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MEASURING OUTPUT, INPUT AND TOTAL FACTOR PRODUCTIVITY IN AUSTRALIAN AGRICULTURE: AN INDUSTRY-LEVEL ANALYSIS

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This paper uses the growth accounting approach to estimate total factor productivity in the Australian agriculture industry between 1949 and 2012. To shed light on an unresolved debate on quantifying the roles of capital and labor, we compare the "ex-ante" and "ex-post" approaches to the estimation of returns to capital and labor, and find the former performs better than the latter in the context of the agricultural production account. We also demonstrate how the measurement of agricultural productivity may be improved by accounting for heterogeneity in output and input quality. Finally, our estimates are distinct from existing statistics in both the time length and industry coverage and provide new information about the long-term trend of agriculture productivity in Australia.

JEL Codes: C43, D24, Q18

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1. INTRODUCTION

Increasing productivity is recognized as the most important source of growth in output and income in the Australian farm sector. Regardless of estimation methods and data sources used, analysts have generally reached the consensus that, over the past five decades, a significant proportion of agricultural output expansion in Australia can be attributed to productivity growth (Mullen, 2010; Productivity Commission, 2011). Productivity growth has also been important for farmers to use natural resources efficiently and to maintain international competitiveness despite unfavorable trends in their terms of trade, adverse climate conditions, an ageing population and limitations on the supply of arable land.

The total factor productivity (TFP) index is widely used to measure agricultural productivity performance because it provides a broad indication of how efficiently farmers combine all inputs to produce outputs. To measure TFP, researchers can aggregate various agricultural outputs (i.e. crop and livestock products) into an index of total output and compare this to an index of total input (i.e. land, labor, capital, and intermediate inputs). Specifically, the ratio of

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the two indexes gives the index of TFP, and movement in the TFP index over time is a measure of productivity growth.

In the literature, two distinct approaches have been used to estimate productivity in Australia's agriculture industry. The first approach, commonly known as the "bottom-up" approach, is derived from farm level data. For example, Islam *et al*. (2014) based their estimation on the Färe-Primont index method, while Knopke *et al*. (1995); Mullen and Cox (1996) and Zhao *et al*. (2012) used the Fisher or Törnqvist indexes to estimate TFP in the Australian broadacre agriculture industry. The study by Islam *et al*. (2014) decomposes profitability into price effects and TFP growth, and further decomposes TFP growth into changes in technological progress, scale effects, and output and input mix efficiency. The studies by Knopke *et al*. (1995); Mullen and Cox (1996) and Zhao *et al*. (2012) also derive a TFP measure for the Australian broadacre and dairy industries, and link TFP growth to its drivers, such as public R&D investment, on-farm innovation and so on. Although widely used, the bottom-up approach is subject to certain limitations. Importantly, survey data are not available for all agricultural industries in Australia (such as horticulture) or for an extended historical period, hence this method cannot be used to estimate TFP for the agricultural sector as a whole, or to support analysis of long time series.

The second approach, commonly referred to as the "top-down" approach, derives productivity directly from the national accounts data. Powell (1974); the Productivity Commission (2005) and the Australian Bureau of Statistics (2007) used this approach to construct TFP estimates. In particular, the Australian Bureau of Statistics (ABS) regularly publishes two types of TFP estimates—one based on value added, and the other based on gross output. The former is available from 1986 and the latter from 1995, however both measures cover not only agriculture but also the forestry and fishing industries. Since data used in these studies are compiled from the national accounts, the estimates of TFP that are derived from them are suitable for cross-sector and cross-country comparison. However, a notable weakness of these analyses is that some of the techniques used for data compilation are out of date. For example, land quality should be accounted for when constructing the TFP measure, and the treatment of self-employed labor and intermediate inputs could be improved to allow TFP to more accurately reflect its underlying drivers. Furthermore, TFP measures obtained from these studies are available only for the most recent two and half decades. As a result, little is known about historical trends in Australian agricultural productivity.

This paper uses data from Australia's National Accounts statistics and a long-running farm survey program to derive a TFP index for the Australian agriculture industry over an extended time period—1949 to 2012.[1] Our estimation adopts techniques developed by the Economic Research Service of the US Department of Agriculture (ERS-USDA), and incorporates the most recently-

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[1] The data used in this paper were constructed based on Australian financial year that runs from 1 July to 30 June in the following year. However, in the presentation of statistics, we have adopted international convention to label the financial years in the form of calendar year. For example, unless otherwise specified, 2012 represents the period from 1 July 2012 to 30 June 2013.

developed methods for constructing the agricultural production account (Ball *et al.*, 1997; ERS-USDA, 2009).

In addition to producing an extended time series of TFP estimates for the Australian agriculture industry, this study makes three distinct contributions to the literature on estimating agricultural productivity. First, we demonstrate the feasibility of combining data from national accounts statistics and farm surveys to estimate agricultural TFP. Second, we adjust for heterogeneity in the quality of some outputs and inputs to correct biases that may arise when these are treated as homogenous. Third, we compare two approaches, namely the "ex ante" and "ex post" approaches, for defining the rates of return used when measuring the returns to capital services and labor inputs. Theoretically, the "ex ante" approach assumes that, since farmers cannot accurately predict rates of return on capital investments, their decisions are based on "expected" rates of return. In contrast, the "ex post" approach assumes that farmers have "perfect foresight" in predicting rates of return (Diewert, 2005; Oulton, 2005). While both methods are currently used in the estimation of user cost of capital assets, there are substantial practical differences between these methods, and our comparison generates novel insights that inform an ongoing debate about which method best allows the roles of capital and labor to be properly quantified.

The remainder of the paper is arranged as follows. Section 2 describes the growth accounting approach that is used to estimate agricultural TFP and its growth. Section 3 outlines the procedure for constructing outputs and inputs for the Australian agriculture industry, and contains a brief description of the data sources used. Section 4 discusses the estimates of TFP for the Australian agricultural industry, and the related changes in input and output shares. This section also discusses some potential factors underlying the observed growth in productivity. Section 5 presents robustness checks of our estimates. Conclusions are drawn in Section 6.

2. The TFP Measure and Index Number Approach

At the industry level, an agricultural TFP index (i.e. TFP^{t} in equation (1)) is generally defined as a gross output index divided by a total input index. Under strict neoclassical assumptions of Hicks-neutrality of the production technology, perfect competition and constant returns to scale, growth of the TFP index measures the rate of technological progress in the industry (Balk, 2008; OECD, 2001).

$$\mathrm{TFP}^{t}=\frac{X_{O}^{t}}{X_{I}^{t}} \tag{1}$$

where X_{O}^{t} and X_{I}^{t} are gross output and total input indexes at time t. The gross output index is measured by summing over commodities and/or commodity groups of output from agricultural production such that $X_{O}^{t}=\sum_{i} x_{Oi}^{t}$ ($i=1,\ldots,n$ types of outputs). Similarly, the total input index is a measure of all inputs such that $X_{I}^{t}=\sum_{j} x_{Ij}^{t}$ ($j=1,\ldots,m$ types of inputs).

Gross output and total input indexes can be derived using either the direct or indirect approach (OECD, 2001) and, in both cases, an index formula needs to be chosen for the aggregation. Using the direct approach, quantities of specific outputs and inputs, measured in physical units (such as tons or kilograms), are aggregated using an index formula with the corresponding prices (or values) as weights. In contrast, using the indirect approach (introduced by Jorgenson and Griliches (1967)), indexes of the average price for both gross output and total input are estimated using relevant quantities as weights. Volume indexes of output and input are then calculated by dividing the values of output and input by their corresponding average price indexes. Theoretically, the two methods are equivalent, but in practice, they may generate quite different results because most index formulas are not consistent in aggregation (Diewert, 1978).

For the indirect approach to produce meaningful and accurate productivity estimates, two conditions must be satisfied. First, data must satisfy the accounting identity whereby total value equals the price multiplied by the quantity. Second, the chosen index formula must satisfy the factor reversal condition, meaning that the index of total value must be exactly equal to the product of the price and quantity indexes at all levels of aggregation.

In existing productivity analyses, the Fisher and Törnqvist index formulas are both commonly used. Either of these indexes can be used when the form of the underlying production function is unknown, because both provide second-order approximations to arbitrary production functions (Diewert, 1976; Diewert, 1992; Jorgenson, 1986). However, only the Fisher index also satisfies the factor reversal test (Diewert, 1992).

In this study, we have chosen the indirect Fisher index also because of an important consideration. Specifically, Allen and Diewert (1981) suggested that if quantity ratios change more than price ratios, the indirect approach should be used for the measurement of productivity indexes, and vice versa. Agricultural production is influenced by highly variable climate conditions; hence the variation of quantity ratios is typically larger than that of price ratios. For these reasons, and because statistics on the prices of agricultural commodities are more readily available and more reliable than statistics on quantities, we use the Fisher index to construct average price indexes of gross output and total input such that

$$(2)\qquad P_F(p_k^{t-1},p_k^t,x_k^{t-1},x_k^t)=\left[\frac{p_k^t x_k^{t-1}}{p_k^{t-1}x_k^{t-1}}\frac{p_k^t x_k^t}{p_k^{t-1}x_k^t}\right]^{1/2}$$

where p_k^{t-1} and p_k^t are vectors of prices in time $t-1$ and t, and x_k^{t-1} and x_k^t are the corresponding vectors of quantities. $k=O,I$ represents output and input. Given total values of output and input ($\mathrm{R}_\mathrm{k}^\mathrm{t}$), the output and input indexes can be estimated using the following expression

$$(3)\qquad \mathrm{X}_\mathrm{k}^\mathrm{t}=\frac{\mathrm{R}_\mathrm{k}^\mathrm{t}}{P_F(p_k^{t-1},p_k^t,x_k^{t-1},x_k^t)}$$

Substituting equations (2) and (3) into (1) leads to the TFP estimation.

This approach was also used by the ERS-USDA (Ball, 1985; Ball *et al.*, 1997) and by Agriculture and Agri-Food Canada (Cahill and Rich, 2012).

Finally, a time series productivity index is derived by multiplying the Fisher price indexes over two adjacent periods (i.e. the index for *t-1* and *t* and that for *t* and *t+1* as illustrated in equation (2)). The resulting measure is called a "chained" index. Alternatively, the time series index can be derived by making a series of direct comparisons between period *t* and the base period. This can be achieved simply by setting *t-1* equal to 0 in equation (2). The time series calculated in this way is called a "direct" index. When measuring TFP, a "chained" index is preferred to a "direct" index for two reasons (Zhao *et al.*, 2012). First, given that the purpose of the TFP index is to measure technological progress over a long period of time, chained indexes allow a closer match between technologies in consecutive time periods than is obtainable with direct indexes, where periods might be considerably further apart. Second, the Laspeyres–Paasche spread is likely to be smaller between adjacent periods (Diewert, 1978) than the spread between periods that are a long way apart, and as a result the chained Fisher index is more likely to represent the "true" underlying technology.

3. The Agricultural Production Account

We have constructed a production account for the Australian agriculture industry using the most up-to-date international practices (Ball *et al.*, 1997; ERS-USDA, 2009). Three categories of outputs (crops, livestock and other output obtained from primary and inseparable secondary activities[2]) and four categories of inputs (capital, land, labor and intermediate inputs) define the multi-output and multi-input production system. Data used to construct the Australian agricultural production account are obtained from ABS National Accounts statistics and from farm surveys conducted by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES).

3.1. *Output*

Agricultural outputs include all commodities (such as crop and livestock products) and services that are produced by farms and/or represent returns to farming activities, net of on-farm consumption. We view on-farm consumption as an intra-sectoral transfer, and therefore net it out of both output and intermediate inputs—a similar treatment to that used by the ERS-USDA.[3]

Physical quantities of each product and service are compiled using the ABS Agricultural Census, ABARES farm surveys and the ABS National Accounts statistics. In theory, physical quantities of all crop and livestock products are estimated as the sum of "commodities sold or transferred off farms" and "net

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[2] According to SNA/FAO/Eurostat, "inseparable secondary activities" refers to activities that usually incur costs and cannot be separately observed from the "primary" activities. Examples include processing of raw agricultural commodities on farms, agricultural tourism, and provision of machine services for hire, and others.

[3] The ERS-USDA treats on-farm consumption as "inter-temporal consumption," while Eurostat treats it as "inter-branch activities." Both methods are valid but often generate different estimates of inventories.

additions to inventory". In practice, this method is only applied to livestock products in Australia. For crops, physical quantities produced are indirectly derived by multiplying yield per hectare by the area sown. Furthermore, since no statistics are available on the physical quantities of services produced by farms, volume measures, defined as the total value of those services divided by a corresponding price index, are used as substitutes.

Market prices of all crop and livestock products are collected in ABARES farm surveys, and are defined as the farmers' receipt price at the farm gate. When statistics are not available, either the unit value (defined as the sales value divided by the physical quantity sold) or an index of prices received by farmers for the same (or similar) products or services is used for imputation. The latter are derived from data collected in ABARES farm surveys.

Market prices measure the marginal value of outputs, and so the impact of taxes and subsidies need to be considered when designing the weights used for aggregating outputs. In particular, it is standard practice to exclude taxes and include subsidies in the weights (OECD, 2001). In Australia, market prices of wool and milk were previously subsidized through the wool reserve price scheme and the milk exporting scheme respectively. As such, government indirect payments have been included in the price measure used for these commodities. However, taxes levied on farmers (or subsidies provided) by federal and state governments are excluded. In Australia, these taxes/subsidies also include those related to drought support and rural adjustment scheme payments, among others.

3.2. *Intermediate Inputs*

The treatment of intermediate inputs is similar to that of outputs. Five categories of intermediate inputs have been included in the production account, namely fuel, lubricants and electricity; fertilizers, chemicals and medicine; seeds, fodder and livestock purchases; repairs and maintenance; and other materials and services.

Data describing these inputs were obtained from several sources. From 1978 to the present, the ABARES series of "Major Components of Australian Farm Costs" (ABARES, various issues) is used. For the period 1949 to 1978, statistics were obtained from ABARES' "Historical Trends in Australian Agricultural Production, Exports, Incomes and Prices: 1952 to 1978" (ABARES, 1980) and ABARES' "Australian Rural Production, Exports, Farm Income and Indexes of Prices Received and Paid by Farmers: 1949 to 1970" (ABARES, 1971). The process used to measure each category of intermediate inputs is discussed in more detail below.

Fuel, lubricants and electricity Quantities and prices of petrol, diesel, gas and electricity used for farm production are collected or derived separately, and prices are used as weights for aggregation. Quantities are sourced from ABARES' Agricultural Commodities database (ABARES, various issues), while prices are sourced from ABARES' Farm Commodity Price Survey. Where these statistics are not available, the ABARES index of prices paid by farmers for "*fuel, lubricants and electricity"* is used as a substitute. The volume is obtained by dividing expenditure on these inputs by the imputed price index.

Fertilizers, chemicals and medicines To account for differences in quality between different products and its change over time, we construct the price index for this category of inputs using commodity-level prices and quantities. A Fisher price index is estimated using prices of five major fertilizers, eight herbicides and numerous livestock medicines, with quantities used as weights. The volume measure for this category is then calculated as total expenditure divided by the price index. Where available, data on quantities and prices of individual commodities are sourced from ABARES' Agricultural Commodities database (ABARES, various issues); otherwise, ABARES' farm survey data are used for imputation.

Seed, fodder and livestock purchases This group of inputs includes purchased feed crops and seed, as well as those produced on-farm, minus changes in inventory. This treatment of seed and fodder (i.e. withdrawing on-farm consumption of crops and seed from inventory) is similar to that used by the ERS-USDA, and it is also applied to purchases and cross-farm transfers of livestock. Total expenditure on this group of inputs is obtained from ABARES' Agricultural Commodities database (ABARES, various issues), and the price index is sourced from ABARES' farm survey data. The volume is derived as total expenditure divided by the price index.

Repairs and maintenance Total expenditure on these items is obtained from ABARES' Agricultural Commodities database (ABARES, various issues). The price of the category is obtained from ABARES' farm survey data. The volume is derived as total expenditure divided by the price index.

Other materials and services Other purchased intermediate inputs include customized services, hire of plant and machinery, packaging and transportation, irrigation water purchases, among others. On average, they account for around 5 percent of total expenditure on intermediate inputs. There are no price statistics for this category, so we use the price index for all intermediate inputs as a substitute. As is the case for other intermediate inputs, the implicit quantity of this category is derived as total expenditure divided by the price index.

3.3. *Measuring the Capital Input*

A three-step procedure is employed to measure the capital input. The first step is to construct the productive capital stock for each asset type. Following ABS (2007) and Ball *et al.* (2008), total capital assets are split into three types, namely depreciable assets, land, and other non-depreciable assets. For depreciable assets, the perpetual inventory method is used to derive the productive capital stock from investment data. For land, the productive capital stock is estimated by dividing the total market value by the GDP deflator. For non-depreciable assets, total market value is divided by the price index for non-depreciable agricultural assets (ABS, 2012).

The second step is to construct rental prices (or user costs). Ball *et al.* (2008) suggest this can be done by multiplying "ex ante" rates of return by asset prices. However, in most existing studies, "ex post" rates are used instead. In this paper, we derive rental prices using both methods. The reason for doing this is to investigate differences in the estimation of capital services that arise when using "ex ante" and "ex post" rates, and to identify the circumstances when each should be used.

In the third step, total capital service flows are derived from the productive capital stocks and rental prices. Specifically, total capital service flows are defined as the sum of all individual capital services, which in turn are estimated by multiplying the productive capital stock by the relevant rental price. The total price index is aggregated from the rental rates for all types of assets, and the quantity is estimated by deflating the total capital services value by the price index.

Data on investments and purchase prices of each type of capital asset are sourced from the Australian National Accounts for the combined Agriculture, Forestry and Fishing industry. The gross output value share of agriculture in this combined sector is used to distinguish investments in the agriculture sector from those in the forestry and fishing sectors. By doing this, it is implicitly assumed that farmers' investment patterns are the same as those of individuals in the forestry and fishing sectors, and that investment in each sector is proportional to their output value shares.[4]

Capital Stock

Depreciable capital assets Depreciable assets include non-dwelling buildings and structures, plant and machinery, and transportation vehicles. Using the perpetual inventory method, we define the stock of capital at time. for each of these asset types, $K(t)$, as the sum of all past investments at the constant price, $I(t-\tau)$, weighted by the relative efficiencies of capital goods of each age τ, $S(\tau)$.

$$K(t)=\sum_{\tau=0}^{\infty} S(\tau)I(t-\tau) \tag{4}$$

To implement equation (4), the loss of efficiency or decay of investment goods (or the need for replacement of productive capacity) must be specified. Following Ball *et al.* (2008), we use a rectangular hyperbola functional form to define the decay process of investment goods such that

$$\begin{aligned} S(\tau) &= \frac{L-\tau}{L-\beta\tau} \quad \text{if } 0 \le \tau \le L \\ S(\tau) &= 0 \quad \text{if } \tau > L \end{aligned} \tag{5}$$

where L is the service life of the asset and β is the decay parameter. The aggregate decay function is thus constructed as the weighted sum of individual decay

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[4] This assumption may not be a perfect reflection of reality but is unlikely to cause major inaccuracy in our estimates for two reasons. First, agriculture accounts for the vast majority of total output from the agriculture, forestry and fishing industry (around 85.0 percent over the period 1975–2011) (ABARES, various issues). Second, investment and output are highly correlated on Australian farms. According to ABARES' farm survey data, the correlation coefficient between these variables for broadacre farms was above 0.8 between 1978 and 2013. Therefore, investment shares for the Agriculture, forestry and fishing industry are likely to be a good approximation for the agriculture industry alone.

functions, where the weights are the probabilities or frequencies of occurrence of each possible service life. Here, equation (5) provides a general model that incorporates several types of depreciation as special cases.

Each type of depreciable asset has a different service life. In this study, the average asset service lives for non-dwelling buildings and structures, plant and machinery, and transportation vehicls are assumed to be 40, 20 and 15 years respectively. These assumptions are based on the estimates of Ball *et al.* (2008), who analysed agricultural data from OECD countries between 1973 and 2002.[5] Following Ball *et al.* (2008), it is further assumed that the depreciation process is defined over a standard normal distribution truncated two standard deviations before and after the mean service life.

The decay parameter (β) is restricted to values between 0 and 1, reflecting the assumption that efficiency declines more quickly in the later years of the service life (Penson *et al.*, 1987; Romain *et al.*, 1987). Although there is limited empirical evidence to define the values of β, it is reasonable to assume that the efficiency of a capital asset declines smoothly (or continuously) over most of its service life. Furthermore, decay parameters are assumed to vary between assets. Consistent with previous studies (Ball *et al.*, 1997; Ball *et al.*, 2008), here decay parameters are set to 0.75 for non-dwelling buildings and structures, and 0.5 for other capital assets. These assumptions are the same as those used by the ABS for agriculture.

Land Compared with other capital assets, land is not homogeneous in quality across regions and can differ in its efficiency for agricultural production. To adjust for land quality differences, we have included the land area operated and the average unimproved value of land for 32 agricultural survey regions throughout Australia. Furthermore, we distinguish between land used for cropping and grazing in each region. Land area data are obtained from the ABS Agricultural Census.[6] Unimproved land values are measured as the total market value of land minus the value of buildings, structures and other improvements. Data for these variables are taken from ABARES farm surveys. Total land stock is aggregated from different land types in each region, with unit values of unimproved land used as weights. The land stock is adjusted for heterogeneity in quality using a hedonic function.[7]

Inventory and other non-depreciable assets This category of capital assets includes the opening inventory of livestock and crops, as well as the stock of other cultivated biological resources (vines, trees, etc.) and intellectual property. The number of cattle, sheep, pigs and other animals on farms are sourced from ABARES' Agricultural Commodities database (ABARES, various issues).

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[5] The assumed average service life for each type of asset used in this paper are close but not identical to those used by the ABS, which are derived from detailed asset life schedules from the Australian Taxation Office (ABS, 2007). Specifically, the ABS uses average service lives of 43–54, 17–23 and 19–21 years for non-dwelling buildings and structures, plant and machinery and transportation vehicles, respectively. The primary difference between these two sets of estimates reflects the fact that some of the ABS estimates (for example, transportation vehicles) are made for all market sectors, while the estimates used in this paper are for the agriculture sector alone.

[6] Land used as conservation reserves are excluded from the area operated.

[7] The hedonic approach that is used in our paper follows the practice used by ERS-USDA. For more details about this approach, please refer to Ball *et al.* (2008).

Implicit quantities of opening stocks of crops, other cultivated biological resources and intellectual property are obtained from ABS National Accounts statistics.

Including the stock of other cultivated biological resources and intellectual property in the capital stock is a feature specific to our estimation of agricultural productivity in Australia. Specifically, the intellectual property category includes branding/packaging of agricultural products, specific management skills, and others. According to Corrado *et al.* (2005, 2006), such intellectual properties are kinds of intangible assets which, like physical capital, make an important contribution to the growth of agricultural output. Not including these inputs would potentially introduce a bias into the productivity estimates. In the past, intangible assets were typically unaccounted for in the measure of input, and hence neglected in productivity analysis. However, the importance of these inputs has been recognized in more recent analyses of productivity (Barnes, 2010; Elnasri and Fox, 2014).

Following these developments in the literature, we include intellectual properties and the stock of other cultivated biological resources in the estimation of capital. Assets of this kind are assumed to be subject to very little depreciation (Griliches, 1988; Haskel and Wallis, 2013). We are of the view that accounting for these two types of assets constitutes a small, but noteworthy, improvement over existing methods in the measurement of agricultural productivity.

Price of Capital Services

The rental price of capital goods is derived by analysing farmers' investments. Specifically, to maintain the efficiency of productive capital, farmers make investments in their capital stock. This investment process continues as long as the net present value of revenue generated by an additional unit of capital exceeds its opportunity cost (or the purchase price).

$$P * \frac{\partial Y}{\partial K} = rW_K + r\sum_{t=1}^{\infty} W_K \frac{\partial R_t}{\partial K}(1+r)^{-t} = c \tag{6}$$

where P is the price of output, W_K is the price paid for a new unit of capital, R_t is replacement investment, r is the real discount rate and c is the rental rate of capital.

Equation (6) defines the rental price of capital in equilibrium, which consists of two components. The first term, rW_K, represents the opportunity cost associated with the initial investment. The second term, $\sum_{t=1}^{\infty} W_K \frac{\partial R_t}{\partial K}(1+r)^{-t}$, is the present value of the cost of all future replacements required to maintain the productive capacity of the capital stock.

Let F_K denote the present value of the stream of capacity depreciation per unit of capital asset (K) according to the mortality distribution m such that $F_K = \sum_{t=1}^{\infty} m_t(1+r)^{-t}$, where m_t represents the decline in efficiency, or the mortality rates for capital goods of different ages. Replacement requirements at time t, R_t, can thus be written as a weighted sum of past investment, which should always be equal to capacity depreciation. It can be shown that $\sum_{t=1}^{\infty} \frac{\partial R_t}{\partial K}(1+r)^{-t} = \sum_{t=1}^{\infty} F_K^t = \frac{F_K}{1-F_K}$, and thus the rental rate of capital assets can be written as

$$c = \frac{r W_K}{1 - F_K} \tag{7}$$

where F_K is defined by equation (6) for depreciable assets; and for land and other non-depreciable assets, F_K is zero. Equation (7) shows that the rental rate (c) depends on the rate of return (r).

The standard method for estimating the rate of return is to use an "ex post" method (Christensen and Jorgenson, 1969; Jorgenson *et al.*, 1987; Jorgenson and Griliches, 1967). In this method, the rate of return is derived using the condition that the sum of returns across all assets equals total observed profits (i.e. capital is the residual claimant). A primary assumption underlying the "ex post" method is that investors have perfect foresight—i.e. investors are able to predict the ex post rate of return with certainty before making their capital investment decisions (Oulton, 2005; Balk, 2008).

The alternative is to use the "ex ante" method, in which case the rate of return is derived from an external source, such as the financial market (Schreyer *et al.*, 2003; Schreyer, 2004,). Relative to the "ex post" method, the "ex ante" method has a weaker theoretical foundation, but tends to yield more realistic rates of return for deriving capital services across asset types and over time. Since this method does not require the assumption of perfect foresight, "ex ante" rates can be quite different to "ex post" rates, particularly in the short run.

In practice, both the "ex post" and "ex ante" methods are widely used for choosing rates of return. It is hard to decide which method is preferred, although Oulton (2005) proved that either "ex ante" or "ex post" rates could be close to the true measure under certain conditions. In this paper, we use both methods to estimate rates of return and capital services, and compare the results. Since farmers' investment behavior is more likely to be affected by expected rates of return (i.e. "ex ante" rates) than by realized rates of return (i.e. "ex post" rates), the "ex ante" estimate is considered slightly more appropriate than the "ex post" estimate, particularly in the short run. In the long run, estimates obtained from both methods are expected to converge.

To date, no consensus has been reached regarding the specification of "ex ante" rates in the literature. Ball *et al.* (1997) and Ball *et al.* (2008) suggest using the real interest rates, or the yield on AAA rated "investment grade" corporate bonds with an adjustment for inflation (or the nominal opportunity cost of invested funds), as an approximation of these rates. Although this is common practice, Andersen *et al.* (2011) argue that the use of real interest rates may disproportionally affect the estimation of rental rates for capital assets with different service lives. In particular, "assets with relatively longer (shorter) service lives are given relatively more weight in the indexing procedure when interest rates are increasing (decreasing)" (Andersen *et al.*, 2001, p. 723). Instead, they support the use of fixed interest rates (for example, 4 percent).

The difference between Ball *et al.* (1997) and Andersen *et al.* (2011) on the choice of ex ante rates can be better appreciated by considering equations (4)–(7).[8] In sum, if F_K (the present value of the stream of capacity depreciation on one unit of capital asset K) is sensitive to rates of return, then fixed rates are preferred. Otherwise, real rates are preferred. In our case, F_K (derived from equation (4)) is only affected by the average rates of return over the service life of each

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[8] More detail about the derivation is available on request.

capital asset. Thus, capital service values estimated using fixed rates will be similar to those obtained using the real rate, as long as the fixed rate is equal to the mean of real rates. Below, we estimate "ex ante" rates using real rates, and compare a range of fixed rates as a robustness check.

3.4. *Measuring Labor Inputs*

The index of total labor input is aggregated from two types of labor that are distinguished by their employment status: employed and self-employed. The separation of these two types of labor is essential, as compensation for farm operators and their family members is usually combined with farm profits, and could be quite different to the compensation paid to their hired counterparts (Powell, 1974; Zhao *et al.*, 2012). Failure to account for this issue would bias the estimated labor input index.

For each type of labor, the quantity is defined as hours worked. Specifically, the total quantity of labor used in production is estimated by multiplying the number of hired, self-employed and unpaid family laborers by the average number of hours worked by individuals in each of these groups. These data are sourced from ABARES' Agricultural Commodities database (ABARES, various issues). Differences in labor quality (as reflected in wages) are accounted for using a quality adjusted index provided by the ABS (2012). This index is estimated using Population Census Data, cross-classified by sex, age and education.[9]

Average hourly compensation for hired labor is derived by dividing the total payment to employed labor by the number of hours worked. The total payment to hired labor is sourced from statistics in the Australian National Accounts (various issues released by the Australian Bureau of Statistics. Consistent with methods used in the U.S. and Canada, this treatment includes employers' contributions to social security, as well as unemployment compensation and other supplements to wages and salaries. From a producer's point of view, these supplements should be included in the calculation of the marginal product of workers, in addition to wages and salaries.

Since data on average compensation are not directly available for self-employed and unpaid family members, we use two different approaches to impute these data, one corresponding to each of the approaches used to derive capital services. When the "ex post" method is used to determine the rate of return for capital inputs, compensation for self-employed workers is imputed from the wages of hired workers with similar demographic characteristics. This is because there is only one degree of freedom for the production account implied by the assumed zero profit condition, and this is used to derive the "ex post" rate of return to capital.[10] Conversely, when the

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[9] To account for heterogeneity in labor quality, the ABS has used the approach adopted by the U.S. Bureau of Labor Statistics (BLS) and the ERS-USDA (Ball, 1985). Underlying this approach is the neoclassical assumption that (hourly) wages equal the marginal value product, which is used as a proxy indicator for labor quality. Wage differentials between various types of labor have been used to quality-adjust the labor input. More details about the approach are provided by Reilly *et al.* (2005) and Wei *et al.* (2012).

[10] Under neoclassical assumptions and the free entry condition, profit for the whole industry is zero. When using the "ex post" method, one can derive "ex post" rates by dividing the gross value of output minus the cost of labor and intermediate inputs by the stock of capital (Diewert and Morrison, 2005; Oulton, 2005).

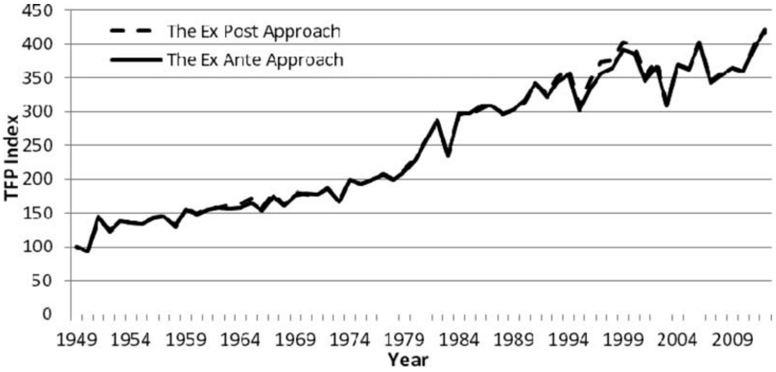

Figure 1. Agricultural TFP Index: 1949 to 2012 (1949 = 100)

"ex ante" method is used to determine the rate of return to capital, hourly compensation for self-employed workers is imputed by dividing the gross value of output less the cost of capital services and intermediate inputs by the total number of hours worked. In this case, self-employed labor is the residual claimant and therefore earns additional compensation for entrepreneurship.

4. Patterns of Agricultural Productivity and Its Underlying Sources

Agricultural productivity in Australia and its growth are estimated using both the "ex post" and "ex ante" methods for the period 1949 to 2012. Using results obtained from this estimation, we first present the pattern of productivity and its growth over time (Figures 1 and 2). The estimated capital services and labor inputs are then compared to show differences between the two methods that have been used (Figures 3–5). Finally, we decompose growth in TFP into output and input growth to provide insight into the source of productivity growth.

Figure 2. TFP Growth Over Six Decade-Long Sub-Periods

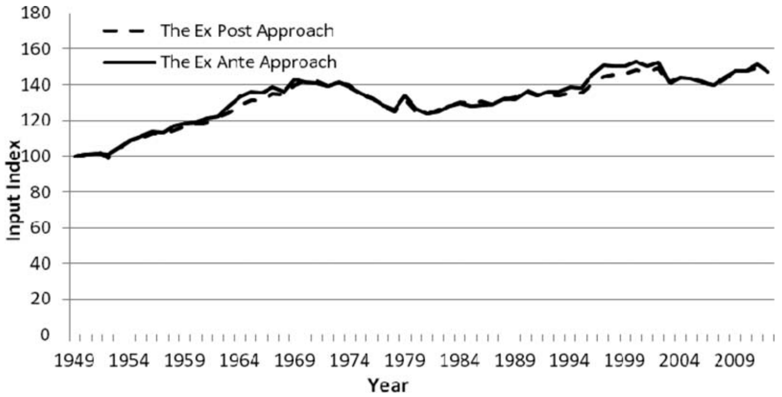

Figure 3. Aggregate Input Indexes, 1949 to 2012 (1949 = 100): Comparison between the "Ex Ante" and "Ex Post" Methods

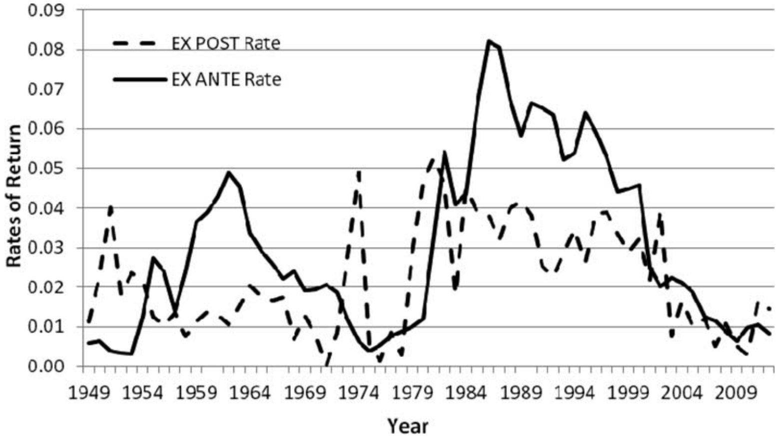

Figure 4. Comparison of "Ex Post" and "Ex Ante" Rates

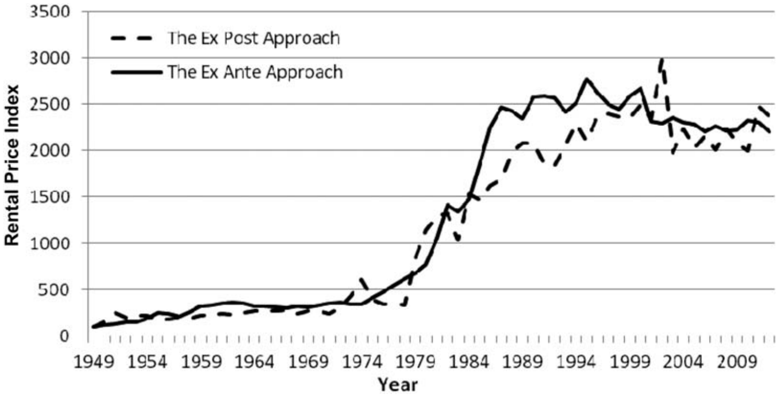

Figure 5. Comparison of Rental Prices Index of Capital Service (1949 = 100)

TABLE 1

Decomposition of TFP Growth, 1949–2012: Output and Intermediate Inputs

	1949–2012		1949–1980		1980–2012	
	Growth Rate	Share (%)	Growth Rate	Share (%)	Growth Rate	Share (%)
Total Factor Productivity Index	2.13	-	1.99	-	1.25	-
Gross Output Growth	2.61	100	3.01	100	1.81	100
Crops	3.97	44.4	4.10	35.8	2.16	53.0
Grains	3.23	25.8	4.31	21.8	−0.05	29.6
Oilseeds	7.37	0.8	12.36	0.4	6.78	1.3
Vegetables and melons	4.73	5.3	3.78	3.9	6.65	6.8
Fruits and nuts	2.03	4.9	1.99	4.3	3.52	5.2
Cotton, tobacco and other horticulture	4.78	2.8	3.85	0.9	7.22	5.2
Other crops	1.20	4.8	4.5	4.4	1.15	4.9
Livestock	1.43	53.4	2.35	61.9	1.29	44.9
Red meat	2.45	22.1	3.02	30.5	2.35	15.1
Poultry	5.92	2.7	6.15	4.5	5.83	1.2
Egg	0.89	2.0	0.55	1.6	3.91	2.2
Wool	−0.26	17.1	1.51	14.2	−1.05	18.5
Milk and dairy products	0.94	9.3	0.46	10.8	3.23	7.8
Other livestock products	0.81	0.2	0.33	0.2	3.13	0.1
Other output	3.79	2.2	3.75	2.3	3.78	2.2
Intermediate Inputs	0.89	42.7	1.99	46.0	1.46	39.3
Fuel, lubricants and electricity	0.01	4.3	2.51	4.4	0.65	4.1
Fertilizer	0.82	4.1	3.32	4.2	2.33	3.9
Chemicals and medicine	4.20	2.4	3.64	1.8	4.21	2.9
Seeds, fodder and livestock purchases	1.36	8.8	2.72	9.6	2.41	8.1
Marketing and packaging	0.00	8.9	1.27	11.0	0.40	7.1
Repairs and maintenance	1.50	5.7	1.86	6.0	2.65	5.3
Plant hire	0.47	1.6	2.35	2.1	3.46	1.2
Other materials and services	0.45	6.9	0.59	7.0	0.39	6.6

4.1. *Agricultural TFP and Its Growth*

Australian agriculture has experienced rapid productivity growth over the past six and a half decades (Figure 1). By our estimation, the long-term growth rate of TFP is 2.1 percent a year between 1949 and 2012 (Table 1), after smoothing year-to-year fluctuations by regressing the logarithm of TFP against time. This rapid growth in TFP is associated with significant output growth (2.6 percent a year) that outstripped input growth (0.5 percent a year).

Relative to the long-term trend, short-term productivity growth in Australian agriculture was also strong until the 1980s. When the whole period is split (arbitrarily) into six decade-long sub periods, productivity growth rates are positive in all periods.[11] Furthermore, the average annual rate of growth exceeds (or is close to) 2.0 percent a year in four out of the six periods (Figure 2). This result is consistent regardless of whether the "ex ante" or "ex post" method is used to estimate capital services (Table 2).

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[11] In this paper, we depict productivity growth rates by decade. This is because Australian agricultural productivity growth is influenced more by weather and climate conditions rather than business cycles (Sheng *et al.*, 2011). This makes it difficult to derive useful information from the standard, business-cycle based analysis.

TABLE 2
Decomposition of TFP Growth, 1949–2012: Land, Capital and Labor

	The EX ANTE Approach		The EX POST Approach	
	Growth Rate	Share (%)	Growth Rate	Share (%)
Time Period: 1949–2012				
Total Factor Productivity Index	2.13	-	2.13	-
Gross Input Growth	0.48	100	0.48	100
Land	−0.19	8.9	−0.21	6.4
Capital	2.45	19.7	1.77	25.3
Non-dwelling building and structures	3.29	28.4	1.60	46.7
Plant and machinery	2.32	53	2.08	39.2
Transportation vehicles	1.54	17.5	1.46	9.4
Others	1.57	1.1	1.54	4.7
Labor	−1.28	28.6	−1.31	25.6
Hired labor	−0.7	42	−0.7	38.9
Self-employed labor	−1.7	58	−1.7	61.1
Time Period: 1949–1980				
Total Factor Productivity Index	1.99	-	1.99	-
Gross Input Growth	1.02		1.02	
Land	0.89	7.3	0.15	5.7
Capital	3.54	13.8	2.61	19.9
Non-dwelling building and structures	4.82	3.3	2.85	8.4
Plant and machinery	3.59	7.5	2.63	7.9
Transportation vehicles	1.95	2.8	1.75	2.1
Others	2.10	0.2	1.62	1.4
Labor	−1.38	32.9	−1.50	28.4
Hired labor	−1.9	11.6	−1.9	10.0
Self-employed labor	−1.09	21.3	−1.28	18.4
Time Period: 1980–2012				
Total Factor Productivity Index	1.24	-	1.26	-
Gross Input Growth	0.57		0.55	
Land	−0.68	10.3	−0.63	7.1
Capital	1.55	25.4	1.11	30.9
Non-dwelling building and structures	1.35	8.3	0.69	15.8
Plant and machinery	0.63	13.1	0.32	11.9
Transportation vehicles	0.51	3.8	0.21	2.5
Others	0.35	0.2	0.13	0.7
Labor	−1.30	25.0	−1.40	22.7
Hired labor	0.67	10.0	0.70	8.9
Self-employed labor	−2.6	15.0	−2.77	13.8

However, a significant slow-down in productivity growth occurred in the most recent decade. Between 2000 and 2012, the annual growth rate of agricultural TFP is 0.6 percent a year using the "ex post" method and 0.8 percent a year using the "ex ante" method. This is much lower than the annual average over the remaining sub-periods, namely 2.4 percent a year and 2.3 percent a year respectively. This phenomenon has been observed in previous studies, and some potential reasons for the slow-down have been investigated (World Bank, 2007; Sheng *et al.*, 2011).

The estimated TFP indexes obtained using the "ex post" and "ex ante" methods closely track each other over time, and generate similar productivity growth rates for the whole period. However, in each of the sub-period comparisons, differences in TFP growth estimates obtained using the two methods are apparent.[12] In particular, notable differences between the aggregate input indexes mainly occur in two time periods: the early 1960s and the 1990s (Figure 3). In both periods, the input series obtained when using the "ex post" method is smaller than that obtained when using the "ex ante" method, and therefore the TFP estimate is higher when using the "ex post" method. Since the "ex post" and "ex ante" methods differ only in the treatment of capital services (including land) and labor, estimates of these inputs are responsible for the disparity between the aggregate TFP indexes.

4.2. *Capital Services and Labor Inputs: the Ex Post vs. the Ex Ante Approaches*

The "ex post" and "ex ante" methods may generate different estimates of both the capital services and labor inputs. To ensure that TFP estimates are robust, we first compare the different estimates of capital services, and then consider the corresponding labor estimates.

Comparison of Capital Services

The estimate of capital services depends on the productive capital stock and the rental price. They are both sensitive to rates of return, and so our discussion starts with a comparison of these rates when using the "ex post" and "ex ante" methods (Figure 4).[13]

Over the period from 1949 to 2012, the average rates of return estimated using the "ex post" and "ex ante" methods are 2.2 percent and 3.0 percent respectively. Differences between these two rates primarily occur in two time periods—the early 1960s and the late 1980s—when the "ex ante" rate is significantly higher than the "ex post" rate. A possible explanation for this is that "money illusion" (Oulton, 2005), resulting from strong inflation over these two periods (in particular, the early 1980s) drove expected rates of return higher than realized rates. In this circumstance, the perfect foresight assumption is obviously invalid, and the "ex ante" method is therefore more suitable than the "ex post" method. Specifically, rental prices of capital services that are estimated using "ex ante" rates are closer to the true measure, and are higher than those estimated using "ex post" rates, particularly in the short run (Figure 5).

Overall, rental prices of capital services estimated using "ex post" rates grew at 5.3 percent a year from 1949 to 2012, slightly slower than rental prices obtained using "ex ante" rates, namely 5.4 percent a year. Moreover, during the 1980s, the gap was more significant, with rental prices estimated using "ex ante" rates around 20 percent higher (on average) than those obtained using "ex post" rates. Over the same period of time, a significant gap between the two indexes of capital services emerged (Figure 6), primarily reflecting this difference between the "ex ante" and "ex post" rates of return.

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[12] The magnitude of the difference that exists in each period depends on the start and end point of the sub-period.

[13] The rental rates and capital service estimates for each class of asset that are obtained when using the "ex post" and "ex ante" methods are available on request.

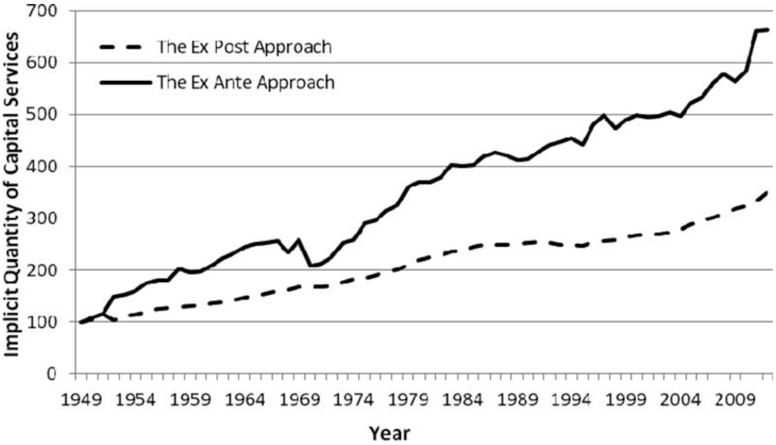

Figure 6. Comparison of Capital Services (1949 = 100)

To extend our comparison of rental prices to the estimated quantities of capital services, the effects of different rates of return on farmers' investments also need to be considered. As shown in equation (7), higher rental prices reflect a greater willingness to make investments to replace obsolete assets. This implies that when the "ex ante" method is used, realized investment will be greater than that predicted by the "ex post" method, because the "ex post" method generally underestimates rates of return relative to the "ex ante" method. As such, it is not surprising to see that capital services estimated using the "ex ante" method increase more quickly than those obtained when using the "ex post" method. Specifically, capital services grew at 2.4 percent a year from 1949 to 2012 when using the "ex ante" method, compared with 1.8 percent a year when using the "ex post" method (Figure 6).

In sum, relative to the "ex ante" method, the "ex post" method generally overestimates TFP growth by underestimating capital services, particularly in the short run.

Comparison of Labor Inputs

Corresponding to each of the methods used to estimate capital services, two different methods have been used to estimate the labor input in this analysis. The two methods differ only in the treatment of the user costs of self-employed workers, since other components of the labor input—namely the quantities of hired and self-employed labor used, and the prices of hired workers—are equal. As noted in Section 3, when the "ex post" method is used in the estimation of capital services, the per-hour user cost of self-employed workers is imputed from that of hired workers. Conversely, when the "ex ante" method is used, the average user cost of self-employed workers is estimated by dividing the residual of total output value less the value of capital, intermediate inputs and hired labor by the total number of hours worked by self-employed workers.

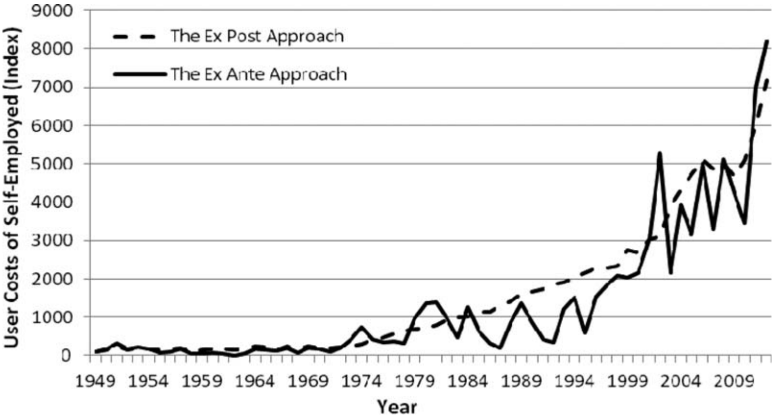

Figure 7. User Costs of Self-Employed Workers (1949 = 100)

Of these two sets of estimates, the per-hour user cost of self-employed workers obtained using the "ex ante" method is slightly higher in the long run (Figure 7). Specifically, although the "ex ante" per-hour user cost of self-employed workers was lower than the "ex post" estimate for most of the time between 1973 and 2010, it accelerated in the most recent decade, and overtook the "ex post" measure in 2010. Overall, the "ex ante" estimate grew at 7.2 percent a year from 1949 to 2012, slightly faster than the "ex-post" estimate which grew at 7.0 percent a year. The difference in the growth of the two estimates, to some extent, reflects the fact that, in the long run, farm owners and their family members obtain compensation for their entrepreneurship in addition to payment for their labor input.

Moreover, the per-hour user cost of self-employed workers is more variable over time when the "ex ante" method is used than when the "ex post" method is used (Figure 7). Specifically, the standard deviation of the series obtained when the "ex ante" method is used is 0.7 over the period 1949–2012, much higher than that associated with the "ex ante" method, namely 0.3. In particular, throughout the 1980s, the estimates derived from the "ex ante" method are consistently more variable than the "ex post" estimates. Volatility in the short-run return to farm owners' labor is consistent with the observed behavior of farm owners in Australia. Specifically, in the event of external shocks (such as unexpected changes in climate conditions and prices), farm owners can choose to forego compensation for their labor input in the short run, in exchange for a higher rate of return on capital in the long run.

Differences between these methods in the per-hour user cost of self-employed workers (Figure 8) do not significantly affect estimates of aggregate labor inputs (Figure 9). Specifically, despite short-term differences in the price of the aggregate labor input, the aggregate labor input quantity declines by 1.3 percent a year from 1949 to 2012 regardless of which method is used.

Finally, it is interesting to note that both estimates show the labor input provided by self-employed workers declined at 1.7 percent a year, much faster than the 0.7 percent a year decline for hired workers. This suggests that, in relative

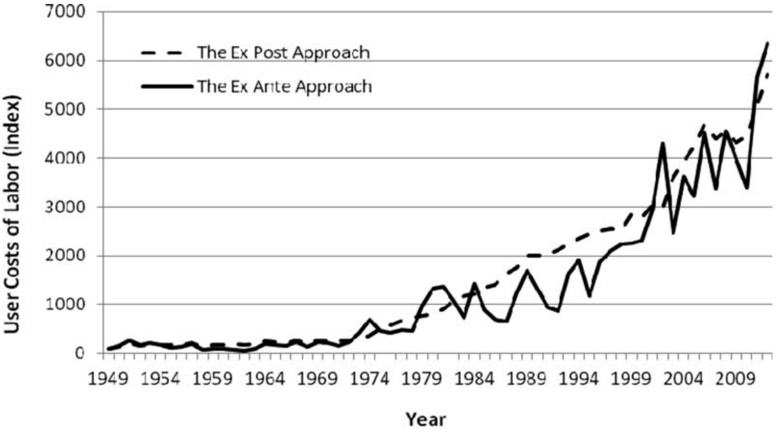

Figure 8. The Price of Aggregate Labor Inputs (1949 = 100)

terms, there has been a shift away from self-employed to hired labor in Australia's agricultural industry, although the total labor input has been steadily declining over time (Figure 10).

4.3. *Decomposition Analysis of Output and Input*

As discussed in Section 2, productivity growth can be defined as the change in output divided by change in input. This section decomposes productivity growth into the growth in output and the growth in input, and examines the patterns they have followed over an extended period of time. Three observations are discussed below:

First, rapid growth in gross output over the past six decades was primarily a result of expansion in crop production (Table 1). Between 1949 and 2012, total crop production grew by 4.0 percent a year, accounting for more than 70 percent

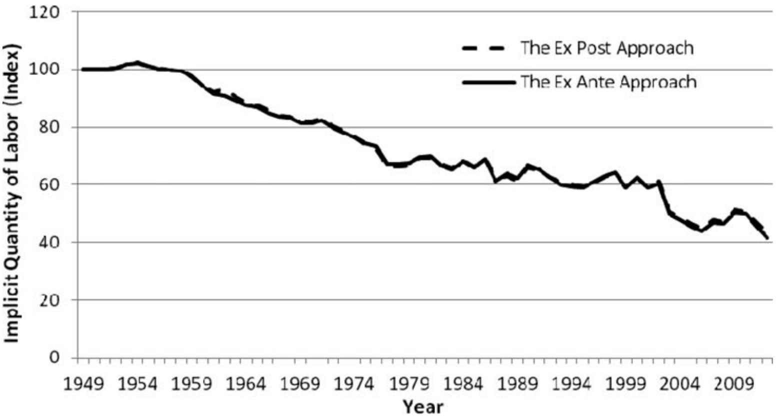

Figure 9. The Quantity of Aggregate Labor Inputs (1949 = 100)

Figure 10. Labor Inputs of Hired Worker and Self-Employed (1949 = 100)

of gross output growth. In contrast, livestock production grew relatively slowly, at an average annual rate of 1.4 percent a year. As a result, the proportion of crop products in total output increased from 36 percent to 53 percent between 1949 and 2012. Although the precise reasons for this change in output structure are unclear, it can nevertheless be envisaged that changes in both relative prices and productivity growth could be important (Diewert and Morrison, 1986). The former is likely to have been more influential in the short term, while the latter could be a key determinant in the long term. In Australia's agriculture industry, productivity in the cropping sector has outgrown livestock sector productivity since the 1970s. This is partly because production cycles in cropping are longer than those in the livestock industries, and thus livestock producers have relatively fewer opportunities to adopt capital intensive technologies (Lawrence and McKay, 1980; Mullen, 2007).

Secondly, agricultural productivity growth over the past six decades has been associated with a significant increase in the capital-labor ratio. This phenomenon is reflected in the increasing share of capital in total input relative to that of labor (Table 2). In particular, service flows from "non-dwelling buildings and structures" and "plant and machinery" have increased at an annual growth rate of close to 2.0 percent a year, while service flows from "transportation vehicles" increased by around 1.5 percent a year. Overall, capital services increased at an average annual growth rate of 2.5 percent a year between 1949 and 2012, while the labor input decreased at an average rate of 1.3 percent a year over the same period (mainly due to the decline in the use of self-employed labor). As a result of these changes, capital intensity has increased considerably over the past six decades.

Thirdly, there was a significant change in the composition of this input category between 1949 and 2012 (Table 1). In particular, although the use of intermediate inputs increased at 0.9 percent a year, a much lower rate than that of capital services, growth differed considerably between specific intermediate inputs. For example, growth of "crop chemicals and livestock medicines", "seed and fodder"

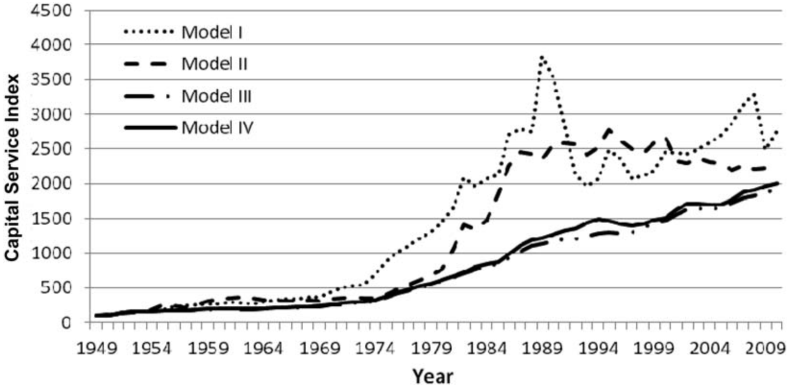

Figure 11. Comparison of Capital Services Estimated Using Different “Ex Ante” Rates (1949 = 100)

Note: Model I, II and III use the nominal interest rate, the smoothed real interest rate and a fixed rate of return (i.e. 4 percent a year) to approximate the “ex ante” rate respectively to estimate capital services. Model IV uses a real interest rate which has the mean equal to the fixed rate.

and “repair and maintenance services” was considerably greater than that of other intermediate inputs. Although the relationship between industry-level productivity growth and changes in the mix of intermediate inputs is not well understood, the phenomenon is consistent with the findings obtained from some previous studies. For example, as Sheng *et al*. (2016) demonstrated, substitution of certain types of intermediate inputs (such as pesticides and herbicides) for labor and capital is strongly associated with farming innovation, and can magnify technological progress.

5. Robustness Check

Using different “ex ante” rates may generate different estimates of aggregate capital services, since each capital asset may have its own service life (Anderson *et al*., 2011). To check the robustness of our estimates, we compare the values of total capital services that are obtained by aggregating service flows from three assets (non-dwelling buildings and structures, plant and machinery and transportation vehicles) with different service lives. Specifically, we compare three scenarios which differ only in the rate of return used: a nominal rate (i.e. the yield of AAA rated corporate bonds), the real rate (i.e. the nominal rate adjusted for inflation) and 4 percent fixed “ex ante” rate of return as used in Anderson *et al*. (2012). These scenarios are respectively labeled as Models I, II and III in Figure 11.

The results suggest that the estimated capital services have similar growth rates when using the nominal (Model I) and real rates of return (Model II), but these appear to be different from the growth rate obtained when the fixed “ex ante” rate of return is used (Model III). To gain further insight into the disparity between these estimates, we construct another scenario (Model IV) which assumes an average 4 percent real rate of return over the whole period, but retains the pattern of year-to-year variation of the real rate (Model II). The results of this model are similar to those of Model III, suggesting that capital service estimates are more sensitive to the long-term average of the rate of return than to short-term variability in this rate.

6. Concluding Remarks

This paper provides a measure of TFP for the Australian agriculture industry over the past six and a half decades. It adopts growth accounting methods, and demonstrates the feasibility of using the data from the National Accounts and farm survey data to construct a TFP measure for the agriculture industry. It shows how to improve the current measurement of TFP by making adjustments to control for heterogeneity in the quality of various outputs and inputs. This study also advances the debate on measuring TFP, by applying and comparing the "ex ante" and "ex post" methods for estimating the capital services and labor inputs.

We show that from 1949 to 2012, agricultural TFP growth in Australia was rapid, at an average growth rate of 2.1 percent a year. Moreover, our analysis of the patterns of output and input growth suggests that productivity growth was characterized by a strong output expansion and moderate input growth. Productivity growth was also associated with changes in the output mix, and by the substitution of capital and intermediate inputs for labor and, to a lesser extent, by substitution of intermediate inputs for capital. The change in output mix is a reflection of structural changes in the agricultural industry (namely a shift towards cropping), while changes in the input mix are considered to be the result of innovation and technological progress in the farming industry. The latter could be induced by changes in the relative prices of labor, capital and intermediate inputs (Hayami and Rutten, 1970) and could have been made possible by the substitution between these inputs (Sheng *et al*., 2016).

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