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# MEASURING PRODUCTIVITY GROWTH IN AUSTRALIAN BROADACRE AGRICULTURE

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**An important source of growth for Australian broadacre agriculture has been technical progress. We compare alternative measures of productivity growth including the traditional Tornqvist-Thiel total factor productivity index; variants of this approach that allow decreasing returns to scale; the Fisher ideal index; other nonparametric measures that do not impose particular functional forms and an econometric estimate from a translog industry cost function. The annual growth in productivity in broadacre agriculture over the period from 1953 to 1994 was in the range of 2.4 to 2.6 per cent and hence was quite robust to measurement technique.**

## *Introduction*

An important source of growth for Australian agriculture has been technical progress and hence one objective of publicly funded research, extension and education programs has been to enhance the rate of technical progress or productivity growth.[1] Measuring productivity growth has been an important area of economic research. Identifying sources of productivity growth in Australian agriculture has been a less fruitful area of research but in recent work, Mullen and Cox (1995) related productivity growth to public research expenditure and other variables and estimated that the rate of return to investment in research in broadacre agriculture in Australia may have been in the order of 15 to 40 per cent over the 1953 to 1988 period.

Productivity growth in Australian agriculture has usually been measured using a Tornqvist-Thiel or Christensen and Jorgenson (1970) total factor productivity (TFP) index, as the difference in the rate of growth in aggregate outputs and the rate of growth of aggregate inputs. Recent studies of this type include those by Lawrence (1980);

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1 There is a growing awareness that the role of the public sector in providing such programs should be related to 'market failure'

Lawrence and McKay (1980); Paul (1984); Paul, Abbey and Ockwell (1984); Beck, Moir, Fraser and Paul (1985); and Males *et al.* (1990). These studies used data from ABARE's surveys of rural industries. Lawrence and McKay (1980) estimated that between 1952-53 and 1976-77, productivity in the Australian sheep industry increased at an average rate of 2.9 per cent per year. Beck *et al.* (1985) estimated that average growth in productivity was 2.7 per cent per year from 1952-53 until 1982-83 with variations both between years and between climatic zones. Males *et al.* (1990), estimated that the average rate of productivity growth in broadacre agriculture continued to decline to 2.2 per cent over the 1978 to 1989 period. Using a similar dataset to Males *et al.* but one which extended to 1994, Knopke, Strappazzon and Mullen (1995) found that productivity had grown at a rate of 2.7 per cent a year. They noted significant differences between broadacre industries, climatic zones and states and found that large farms, where size was defined in terms of stocking rate, had higher rates of productivity growth than medium and small farms.

The traditional Christensen and Jorgenson (C&J) total factor productivity (TFP) index number approach is only exact under quite restrictive assumptions about the structure of technology and the nature of technical change in agriculture. At the very least it requires that the technology can be represented by a translog transformation function (Cox and Chavas, 1990) but as applied in all the studies above, it also requires constant returns to scale and neutral technical change. If these conditions do not hold then there is a danger that this measure will give a biased estimate of productivity growth. As Cox and Chavas argue (1990, p. 450): 'In the investigation of technical change, it appears desirable to develop a methodology that does not depend, as much as it is possible, on the parametric specification of the underlying technology'.

Hence there has been renewed interest in comparing the theoretical properties and empirical performance of alternative measures to the C&J TFP index. Caves, Christensen and Diewert (1982) developed adjustments to the C&J index that allowed nonconstant returns to scale. Diewert (1992) pointed out that like the C&J index, the Fisher Ideal index is superlative since it is exact for a quadratic (flexible) representation of technology. He argued that the Fisher Index could be preferred to the C&J index because of the way in which it satisfies the tests associated with both the axiomatic and economic approaches to index numbers.

The econometric approach based on cost or profit functions has been used less often to analyse these issues. Australian studies of this nature include those by McKay, Lawrence and Vlastuin (1982) and Wall and Fisher (1990). The attractions of the econometric approach are that, unlike index number and nonparametric approaches, it provides goodness of fit measures, and allows an examination of important aspects of technology such as returns to scale, the extent of bias in technical change, and the demand for inputs. One drawback is that this approach imposes a particular functional form which may not represent the technology accurately.

In a marked departure from index number approaches, Chavas and Cox (1994) developed a nonparametric measure of productivity growth which has the attraction that it does not impose a particular functional form such as the translog or the quadratic. This approach allows for fairly general multi-output, multi-input technologies, allows considerable flexibility in modelling technical change, and is relatively easy to implement empirically using standard concave programming techniques.

These alternatives to the traditional C&J TFP index have not been applied in Australian agriculture. Each of the alternative approaches has strengths and weaknesses. To the extent that these alternative approaches generate robust measures of the technology of interest, then we have greater confidence in our more traditional methods and associated results. To the extent these alternative approaches generate widely divergent measures, we are given cause to reflect further on the relative strengths and weakness of these alternatives, the data we are analysing, and the usefulness of our theory for the purposes at hand.

Hence the objective of this paper is to investigate how robust is the estimated rate of growth of productivity to the measurement technique used and to provide information about productivity growth in broadacre agriculture over the period from 1953 to 1994. Preliminary work in this area has been reported in Mullen, Strappazzon, Cox and Knopke (1995) and Strappazzon, Mullen and Cox (1995). This research indicated that productivity growth in broadacre agriculture was in the range 1.8 to 2.2 per cent for the period 1953 to 1988. This paper updates and extends this previous work using a data series extending to 1994 rather than 1988.

In the next section the data used in this study are described. Then follows a section in which the measurement of productivity is explained at a conceptual level in terms of input and output distance functions. The four approaches used to measure productivity in this study are alternative ways of making this conceptual framework operational. The approaches used include:

- traditional index number approaches such as Paasche, Laspeyres, Christensen and Jorgenson, and the Fisher Ideal indices;
- a scale adjusted version of the C&J index suggested by Caves, Christensen and Diewert (1982);
- a nonparametric measure developed by Chavas and Cox (1994);
- a measure derived from a translog cost function for broadacre agriculture.

Each approach and its results are described in succeeding sections. Finally some conclusions are drawn about productivity growth in broadacre agriculture over the period 1953 to 1994 and about the way in which productivity is measured.

## *Data*

The data used in this study were obtained from the Australian Bureau of Agricultural and Resource Economics (ABARE). The ABARE has been collecting farm survey data since 1952. In that time the target population for the surveys has been broadened from the Australian sheep industry, defined to include all farms carrying at least 200 sheep, to those engaged in broadacre agriculture in Australia, as covered by the Australian Agricultural and Grazing Industries Survey. More information about the extent of the surveys, the methodology used and the definition of variables can be found in several papers by ABARE staff (Paul, 1984; Beck, Moir, Fraser and Paul, 1985; and Knopke, 1988). Our sample was drawn from those who had more than 200 sheep to enable us to use a sample extending back to the original sheep industry surveys. One implication of defining the survey population in this way is that our sample is different from that used by Knopke, Strappazzon and Mullen (1995) in that the sample used here does not include specialist crop farmers.[2] The number of producers in the sample ranged from 600 to 700. The outputs were crop, livestock sales, wool and other outputs. The inputs were contracts, services, materials, labour, livestock purchases, use of livestock capital, use of land capital, and use of plant and structures. There were series for the value, price and quantity of these inputs and outputs[3]. Other data series available included indices for the terms of trade and pasture growth (a proxy for weather).

We have divided these data into three sub-periods—1953-68, 1969-84 and 1985-94—to examine changes in the structure of broadacre agriculture and in the rate of productivity growth. As can be seen from the accompanying graphs of productivity growth, climatic conditions have had significant but irregular impacts which have made the choice of sub-periods arbitrary but we have tried to identify years at the end of each period which seem to reflect the trend for the period. The middle period was the most variable and we chose to include both the major drought in 1983 and the recovery from this drought in the this period.

2 Knopke *et al.* (1995) found that cropping specialists had higher rates of productivity growth over their sample period than did livestock specialists.

3 Value data were always available. For inputs, quantity series were derived using ABARE price series. For outputs, in some cases quantity data were directly available and in other cases they were derived from the value and price series. In constructing indices a standard approach of deriving quantity indices from value and price series was used to ensure the price times quantity gave value.

The revenue and cost shares of the outputs and inputs for the three periods are detailed in Table 1. The middle period was characterised by a major slump in the price of wool and a consequent increase in cropping and beef enterprises (although the latter trend cannot be observed from this data in which cattle and sheep trading are aggregated). In the final period the importance of the wool industry as a source of income recovered to some degree, presumably at the expense of the beef industry as the share of income from cropping was largely unchanged. Turning to inputs, there was surprisingly little change in the shares of purchased inputs as reflected by the contracts, services and materials categories. However the share of labour, comprising both family and hired labour, declined. Livestock trading expenses also declined. The share of costs attributable to land, estimated as the market value of land times a real interest rate, doubled from the middle to the last period. While this opportunity cost approach is a standard method for valuing the flow of services from land, it has contributed to costs exceeding revenue during the last period and presumably overstates the value farm families are prepared to accept from this asset.

TABLE 1
*Revenue, Revenue and Cost Shares by Period*

| | 1953-1968 | 1969-1984 | 1984-1994 |
|---|---|---|---|
| **Revenue Shares** | | | |
| Crops | 0.20 | 0.36 | 0.34 |
| Livestock | 0.31 | 0.33 | 0.26 |
| Wool | 0.46 | 0.29 | 0.37 |
| Other | 0.03 | 0.02 | 0.03 |
| **Cost Shares** | | | |
| Contracts | 0.02 | 0.02 | 0.02 |
| Services | 0.08 | 0.09 | 0.09 |
| Materials | 0.21 | 0.24 | 0.23 |
| Labour | 0.29 | 0.25 | 0.22 |
| Livestock | 0.14 | 0.11 | 0.06 |
| Livestock use | 0.03 | 0.02 | 0.03 |
| Land use | 0.10 | 0.10 | 0.20 |
| Plant, equipment use | 0.13 | 0.18 | 0.16 |
| **Revenue per farm ($)** | 16581 | 53892 | 143197 |

### *Measures of Productivity Growth*

Index numbers have been widely used to measure productivity growth and there is now an extensive literature which demonstrates the relationship between index number approaches and economic theory.

For example, Caves, Christensen and Diewert (1982) demonstrated that the traditionally used TFP index, often referred to as the Tornqvist-Theil or the Christensen and Jorgenson (1970) total factor productivity (C&J TFP) index is exact for technology which can be represented by a translog transformation function (for which the second order coefficients are equal across time periods or firms). Diewert (1992) similarly showed that the Fisher index is exact if the underlying technology can be represented by a quadratic production function. The Laspeyres and Paasche indices are exact for linear production functions but require that inputs are used in fixed proportions. Index numbers which are exact for flexible functional forms such as the translog and quadratic are referred to by Diewert as superlative indices.

The link between theory and index number procedures has been provided by the concept of Malmquist input and output indices based on input and output distance functions (see Caves, Christensen and Diewert, 1982). Similarly, nonparametric measures of productivity such as data envelopment analysis, a primal or production function measure, and the Chavas and Cox (1994) dual measure, were derived from these concepts.

Following Chavas and Cox (1994) we start with a production function:

$$y_1 = F^T(y,x)$$

where $y_1$ is the first output, y is all other outputs and x represents inputs. For the underlying technology implied by the production possibility set T, the input distance function can be defined as:

$$(1) \qquad D_T(y,x) = \max_\delta\{\delta\text{: } F^T(y, x/\delta) \geq y_1\}$$

where $\delta$ is the radial (proportional) rescaling factor that brings the inputs, x, back to the frontier isoquant. The input distance function contains the same information as the production function and yields the frontier isoquant of a production set $IS_T(y) = \{x\text{: } D_T(y,x) = 1)\}$ (Shephard, 1970, p. 67). Hence, the input distance function completely characterises the technology T and measures the proportional (or radial) reduction in all inputs x, $\delta$, that would bring the firm to the frontier isoquant $IS_T(y)$. The input distance function has been of great interest in efficiency analysis. It is the reciprocal of the Farrell (1957) measure of technical efficiency, where $1/D_T(y,x) = 1$ corresponds to technical efficiency while $1/D_T(y,x) < 1$ identifies technical inefficiency. Similarly, $[1-1/D_T(y,x)]$ can be interpreted as the proportional reduction in production costs that can be achieved by moving to the frontier isoquant.

The output distance function comes from an input requirements function

$$x_1 = g^T(y,x)$$

where $x_1$ is the minimum amount of the first input required to produce the vector of outputs, y, given the levels of other inputs, x . From this, the output distance function can be written as:

$$(2) \quad F_T(y,x) = \min_\delta \{\delta : g^T(y/\delta, x) \leq x_1\}$$

where $\delta$ is the radial (proportional) rescaling factor that brings the outputs, y, back to the frontier production correspondences. The output distance function yields the frontier correspondence $FC_T(x) = \{y: F_T(y,x) = 1\}$ (Shephard, 1970, p. 209). It follows that $F_T(y,x)$ in (2) defines the substitution alternatives among the outputs y, given inputs x. Hence, as with the input distance function, the output distance function provides a complete characterisation of the underlying technology where $1/F_T(y,x)$ measures the proportional rescaling of all outputs, y, that would bring the firm to the frontier production correspondence $FC_T(x)$. Then, $[1/F_T(y,x) - 1]$ can be interpreted as the proportional increase in revenue that can be achieved by moving to the frontier correspondence.

Assuming that each observation is technically efficient, Caves *et al.* (1982, p. 1407) propose the input based productivity index:

$$(3) \quad IP = 1/D_T(y,x)$$

which measures the radial inflation factor for all inputs such that the inflated inputs $(IP.x) = x/D_T(y,x)$ lie on the frontier isoquant $IR_T(y)$ generated by technology T. In this context, a firm choosing (y,x) has a higher (lower) productivity than the reference technology T if $IP > 1$ $(< 1)$.

Caves *et al.* (1982, p.1402) also propose the output based productivity index:

$$(4) \quad OP = F_T(y,x)$$

which measures the radial deflation factor for all outputs by which the deflated outputs $(y/OP) = y/F_T(y,x)$ lie on the frontier correspondence $FC_T(x)$ generated by technology T. Thus, a firm choosing (y,x) has a higher (lower) productivity than the reference technology T if $OP > 1$ $(< 1)$.

Under constant returns to scale, the input and output distance functions are reciprocal to each other (Shephard, 1970, pp. 207-208) and the input based and output based productivity measures in (3) and (4), respectively, will be identical (Caves *et al.*, p. 1408).

Both index number and nonparametric approaches can be shown to be consistent with these conceptual measures of productivity. However they require further assumptions about the nature of technology in the case of index number approaches, or behavioural assumptions in the case of nonparametric approaches, to become empirically tractable.

*Index Number Measures of Productivity Growth*

Index number procedures are based on assumptions about the functional form which can be used to represent production technology. The Laspeyres and Paasche indices are based on the restrictive assumption that production is linear and inputs and outputs are used in fixed proportions. More reasonably, the Fisher Ideal index is based on a quadratic production technology and can be estimated as the geometric mean of the Laspeyres and Paasche indices as in equation 5:

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \frac{1}{2}\Sigma_j \ln\left(\frac{P_{jt-1}\cdot Y_{jt}}{P_{jt-1}\cdot Y_{jt-1}}\right)\cdot\left(\frac{P_{jt}\cdot Y_{jt}}{P_{jt}\cdot Y_{jt-1}}\right) \quad (5)$$
$$- \frac{1}{2}\Sigma_i \ln\left(\frac{W_{it-1}\cdot X_{it}}{W_{it-1}\cdot X_{it1}}\right)\cdot\left(\frac{W_{it}\cdot X_{it}}{W_{it}\cdot X_{it-1}}\right)$$

where Y and X are quantities of outputs and inputs and P and W are prices of outputs and inputs.

The traditional Christensen and Jorgenson (1970) total factor productivity (C&J TFP) index is based on the assumption that the underlying technology can be represented by a translog production function and is defined as:

$$(6) \quad \ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \frac{1}{2}\sum_j (R_{jt} + R_{jt-1}) ln\left(\frac{Y_{jt}}{Y_{jt-1}}\right) - \frac{1}{2}\sum_i (S_{it} + S_{it-1}) ln\left(\frac{X_{it}}{X_{it-1}}\right)$$

where $R_{jt}$ is the share of total revenue of product j and $S_{it}$ is the share of total costs of input i. Expressed in this form, (5) and (6) give a rate of growth of TFP which is converted to an index by setting the index to 100 in a particular year and using the growth rate from (5) and (6) to accumulate the indices.[4] These measures assume that the technology is characterised by constant returns to scale and neutral technical change.

Without knowing the true production function it is difficult to discriminate between superlative indices. Diewert (1992) advocated the Fisher Ideal index because it was the only measure to satisfy all 20 mathematical properties expected of index numbers. A critical test in the choice between the C&J and Fisher indices is what Diewert referred to as the factor reversal test (Diewert, 1992, p. 222) which states that the product of the price index and the quantity index equals the ratio of values over the periods for which the indices are constructed. The Fisher index passes this test but the C&J index does not. Hence in

4 In practice the TFP Index reported here was estimated as the ratio of Tornqvi- Theil approximations of Divisia indices of aggregate output to aggregate input which effectively are the two parts of the right hand side of (5).

constructing the C&J indices of aggregate quantities of inputs and outputs, the only way of ensuring that price times quantity equals value is to choose either direct price and implicit quantity indices or the reverse.

Allen and Diewert (1982) pointed out that when there was little variation in price and quantity ratios, this choice was of little consequence but when this was not the case, significant differences in productivity measures could arise. They suggested that if quantity ratios change more than price ratios (i.e., quantity changes are less proportional than price changes), direct price indices and implicit quantity indices be used in deriving productivity indices and vice versa when prices change more than quantities. To assist this choice they suggested regressing the log of the ratio of price (quantity) in the first period to price (quantity) in the last period against a constant. If the sum of squared residuals from the price regression was less than that from the quantity regression, that is price ratios were less variable than quantity ratios, then direct price and implicit quantity indices should be used.

In the past, the ABARE (Males *et al.*, 1990) has generally used direct price, implicit quantity indices. However in applying Allen and Diewert's test to the present data set over the period from 1953 to 1994, the residual sum of squares for input prices (6.60) was much larger than for input quantities (0.86) suggesting the use of implicit price, direct quantity indices for inputs. The residual sum of squares for the prices of outputs (0.72) was less than that for the quantities of outputs (1.18). Our approach has been to construct a C&J productivity index using a direct quantity index for inputs and an implicit quantity index for outputs, as suggested by the Allen and Diewert tests, although we found little difference between this index and one constructed using direct quantities for both inputs and outputs.

Turning to results, the preferred Fisher index grew at a rate of 2.5 per cent per year[5], reaching 289 in 1994 (Table 3). This growth came from an annual growth in outputs of 3.5 per cent offset by increased use of inputs of one per cent. In 14 years (out of 42) the index fell. The growth in outputs, inputs and productivity in the three sub-periods is detailed in Table 2. Recall that the middle period was highly variable and hence the identification of trends is subjective. Nevertheless there is some evidence that while the growth in outputs has slowed, the growth in the use in inputs has slowed even more, resulting in an increase in the rate of productivity growth.

5 The compound rate of growth was obtained by regressing the log of TFP against a time trend. The annual growth rate was obtained by subtracting one from the exponent to the coefficient of the time trend.

TABLE 2
*Average Growth in Outputs, Inputs and Productivity (Fisher Index)*

| | 1953-94 | 1953-68 | 1969-84 | 1985-94 |
|---|---|---|---|---|
| Outputs (%) | 3.5 | 4.5 | 2.4 | 2.6 |
| Inputs (%) | 1.0 | 2.5 | 0.6 | 0.1 |
| Productivity (%) | 2.5 | 2.0 | 1.8 | 2.5 |

The C&J index computed from direct input quantities and implicit output quantities (referred to as the C&J mix index in tables and figures below), tracked the Fisher index almost exactly, growing at an average rate of 2.5 per cent, and reaching 288 in 1994. On the other hand, the direct price C&J index was always greater than the preferred C&J mix index, growing to 303 in 1994. The average annual rate of growth was 2.5 per cent per year. We found that the Paasche and Laspeyres indices grew to 285 and 294 in 1994. Hence the direct price C&J index lay outside bounds provided by the Paasche and Laspeyres indices. This is one of the tests identified by Diewert (1992, p. 219) which indices should satisfy. These results suggest that if C&J productivity indices are to be used, then the choice between the direct price and direct quantity variants may be significant, particularly when the observation period is long. At the very least the tests proposed by Allen and Diewert (1982) ought to be applied as the basis of choosing between direct price and direct quantity approaches. Further, given the divergences that may arise using the C&J approach over long observations periods, the Fisher Ideal index is a safer alternative.

### *Caves, Christensen and Diewert TFP Measures*

To this point constant returns to scale has been assumed. Working with the C&J Index, Caves, Christensen and Diewert (1982) relaxed this assumption by adding a scale adjustment factor to (6). When returns to scale are not constant, output and input distance functions are not coincident. The scale adjustment factor for a C&J TFP index based on the output distance function is:

$$r = \frac{1}{2}\sum_{n}\left(S_n^1(1-\varepsilon^1)+S_n^0(1-\varepsilon^0)\right)\ln\left(\frac{X_n^1}{X_n^0}\right)$$

where $\varepsilon$ is estimated as the ratio of costs to revenue assuming profit maximization and decreasing returns to scale.[6] The scale adjustment

6 Note the inconsistencies in the definition of $\varepsilon$ on pages 1406 and 1408 of Caves *et al.* (1982). Note also that these scale adjustment factors only hold for decreasing returns to scale.

factor when the C&J TFP index is based on the input distance function is:[7]

$$R = \frac{1}{2}\sum_i [\left((\varepsilon^1)^{-1} - 1\right)R_i^1 + \left((\varepsilon^0)^{-1} - 1\right)R_i^0]\ln\left(\frac{Y_i^0}{Y_i^1}\right)$$

These scale adjustment factors were added to our C&J index (based on direct input quantity and implicit output quantity indices) to give input and output based measures. The levels of these indices were 312 and 291 in 1994, with average rates of growth of 2.6 and 2.4 per cent respectively.

Chavas and Cox (1994, p. 16) pointed out that an unresolved question is how to choose between an input-based and an output-based productivity index when technology departs from constant return to scale. Our approach has been to calculate the geometric mean of the output and input measures and this is presented in Table 3 as the CCD index. It reached 301 in 1994 and grew at the rate of 2.5 per cent. It also shadows the Fisher index very closely and the two were not distinguishable when plotted.

If broadacre agriculture was characterised by decreasing returns to scale, the output based measure of TFP would consistently exceed the input measure and (6) would understate the rate of productivity growth because it was contaminated by scale effects that offset technical progress. This was the case until 1984 but since then, a time in which expenditure has exceeded revenue, the input based measure has exceeded the output based measure.

The possibility of a period of increasing returns to scale has at least two implications. First (6) overstates the rate of productivity growth. Second Caves, Christensen and Diewert (1982) pointed out that were the industry characterised by increasing returns to scale, the scale adjustment factors above could not be computed from the data.

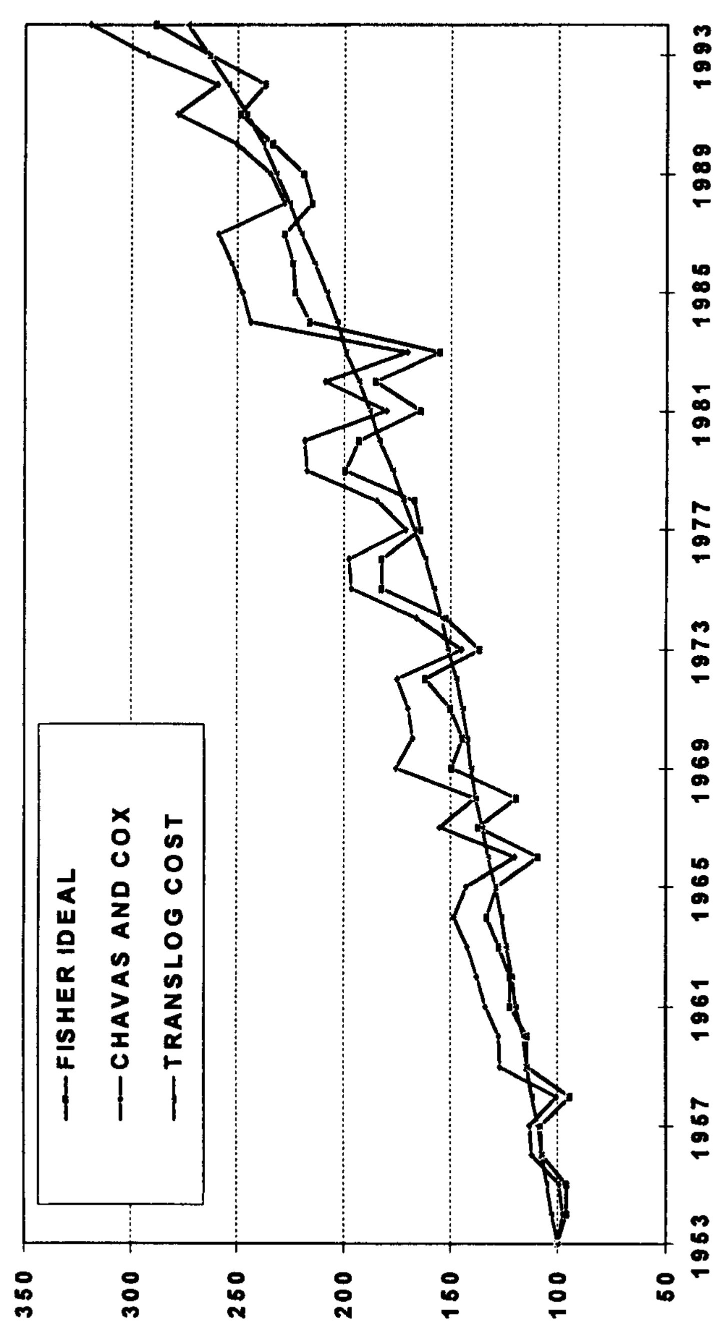
As is common with all nonparametric measures, we have no means of judging whether the output and input based productivity measures are significantly different in a statistical sense and hence we have no way of knowing whether departures from constant returns to scale are statistically significant. However, the divergences from constant returns to scale appear to have been small and average annual rates of productivity growth from the alternative measures are very similar.

### *Chavas and Cox Nonparametric Measures*

Afriat (1972), Banker and Maindiratta (1988), and Chavas and Cox (1992) have shown that productivity indices based on distance functions can be readily computed with standard nonparametric tech-

7 Again there seems to by a 'typo' in the presentation of this equation on p. 1408 of Caves *et al.* (1982).

FIGURE 1
*Comparison of Alternative Total Factor Productivity Measures for Australian Broadacre Agriculture (1953 = 100)*



niques. The attraction of these methods is that they further generalise the measurement of productivity by avoiding the imposition on the production technology of a particular functional form such as the translog. Both primal and dual approaches to representing technology nonparametrically have been developed and provide nonparametric bounds on the underlying production technology (Banker and Maindiratta, 1988).

The derivation of primal and dual nonparametric measures under profit maximization is detailed in Chavas and Cox (1994) and in Cox, Mullen and Hu (1996). We have restricted our attention to the dual measures. Chavas and Cox (1994, p. 13) concluded that in situations where there were significant variations in prices, as was the case for Australian broadacre agriculture from 1953 to 1994, the dual approach, which generates an upper bound representation of technology, may be more informative than the primal approach.[8] The primal approach is similar to the data envelope analysis approach (Zeitsch and Lawrence, 1993).

Following Chavas and Cox (1992), we allow for technical change through an additive augmentation hypothesis that defines the functional relationship between actual netputs, $x_{it}$, and 'effective netputs', $X_{it}$, as

$$(7) \quad X_{it} = x_{it} - A_{it},\ I \in N;\ t \in T,$$

where $A_{it}$ are technology indices associated with the $i^{th}$ netput and the $t^{th}$ observation, $N = \{N_O, N_I\}$ denotes the set of netputs ($N_o$ denoting outputs, $N_I$ denoting inputs), and T denotes the set of observations (years). Basically, the technology indices, $A_{it}$, in (7) 'augment' the actual quantities into effective quantities. In this context, the augmented profit maximization problem denominated in effective (versus actual) netputs becomes:

$$(8) \quad \Pi(p_t, A_t) = \max_x [p_t'(X + A_t): X \in F^e]$$

$$= p_t'A_t + \max_X [p_t'X: X \in F^e],$$

for $t \in T$ and where $A_t = (A_{1t}, \ldots, A_{nt})'$ is a (n×1) parameter vector for the $t^{th}$ observation, $p_{it} = (p_{1t}, \ldots, p_{nt})'$ is the vector of observed netput prices, and X is a (n×1) vector of effective netputs.

The production technology $F^e \subset \mathbb{R}^n$ in (8) is an 'effective technology' expressed as: $X_t \in F^e$, $X_t = (X_{1t}, \ldots, X_{nt})'$ being a (n×1) vector of effective netputs for the t-th observation. Associated with (8) is an empirically tractable, augmented Weak Axiom of Profit Maximization (i.e., the augmented counterpart to the Varian's WAPM inequalities):

8 Chavas and Cox (1994) found no evidence of technical progress when using the primal measures of productivity growth.

(9) $p_t' X_t \geq p_t' X_s$, for all s, t $\in$ T,

(9′) $p_t' [X_t - A_t] \geq p_t' [x_s - A_s]$, for all s, t $\in$ T

where $x_{it} = (x_{1t}, \ldots, x_{nt})'$ is the (nx1) vector of observed netputs at observation t. Augmentation parameters, the A's, that satisfy equation (9′) for a given data set T yield the corresponding effective netputs, $X_t = x_t - A_t$, which necessarily satisfy the WAPM condition (9) for *all* s, t $\in$ T.

We solve (9′) by minimizing the sum of $(X_{it} - x_{it})^2$, a least squares criterion, across netputs and time periods. Noting that $A_{it} = x_{it} - X_{it}$, this quadratic objective function yields augmented netputs that are as close to the actual data as possible, minimising the extent of technical change required to satisfy the augmented WAPM in (9′). Following Chavas, Aliber and Cox (1996) we also impose a form of nonregressive technical change by restricting the output augments (i.e., $A_{it}$ for $I \in N_O$) to be greater than or equal to a 5 year moving average of previous output augments. As the nonregressive technical change and augmented WAPM constraints in (9′) are linear, the resulting optimization is a standard quadratic program which we solve using GAMS/MINOS software. This solution yields augmented netputs that satisfy (9′) at every observed data point.

The associated empirical representation of the underlying augmented technology is given by

(10) $F_T^e = \{X: Pt'X \leq Pt'X_t,\ t \in T;\ X_i \geq 0 \text{ for } I \in N_0; X_i \leq 0 \text{ for } I \in N_1\}.$

Note that this recovered technology must hold for *any effective netput X*, given the augmented netputs from (9′). This provides the empirical basis for estimating technical change under the maintained behavioural and technology assumptions.

Nonparametric analysis uses programming techniques to compute the input and output distance functions which measure the extent to which the observed netputs have to be rescaled in order to reach the efficiency frontier associated with (10). In this augmented profit maximization context, the input distance function associated with this dual, upper bound representation of the technology yields an input based, radial measure of TFP. For an observed netput vector $x = (x_O, x_I)$ with associated prices $p = (p_O, p_I)$, this input based TFP measure can be obtained from the solution of the linear programming problem:

(11) $Q_I(x, A) = \min_k \{k: p_{Ot}' x_O + p_{It}' (k\, x_I) \leq p_t X_t;\ X_t = x_t - A_t;\ t \in T;\ k \in \mathbb{R}^+\}$,

where $Q_I$ is the smallest proportional rescaling of all inputs, $x_I$, that remains feasible in the production of outputs, $x_O$, under the effective technology $F_T^e$ in (10). An index $Q_I > 1$ ($< 1$) means that the netput vector $x = (x_O, x_I)$ uses a better technology (an inferior technology) compared to the reference technology represented by $F_T^e$. Note from (1), (3) and (11) that the $Q_I$ is equivalent to IP in this augmented profit maximization context.

Similarly, the dual, output based radial TFP index associated with observation x is defined as

$$(12)\quad 1/Q_O(x, A) = \max_k\{k: p_{Ot}'(k\, x_O) + p_{It}'\, x_I \le p_t X_t;\ X_t = x_t - A_t;\ t \in T;\ k \in \mathbb{R}^+\},$$

where $Q_O$ is the largest proportional rescaling of all outputs, $x_O$, that remains feasible using the inputs, $x_I$, under the effective technology $F_T^e$ in (10). An index $Q_O > 1$ ($< 1$) means that the netput vector $x = (x_O, x_I)$ uses a better technology (an inferior technology) compared to the reference technology represented by $F_t^e$. Note from (2), (4) and (12) that the $Q_O$ is equivalent to OP in this augmented profit maximization context.

The Chavas and Cox nonparametric measure for disaggregated outputs and inputs, C&C, is presented in Table 3. Since $Q_I = Q_O$ only under constant returns to scale, we use the geometric means of these two productivity measures in our results below. The level of this index reached 320 in 1994 with an average annual growth in productivity of 2.6 per cent. While the trends, variations and productivity growth rates are quite similar, the C&C TFP measure generates slightly higher productivity growth than the other measures in Table 3.[9]

TABLE 3

*Alternative Measures of Productivity Growth*

| | Fisher | C & J Mix | C & JDP | CCD | C & C | Cost |
|---|---|---|---|---|---|---|
| 1953 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1954 | 96 | 96 | 98 | 97 | 97 | 103 |
| 1955 | 96 | 96 | 98 | 96 | 97 | 105 |
| 1956 | 107 | 107 | 108 | 107 | 111 | 107 |
| 1957 | 108 | 108 | 109 | 108 | 113 | 109 |
| 1958 | 94 | 94 | 98 | 94 | 98 | 112 |
| 1959 | 114 | 114 | 120 | 115 | 123 | 114 |
| 1960 | 114 | 114 | 120 | 115 | 123 | 116 |
| 1961 | 122 | 122 | 128 | 123 | 131 | 119 |
| 1962 | 122 | 122 | 129 | 123 | 133 | 121 |
| 1963 | 127 | 127 | 134 | 127 | 137 | 124 |
| 1964 | 133 | 133 | 140 | 133 | 145 | 126 |

9 Part of this is due to the non-regressive technical change smoothing assumptions. Dropping this assumption generated lower TFP results than those in Table 3.

| | Fisher | C & J Mix | C & JDP | CCD | C & C | Cost |
|---|---|---|---|---|---|---|
| 1965 | 128 | 128 | 135 | 129 | 140 | 129 |
| 1966 | 109 | 109 | 116 | 111 | 117 | 132 |
| 1967 | 137 | 137 | 144 | 137 | 152 | 135 |
| 1968 | 119 | 118 | 125 | 119 | 131 | 138 |
| 1969 | 149 | 149 | 157 | 150 | 167 | 140 |
| 1970 | 144 | 143 | 152 | 144 | 159 | 142 |
| 1971 | 150 | 150 | 158 | 151 | 162 | 144 |
| 1972 | 162 | 162 | 171 | 162 | 170 | 147 |
| 1973 | 136 | 136 | 143 | 139 | 141 | 151 |
| 1974 | 152 | 151 | 159 | 151 | 163 | 154 |
| 1975 | 182 | 181 | 189 | 177 | 192 | 158 |
| 1976 | 182 | 182 | 189 | 177 | 192 | 162 |
| 1977 | 164 | 163 | 170 | 159 | 167 | 167 |
| 1978 | 167 | 166 | 174 | 161 | 173 | 172 |
| 1979 | 199 | 198 | 208 | 192 | 207 | 177 |
| 1980 | 193 | 193 | 202 | 187 | 208 | 183 |
| 1981 | 164 | 163 | 171 | 159 | 172 | 188 |
| 1982 | 185 | 185 | 194 | 182 | 200 | 193 |
| 1983 | 155 | 155 | 163 | 148 | 164 | 199 |
| 1984 | 216 | 215 | 226 | 216 | 234 | 203 |
| 1985 | 223 | 223 | 234 | 224 | 238 | 208 |
| 1986 | 224 | 223 | 234 | 225 | 243 | 214 |
| 1987 | 228 | 228 | 239 | 230 | 250 | 220 |
| 1988 | 215 | 215 | 225 | 216 | 220 | 226 |
| 1989 | 219 | 219 | 229 | 220 | 227 | 232 |
| 1990 | 234 | 233 | 245 | 236 | 243 | 238 |
| 1991 | 249 | 249 | 261 | 254 | 271 | 246 |
| 1992 | 237 | 236 | 247 | 238 | 253 | 255 |
| 1993 | 263 | 262 | 275 | 270 | 285 | 264 |
| 1994 | 289 | 288 | 303 | 301 | 311 | 274 |
| Average Rate | 2.5% | 2.5% | 2.5% | 2.5% | 2.6% | 2.4% |

C & J: Christensen and Jorgenson index DP: direct price
CCD: Caves, Christensen and Diewert index allowing scale adjustment
C & C: Chavas and Cox nonparametric measure
COST: Measure from translog cost model

### *Measuring Productivity Growth from a Translog Cost Model*

Econometric approaches based on cost or profit functions, such as those by McKay, Lawrence and Vlastuin (1982) and Wall and Fisher (1990) have been used to examine important aspects of technology such as returns to scale, the extent of bias in technical change, and the demand for inputs. This is not possible using index number and nonparametric approaches. A further attraction of the econometric approach is that it provides goodness of fit measures. One drawback is that this approach imposes a particular functional form.

We used a translog cost function to estimate the extent and nature of productivity growth in broadacre agriculture. The most general form of a multi-product, multi-input cost model in this context is represented as:

$$
\begin{aligned}
\ln C = \; & \alpha_0 + \Sigma_i \alpha_i \ln W_i + \frac{1}{2} \Sigma_i \Sigma_j \gamma_{ij} \ln W_i \ln W_j + \Sigma_k \beta_k \ln Q_k \\
& + \frac{1}{2} \Sigma_k \Sigma_l \beta_{kl} \ln Q_k \ln Q_l + \Sigma_i \Sigma_k \rho_{ik} \ln W_i \ln Q_k + \Sigma_r \theta_r T_r \\
& + \frac{1}{2} \Sigma_r \Sigma_s \theta_{rs} T_r T_s + \Sigma_i \Sigma_r \phi_{ir} \ln W_i T_r + \Sigma_k \Sigma_r \psi_{kr} \ln Q_k T_r \\
& + \Sigma_u \delta_u \ln Z_u + \frac{1}{2} \Sigma_u \Sigma_v \delta_{uv} \ln Z_u \ln Z_v + \Sigma_u \Sigma_i \varepsilon_{ui} \ln Z_u \ln W_i \\
& + \Sigma_u \Sigma_k \eta_{uk} \ln Z_u \ln Q_k + \Sigma_u \Sigma_r \kappa_{ur} \ln Z_u T_r
\end{aligned} \tag{13}
$$

where M products are represented by the $Q_k$ terms, prices of N variable inputs by the $W_i$ terms, quantities of H fixed inputs by the $Z_u$ terms and the technical change and weather terms by $T_1$ and $T_2$. The variable cost of production, C, is the sum of expenditures on the variable inputs. Written in this form, the cost function implies that some inputs, $Z_u$, cannot adjust to their long run equilibrium positions within one time period. A more detailed discussion of specification issues associated with this model such as nonparametric testing of alternative ways of aggregating netputs and the treatment of fixed inputs and results can be found in Mullen and Cox (1994)

Our preferred model had four outputs, six variable and two fixed inputs (land and plant and structures), with linear weather and time trend variables. The estimated system of equations included the cost equation, five input cost share equations and the four output revenue equations but not the shadow value of fixed input equations. Homogeneity in prices and symmetry were imposed but no explicit restrictions were placed on the nature of scale economies or technical change.

The estimated model did not satisfy all the conditions of a well behaved cost function. While it was monotonic with respect to outputs at all observations and with respect to input prices at the point of approximation, it was not monotonic with respect to the price of the use value of livestock capital in three years. While it was monotonic in fixed inputs at the point of approximation, it was not monotonic at all data points, particularly for land. It was concave in input prices but not convex in 'other outputs' as indicated by the significance of the estimated elasticities of input substitution and output transformation. The own price elasticity of transformation of 'other outputs' was negative which in simpler terms means that this supply curve had the wrong slope. The estimated cost function was not linearly homogenenegative which in simpler terms means that this supply curve had the wrong slope. The estimated cost function was not linearly homogeneous in input prices but this hypothesis was maintained. The hypothesis that technical change has been neutral in broadacre agriculture was rejected.

Referencing Ohta, Ball and Chambers (1982) define the rate of technical progress as:

$$(14)\quad \varepsilon_t = \partial \ln C / \partial T_1 = (\theta_1 + \Sigma_j \theta_{ij} T_j + \Sigma_i \phi_{1i} \ln W_i + \Sigma_i \psi_{1i} \ln Q_i + \Sigma_i \kappa_{1i} \ln Z_i)$$

This can be calculated at every data point but at the point of expansion reduces to $\theta_1$. Note that this measure of the rate of cost reduction is only equivalent to the production function based measure of productivity growth when the industry is characterised by constant returns to scale. Antle and Capalbo (1988 p.45) define the relationship between these two measures as being:

$$(15)\quad \partial \ln C / \partial T_1 = (\textstyle\sum_{i=1}^{m} \partial \ln C / \partial \ln Q_i) R_1 \partial \ln F / \partial T_1$$

where $R_1 \partial \ln F/\partial T$ is the primal multi-product rate of technical change. Hence the rate of cost reduction can be divided by the sum of the $\beta_k$'s (which are estimated as the fitted values of the output revenue shares in the case of a translog model) to derive the equivalent primal measure of the rate of productivity growth.

If the industry is characterised by decreasing returns to size, then the rate of cost reduction is larger than the rate of technical change (Chambers 1988, p. 215 ). At the means of the data, the annual rate of cost reduction was 2.9 per cent.[10] The industry was characterised by decreasing returns to size and hence the annual rate of technical change was 2.3 per cent. The size adjustment was largest in the 1950s and 1960s. This rate of growth was converted to an index similar to the TFP indices by setting the index to 100 in 1953 and using the growth rate of technical change to accumulate the index.[11] The average annual rate of productivity growth was 2.4 per cent. The rate of productivity growth from this restricted translog model is similar to the other measures of productivity growth even though it is a short run estimate of productivity growth.[12]

10 The reader should recall that the estimated coefficients from this model are short run elasticities and hence the extent of decreasing returns to size may not be so great in the long run.

11 The index fell as it came from a rate of cost diminution but we have rescaled it (dividing it into 10000) to get an index of similar form to the TFP indices.

12 The rate of growth from a model in which all inputs were treated as being variable was 1.8 per cent.

## *Concluding Comments*

Recent developments in the measurement of technology and productivity change have enriched the tools available to applied economists. In this paper we have set out to estimate the rate of productivity growth in Australian broadacre agriculture for the period and to examine how robust this estimate is to the technique used to measure it. We used ABARE survey data from 1953 to 1994 and our results apply to this period. The techniques we examined included:

- traditional index number approaches such as Paasche, Laspeyres, Christensen and Jorgenson, and the Fisher Ideal indices;
- a scale adjusted version of the C&J index suggested by Caves, Christensen and Diewert (1982);
- a nonparametric measure developed by Chavas and Cox(1994);
- a measure derived from a translog cost function for broadacre agriculture.

These parametric and nonparametric methodologies differed in the extent to which they imposed structure on the nature of technology relating to neutrality, returns to scale, and functional form. Each of the alternative approaches has strengths and weaknesses which we attempted to elucidate. An important drawback of all the nonparametric measures is that they do not provide goodness of fit statistics for their estimates of productivity growth. Hence we can not judge whether the differences observed above are statistically significant.

While we have no firm basis for choosing between the four broad classes of measurement technique used here, we were able to compare measures within the traditional index number class. Our results support Diewert's preference for the Fisher Ideal index. While the Christensen and Jorgenson TFP index is widely used it does not pass the factor reversal test and hence a choice is required between using direct price and direct quantity variants. Analysis of changes in prices and quantities suggested, that at least for this data set, the choice was a significant one and that an index of productivity should be based on direct quantity and implicit price indices. The fact that this choice has to be made is a strong argument for the use of the Fisher index.

While the translog cost model generated TFP measures very similar to the index number approaches, the model failed to satisfy many of the properties required of a well behaved cost function. Since the index number measures used above implicitly represent the technology by translog or quadratic functions, it seems likely that these measures also fail to meet theoretical requirements at every data point. In contrast the Chavas and Cox nonparametric TFP measure is derived from a very general multi-input, multi-output production technology that satisfies the theoretical requirements of profit maximising behaviour at every data point and imposes very little a priori structure. A key strength of this approach is that it results in TFP measures that are very 'close' to both the data and the theory. However, as with the index number approaches, statistical goodness of fit measures are not available.

For the period 1953 to 1994 the rate of productivity growth in Australian broadacre agriculture was in the range 2.4 to 2.6 per cent suggesting that this parameter is quite robust to the measurement technique used. Hence we can have greater confidence in our more traditional methods, such as the Fisher index and associated results.[13] We found evidence of biased technical change from the translog and Chavas and Cox approaches but the evidence with respect to scale economies was not clear cut. The scale elasticity estimated from the short run translog cost function indicated decreasing returns to scale. As well, the input and output distance function measures from both the Chavas and Cox and the Caves, Christensen and Diewert approaches were not equal providing little evidence of constant returns to scale. However we do not know whether these differences were statistically significant and the geometric mean of the latter measure could not be distinguished from the Fisher index.

There were 14 years in which Australian agricultural productivity declined. Much of this short term variation can be explained by weather conditions. Although cross country comparisons should be made cautiously, an average annual rate of productivity growth of 2.5 per cent is larger than those reported by Thirtle and Bottomley (1992) for UK agriculture from 1967-90 and those reported by Alston, Chalfant and Pardey (1993, p. 9) from several studies of US agriculture. Perhaps one explanation for Australia's higher rate of productivity growth is that, as noted by Alston, Chalfant and Pardey (1993, p. 14), Australia was second only to Canada of OECD countries in 1985 in the level of its research intensity (defined as the ratio of research expenditure to agricultural GDP).

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13 This conclusion needs to be qualified to the extent that over the shorter 1953 to 1988 period, Mullen *et al.* (1995) found larger divergences between these measures.

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