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Comparing agricultural total factor productivity between Australia, Canada and the United States

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Abstract

This paper compares Australian agricultural productivity with that of Canada and the United States for the period 1961 to 2006. Using a growth accounting approach, we develop a production account for agriculture to derive input and output price indexes, adjusted for purchasing power parity and to enable estimation of consistent agricultural total factor productivity index numbers between countries. In contrast to previous studies, both the level and growth rate of agricultural productivity are compared. While Australian agricultural productivity remains below that of Canada and the United States, it has been maintained relative to the United States and has improved relative to Canada. We also consider possible drivers of productivity differences across countries and implications for the international competitiveness of Australian agriculture.

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1 Introduction

Growth in agricultural production throughout the world has been unprecedented over the past half century, driven by the significantly increased food demand of a growing population. On the back of the green revolution, global agricultural production has more than tripled since the early 1960s. As well, productivity growth played an important role; its contribution to agricultural output growth increased to more than three-quarters by the 2000s (Fuglie & Wang 2012).

Possessing relatively abundant capital and land, Australia, Canada and the United States have been lead adopters, among developed countries, of labour-augmenting technologies. These countries achieve the highest output per worker, compared with the developed economies of Japan, South Korea and Taiwan which have achieved the highest yields (Fuglie & Wang 2012). However, recent evidence suggests yield (Alston et al. 2010b; World Bank 2007) and total factor productivity (TFP) growth (Sheng et al. 2011b) are slowing in some agricultural industries in some developed countries. This, in turn, has raised concerns about the sustainability of labour-augmenting technological progress.

This paper develops a method to estimate agricultural TFP consistently between countries. It presents a comprehensive comparison of output, input and TFP levels in Australia, Canada and the United States and their changes over time for the period 1961 to 2006. These countries possess well-developed agricultural production systems, but have realised different productivity levels and growth patterns. Comparing productivity between these countries can be useful in understanding how productivity growth can be improved.

In contrast to previous literature (such as Fuglie 2010), this paper gathers price information from individual countries to allow use of conventional index methods, whereby revenue and cost shares are used as weights in input and output aggregation. As well, the accounting identity (where total output value equals total input value) is used to derive unobserved returns to labour, enforcing the assumption of constant returns to scale. In addition, a quality adjustment has been applied to land and some intermediate inputs among all three countries in order to eliminate the unfavourable impact of embodied technological progress on productivity estimation.

The results show that Australian agriculture has experienced rapid productivity growth over four decades, which has improved Australia's productivity level relative to Canada and maintained it relative to the United States in the long run.

Despite obvious differences, some common drivers of agricultural productivity levels and growth rates between the three countries are evident. Supportive evidence is found for two hypotheses. First, all three countries have experienced capital deepening as a consequence of technological progress. In particular, significant technological progress has been embodied in capital investment and intermediate input use (Mundlak 2005). Second, there is strong correlation between average farm size and aggregate agricultural productivity level, possibly related to more efficient resource allocation. Agricultural research and development (R&D) investment and associated international spill-ins are also likely to be important drivers behind the productivity trends observed for Australia, Canada and the United States.

This paper also uses relative output price estimates to show that the competitiveness of Australian agriculture has declined relative to the United States and Canada. Although agricultural productivity growth has helped offset rising input costs in Australia, particularly for labour and intermediate inputs, Australia's international competitiveness has weakened relative to the United States and Canada, due to increasing relative input prices and a recent slowdown in productivity growth.

2 Literature review of method and data

The growth accounting-based index number method is one of the most popular approaches for estimating agricultural TFP, due to its simplicity and flexibility in modelling the multi-output and multi-input production process. The method, based on Christensen and Jorgenson (1970), Diewert (1976; 1978) and Caves et al. (1982), employs a 'superlative' index (typically, a Fisher or Törnqvist index, which provides a second-order approximation to any arbitrary linear homogenous production function) to aggregate output and input quantities using revenue and cost shares as corresponding weights. The ratio of aggregate output over aggregate input is used to measure TFP and the difference between output growth and input growth is used to measure TFP growth.

While several individual country studies have used these index number methods to estimate agricultural productivity (Ball 1985; Ball et al. 1997b; Fuglie et al. 2012; Jorgenson et al. 1987; OECD 2001), international comparisons remain challenging. Obtaining the data needed for cross-country comparisons remains the most problematic issue, with some economists warning of 'insurmountable data constraints' in producing a detailed commodity dataset for agriculture across countries (Craig et al. 1997; Fuglie et al. 2012). Where established datasets are available, differences in the treatment of variables limit comparability of input and output panel data (Capalbo et al. 1990).

Given these limitations, most cross-country comparisons have drawn on Food and Agriculture Organization (FAO) data. Despite a lack of price information and incomplete input coverage, the FAO dataset covers many countries over a long term. For example, Craig et al. (1994 and 1997) estimated agricultural land and labour productivity for 98 countries between 1961 and 1990 and found that input mix, input quality and public infrastructure were significant factors explaining agricultural productivity growth differences between countries. While such partial productivity measures are likely to overstate the overall efficiency improvements (because they do not account for changes in capital and intermediate inputs), they provide some indication of factor-saving technical change (Fuglie 2010).

Coelli and Rao (2005) used FAO data to compare agricultural TFP for 93 countries between 1980 and 2000 using a Malmqvist index and data envelopment analysis (DEA). The Malmqvist index method allows inputs and outputs to be aggregated through a distance function, without the need for price data. The results find that agricultural TFP growth was strong across all countries before 2000, with some evidence of catch-up between low and high performing countries.

Later, Ludena et al. (2007) revisited the Malmqvist index method to estimate TFP growth for disaggregated agriculture subsectors (crops, ruminant, and non-ruminant livestock) for 116 countries between 1961 and 2006. The study found TFP growth convergence between developing and developed countries for crop and non-ruminant production activities, yet divergence in ruminant sectors.

While the Malmqvist index method has some advantages, such as countries are not necessarily assumed to share identical production technologies, it also has disadvantages. In particular, it is sensitive to the set of countries compared and the number of variables in the model (Lusigi & Thirtle 1997). Without a large cross-section of countries, TFP estimates are likely to suffer from measurement error. Also, estimates from Malmqvist index numbers often seem implausible (Coelli & Rao 2005; Headey et al. 2010), possibly because of the unrealistic implicit shadow prices derived for aggregation (Coelli & Rao 2005).

Wherever reliable price data are available, 'superlative' index methods are preferred. Superlative index numbers are most widely adopted by national statistical agencies and are recommended by the OECD (2001) for periodic productivity statistics. Fuglie (2010) used a Törnqvist index to estimate and compare agricultural TFP growth for 171 countries. While FAO data were employed, these were augmented using a fixed set of average global prices from Rao et al. (2002) for revenue shares and using input elasticities from country-level case studies for cost shares. At an aggregate global level, Fuglie (2010) found that global agricultural TFP growth had accelerated in recent decades, particularly among developing countries such as China and Brazil. This contrasts with recent estimates of yield and labour productivity which find a global slowdown (Alston et al. 2009; 2010b).

To address the data challenges facing international comparisons of agricultural productivity, Ball et al. (1997a; 2001; 2010) developed an internationally consistent production account system for collecting agricultural input and output data from individual countries. After examining various approaches for consistent inter-region comparisons of agricultural prices, quantity and productivity (Ball et al. 1997a), the Fisher index with an Eltetö-Köves-Szulc formula (Eltetö & Köves 1964; Szulc 1964) and the Törnqvist index with the Caves-Christensen-Diewert formula (Caves et al. 1982) were found as two options suitable for international comparisons. Ball et al. (2001; 2010) conducted two empirical studies to examine these approaches.

Ball et al. (2001) compared agricultural TFP between the United States and nine European Union countries—Belgium, Denmark, France, Germany, Greece, Ireland, Italy, the Netherlands and the United Kingdom. Using 1990 as the base year, Ball et al. (2001) derived bilateral Fisher price indexes adjusted by purchasing power parity and then by the Eltetö-Köves-Szulc formula for transitivity. Indirect quantity indexes of outputs (inputs) were then estimated as total output (input) value divided by the corresponding price index. The results showed that agricultural productivity converged between the United States and nine European Union countries between 1973 and 1993. As such, most disparity in output has arisen from differences in input use.

Ball et al. (2010) further developed the methodology using Törnqvist price indexes and the Caves-Christensen-Diewert formula for imposed cross-country transitivity. A richer dataset (with more complete output and input categories) enabled comparison of relative competitiveness between the United States and 11 European Union countries—Belgium, Denmark, France, Germany, Greece, Ireland, Italy, the Netherlands, Spain, Sweden and the United Kingdom—measured by relative output prices between 1973 and 2002. In contrast to Ball et al. (2001), Ball et al. (2010) found that the apparent catch-up of the European Union countries had been reversed after the mid 1990s, which significantly weakened the competitiveness of European Union agriculture on global markets, relative to the United States.

Using the method Ball et al (1997a; 2010) advanced, this paper uses country-level data for Australia, Canada and the United States to compare agricultural productivity and competitiveness between countries. Some insights on the disparities in agricultural productivity levels, growth rates and determinants are identified.

3 Measuring output, input and total factor productivity in agriculture

Agricultural TFP is estimated and compared following Ball et al. (1997a and 2010). The method has three stages: indirect estimation of aggregate outputs and inputs, consistent treatment of outputs and inputs across countries, and the purchasing power parity adjustment for cross-country comparability.

Aggregating outputs and inputs

TFP is measured as the ratio of total output (Y_t) to total input (X_t); its growth is measured as the difference between output and input growth rates (estimated using logarithmic differentials to time t).

$$TFP_t = \frac{Y_t}{X_t} \quad (1)$$

$$\frac{dln(TFP_t)}{dt} = \frac{dln(Y_t)}{dt} - \frac{dln(X_t)}{dt} \quad (2)$$

Both the direct and indirect methods can be used for estimating multiple outputs and multiple inputs used in agricultural production. Given the availability of value data for most outputs and inputs, an indirect approach is used whereby aggregate output (input) quantity equals the gross value of outputs (inputs) divided by a corresponding price index. Assuming perfect competition and a linearly homogenous production function, direct and indirect quantity estimates are equivalent under a superlative index that satisfies the factor reversal test (Diewert 1992).

Aggregate price indexes used to estimate implicit output and input quantities are estimated using a Törnqvist index to approximate a linear homogeneous translog function, such that

$$\ln\left(\frac{P_t}{P_{t-1}}\right) = \frac{1}{2} * \sum_i (R_{it} + R_{i,t-1}) \ln\left(\frac{P_{it}}{P_{i,t-1}}\right) \quad (3)$$

$$\ln\left(\frac{W_t}{W_{t-1}}\right) = \frac{1}{2} * \sum_j (S_{jt} + S_{j,t-1}) \ln\left(\frac{W_{jt}}{W_{j,t-1}}\right) \quad (4)$$

where R_i is the revenue share of the ith output and S_j is the cost share of the jth input. P_i and W_j are the prices of ith output and jth input, respectively.

The Törnqvist index only satisfies the weak factor reversal test; however, Ball et al. (1997a) showed that the index retains a high degree of characteristicity when combined with the Caves-Christensen-Diewert formula for transitivity (Drechsler 1973).

Treatment of output and inputs

Agricultural production account data are defined and collected consistently between countries. Each variable is described in this section. All data were collected on a calendar year basis. For Australia, this meant converting financial year data by taking a simple average of two consecutive financial years.

Outputs

Output variables were collected under three categories: crops, livestock and other outputs. Crop outputs included grains and ensilage, oil seed, vegetables and melons, fruits and nuts. Livestock outputs included slaughter livestock (red meat), poultry and eggs, and other animal products (dairy and wool). Other outputs included 'non-separable secondary activities' such as income from machinery hire and contract services.

Primary agricultural outputs included deliveries to final demand as well as intermediate demand and on-farm use. Primary output is approximated by total sales plus non-market transactions (that is, cross-industry transfers through long-term contracts and on-farm use such as animal feed). Where production statistics are not directly available, primary output is approximated from changes in inventory for each commodity.

Outputs from non-separable secondary activities are defined as goods and services whose costs cannot be observed separately from those of primary agricultural outputs. Two types of secondary activities are included: on-farm production activities, such as the processing, packaging and marketing of agricultural products and services provision, such as machinery hire and land lease.

Government direct taxes are included in agricultural outputs, while indirect taxes and subsidies are deducted. However, the differences in government direct taxes between countries may distort differences in total output.

Equation (3) is used to aggregate output prices using their corresponding revenue share. The implicit aggregate output quantity is then defined as the total agricultural output value over the aggregate price index.

Inputs

Input variables were collected under four categories: capital, land, labour and intermediate inputs. Capital and land inputs are estimated as service flows.

Capital

Following Ball et al. (2001 and 2010), three types of capital inputs are defined as non-dwelling buildings and structures, plant and machinery and transportation vehicles. While relevant, the inventory of crops, livestock and other biomass resources, such as vineyards and orchards, are not included because of inadequate value data. However, these capital inputs are likely to represent a relatively small proportion of total capital.

The measurement of capital input begins with using real investments in constant prices to calculate capital stock of the three types of capital goods. At each time point t, the stock of capital $K(t)$, is the sum of all past investments, $I_{t-\tau}$, weighted by the relative efficiencies of capital goods of each age τ , S_τ.

$$K_t = \sum_{\tau=0}^{\infty} S_\tau I_{t-\tau} \qquad (5)$$

Using equation (5) to estimate capital stock, the efficiencies of capital goods have to be defined explicitly. Similar to Ball et al. (2010), two parameters including the service life of the asset, L, and a decay parameter, β, are used to specify the functional form, $S(.)$ such that

$$S(\tau) = (L - \tau)/(L - \beta\tau), \text{ if } 0 \leq \tau \leq L,$$

$$S(\tau) = 0, \text{ if } \tau > L \qquad (6)$$

Each type of capital asset has an assumed distribution of actual service life which provides some mean service life $\bar{L}$. In this analysis, the asset lives for non-dwelling buildings and structures, plant and machinery, and transport and other vehicles are assumed to be 40 years, 20 years and 15 years, respectively, with an assumed standard normal distribution truncated at points two standard deviations before and after the mean service life.

The decay parameter β can take values between 0 and 1, with $\beta = 1$ implying that the capital asset does not depreciate over its service life. Although there is little empirical evidence on appropriate values of β, it is still reasonable to assume that the efficiency of a capital asset declines smoothly over most of its service life. Following Ball et al. (2001), decay parameters are set to be 0.75 for non-dwelling buildings and structures and 0.5 for all other capital assets, which reflect the assumption that efficiency declines more quickly in the later years of service (Penson et al. 1987; Romain et al. 1987).

The aggregate efficiency function was constructed as a weighted sum of individual efficiency functions where the weights are the frequency of occurrence.

Rental rate

Assuming the sector invests when the present value of the net revenue generated by an additional unit of capital exceeds the purchase price of the asset, the farm sector will invest in capital stock formation until:

$$P = \frac{\partial Y}{\partial K} = rW_K \sum_{t=1}^{\infty} W_K \frac{\partial R_t}{\partial K} (1+r)^{-t} = c \tag{7}$$

where c is the implicit rental price of capital, r is the real rate of return and $\mathrm{W_K}$ is the initial investment.

The rental price c consists of two components: the opportunity cost associated with the initial investment, rW_K, and the present value of the cost of all future replacements required to maintain the productive capacity of the capital stock, $\sum_{t=1}^{\infty} W_K \frac{\partial R_t}{\partial K} (1+r)^{-t} s$.

Let F denote the present value of the rate of capital depreciation on one unit of capital according to the mortality distribution m

$$F = \sum_{t-1}^{\infty} m_t (1+r)^{-t} \tag{8}$$

where $m(\tau) = -[S(\tau) - S(\tau - 1)]$ for $\tau = 1, \dots, L$.

It can be shown that $\sum_{t=1}^{\infty} \frac{\partial R_t}{\partial K} (1+r)^{-t} = \sum_{t=1}^{\infty} F^t = \frac{F}{1-F}$ such that

$$c = \frac{rW_K}{1-F} \tag{9}$$

Following Ball et al. (2010), the real rate of return r is approximated with an *ex-ante* rate, estimated as the nominal yield on one-year government bonds less the rate of inflation (as measured by the implicit deflator for gross domestic product). The choice of interest rate is widely debated. Andersen et al. (2011) argued that use of a fixed interest rate generates more plausible estimates of capital services in the United States than use of an annual market rate, while Jorgenson & Schreyer (2012) proposed to use the residual of output value deducting input costs for an endogenous real interest rate. To test the sensitivity of measured capital services to different real interest rates, both *ex-ante* and *ex-post* rates were estimated through an auto-regression integrated moving average process. The *ex-ante* rate was chosen for this study as it was found less volatile than the *ex-post* rate.

Land

Land is also estimated as the value of land stock multiplied by a rental price. The stock of land was estimated implicitly as total land value divided by a constructed Törnqvist price index. The rental price of land was obtained using a hedonic function.

Observed agricultural land prices can be affected by many factors unrelated to agricultural production, such as urbanisation pressures, distance to major cities and government land release policies. Also, spatial differences in land quality may prevent direct comparison of prices between regions and over time. To address these problems, comparable land price indexes for each country were constructed using hedonic regression methods.

In this paper, the hedonic price of land is a generalised linear function of its characteristics relevant to agricultural production and some control variables. The function uses the Box-Cox (1964) transformation to represent the dependent variable and each continuous independent variable:

$$W_L(\lambda_0) = \sum_n \alpha_n X_n(\lambda_n) + \sum_d \gamma_d D_d + \varepsilon \qquad (10)$$

where $W_L(\lambda_0)$, representing the price of land, is the Box-Cox transformation of real observations, when $W_L > 0$, that is

$$W_L(\lambda_0) = f(x) = \begin{cases} \frac{W_L^{\lambda_0}}{\lambda_0}, \lambda_0 \neq 0 \\ lnW_L, \lambda_0 = 0 \end{cases} \qquad (11)$$

Similarly, $X_n(\lambda_n)$, a vector of land characteristics associated with agricultural production, is the Box-Cox transformation of the continuous quality variable X_n where

$$X_n(\lambda_n) = f(x) = \begin{cases} (X_n^{\lambda_n} - 1)/\lambda_n, \lambda_n \neq 0 \\ lnX_n, \lambda_n = 0 \end{cases} \qquad (12)$$

and D is a vector of country dummies used to control for external factors. For simplicity, it is approximated with a group of region and time dummy variables and not subject to transformation; λ, α and γ are unknown parameter vectors to be determined in the regression and ε is a stochastic disturbance term. This expression can assume linear, logarithmic and intermediate nonlinear functional forms depending on the transformational parameter.

To employ the hedonic model, regional land prices and land characteristics were observed for each country in 2005. Land characteristic data for 2005 were sourced from the USDA World Soil Resources Office and selected following Eswaran et al. (2003) and Sanchez et al. (2003). GIS mapping was used to overlay country and regional boundaries with land characteristics data according to particular soil categories, including soil acidity, salinity, and moisture stress. The three countries use more than 18 common variables to capture environmental attributes.

Two additional attributes affecting the price of agricultural land should be considered: irrigation and population accessibility. Irrigation (the percentage of cropland irrigated) was included as a separate indicator of production capacity in water-stressed areas, as well as an interaction term between irrigation and soil acidity. A population accessibility index could be used to control for the impact of urbanisation and economic development on land prices; however, it was not included in this analysis due to data constraints. Such indexes have been constructed in previous literature by using a gravity model of urban development, and provided a measure of accessibility to population concentrations (Shi et al. 1997).

Intermediate inputs

Intermediate inputs comprise all materials and services consumed, excluding fixed capital, land and labour inputs. It includes 10 categories, namely: fuel, electricity, fertilisers and chemicals, fodder and seed, livestock purchases, water purchases, marketing services, repairs and maintenance, plant and machinery hire, and 'other materials and services'.

Fuel (including lubricants) and electricity are estimated from the total quantity consumed and the farmers' prices paid for petrol, off-road automobile diesel oil, liquefied natural gas and electricity. A fuel price index was calculated using quantity consumed for petrol, automobile diesel oil and liquefied natural gas as weights. This price index was also used for deflating electricity expenditure.

Other intermediate inputs were estimated as implicit quantities. Price indexes were sourced domestically, except for pesticides and chemicals where quality-adjusted price data were sourced from the World Bank World Development Indicator database and FAO statistics. The quality-adjusted data were for 2005 and used with domestic time-series prices to impute a trend.

Consistent with the treatment of output, intermediate inputs were valued at farm-gate prices, including direct taxes and excluding indirect taxes and subsidies.

Labour

Labour is defined as total hours worked by hired, self-employed and unpaid family workers. Because data were only available on agricultural employment, total hours worked was imputed by multiplying the number of workers by the average hours worked per week.

Wages were not used to estimate the value share of labour inputs. This is because hourly wages do not capture total compensation to farm workers given the likelihood that additional employee benefits (such as lodging and superannuation contributions) were not included in wage statistics. In addition, compensation to self-employed workers is not directly observable.

Instead, the real cost of total labour use was derived using the accounting assumption that the value of total output equals the value of total input. This enabled real wages to be estimated as the real labour compensation (or total output value minus capital, land and intermediate input costs) divided by the total hours worked. Finally, hired, self-employed and unpaid family workers are distinguished and their different prices due to education levels and work experience were used to adjust for labour quality in all three countries.

Purchasing power parity adjustment

To enable cross-country comparisons, price variables measured in local currencies were converted to a common 'international' currency. While variations in exchange rates are available, movements in agricultural output and input prices do not necessarily coincide with variations in exchange rates. Instead, relative price indexes for agricultural output and inputs were constructed to capture each country's purchasing power parity.

For example, the purchasing power parity of wheat in Australia was defined as the number of Australian dollars required to purchase the same quantity of wheat as one 2005 United States dollar. The Törnqvist index was used to chain link 2005 relative prices to construct a time series.

Using the United States output price in the base year (2005) as the numeraire, prices were normalised using their purchasing power parities. Then, to enable comparability, the transitive Caves-Christensen-Diewert index in log-change form was defined as:

$$lnP_{CCD}^{ij} = \frac{1}{2} * \sum_{n=1}^{N} \left(s_i + \frac{1}{C} * \sum_{k=1}^{C} s_k\right)\left(lnP_n^i - \overline{lnP_n^k}\right) - \frac{1}{2} * \sum_{n=1}^{N} \left(s_j + \frac{1}{C} * \sum_{k=1}^{C} s_k\right)\left(lnP_n^j - \overline{lnP_n^k}\right) \quad (13)$$

where $s_f = p_n^f y_n^f / \sum_{n=1}^{N} p_n^f y_n^f, f = i, j, k$ and $\overline{lnP_n^k} = \frac{1}{C} * \sum_{n=1}^{N} P_n^k . P_n^i$.

P_n^j represents the price of the n-th output (input) in country i and j (i, j = 1,2, … , I) and c is the revenue (cost) share of the k-th commodity in total output (input).

Finally, these purchasing power parity prices can be divided by the exchange rate to translate them into relative output and input prices in US dollar terms so as to measure international competitiveness. Variations in exchange rates are thus reflected in the relative output and input prices.

4 Data sources

Production accounts for agriculture were complied for Australia by ABARES, for Canada by Agriculture and Agri-food Canada and for the United States by USDA ERS. These accounts provide the data used in this paper. Data were collected for the period from 1960 to 2006 for all variables, except for capital investment where a longer time series was used that began at the earliest available year for each country. A brief description of the data sources for each country is outlined here and a complete variable list is provided in Appendix A.

Australia

Agricultural output data were sourced primarily from the ABARES Agricultural Commodity Statistics. For smaller commodity items, where price data were not available, a general ABARES farm prices received index was used.

Capital investment data were taken from the Australian Bureau of Statistics National Accounts Database and backcast to 1860 using data from Butlin (1977) and Powell (1974). Since no data are available, the deflator for transportation vehicles between 1920 and 1960 is assumed to be the same as that for plant and machinery.

The Australian agricultural census was used to estimate land area. Land prices were estimated using Australian Agricultural and Grazing Industry Survey data after 1978 and backcast to 1960 using a GDP deflator. For the base year (2005), more detailed data on land area and prices across 226 statistical local areas were collected for the hedonic modelling exercise.

Intermediate inputs (including total expenditure and price indexes) were sourced from ABARES Agricultural Commodity Statistics.

Labour input was estimated as total number of hours worked, calculated by multiplying the number of workers by the average number of hours worked. The average hours worked was obtained from the Australian Bureau of Statistics Population Census.

Canada

Production data were not available for Canada, but were estimated from total income from sales to processors, consumers, exporters and farm households (including within-sector use, waste, dockage, loss in handling and changes in closing stocks). Output price data were available from Statistics Canada CANSIM tables. Some non-separable forestry outputs were included in aggregate output estimates.

A capital investment data series was compiled for the period 1926 to 2006. As the data series for early and recent years were not available, some imputations were applied both at the beginning and end of the investment series. Investment deflators (or price index) between 1926 and 1935 were constructed with import price data taken from Trade of Canada. For other years, disaggregated deflators for each asset grouping are available directly from the national account statistics.

The value of land services was measured with rental income from land lease. These data were sourced from Statistics Canada, as part of the Agricultural Value-Added Account. All data series started from 1981, with land area sourced from the Canadian Agricultural Census and land price from the Canadian Agricultural Value-Added Account. They were backcast using a fixed ratio.

Data on intermediate inputs were taken from the Supply Disposition Balance Sheets and other industry statistics. Individual price indexes were from Statistics Canada or were imputed using a combination of prices. Finally, for inputs where data were unavailable, values were estimated to be 1 to 3 per cent of total costs and were added into the production account of agriculture.

Hired labour was estimated with data from the Canadian Labour Force Survey and the Population Census of Canada. Estimation of self-employed labour input (defined as the number of hours worked) was based on the Canadian Agricultural Census. The number of days worked were then converted into number of hours worked assuming 10 hours a day worked for 1961 to 1991 and using Canadian Labour Force Survey data for 1991 onwards. The input of unpaid family members was estimated as a proportion of self-employed labour input.

United States

Most data is sourced from the US Census of Agriculture and the US Agricultural Resource and Management Survey data. The USDA ERS compiles state-level data on farm cash receipts which were aggregated to construct agricultural output values. Agricultural prices data were also sourced from the USDA for most outputs and intermediate inputs.

Capital investment data were sourced from the Bureau of Economic Analysis and deflators for transport vehicles from the Bureau of Labour Statistics. For non-dwelling buildings and structures, the implicit price deflator from the US National Accounts was used.

Shire-level land area data were collected from the US Census of Agriculture and prices from the annual USDA survey on agricultural land values.

Labour data for hired and self-employed workers were sourced from the US Census of Population and the US Current Population Survey.

Intermediate input data were sourced from the USDA state farm income database. Price data were sourced from the National Accounts, the US Monthly Energy Review and USDA agricultural prices database.

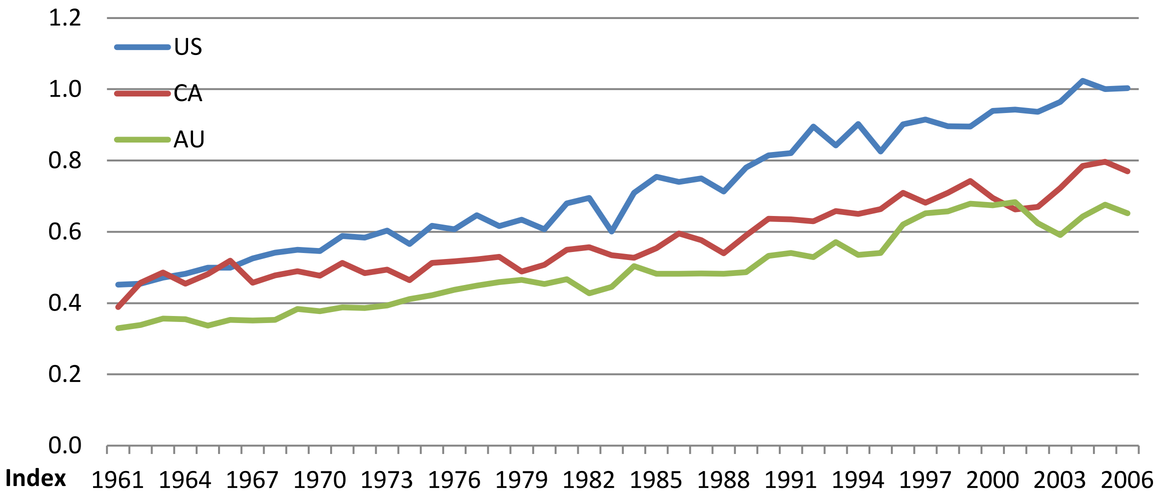
5 Empirical results

Relative productivity between Australia, Canada and the United States

Australian agricultural TFP was generally below the level achieved by the United States and Canada from 1961 to 2006 (although in 2001 Australia's TFP level briefly exceeded the level achieved by Canada) (Figure 1), but its growth was relatively strong. Between 1961 and 2006, the annual growth rate of agricultural TFP in Australia was 1.6 per cent a year on average, higher than in Canada (1.2 per cent a year), and only modestly lower than in the United States (1.8 per cent a year). The relatively strong TFP growth in Australia allowed Australia to improve its TFP level relative to Canada and to maintain its TFP level at around 70 per cent of the United States (Figure 2).

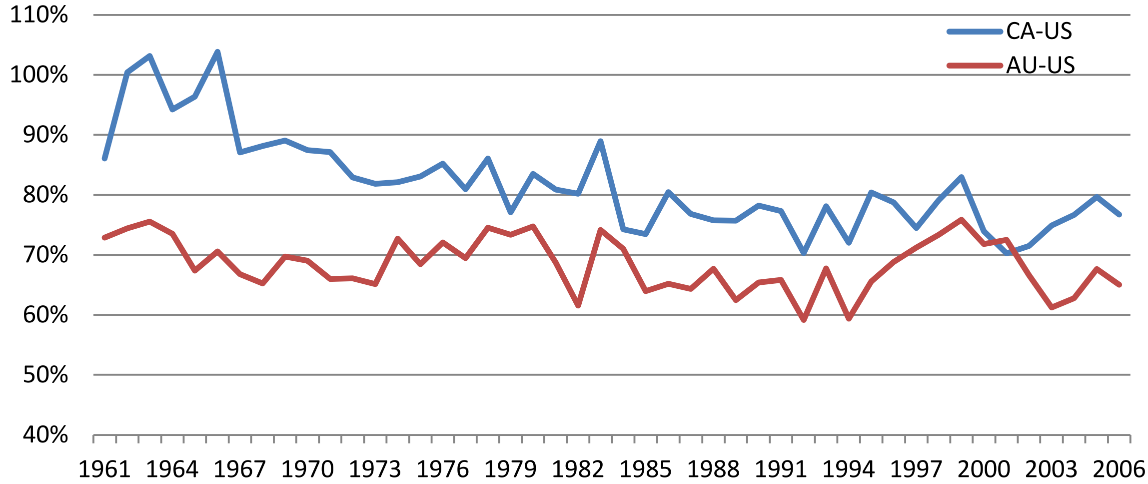
While Canada and the United States had similar levels of agricultural TFP during the 1960s, they have since diverged. The level of agricultural productivity in Canada fell to 75 per cent of the United States level on average over the past decade.

Figure 1 Comparable agricultural TFP levels: Australia, Canada and the United States, 1961 to 2006



Note: Detailed results are shown in Appendix B.

Figure 2 Agricultural TFP levels relative to the United States, 1961 to 2006



A further analysis on productivity growth between the three countries in the most recent decade showed that Canada experienced a downturn in agricultural productivity associated with drought in the early 2000s, but it did not experience a sustained slowdown. In contrast, Australia experienced a slowdown in agricultural productivity from 1998. This slowdown enlarged the productivity gap between Australian agriculture and its North American competitors between 2002 and 2006. The finding is consistent with Sheng et al. (2011b) who identified a turning point in broadacre agricultural productivity in Australia after the mid 1990s, associated with poor seasonal conditions and a declining intensity of public R&D investment.

Drivers of agricultural productivity growth

There are likely to be common factors driving agricultural productivity growth between countries. In the literature, these factors include technological progress and innovation, capital deepening, market competition and policy reforms aimed at reducing factor market distortions.

Investments in R&D are widely believed to be the most important source of technological progress and innovation driving agricultural productivity growth across countries (Alston 2010). In the United States, significant capacity for agricultural R&D investment by the private sector has played an important role (Huffman & Evenson 2006). For example, between 1970 and 2006, real agricultural R&D investment increased from US$5.6 billion to US$10.8 billion (in 2005 dollars), with more than half of this investment from the private sector. In 2000, the United States accounted for one-quarter of global agricultural R&D investment and one-third of OECD agricultural R&D investment. This capacity for generating new knowledge and technologies in part explains the consistently high productivity levels achieved by the United States.

In comparison, Canada and Australia are considerably smaller and rely more heavily on public R&D investment and international spillovers. Over the past two decades, more than two-thirds of agricultural R&D in these countries has been publicly funded, despite an increase in private sector investments (Table 1). International spillovers are also recognised as an important source of agricultural productivity growth. For example, Sheng et al. (2011a) found foreign agricultural spill-ins (measured by US public R&D investment) had accounted for around one-third of TFP growth in Australian broadacre agriculture between 1952–53 and 2006–07.

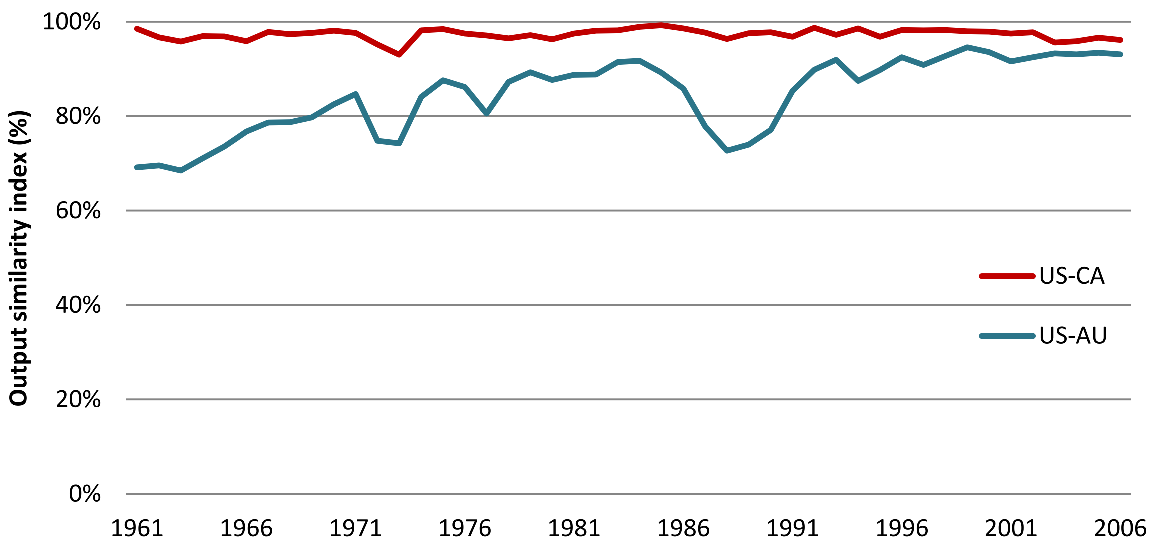
Table 1 Share of public expenditure in total agricultural R&D investment, 1981, 1991 and 2000 (%)

Countries	1981	1991	2000
United States	50.7	49.0	48.5
Canada	82.7	78.5	66.0
Australia	94.1	78.0	75.2
OECD (22)	56.4	51.5	45.7

Source: Pardey et al. 2006

The potential for Australia to make use of technological spillovers from the United States may be increasing. The similarity in agricultural output between the United States and Australia has increased from 0.69 to 0.93 (Figure 3), as suggested by the output similarity index (see Appendix C). Absorptive capacity associated with increased education and knowledge may also increase the uptake of international spillovers.

Figure 3 Output similarity indexes, 1961 to 2006



In Australia, a shift toward capital deepening through adoption of labour augmenting technology (Figure 4) has driven agricultural productivity. Because technological progress is often embodied in advanced capital and intermediate inputs, productivity growth may be positively related to growth in their use (Ball et al. 2001). Over the 45-year period of this analysis, capital services inputs used in Australian agriculture increased by an average of 1.9 per cent a year (Figure 5). In contrast, Canada and the United States have reduced their capital services inputs since the mid 1980s.

Figure 4 Capital–labour ratio in agriculture, 1961 to 2006

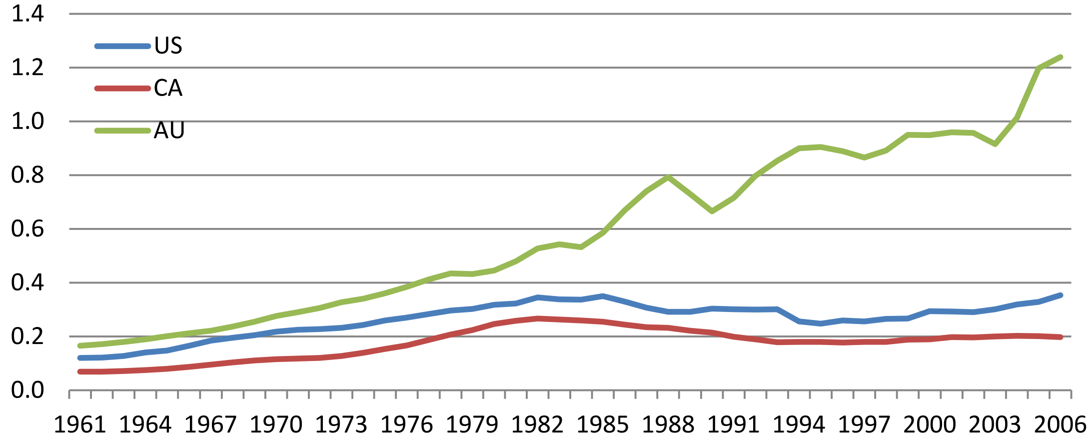
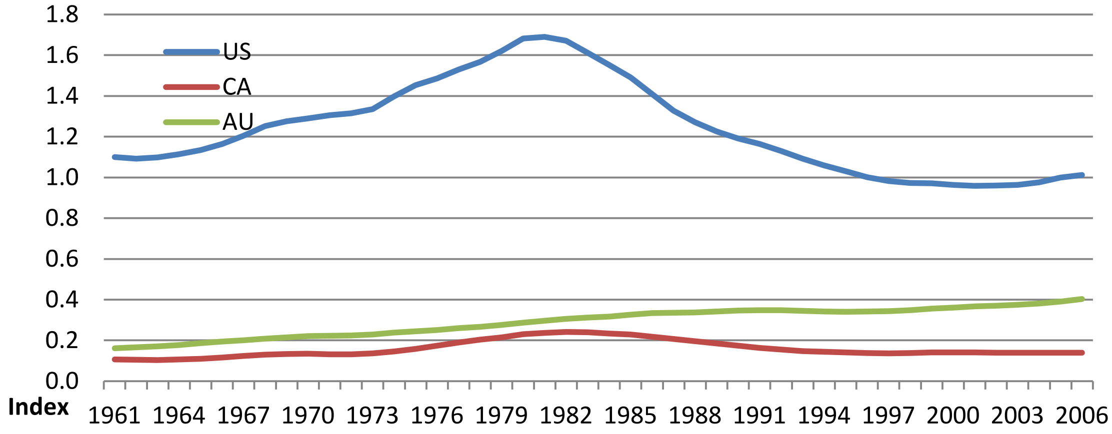
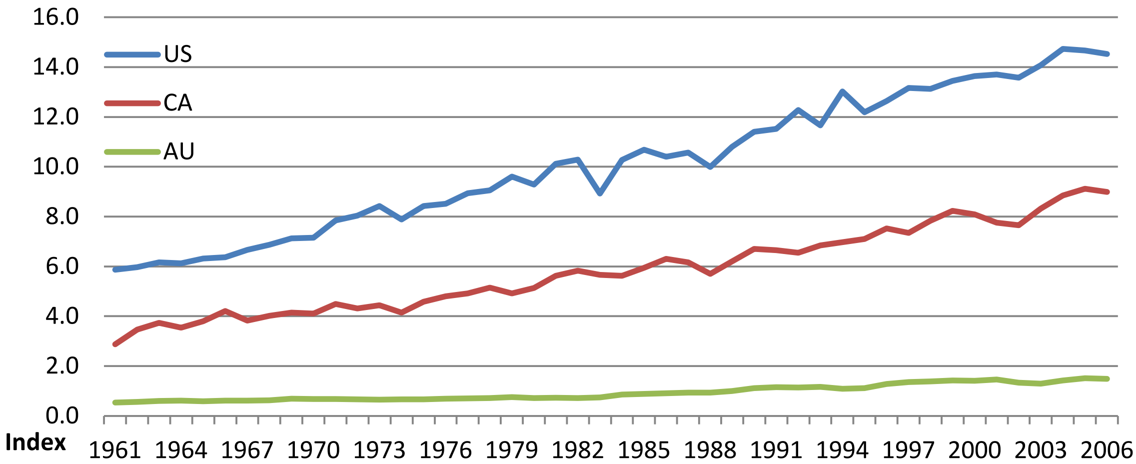


Figure 5 Capital service inputs, 1961 to 2006



Australia's rapidly increasing capital intensity may reflect a number of factors, including an abundance of land and remoteness to major export markets. Given an abundance of land, Australian agriculture has specialised in extensive non-irrigated cropping and grazing activities. These activities rely heavily on capital inputs, such as cropping machinery and fences, making capital intensity increase more quickly than in other countries. On average, Australian agriculture uses around 10 times more land per unit of output than the United States and around six times more land per unit of output than Canada, even after adjusting for land quality differences (Figure 6). Therefore, although land input requirements per unit of output have reduced to one-third of those used in the 1960s, Australian agriculture is likely to remain relatively land-intensive.

Figure 6 Land partial factor productivity, 1961 to 2006



Other factors, such as lack of irrigation water, climate variability and higher transport costs associated with dispersed and remote agricultural sectors, make it difficult for Australian agriculture to make more efficient use of physical capital and intermediate inputs. For example, one in eight Australians reside in rural areas compared to one in four Canadians and one in five Americans (Table 2). Disperse populations require more resources for efficient transportation and communication and realise fewer gains from economies of scale, competitive pressure on producers and access to agglomeration economies (Dolman et al. 2007). As a consequence, transportation costs in Australia, relative to the United States and Canada, have significantly increased over time.

Australia's climate is also more variable than that of Canada and the United States, with more frequent and widespread droughts having a significant impact on long-term productivity. Such influences make efficient input utilisation difficult and may divert capital and intermediate inputs from agricultural production toward risk management. Drought events are likely to have had a greater impact on Australian agricultural productivity relative to Canada or the United States.

Table 2 Population distribution and transport infrastructure, 2010

	Population density (persons per sq km)	Urban population (% of total population)	Road length (km per '000 persons)	Rail length (km per '000 persons)
United States	34	82	21	0.7
Canada	4	81	41	1.7
Australia	3	89	37	0.4

Source: World Development Indicator Database (World Bank 2012).

Structural changes and associated resource reallocation have also improved agricultural productivity across countries. It is widely observed that larger farms are more productive than smaller farms. For example, larger farms may be able to exploit superior production technologies not viable for use on smaller farms (Sheng et al. 2011c). For all three countries, the number of farms has decreased over time (Figure 7) and, consequently, average farm size (in terms of output per farm and land area per farm) has significantly increased (Figure 8). Increases in average farm size in Australia over the 1990s and in Canada after 2000 are consistent with periods of rapid agricultural productivity growth in both countries.

Figure 7 Number of farms, 1961 to 2006

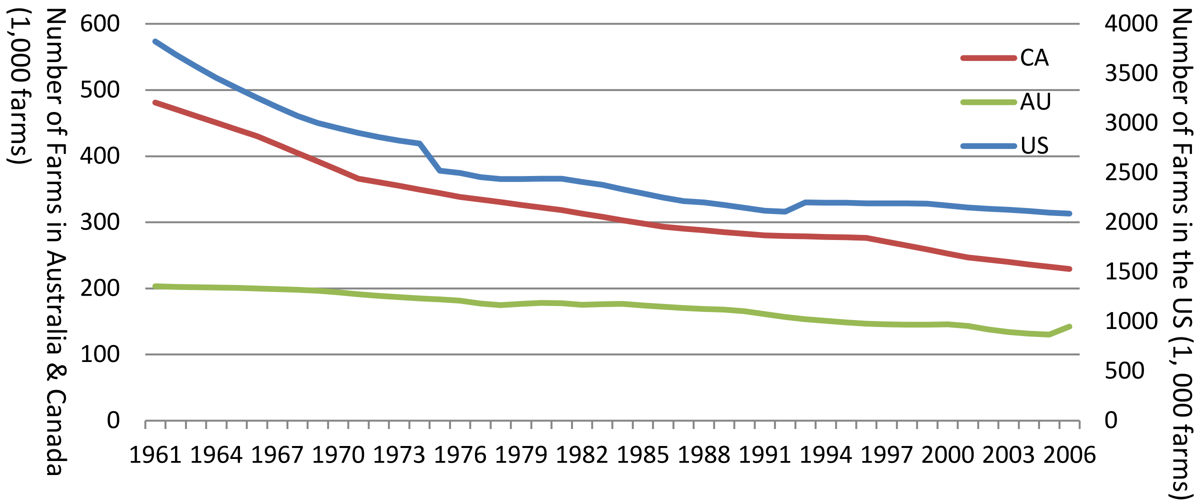
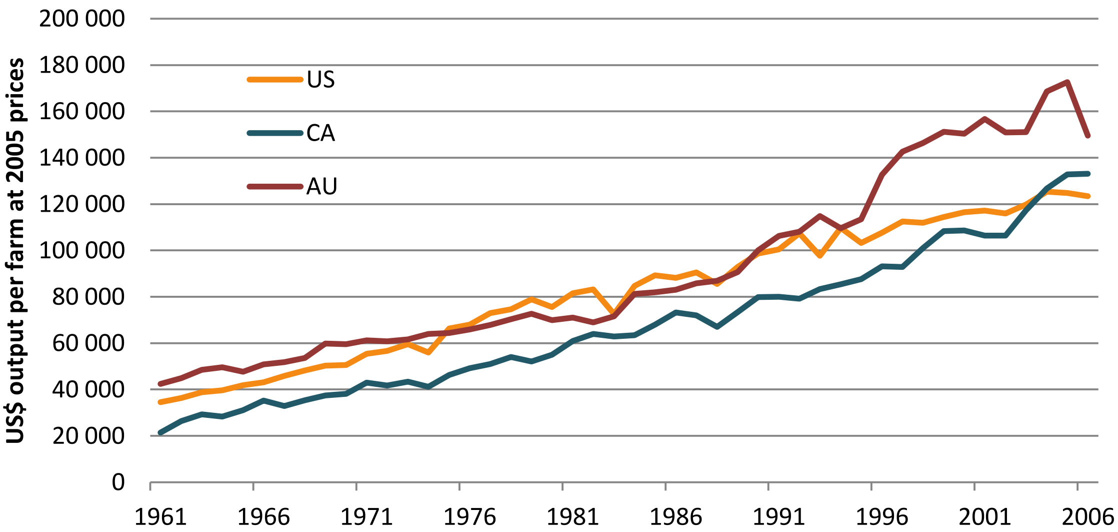


Figure 8 Average farm size, 1961 to 2006



6 Agricultural productivity, input prices and international competitiveness

Relative output prices, in US dollar terms, are a useful indicator of international competitiveness since, under the assumption of perfect competition and zero profits and after removing subsidies, they reflect comparable unit costs of production. By comparing trends in relative output prices, changes in relative competitiveness and the role of productivity growth can be examined for Australia, Canada and the United States between 1961 and 2006. Both agricultural productivity and changes in relative input prices are major determinants of international competitiveness of agricultural products on world markets.

The competitiveness of Australian agriculture, relative to the United States and Canada, has declined since the 1980s, as shown by their relative output prices (Figure 9). The decline mostly reflects increasing unit production costs for cropping outputs (Figure 10). While unit costs of livestock production have also increased, particularly relative to the United States, these increases were broadly in line with those paid by Canada during the 1990s (Figure 11). During the 2000s unit costs of Australian livestock production increased again, although this is likely to be heavily driven by increased feed prices associated with drought.

Figure 9 Relative output prices, 1961 to 2006

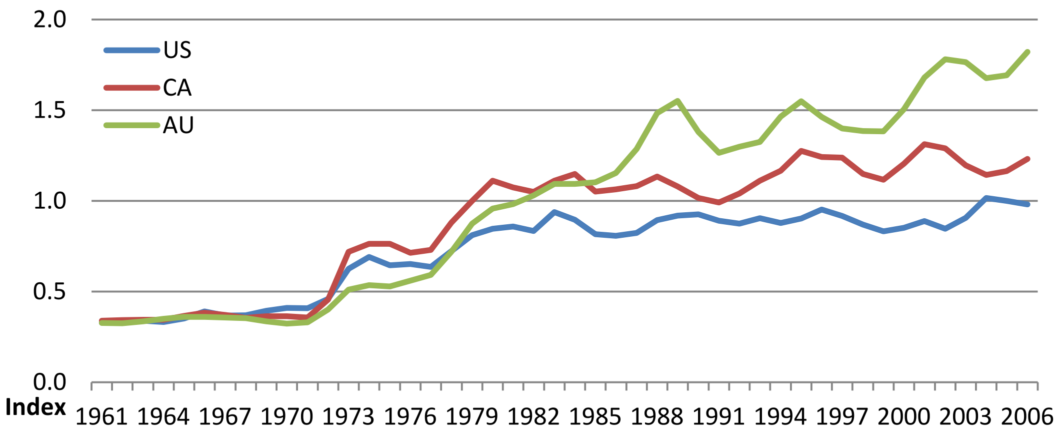


Figure 10 Crop output price index, 1961 to 2006

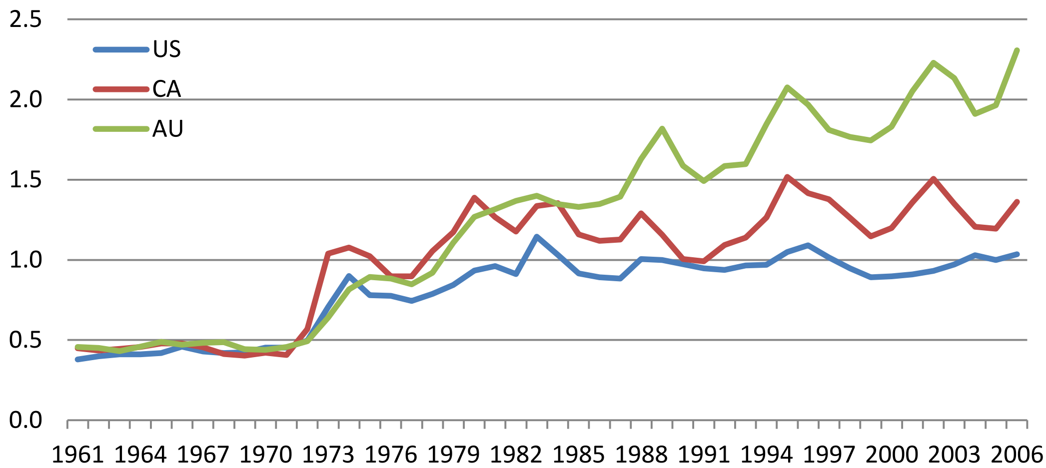
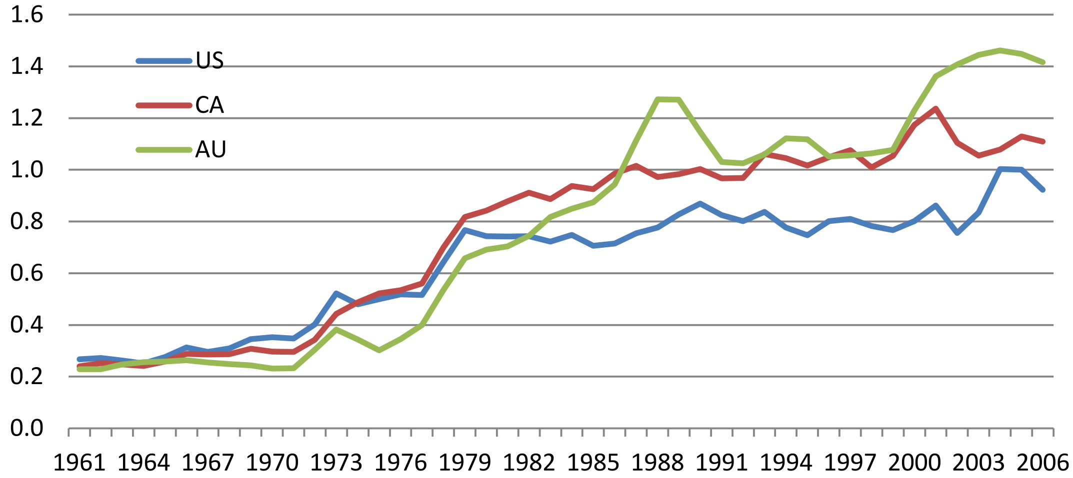


Figure 11 Livestock output price index, 1961 to 2006



Most of the decline in relative competitiveness is likely to relate to increasing real input prices in Australia relative to the United States and Canada, rather than to agricultural productivity. Before 1985 inputs were relatively cheap in Australia, particularly land and capital inputs. While strong productivity growth should have increased the relative competitiveness of Australian agriculture during the 1990s, relatively rapid growth in input prices offset much of this improvement (Figure 12). In particular, the price of labour and intermediate inputs increased relative to Canada and the United States (Figures 13 and 14). Over the past decade, the slowdown in agricultural productivity growth is likely to have exacerbated differences in agricultural competitiveness. Exchange rates have varied over this period and may have had some impact on input prices and therefore on competitiveness during particular periods.

In comparison, while the relative competitiveness of Canadian agriculture also declined somewhat relative to the United States, this trend was mostly driven by slower productivity growth. Relative input prices in Canada and United States have tracked each other closely.

Figure 12 Relative input price index, 1961 to 2006

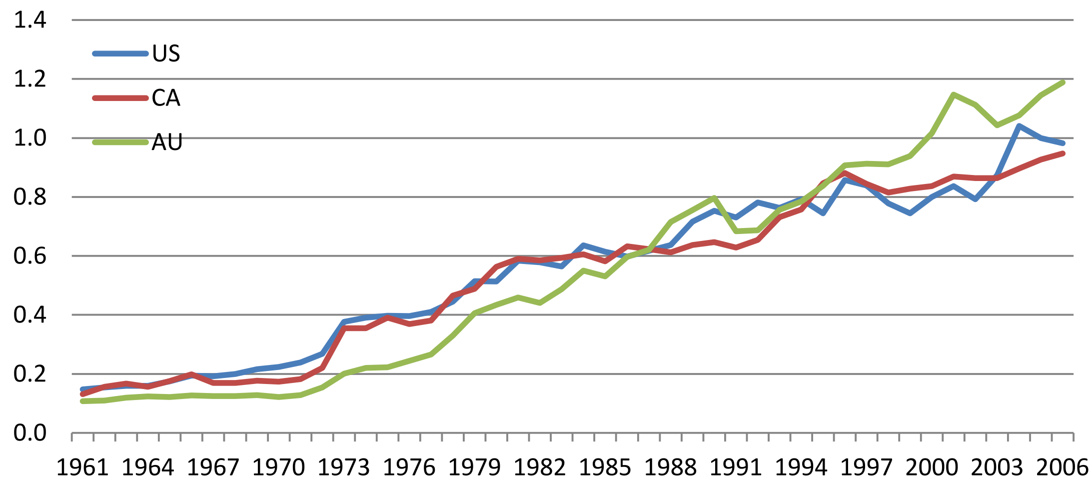


Figure 13 Relative labour prices, 1961 to 2006

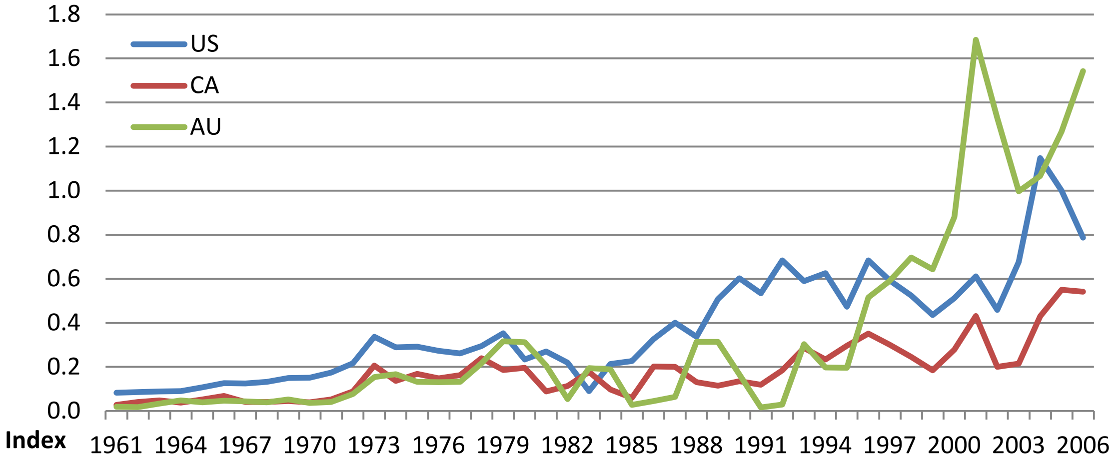
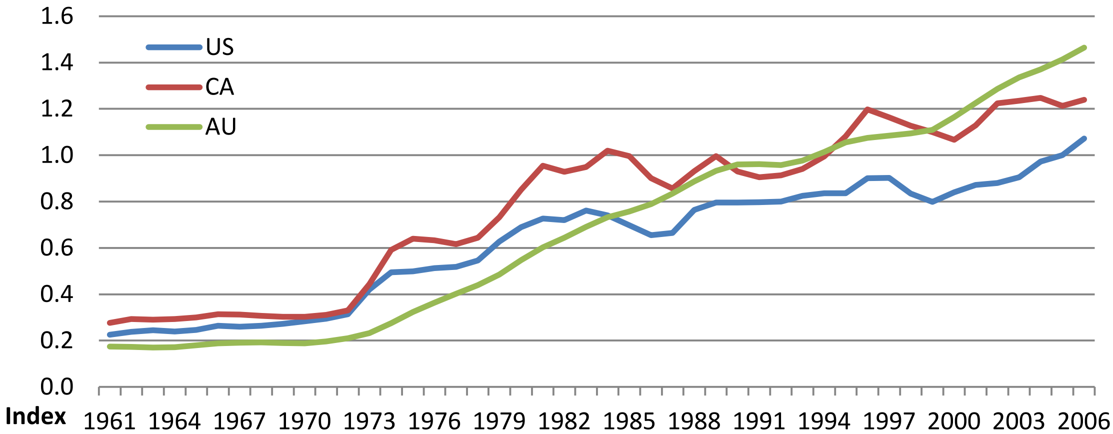


Figure 14 Relative intermediate input prices, 1961 to 2006



7 Conclusions

This paper has compared agricultural productivity between Australia, Canada and the United States between 1961 and 2006 using growth accounting based index numbers. A consistent production account for each country's agriculture sector was developed and a multilateral index applied to construct comparable aggregate output, input and TFP indexes.

The results show that Australian agricultural productivity has been below that of the United States and Canada. However, strong productivity growth over the past four decades has allowed Australian agriculture to improve its productivity relative to Canada, though the productivity gap relative to the United States still remains.

Agricultural productivity differences are likely to relate to each country's capacity for R&D and international spillovers, capital deepening and reallocation of resources within the sector, including a shift toward larger, more efficient enterprises.

Although agricultural productivity growth has helped offset rising input costs in Australia, particularly for labour and intermediate inputs, Australia's international competitiveness has weakened relative to the United States and Canada, especially in recent years. Given that input prices are typically beyond the control of farm decision-makers, pursuing productivity growth through adoption of input-saving technologies and practices is needed to maintain the competitiveness of Australian agriculture.

Appendix A: Agriculture production account

Crops			**Livestock**	**Other outputs**	**Land**	**Capital**	**Labour**	**Intermediate inputs**
Grains and oilseeds	*Fruits and nuts*	*Vegetables*	*Livestock*	*On-farm activities*	*Land*	*Capital*	*Labour*	*Materials*
Barley Canola Caster Cottonseed Flaxseed Hay and silage Maize Oats Peanut Rice Rye Safflower Sorghum Soybean Sunflower Triticale Wheat *Other crops* Cotton lint Tobacco Horticulture Floriculture Greenhouse nursery Sugar beet Sugar cane Mushrooms Other crops not included elsewhere	Almonds Apples Apricots Avocados Bananas Cherries (sweet) Cherries (tart) Cranberry Dates Figs Grapefruit Grapes Hazelnuts Lemons and limes Macadamias Mandarins Mangoes Nectarines Olives Oranges Peaches Pears Pecans Plums Prunes Strawberries Tangelos Tangerines Walnuts Other fruit and nuts	Asparagus (fresh, processing Snap beans, Beans (dry, processing) Broccoli Cauliflower Cabbage Capsicum Celery Cucumber (fresh, processing) Corn (fresh, processing) Honeydew Lettuce Lentils Onions Peas (dry, green) Potatoes Rock melon Spinach (fresh, processing), Sweet potatoes Tomatoes fresh, processing), Watermelon Other vegetables	Cattle and Calves Ducks Chickens and broilers Eggs Hogs Milk, butter, cheese Sheep and lambs Sheep Turkey Wool	Marketing Packaging Processing *Services* Contract services Machinery hire Land lease Other services	Land services	Buildings and structures (non-dwelling) Plant and machinery Transportation and other vehicles	Operator labour/hired labour/unpaid workers	Chemicals Electricity Fertiliser Fodder and seed Fuel and lubricant Livestock purchases Water purchases Other materials *Services* Marketing Plant and machinery hire Repairs and maintenance Veterinary services Other services

Appendix B: Comparison of agricultural productivity levels in Australia, Canada and the United States, 1961–2006

Year	Australia	Canada	United States
1961	0.329	0.389	0.452
1962	0.338	0.457	0.455
1963	0.356	0.486	0.471
1964	0.354	0.454	0.482
1965	0.337	0.481	0.499
1966	0.353	0.519	0.500
1967	0.351	0.457	0.525
1968	0.353	0.477	0.542
1969	0.383	0.489	0.549
1970	0.377	0.477	0.546
1971	0.388	0.512	0.588
1972	0.386	0.484	0.584
1973	0.393	0.494	0.604
1974	0.411	0.464	0.566
1975	0.422	0.512	0.617
1976	0.438	0.517	0.607
1977	0.449	0.523	0.646
1978	0.459	0.530	0.616
1979	0.465	0.489	0.634
1980	0.454	0.507	0.607
1981	0.467	0.550	0.680
1982	0.428	0.557	0.695
1983	0.446	0.535	0.601
1984	0.504	0.527	0.710
1985	0.482	0.554	0.754
1986	0.482	0.596	0.740
1987	0.483	0.576	0.750
1988	0.483	0.540	0.713
1989	0.487	0.590	0.780
1990	0.532	0.637	0.814
1991	0.540	0.635	0.821
1992	0.529	0.629	0.895
1993	0.571	0.658	0.843
1994	0.536	0.650	0.902
1995	0.541	0.663	0.825
1996	0.620	0.710	0.901
1997	0.652	0.682	0.915
1998	0.658	0.709	0.897
1999	0.679	0.742	0.895
2000	0.674	0.695	0.939
2001	0.683	0.662	0.943
2002	0.624	0.670	0.937
2003	0.591	0.723	0.965
2004	0.643	0.785	1.024
2005	0.677	0.797	1.000
2006	0.652	0.770	1.003

Note: United States agricultural TFP in 2005 is normalised to one.

Appendix C: Output similarity index

An output similarity index was estimated for Australia, Canada and the United States, based on all agricultural outputs. The output similarity index (ω) is given by:

$$\omega = \frac{\sum_{m=1}^{M} f_{im} f_{jm}}{\left(\sum_{m=1}^{M} f_{im}{}^{2}\right)^{1/2} \left(\sum_{m=1}^{M} f_{jm}{}^{2}\right)^{1/2}} \qquad \text{(C-1)}$$

where f_{im} and f_{jm} are the value of production of output m, expressed as a share of the total value of agricultural output in country i (that is, Australia or Canada) and country j (that is, the United States) where there is a total of M different commodity categories for Australia (or Canada) and the United States, and $M = 16$. Data on f_{im} and f_{jm} for Australia and Canada and data on f_{im} and f_{jm} for the United States are obtained from the output value estimates at the current price. For more detailed technical discussion, see Alston et al. (2010a).

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