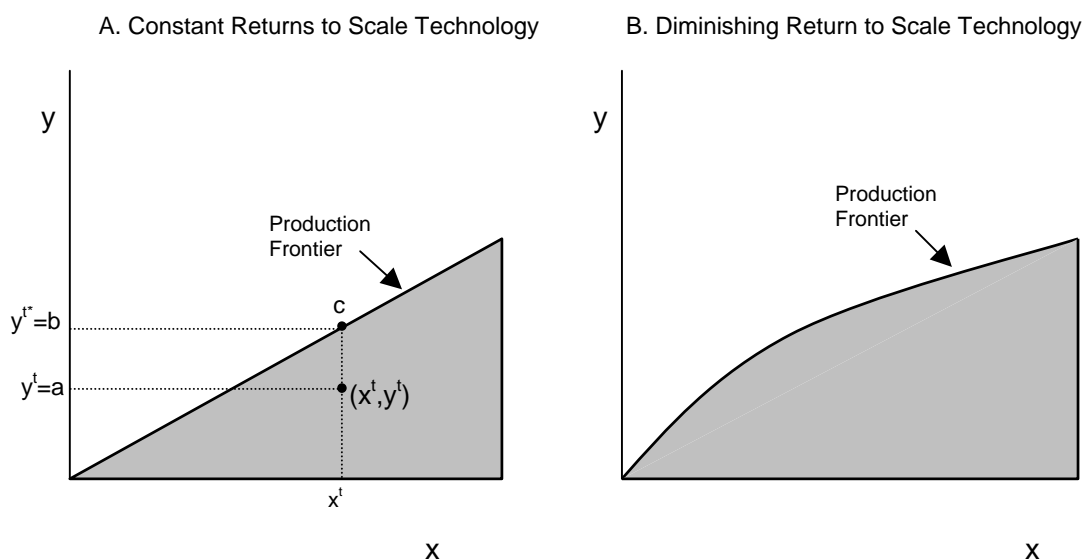
$$D_o^t(\mathbf{x}^t, \mathbf{y}^t) = \inf\{\theta : (\mathbf{x}^t, \mathbf{y}^t / \theta) \in \mathbf{S}^t\} = (\sup\{\theta : (\mathbf{x}^t, \theta \mathbf{y}^t) \in \mathbf{S}^t\})^{-1} \quad (13)$$

where \mathbf{x}^t is a vector of input quantities at time t and \mathbf{y}^t is a vector of output quantities at time t . \mathbf{S}^t describes a production technology or production possibility set that is feasible using the technology available at time t .

The term $\inf\{\theta : (\mathbf{x}^t, \mathbf{y}^t / \theta) \in \mathbf{S}^t\}$ in equation (13) states that of the set of real numbers, θ , where θ is such that the input/output combination $(\mathbf{x}^t, \mathbf{y}^t / \theta)$ is part of the production possibility set that is technically feasible given time t technology, we need to find the infimum or greatest lowest bound of θ . The infimum of θ is the biggest real number that is less than or equal to every number in θ . The last part of equation (13) states that finding this infimum is equivalent to finding the reciprocal of $\sup\{\theta : (\mathbf{x}^t, \theta \mathbf{y}^t) \in \mathbf{S}^t\}$. That is we want to find the reciprocal of the supremum of the set of real numbers θ , where this time θ is the set of real numbers such that for a given input vector \mathbf{x}^t the input/output combination $(\mathbf{x}^t, \theta \mathbf{y}^t)$ is part of the production possibility set that is technically feasible given time t technology. The supremum (sup) of θ is the smallest real number that is greater than or equal to every number in θ .

Figure 1 presents two possible production frontiers in the case where there is one output and one input (ie, \mathbf{x}^t and \mathbf{y}^t are scalars). In panel A the production frontier exhibits constant returns to scale. That is, if we double the level of input we double the level of output. In panel B the production frontier exhibits diminishing returns to scale implying that a doubling in the level of input results in an increase in output that is less than double. The grey shaded area (including the production frontier) on each of the two panels represents the production possibility set, given the production technology shown. It is technically feasible for the economy to be at any point in this set, with the determining factors being the level of input available (ie, how far to the right in Figure 1 the economy is operating at) and how efficiently the level of input is converted into output (ie, given the level of input how close is the level of output to the production frontier) Given the technology shown, it is not possible for the economy to be operating at a point above the production frontier. The point (x^t, y^t) shown in panel A is feasible if the level of input x^t is available for production in the economy. Given that level of input, the economy could produce anywhere along the line $x^t c$.

Figure 1: Production frontiers



The term $D_o^t(\mathbf{x}^t, \mathbf{y}^t)$ in equation (13) is the output distance function based on the input and output vectors at time t . The subscript "O" signals that the distance function is an output distance function. The superscript "t" on the D is important as it signals which period's reference technology (or production possibility frontier) the distance is being measured from.

To calculate $D_o^t(\mathbf{x}^t, \mathbf{y}^t)$, it is necessary to find the largest factor by which all the outputs in the output vector could be increased when making production as technically as efficient as possible, based on the input vector \mathbf{x}^t . $D_o^t(\mathbf{x}^t, \mathbf{y}^t)$ is then the reciprocal of this value. The closer the economy is to the production frontier the smaller the factor increase will be and consequently the larger the value of $D_o^t(\mathbf{x}^t, \mathbf{y}^t)$. If the economy is operating on the frontier then $D_o^t(\mathbf{x}^t, \mathbf{y}^t)$ will take a value of 1. In contrast, when the economy is below the frontier $D_o^t(\mathbf{x}^t, \mathbf{y}^t)$ will be less than 1.

In terms of Figure 1 (panel A), if the economy is operating at point (x^t, y^t) then it is producing output quantity "a". In this case, (x^t, y^t) is technically inefficient. If production were on the frontier, then the output quantity $y^* = b$ could be produced. $a\theta = b$, ie, b is θ times as large as a . Therefore $\theta = b/a$ and $D_o^t(\mathbf{x}^t, \mathbf{y}^t) = \theta^{-1} = a/b = y^t / y^{t*}$. Therefore the distance function is actual output divided by the frontier level of output.

Caves, Christensen and Diewert (1982a and b) define a Malmquist productivity index as:

$$M^t = \frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^t(\mathbf{x}^t, \mathbf{y}^t)} \quad (14)$$

ie, they define their productivity index as the ratio of two output distance functions which both utilise technology at time t as a reference technology. The numerator is the output distance function at time $t+1$ based on period t technology. The denominator is the output distance function at time t based on period t technology.

Instead of using period t 's technology as the reference technology it is possible to construct output distance functions based on period $t+1$'s technology and consequently we may construct a Malmquist productivity index as:

$$M^{t+1} = \frac{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \quad (15)$$

Fare et al (1994) avoid choosing an arbitrary benchmark technology by specifying their Malmquist productivity change index as the geometric mean of the indexes shown in equations (14) and (15). That is:

$$M_o(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{x}^t, \mathbf{y}^t) = \left[\left(\frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^t(\mathbf{x}^t, \mathbf{y}^t)} \right) \left(\frac{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \right) \right]^{\frac{1}{2}} \quad (16)$$

Equation (16) can also be written as:

$$M_o(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{x}^t, \mathbf{y}^t) = \frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^t(\mathbf{x}^t, \mathbf{y}^t)} \times \left[\left(\frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})} \right) \left(\frac{D_o^t(\mathbf{x}^t, \mathbf{y}^t)}{D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \right) \right]^{\frac{1}{2}} \quad (17)$$

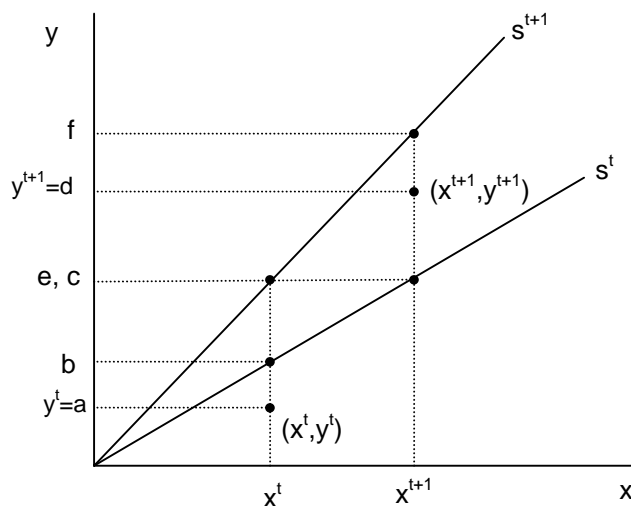
Fare et al (1994) give the following interpretation to the two terms on the right hand side of equation (17):

$$\text{Efficiency change} = \frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^t(\mathbf{x}^t, \mathbf{y}^t)}$$

$$\text{Technical change} = \left[\left(\frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})} \right) \left(\frac{D_o^t(\mathbf{x}^t, \mathbf{y}^t)}{D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \right) \right]^{\frac{1}{2}}$$

Hence the Malmquist productivity index they derive is simply the product of the change in relative efficiency that occurred between periods t and $t+1$, and the change in technology that occurred between periods t and $t+1$.

Figure 2: A Malmquist productivity index



Consider the following example based on Figure 2, which gives the necessary pieces of information to construct a Malmquist output based productivity index. Given two constant returns to scale production frontiers (s^t and s^{t+1}) that describe the technology available in periods t and $t+1$ and also information on the input/output combinations that were realised by the economy during periods t and $t+1$. In period t , the economy used x^t inputs to produce $y^t = a$ outputs. In period $t+1$ the economy used x^{t+1} inputs to produce $y^{t+1} = d$ outputs.

To calculate the efficiency change component we need to construct two distance functions, $D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})$ and $D_o^t(\mathbf{x}^t, \mathbf{y}^t)$. These two functions tell us for each period, how close the level of output actually produced was to the frontier level of output for the same level of inputs based on the technology available in the period under consideration. These two measures describe the relative efficiency of production in each period and both will take values between 0 and 1. Based on Figure 2, $D_o^t(\mathbf{x}^t, \mathbf{y}^t) = \frac{a}{b}$ as the level of output was $y^t = a$, whereas had production be technically efficient, output would have been b .

$$D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}) = \frac{d}{f} \text{ and thus efficiency change equals } \frac{\frac{d}{f}}{\frac{a}{b}} = \frac{d}{f} \frac{b}{a}.$$

To calculate the technical change component we need to use the two distance functions calculated above as well as $D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})$ and $D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)$. $D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})$ measures how close the level of output actually produced in period $t+1$ is to the maximum level of output that could have been produced with x^{t+1} inputs had period t 's technology been available.

In Figure 2, $D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}) = \frac{d}{e}$. Note that $D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})$ can exceed 1 (and does in this case) if technological advancement has occurred. $D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)$ measures how close the level of output actually produced in period t is to the maximum level of output that could have been produced from period t 's inputs, had period $t+1$'s technology been available.

$$D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t) = \frac{a}{c}. \text{ Thus in this example technical change equals } \left[\left(\frac{\frac{d}{e}}{\frac{d}{f}} \right) \left(\frac{\frac{a}{b}}{\frac{a}{c}} \right) \right]^{\frac{1}{2}} = \left[\frac{f}{e} \frac{c}{b} \right]^{\frac{1}{2}}$$

To compute distance functions the researcher needs to know the production technology of or production frontier at all time periods under consideration. Fare et al (1994) who looked at productivity growth in 17 OECD countries, produced a world production frontier nonparametrically using an approach known as activity analysis or Data Envelopment Analysis (DEA). They then compared their 17 countries to the "world" production frontier calculated from data for the 17 countries. Fare, Grosskopf and Margaritis (1996) (hereafter, FGM) followed this approach but used sector level input and output data for New Zealand to produce an aggregate production frontier for the New Zealand market sector. Individual sectors are then compared to this frontier.

The basic approach used in both these studies involved having data for $k = 1, 2, \dots, K$ countries (or sectors in the case of FGM). Each of these countries (or sectors) uses $n = 1, 2, \dots, N$ inputs $x_n^{k,t}$ at each time period t , to produce $m = 1, 2, \dots, M$ outputs $y_m^{k,t}$ (in

FGM each sector produced one output so $m = 1$). The production frontier or technology can be constructed under the assumption of constant returns to scale:

$$S_{CRS}^t = \left\{ (\mathbf{x}^t, \mathbf{y}^t) : \sum_{k=1}^K z^{k,t} y_m^{k,t} \geq y_m^t, \sum_{k=1}^K z^{k,t} x_n^{k,t} \leq x_n^t, z^{k,t} \geq 0, n = 1, \dots, N, m = 1, \dots, M, k = 1, \dots, K \right\} \quad (18)$$

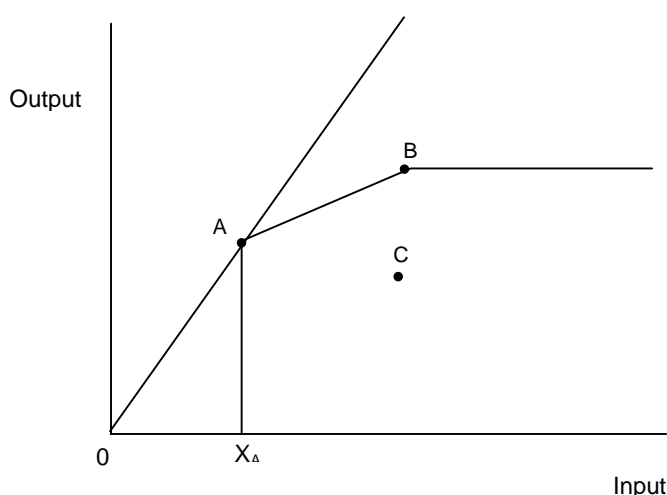
where $z^{k,t}$ is an intensity variable.

It is possible to allow for different returns to scale by adding restrictions involving the intensity variable. For example it is possible to relax the assumption of constant returns to scale by adding the restriction shown in equation (19) which allows for non-increasing returns to scale:

$$\sum_{k=1}^K z^{k,t} \leq 1 \quad (19)$$

Figure 3 illustrates the construction of a production frontier, for a particular period, based on equation (18), in the simple case where we have one input and one output.¹⁴

Figure 3: Construction of a production frontier at time t



In Figure 3 there are three different output-input combinations (A , B and C), which could relate to three countries or three sectors depending on the level at which the analysis is being undertaken. If the restriction shown in equation (19) is imposed, that the sum of the intensity variables must be less than or equal to 1, then the production frontier is the line $0AB$ and the horizontal extension from B . If instead constant returns to scale is imposed (ie, the formulation given in equation (18)), the production frontier is given by the ray from the origin passing through A . In the variable returns to scale case, the production frontier will consist of the line $X_A AB$ and the horizontal extension from B .

A number of economists have expressed scepticism about the practical merit of the DEA approach to identifying an economy-wide or world production frontier. For example, Diewert and Lawrence (1999) stated in relation to FGM's study:

¹⁴ This discussion and figure 2.3 is based on Fare et al. (1994).

Evidently, they just used a variant of DEA analysis, *assuming that the value added outputs of each industry can be produced by every other industry*. This seems to be a rather untenable assumption to say the least and hence we suspect that their measures of efficiency change and technical progress are essentially worthless.

Diewert and Lawrence, 1999: 98

Carlaw and Lipsey (2003) had similar concerns noting that the underlying assumption when using this technique to construct an economy's production frontier from industry level data is that all the industries have the same aggregate production function.¹⁵

Given what we know about technological complementarities and the need to adapt technologies for specific uses, identical production functions across industries is not an acceptable assumption. For example, it is difficult to believe that the application of electricity to communications technologies can be considered to be the same production technology as the application of electricity to mining or machining?

Carlaw and Lipsey, 2003: 10

3.4 The econometric approach to productivity measurement

The econometric approach to productivity measurement involves estimating the parameters of a specified production function (or cost, revenue, or profit function, etc). Examples of the approach using New Zealand data include Grimes (1983), Szeto (2001) and Razzak (2002). Often the production function is expressed in growth rate form and then estimated to yield an estimate of the parameter that reflects the growth in technological progress, which is typically interpreted as a measure of productivity growth.

One advantage of the econometric approach is the ability to gain information on the full representation of the specified production technology. In addition to estimates for productivity, information is also gained on other parameters of the production technology. It is not possible to generate this additional information using the growth accounting or index number approaches. Moreover, because the econometric approach is based on using information on outputs and inputs, there is greater flexibility in specifying the production technology. For example, it is possible to introduce other forms of factor-augmenting technological change other than the Hicks-neutral formulation implied by the growth accounting and index number approaches, and to make allowance for adjustment costs and variation in input utilisation.

Within the econometric framework it is possible to test the validity of assumptions that underpin the growth accounting and index number approaches because of the sampling properties of the production technology. For example, it is possible to test the assumption of constant returns to scale that is often used in the growth accounting approach to productivity measurement.

The increased flexibility and the ability to test the validity of different assumptions of the econometric approach do not come without cost. The use of the econometric approach

¹⁵ Likewise when constructing a world frontier the assumption is that all countries have the same underlying aggregate production function.

raises estimation issues that may call in to question the robustness of parameter estimates. For example, the parameter estimates for a specified technology may appear implausible (such as negative factor income shares for a Cobb Douglas production function), causing researchers to impose *a priori* restrictions on parameter values. Furthermore, when data samples are small, restrictions such as constant returns to scale are often imposed to preserve degrees of freedom. The use of more flexible function forms for the production technology often means that non-linear estimation techniques are required, which bring their own complications. Szeto (2001) provides a good example of the non-linear estimation issues that are often faced by researchers when using the econometric approach to estimate productivity.

A further drawback of the econometric approach is the greater difficulty of explaining the econometric methodology to a range of users, as well as the difficulty in replicating and producing productivity estimates on an ongoing basis. This is why measuring productivity using the econometric approach is best suited to single, one-off studies.

Hulten (2000) has pointed out that the econometric approach to productivity measurement should be viewed as complimentary to the growth accounting and index number approaches for several key reasons. First, index number techniques are often used to construct the output and input series that are used as variables in estimating productivity using the econometric approach, thus “the question of whether or when to use econometrics to measure productivity change is really a question of which stage of the analysis index number procedures should be abandoned” (Hulten, 2000: 23). Second, the relative simplicity of the growth accounting and index number approaches can be used to help interpret the richer results of the econometric approach. Finally, by merging the different approaches, econometrics can be used to help explain TFP. In summary the “potential richness and testable set-up [of the econometric approach] make them a valuable complement to the non-parametric, index number methods that are the normal tool for productivity statistics” (Schreyer and Pilat, 2001: 133).

4 New Zealand’s historical productivity record

This section briefly summarises the results obtained in a number of studies that have attempted to measure productivity growth rates for New Zealand. Figure 4 summarises the growth rates found in studies that included measures of TFP growth, while Figure 5 summarises labour productivity growth rates. This section does not attempt to discuss the robustness of results obtained in any of the studies, rather it illustrates that a number of studies have attempted to measure productivity growth in New Zealand, albeit over different timeframes and by using a number of different measurement techniques. Diewert and Lawrence (1999) chapter 6 reviews more comprehensively a number of the studies featuring in Figures 4 and 5.

In Figures 4 and 5, the timeframe to which the average productivity growth relates is shown by the placement and length of the horizontal bars. The number in the centre of the bar is the average annual growth rate for that period.

Razzak (2002) used an OLS method that allows for either a deterministic or stochastic trend to produce a number of TFP estimates. Razzak argued that TFP measurement in New Zealand may be affected by several factors. The first factor is whether or not there exists a structural break in the data used. Second, is the nature of the trend. Third is whether the production function exhibits constant or increasing returns to scale.

McLellan (2001) used a growth accounting approach to measure TFP and labour productivity over the classical business cycle using a peak-to-peak approach.¹⁶ This approach attempts to measure trend output growth by removing the cyclical component of growth. TFP was calculated using a Cobb-Douglas production function with labour's share set equal to 0.65. The data used were quarterly production GDP, Labour full time equivalents (FTEs) from the Household Labour Force Survey (HLFS), with a weighting of 0.5 on part-time employment, and a capital stock measure calculated using Statistics New Zealand's productive capital stock data.

The Diewert and Lawrence (1999) preferred TFP series (labelled DL Preferred Series in Figure 4) was constructed using data in the Diewert and Lawrence database. A total output index was formed by aggregating 49 output components and a total input index was formed by aggregating 13 input components, both using a chained Fisher index. All outputs and inputs are expressed in producers' prices. Both indices relate to the market sector. Their database covered the period 1972 to 1998 (March years). Their database drew on labour times series presented in the OECD's *Economic Outlook* and Census based hours worked per person by occupation data from Statistics New Zealand. Their (HLFS Hours) TFP series on the other hand used data derived from the HLFS rather than the Census.

TFP numbers using the "Official" database were also constructed by Diewert and Lawrence. The database was based on Statistics New Zealand (SNZ) data and covered the period 1978 to 1998 (and consequently numbers were based on the System of National Accounts 1968 data). The official database included data on production GDP, labour and capital for 20 separate market sector industries. Chained Fisher TFP series were constructed using industry GDP data, industry hours worked data (drawn primarily from the HLFS, Quarterly Employment Survey (QES) and the Economic Survey of Manufacturing (ESM)), and industry net capital stocks for plant and equipment and building and construction, weighted by user costs with industry specific depreciation rates and asset lives based on Philpott (1992).¹⁷

¹⁶ The 1997 to 2001 period is not a full cycle but represented the most up-to-date period available at the time McLellan (2001) was written. McLellan (2001) also presented trough-to-trough measures.

¹⁷ See Diewert and Lawrence (1999), chapter 4 for more details.

Figure 4: Trend aggregate TFP growth rates (percent per annum)

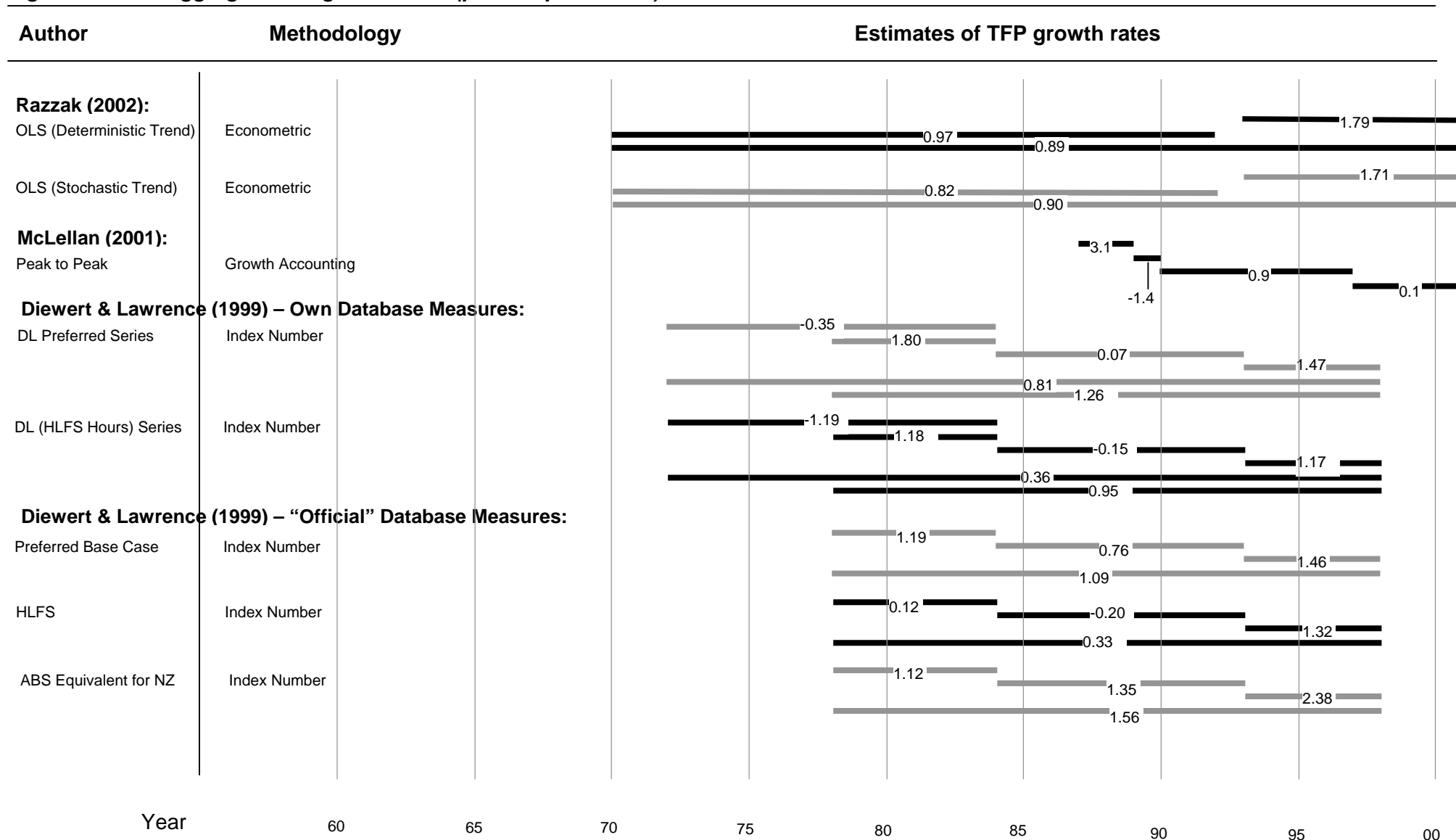


Figure 5: (cont'd): Trend aggregate TFP growth rates (percent per annum)

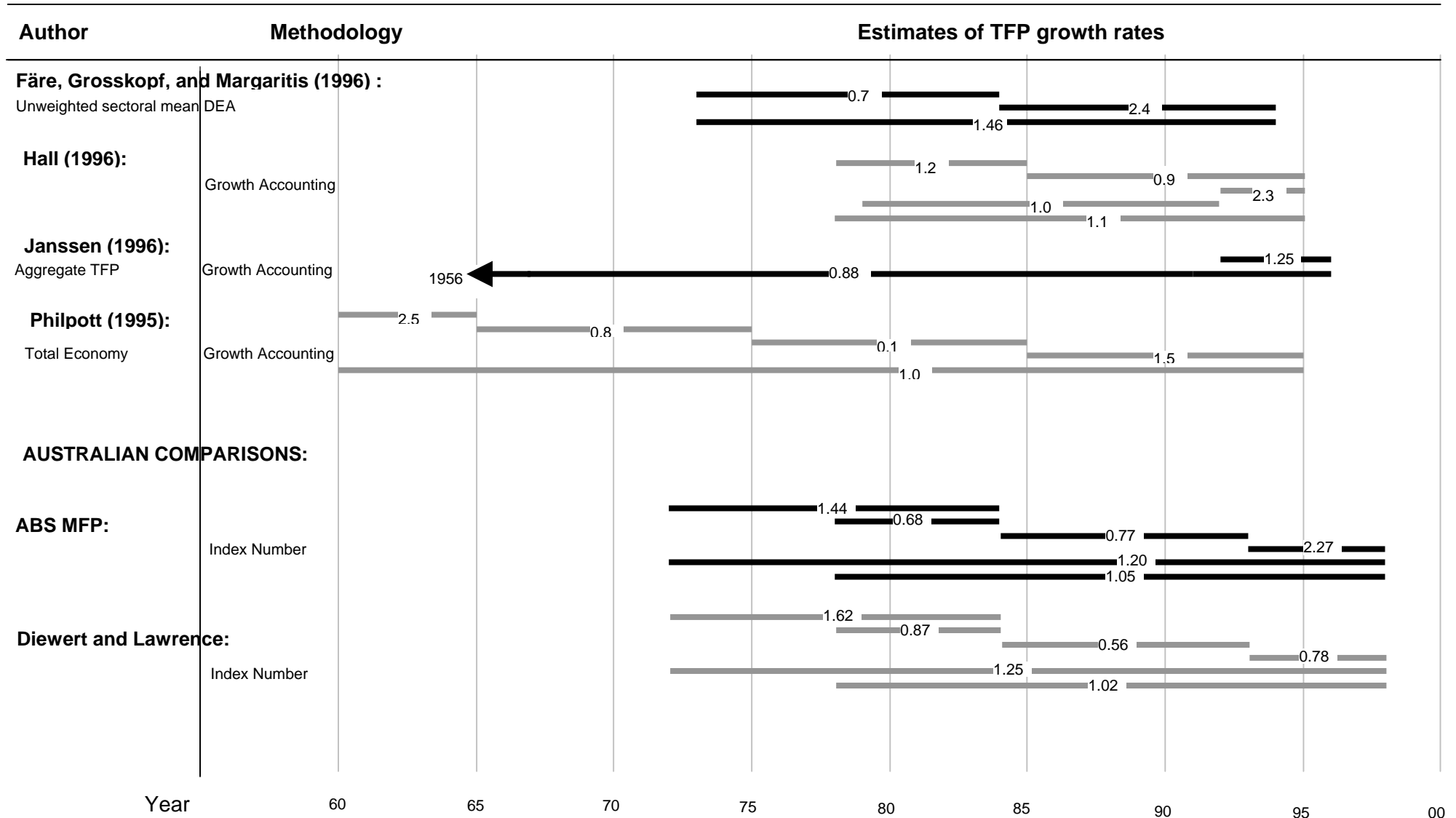
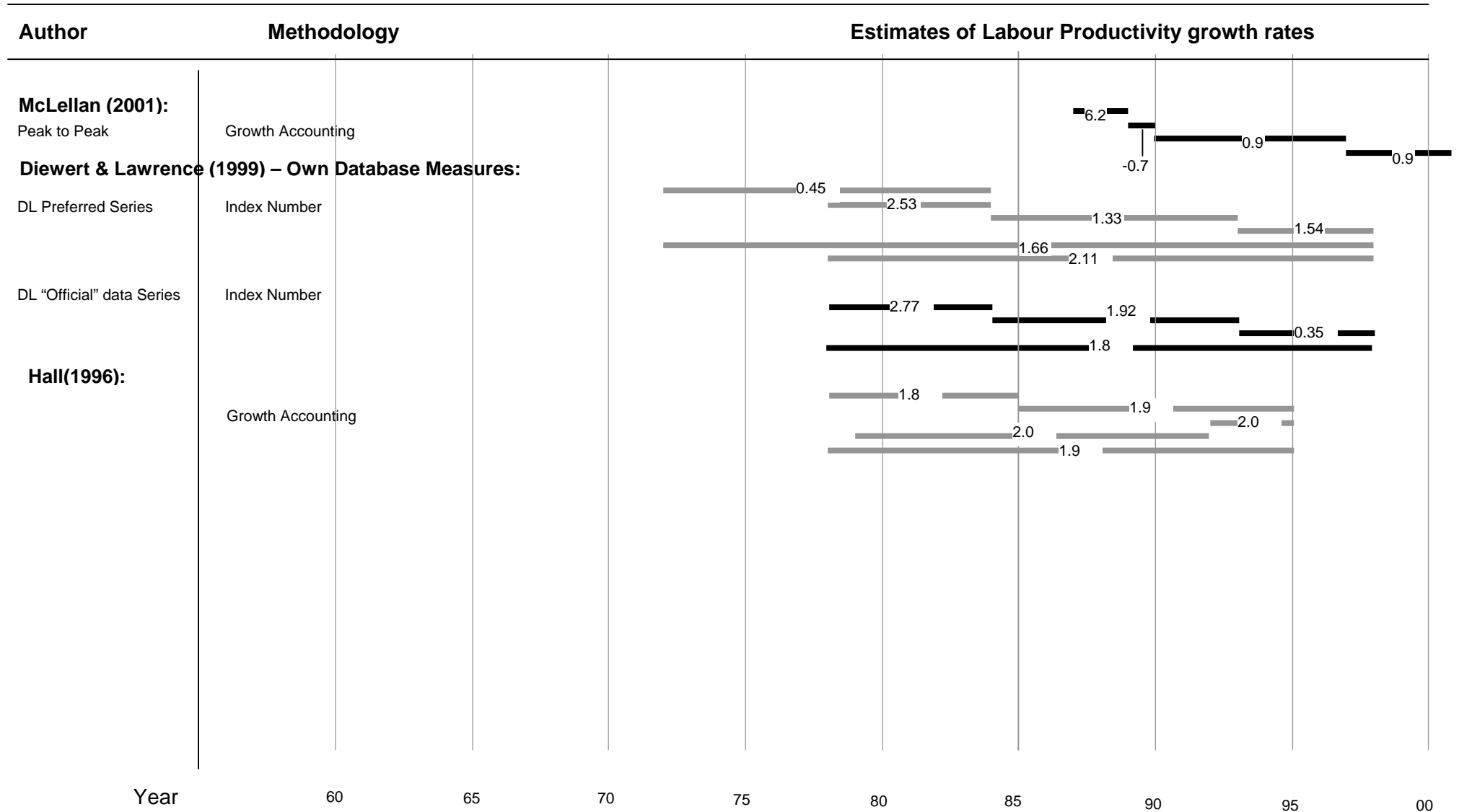


Figure 6: Trend aggregate labour productivity growth rates (percent per annum)



To compare Australian and New Zealand productivity Diewert and Lawrence produced a New Zealand TFP measure based on data from the official database that excluded the finance, insurance real estate and business services industry and the community, social and personal services industry and which took the same weighted averages of the gross and net capital stocks as taken by the ABS. In the Figures above this measure is called “ABS equivalent” for New Zealand.

The focus of Fare et al (1996) was predominantly at the sectoral level. The approach used enabled TFP changes to be decomposed into technical efficiency change and technological change (see section 3.3 for more details). The authors also provided average results for the New Zealand economy based on an unweighted averaging of their sectoral results.

Hall (1996) presented both TFP and labour productivity results based on the growth accounting approach.

Janssen (1996) measures were based on a growth accounting approach that used a Cobb-Douglas production function with capital's share being taken as 0.4. A net capital stock measure was used. Employment was a FTE measure with part-time employment having a weight of 0.35.

Philpott (1996) measures were also based on a growth accounting approach that used a Cobb-Douglas production function with capital's share being taken as 0.4. Data was sourced from the Research Project on Economic Planning (RPEP) database. The capital data used to compute the capital stock growth was the average of the gross and net capital in place. The periods used were aimed at coinciding with the turning points of the business cycle.

Figures 4 and 5 illustrate the difficulty of obtaining a clear sense of how New Zealand has performed in terms of productivity (either TFP or labour productivity) performance. Studies differ in terms of the approach, the methodology, data sources, and choices made by the individual researcher. Janssen (1996) noted:

Comparisons of TFP studies should be treated cautiously. Growth accounting exercises involve numerous judgements about the treatment of inputs and judgements about key parameters (e.g., factor shares). For example, in New Zealand (as in Australia) the growth rate of the gross capital stock is consistently above that of the net capital stock. Therefore, other things being equal, the use of net capital stock data will make our TFP growth estimates larger than studies that use gross capital stock data (e.g., Hall, who uses Philpott's capital stock estimates). Another problem with the Philpott capital stock data is that it does not allow for faster depreciation rates or even scrapping during a period of structural change - thereby understating actual productivity growth (see Chapple (1994); Färe, Grosskopf and Margaritis (1996)).

Janssen, 1996: 6

Differences in productivity measures also arise due to differences in the industry coverage of different studies, and the choice of start and finish periods can also be important when reporting average rates for a particular period.

5 Data issues that influence productivity measurement and research

This section addresses the measurement of inputs and outputs that may influence measured productivity. First the measurement of two of the most important inputs into the production process, namely capital and labour, is considered. Then the measurement of the quantity of output is discussed.

5.1 Capital

The flow of capital services is not usually directly observable and most studies assume that the value of capital services is proportional to the value of the capital stock. There are two broad approaches to measuring the capital stock; these are measures of the gross capital stock and measures of the net capital stock. The gross capital stock approach assumes that a capital good delivers a constant flow of services over its lifetime. Constructing a gross capital stock measure involves summing past purchases of capital goods (ie, investment) in constant prices back as far as the assumed life of the asset. Different types of capital goods will have different assumed asset lives, for example a building will have a longer life than a van. Equation (20) expresses the gross capital stock approach:

$$K_t^G = \sum_{i=1}^L I_{t-i} \quad (20)$$

Net capital stock measures allow the service flow from an asset to fall over time as the asset deteriorates. That is, net capital stock measures allow for depreciation of an asset. As shown in equation (21), the capital stock in time t is equal to the previous periods net capital stock less depreciation plus any additional capital investment made:

$$K_t^N = (1 - \delta)K_{t-1}^N + I_t \quad (21)$$

where δ is the depreciation rate, or proportion of the capital stock that is retired each period. To construct a net capital stock series, a starting value for the net capital stock is required.

Whether to use gross or net capital stocks in productivity studies has been the subject of some debate. For example, Philpott (1992) stated “For use in analyses of production and productivity (for which we intend using our own series) net capital measures are less appropriate than gross capital measures.” Diewert and Lawrence (1999) state:

Some argue that the gross capital approach of effectively assuming no deterioration is more appropriate for Buildings and structures while the net capital stock approach of assuming a steady deterioration is more appropriate for Plant and equipment. ... [T]he ABS actually takes weighted averages of the gross and net capital stock estimates with the weights varying by asset type to more closely approximate the deterioration patterns estimated by the US Bureau of Economic Analysis. In general, we believe the net capital stock approach provides a closer approximation to the contribution of capital assets to the production process and better approximates economic depreciation.

Up until recently there have been no official estimates of the capital stock for New Zealand and consequently researchers have needed to form their own estimates. Any estimate of the capital stock necessarily has to make a number of assumptions, including assumptions about the asset lives of the different capital assets under consideration; the appropriate depreciation rates (when using a net capital stock concept); and how to aggregate different types of capital assets to form an overall measure of the capital stock. Consequently, Diewert and Lawrence (1999: 39) note that “Even in countries where official capital stock estimates are available, many researchers prefer to form their own estimates as their beliefs about the economic characteristics of capital may differ from statistical agency practice.”

Prior to the recent release of an official capital stock series by Statistics New Zealand, the work of Philpott (1992) provided a useful source of annual gross capital stock data. Philpott (1992) provided estimates of the stocks of two types of capital asset types (Building and Construction, and Plant and Equipment) for 22 SNA production groups for the period 1950 to 1990. The estimates were based on the “Perpetual Inventory Method” (PIM).

Since Diewert and Lawrence (1999) published their Treasury Working Paper *Measuring New Zealand's Productivity*, Statistics New Zealand has constructed an official capital stock series back as far as 1971/72. Data on the “productive” capital stock are available, which represents accumulated investment less the accumulated value of the assets retired and the loss of efficiency of those assets still operating. The official capital stock series have been developed using a perpetual inventory model and provide stock data for a number of different asset classifications. The different asset types are: residential buildings, non-residential buildings, other construction, transport equipment, plant and machinery and the intangible fixed assets of mineral exploitation and computer software. Capital stock data are also available at the industry level.

Once capital stock measures for various asset types are available, the researcher then needs to assign each of the asset types a user cost in order to form a total input index. User costs of capital are the implicit rent that the owners of capital goods ‘pay’ themselves in return for the goods services. Measuring user costs is a significant task and the reader is referred to section 5.4 of OECD (2001) and/or appendix D of Diewert and Lawrence (1999) for more details.

5.2 Labour

Accurate measurement of the labour input into the production process is essential if meaningful productivity statistics are to be produced. Information is required on both the quantity and price of labour. To measure the quantity of labour there are several possible measures. These include total employment (in an industry or economy), full-time equivalent employment and total hours worked.

It is important that in each case an adjustment is made to incorporate the labour contributions of self-employed individuals if they are not included in the data. Total employment measures the total number of people who are employed in the economic unit of interest and includes both full-time and part-time workers. Such measures will not accurately represent changes in the amount of labour used in the production process

when the number of average hours worked changes or the mix of full- and part-time employment changes.

Full-time equivalent employment is an improvement over total employment as it incorporates changes in the mix of full- and part-time employment.¹⁸ However, full-time equivalent measures will not reflect changes in average full-time employment hours. Total hours worked is the preferred labour quantity measure.¹⁹ The choice of approach to measure the quantity of labour is important. Typically the different measures result in different growth rates in the amount of labour over time. The higher the measure of labour growth, the lower the productivity measure as more of the growth in output will be accounted for by the growth in the labour input.

The Household Labour Force Survey (HLFS), Quarterly Employment Survey (QES) and Economic Survey of Manufacturing (ESM) are different survey based sources of hours data produced by Statistics New Zealand. The QES is a firm based survey and provides information of the number of hours paid. The HLFS is a private household survey and provides information on the number of actual hours worked. The QES measure of hours paid does not exclude sick leave and holidays, and is unlikely to reflect increases/decrease in the number of hours worked by salaried workers during peak/slack periods. Furthermore, the QES industry coverage is not as great as the HLFS industry coverage. The QES does not cover agriculture, hunting, and fishing industries. The QES also excludes work without pay in the family business and casual employment (eg, cash jobs, cottage industries) and geographical units with less than one full time equivalent (FTE) worker are excluded from the QES hours.²⁰

Sample surveys produced by Statistics New Zealand are redesigned periodically to ensure that the sample adequately reflects the contemporary composition of the population. Changes in sample design may result in some discontinuity in the statistical time series. The "Official" database provided to Diewert and Lawrence (1999) had HLFS and QES data from 1978. In Diewert and Lawrence (1999) the choice of which survey to use had an important influence on the measured growth of the labour input over time.

When hours worked is the quantity measure of the labour input, the corresponding price is the average hourly compensation received. To accurately reflect the cost of labour to the producer, it is important that the compensation data used includes all supplements to wages and salaries (for example, employer contributions to superannuation schemes). The OECD's Productivity Manual notes several issues that relate to the measurement of labour compensation. This includes the allocation of mixed income.

"Mixed income" is the income that accrues to unincorporated enterprises owned by members of households, ie, the self-employed. It is necessary to determine an appropriate allocation of the operating surplus of proprietors and the self-employed into labour and capital components. There are two broad approaches to doing this. The first is to assume that the average hourly compensation of a self-employed person equals that

¹⁸ That said, there is still the issue of determining what constitutes a full time employment position.

¹⁹ Setting aside differences in the quality of labour for the moment.

²⁰ In terms of actual New Zealand labour data, Diewert and Lawrence (1999) highlighted a degree of concern at some of the inconsistencies that existed in labour series that were contained in the "Official" database they received. The authors argued that "The labour data used has a significant impact on measured productivity at both the aggregate and industry levels. Improving the consistency of industry level labour series is a high priority as is improving estimates of the allocation of self employed and proprietors' operating surplus between labour and capital. We also need to assign values to different types of labour input to form more accurate labour aggregates; ie, treating all types of labour input as homogeneous can lead to significant measurement error" (Diewert and Lawrence, 1999: 158)

of the average wage or salary earner. From this an imputed wage bill can be constructed and subtracted from the operating surplus, with the residual being assigned to the capital component. The second approach involves assuming a rate of return on capital to construct a cost of capital bill that can then be subtracted from the operating surplus with the residual being assigned to the labour component.

Up until now we have not taken into account the implications of heterogeneity of the labour inputs. In other words, no allowance has been made for differences in the level of human capital for different workers. When the hours worked by different workers are treated as homogenous, productivity measures are subject to measurement error. Where the average quality of labour is changing over time it is preferable to construct quality-adjusted measures of labour input. The quality of labour has generally been increasing over time.²¹ The OECD Productivity Manual states:

When quality-adjusted measures of labour input are used in growth accounting instead of unadjusted hours worked, a larger share of output growth will be attributed to the factor 'labour' instead of the residual factor 'productivity growth'. In other words, substituting quality-adjusted labour input measures for simple ones can shift the appreciation of the sources of growth, from externalities or spill-overs captured by the productivity residual to the effects of investment in human capital.

OECD, 2001: 46

5.3 Output (GDP)

Definitions of Output

Productivity measures can be based on different definitions of output, gross output and value-added based measures. Gross output and value added can be thought of as different representations of the production process. Gross output measures the goods or services that are produced within an economic unit and that become available for use outside the unit. It represents the value of sales and net addition to inventories but does not factor out the purchase of intermediate inputs. Value added takes gross output as a starting point and deducts the purchase of intermediate inputs. The following discussion draws heavily on the OECD's Productivity Manual (2001).

Consider the following production function, which relates the maximum quantity of gross output (Q) that can be produced from all inputs.

$$Q = H(A, X, M) = A(t)F(X, M) \Rightarrow A(t) = \frac{Q}{F(X, M)} \quad (22)$$

Inputs consist of primary inputs (X) (comprising labour and capital) and intermediate inputs (M). The parameter $A(t)$ captures shifts in what the OECD calls disembodied

²¹ The treatment of training expenses is related to the measurement of human capital, as training can be thought of as an investment in human capital that benefits employers in current and future periods. Yet training costs are treated as an expense in the period in which they are incurred rather than being allocated across the years in which the benefits of training are realised.

technology. However, given Carlaw and Lipsey's critique that was discussed in Section 2.2, it is more appropriate to think of this as TFP or MFP and not technology. Consequently technological change should be thought of as the growth in MFP. To maintain consistency with the source, the terminology used by the OECD is used throughout this section, but the difference between technological change and MFP or TFP should be kept in mind. Technological change has been assumed to be 'Hicks-neutral'. One way to think of technical change is the rate at which the production function shifts over time (ie, $\frac{\partial \ln H}{\partial t}$). With Hicks-neutral technological change $\frac{\partial \ln H}{\partial t}$ equals $\frac{\partial \ln A}{\partial t}$.²² The OECD productivity manual calculated MFP growth as the difference between the growth rate of a Divisia index of output and a Divisia index of inputs. The Divisia index of inputs is made up of the logarithmic rates of change of primary and intermediate inputs, weighted by their respective shares of total input cost (denoted s_X and s_M). Consequently:

$$\% \Delta MFP_{GO} = \frac{\partial \ln H}{\partial t} = \frac{\partial \ln A}{\partial t} = \frac{\partial \ln Q}{\partial t} - s_X \frac{\partial \ln X}{\partial t} - s_M \frac{\partial \ln M}{\partial t} \quad (23)$$

where $\% \Delta MFP_{GO}$ equals the percentage growth rate in MFP based on a gross output measure of output.

Instead of defining a production function, one may define a value added function that illustrates the maximum amount of current price value added that can be produced, given a set of primary inputs and given the prices of intermediate inputs (P_M) and output (P), ie:

$$G = G(A(t), X, P_M, P) \quad (24)$$

If we define productivity change as the shift in the value added function and measure this as the difference between the growth rate of Divisia volume index of value-added and the growth rate of the Divisia index of primary inputs we can write:

$$\% \Delta MFP_{VA} = \frac{\partial \ln G}{\partial t} = \frac{\partial \ln VA}{\partial t} - \frac{\partial \ln X}{\partial t} \quad (25)$$

where $\% \Delta MFP_{VA}$ equals the percentage growth rate in MFP based on a value added measure of output.

²² When technology enters in the form $Y=Af(K,L)$ it is known as Hicks-neutral and shifts in the production function leave all the marginal rates of substitution unchanged. When technology enters in the form $Y=f(K,AL)$ it is known as labour augmenting or Harrod-neutral. If it enters in the form $Y=f(AK,L)$ it is known as capital augmenting.

There is a direct relationship between the two MFP growth measures outlined in (23) and (25), with this relationship being shown below:

$$\% \Delta MFP_{VA} = \frac{1}{s_{VA}} \% \Delta MFP_{GO} \quad (26)$$

where s_{VA} is the nominal share of value-added in gross output. As $0 \leq s_{VA} \leq 1$, MFP growth measures based on value added will be greater than MFP growth measures based on gross output.

How should these two different MFP measures be interpreted? When production technology is Hicks neutral the gross output based productivity measure is a valid representation of disembodied technical change, however this is not the case for the corresponding value added based measure. Technology change in the value-added based measure reflects the ability to translate technical change into income and into a contribution in final demand (OECD, 2001). This interpretation is dependent on equation (22) being a valid representation of the production process. If technological change only operates on primary inputs then this is no longer the case and the value-added based measure becomes the valid measure of technical change and the gross output measure loses its significance.²³ When the unit of interest, such as a firm or industry, is subject to vertical integration and outsourcing, the gross output based TFP measure is usually considered superior as this measure gives a better indication of how much extra delivery to final demand per unit of primary inputs a firm or industry generates.

Extrapolation

In order for productivity measures to be valid it is important that price and quantity indices of output are constructed independently of price and quantity indices of inputs. An example of when this independence assumption is breached is when quantity indices of outputs are based on extrapolation of input series.

From the perspective of productivity measurement, the independence of statistics on inputs and outputs is key. Input-based indicators that are used to deflate output series generate an obvious bias in productivity measures: (labour) productivity growth will either be zero by construction or will reflect any assumption about productivity growth made by statisticians. Occurrences of input-based extrapolation are concentrated in activities where market output prices are difficult to observe. This may create a case for excluding from productivity measurement those industries that are characterised by a large share of non-market producers and thereby avoiding potential biases in output measurement.

OECD, 2001: 33

This paper does not go into detail on how New Zealand output measures are constructed but it should be noted that extrapolation based on input measures is important for

²³ The hypothesis that technology affects only the primary inputs has not usually held up to empirical verification. This calls into question the validity of the value-added based productivity measure. On the other hand, the gross output formulation of technical change has also not always been supported by econometric studies (OECD, 2001).

measuring output in some industries. For example, the contribution to gross domestic product made by the government services industry involves extrapolation by an employment volume indicator.

Terms of Trade

Recent work by Kohli (2002), which examined the impact of terms of trade change on real GDP and real value added, found that real GDP tends to underestimate the increase in real value added and welfare when the terms of trade improve. Kohli found that an improvement in the terms of trade can be viewed as similar to technological progress in that it means, for a given trade balance position, a country can either import more for what it exports, or export less for what it imports. Consequently, an improvement in the terms of trade increases real income, real value added, and welfare. However, the benefits of an improvement in the terms of trade do not show up in the real GDP figures, which focuses on production per se, whereas technological progress does. Kohli notes an improvement in the terms of trade, holding all other prices constant, actually leads to a fall in real GDP due to the GDP deflator increasing.

For example, consider the case in which real GDP is constructed using a Laspeyres index and the price of imports falls (corresponding to a terms of trade increase).²⁴ Given the lower price of imports, it may be expected that the use of imports as inputs in the production process will increase. However, a Laspeyres index approach uses the earlier period's prices of imported inputs as weights meaning that the value of inputs will be higher than in some other index approaches and consequently value added will be measured as being lower. The problem with the Laspeyres index is that it is the change in prices that results in a substitution effect but that the price prior to the change is used to construct the index.

Kohli (2002) argued that:

... real GDP can be a very misleading indicator of a country's welfare in the face of changing terms of trade. It is therefore important to distinguish between real GDP, on the one hand, and real domestic income or real value added, on the other. Real GDP focuses on production possibilities, whereas real income and real value added stress consumption (or more generally absorption) possibilities and, ultimately, welfare. We show that real GDP systematically underestimates growth in real value added when the terms of trade improve. The distinction between real GDP and real value added implies differences between the corresponding price indexes. The implicit GDP deflator, which is obtained by dividing nominal GDP by real GDP, will point at higher inflation than the value-added deflator when the terms of trade improve. In fact, it turns out that a drop in the price of imports, holding all other prices constant, leads to an *increase* in the GDP deflator.

Kohli, 2002: 2

²⁴ Statistics New Zealand uses a chain weighted Laspeyres index to measure real GDP.

Table 1: International comparisons of cumulated percentage growth, 1980-1996

	Laspeyres Real GDP	Implicit Törnqvist Real GDP	Implicit Törnqvist Real value added
United States	60.1	59.4	61.5
Canada	45.4	45.0	46.0
Mexico	35.7	35.5	25.6
Japan	65.2	68.2	68.9
South Korea	265.5	272.2	277.8
Australia	61.0	61.1	62.0
New Zealand	40.6	41.5	49.4
Austria	40.8	40.9	39.8
Belgium	29.7	29.4	32.8
Denmark	38.4	39.0	38.1
Finland	36.6	37.0	42.4
France	32.5	32.0	36.2
Germany	39.8	40.5	43.9
Greece	30.2	27.5	36.8
Iceland	42.5	41.6	39.0
Ireland	106.1	111.1	105.0
Italy	32.8	31.9	37.9
Luxembourg	107.7	107.6	96.5
Netherlands	42.2	43.0	41.6
Norway	59.5	59.2	39.7
Portugal	47.3	48.7	60.0
Spain	46.5	45.7	50.8
Sweden	26.5	26.4	26.6
Switzerland	22.0	22.1	34.5
Turkey	108.3	117.4	111.3
United Kingdom	41.6	40.9	41.3

Source: Table 1 in Kohli (2002).

As shown in Table 1 Kohli found that real GDP severely underestimated growth in real value added for New Zealand, Greece, Italy, Portugal and Switzerland. These countries all experienced significant improvements in their terms of trade over the past two decades. New Zealand's cumulative growth rates in both the Laspeyres and implicit Törnqvist Real GDP figures were around 41% whereas the implicit Törnqvist Real value added growth was quite a bit higher at over 49%. Real GDP overestimated real value added growth for Mexico, Luxembourg and Norway, which experienced a deterioration in their terms of trade. In the case of New Zealand, it should be noted that most of this effect arose between 1986 and 1991. Since then there has been no discernible trend in the terms of trade.

6 Conclusions

This paper has provided a review of conceptual and methodological issues in measuring productivity. Attention was given to the concept of productivity, the relationship between TFP and technological change, and the importance of productivity measures to economists and policy makers. The paper also surveyed four approaches to measuring productivity: the growth accounting approach; the index number approach; a distance function based approach; and the econometric approach. Coverage was given to historical productivity estimates for the New Zealand economy and data issues that influence productivity measurement and research. The range of productivity estimates for the New Zealand economy reflects differences in both methodology and data, as well as the time period under consideration.

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