Comparing agricultural total factor productivity between countries: the case of Australia, Canada and the United States

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[Abstract]
In this paper, Australian agricultural productivity is compared with that of two key competitors — Canada and the United States for the period 1961 to 2006. Using a growth accounting approach, it develops a production account for agriculture to derive input and output price indexes, adjusted for purchasing power parity, and to enable consistent agricultural TFP index numbers to be estimated between countries. In contrast to previous studies, both the level and growth rate of agricultural productivity are compared. While productivity in Australian agriculture remains below that achieved by Canada and the United States, it has been maintained relative to the United States and has improved relative to Canada. The paper also considers possible drivers and the implications for the international competitiveness of Australian agriculture.

[Key Word]
Agricultural productivity, International comparisons, Törnqvist index numbers

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Introduction

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

Technical progress in developed countries has underpinned much of this productivity growth. Between 1961 and 2006, agricultural productivity growth in major developed countries averaged 1.7 per cent a year, far more than that of developing economies, around 1.1 per cent a year (IFPRI, 2011). In addition to maintaining domestic output growth through offsetting various input constraints, productivity growth in developed countries has also expanded the frontier of new technologies and management practices which, in turn, has benefited developing country agriculture.

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

This paper develops a method to estimate agricultural total factor productivity (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 all 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 (see, for example, Fuglie 2010), this paper gathers price information from individual countries to allow use of the conventional index methods,
whereby revenue and cost shares are used as weights in input and output aggregation. Furthermore, the accounting identity (where total output value equals total input value) is used to derive the unobserved returns to labour, enforcing the assumption of constant return in scale. In addition, quality adjustments have been made to land and some intermediate inputs such as fertilizer, chemicals and medicines.

The results show that agricultural productivity in Australia has increased more quickly than in Canada, though it has not kept pace with the United States. Australian agriculture has maintained its productivity level relative to the United States and has improved relative to Canada.

There are some common drivers of agricultural productivity levels and growth rates between the three countries, despite obvious differences. Supportive evidence is found for two hypotheses. First, all three countries have experienced capital deepening as a consequence of technological progress. In particular, significant technology progress has been embodied in capital investment and use of intermediate inputs (Mundlak 2005). Second, there are strong correlations between average farm size and aggregate agricultural productivity level, possibly related to more efficient resource allocation. Agricultural 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.

As implications for Australia, increasing real input prices and slowdown in agricultural productivity growth over the past decade have weakened the competitiveness of agricultural exports on world markets.

The structure of the paper is follows. Section II provides a review of methods and data used in cross-country comparisons of agricultural productivity. Section III develops the data base for each country and describes the method for developing comparable productivity estimates. Section IV documents data sources for Australia, Canada and the United States. Section V presents the results and compares agricultural productivity and competitiveness between Australia, Canada and the United States. Section VI concludes.

**Literature review of method and data**

Due to its simplicity and flexibility in modeling the multi-output and multi-input production process, the growth accounting-based index number method is one of the most popular approaches for estimating agricultural TFP. 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 the TFP and the difference between output growth and input growth is used to measure the TFP growth.

While several individual country studies have used these index number methods to estimate agricultural productivity (Ball 1985; Jorgenson et al. 1987; Ball et al. 1997b; OECD 2001; Fuglie et al. 2012), international comparisons remain challenging tasks. Obtaining the data required 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. 1997b; Fuglie et al. 2012). Where established data sets are available, differences in definitions and units of measurement limit the comparability of input and output panel data (Capalbo et al. 1990).

Given these limitations, most cross-country comparisons have drawn on Food and Agriculture Organisation (FAO). Despite a lack of price information and incomplete input coverage, the FAO data set covers many countries over a long term. For example, Craig et al. (1994; Craig et al. 1997a) estimated agricultural land and labour productivity for 98 countries between 1961 and 1990 and found that input mix, input quality and public infrastructure were all 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 the 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 2040. The study found TFP growth convergence between
developing and developed countries for both crop and non-ruminant production activities, yet divergence in ruminant sectors.

While there are some advantages (including that countries are not assumed to share identical production technologies), there are also disadvantages in adopting the Malmqvist index method. In particular, it is sensitive to the set of countries compared and the number of variables in the model (Lusigi and 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 and Rao 2005, Headey et al. 2010) possibly because of the unrealistic implicit shadow prices that are derived for aggregation (Coelli and Rao 2005).

Wherever reliable price data are available, ‘superlative’ index methods are preferred. Fuglie et al. (2010) used a Törnqvist index to estimate and compare agricultural TFP growth for 171 countries. While FAO data were employed, these were augmented using 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 et al. (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; Alston et al. 2010b).

To address the data challenges facing international comparisons of agricultural productivity, Ball et al. (1997a), followed by Ball et al. (2001) and Ball et al. (2010), has 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 (see Ball et al. 1997a), the Fisher index with an EKS formula (Eltetö and Köves 1964; Szulc 1964) and the Törnqvist index with the CCD formula (Caves et al. 1982) were found as two options suitable for international comparisons. Two empirical studies were made in sequence to examine these approaches.

Ball et al. (2001) compared agricultural TFP between the United States and nine European Union countries (including Germany, France, Italy, the Netherlands, Belgium, the UK,

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2 Superlative index numbers are most widely adopted by national statistical agencies and are recommended by the OECD (2001) for periodic productivity statistics.
Ireland, Denmark and Greece). Using 1990 as the base year, Ball et al. (2001) derived bilateral Fisher price indexes adjusted with purchasing power parity (PPP) and adjusted these for transitivity following the EKS approach. 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 has 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 CCD formula for imposed cross-country transitivity. A richer dataset (with more complete output and input categories) enabled a comparison of relative competitiveness between the United States and eleven European Union countries, 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 has significantly weakened the competitiveness of European Union agriculture on global markets relative to the United States.

Using the method advanced by Ball et al. (1997) and Ball et al. (2010), 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.

**Measuring output, input and TFP in agriculture**

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

**Aggregating outputs and inputs**

Total factor productivity is measured as the ratio of total output \(Y_t\) to total input \(X_t\) and its growth is measured as the difference between output and input growth rates (estimated using logarithmic differentials).

\[
TFP_t = \frac{Y_t}{X_t}
\]  
(1)
As agricultural industry involves multiple outputs production using multiple inputs, outputs and inputs need to be aggregated. Both the direct and indirect methods can be used for aggregating these outputs and inputs. Given price variables are more stable than quantities variables, an indirect approach is used whereby aggregate output (input) quantity equals to 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 function³, such that

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

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

where \( R_i \) is the revenue share of the \( i \)th output and \( S_j \) is the cost share of the \( j \)th input. \( P_i \) and \( W_j \) are the prices of \( i \)th output and \( j \)th input.

**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 machinery hire and contract services.

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³ The Törnqvist index only satisfy the weak factor reversal test, however, Ball et al. (1997) showed that after applying CCD for transitivity, the index retains a high degree of characteristicity (Drechsler 1973).
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 activities are included in agricultural outputs, while indirect taxes are deducted. However, the differences in government subsidies and 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 Ball et al. (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 values 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 price 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, \( S_\tau I_{t-\tau} \), weighted by the relative efficiencies of capital goods of each age \( \tau \), say \( S_\tau \).
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, $\beta$, are used to specify the function form, $S(\cdot)$ such that

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

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

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 $\beta$ was restricted to values between 0 and 1 and follows the assumption that efficiency declines more quickly in the later years of service (Penson et al. 1987; Romain et al. 1987). Given little empirical evidence on appropriate values of $\beta$, it is assumed that the efficiency of a capital asset declines smoothly over most of its service life. Following Ball et al. (2001), estimated decay parameters are 0.75 for non-dwelling buildings and structures and 0.5 for all other capital assets.

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 that 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:

$$P = \frac{\partial Y}{\partial K} = r W_k \sum_{t=1}^{\infty} W_k \frac{\partial R_k}{\partial K} (1 + r)^{-t} = c$$

where $c$ is the implicit rental price of capital.
The rental price $c$ then 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 ($rW_K \sum_{t=1}^{\infty} W_K \frac{\partial R_t}{\partial K} (1 + r)^{-t} s$).

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

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

where $m(t) = -[S(t) - S(t - 1)]$ for $t = 1, ..., L$.

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:

$$c = \frac{rW_K}{1-F}$$  \hspace{1cm} (9)

Following Ball et al. (2010), the real rate of return $r$ is approximated with a real interest 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)\(^4\). 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 (ARIMA) process. The ex-ante rate 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 is estimated implicitly as total land value divided by a constructed Törnqvist price index. The rental price of land is obtained using a hedonic function.

Because 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. Also, spatial differences in land quality may prevent direct comparison of prices between regions and over time. To address these two problems, comparable land price indexes are for each country constructed using hedonic regression methods.

\(^4\) The choice of interest rate is widely debated. For example, Andersen et al. (2011) argued that the use of a fixed interest rate generates more plausible estimates of capital services in the US than the use of an annual market rate while Jorgensen et al. (2012) proposed to use the residual of output value deducting input costs for an endogenous real interest rate.
In this paper, the hedonic price of land is a generalized 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:

\[ W_L(\lambda_0) = \sum_n \alpha_n X_n(\lambda_n) + \sum_d \gamma_d D_d + \epsilon \]  

(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

\[ W_L(\lambda_0) = f(x) = \begin{cases} \frac{w_L^{\lambda_0}}{\lambda_0}, & \lambda_0 \neq 0 \\ \ln W_L, & \lambda_0 = 0 \end{cases} \]  

(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

\[ X_n(\lambda_n) = f(x) = \begin{cases} (X_n^{\lambda_n} - 1)/\lambda_n, & \lambda_n \neq 0 \\ \ln X_n, & \lambda_n = 0 \end{cases} \]  

(12)

and \( D \) is a vector of country dummy variables 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; \( \lambda, \alpha \) and \( \gamma \) are unknown parameter vectors to be determined in the regression and \( \epsilon \) is a stochastic disturbance term. This expression that can assume both linear, logarithmic forms and intermediate nonlinear function forms depending on the transformational parameter.

To employ the hedonic model, regional land prices and land characteristics are observed for each country in 2005. Land characteristic data for 2005 was sourced from the USDA World Soil Resources Office and selected following Eswaren 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, moisture stress and among others. More than 18 common variables are used for all the three countries to capture environmental attributes.

Some additional attributes affecting the production capacity of agricultural land were included: irrigation and population accessibility. Irrigation (that is, the percentage of cropland irrigated) was also included as a separate indicator of production capacity in water stressed
areas, as well as a interaction term between irrigation and soil acidity. A ‘population accessibility’ score was also included to control the impact of urbanisation and economic development (factors beyond agriculture) on land price. These indexes were constructed using a gravity model of urban development, which provides a measure of accessibility to population concentrations (Shi et al. 1997). The index increases as population increases and/or distance from the population centre decreases.

Materials and Services

Intermediate inputs comprise all materials and services consumed, excluding fixed capital, land and labour inputs. It includes twelve categories, namely: fuel, electricity, fertilizers, chemicals, fodder and seed, livestock purchases, water purchases, marketing services, repairs and maintenance, plant and machinery hire, ‘other materials’ and ‘other 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 (ADO), liquefied natural gas (LNG) and electricity. A fuel price index was calculated using quantity consumed for petrol, ADO and LNG as weights. This price index was also assumed for deflating electricity expenditure.

Other intermediate inputs were estimated as implicit quantities. Price indexes were sourced domestically, except for fertilizers and chemicals whereby quality-adjusted price data was sourced from the International Fertilizer Industry Association (IFA). The quality-adjusted data was 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 subsidies.

Labour

Labour was defined as total hours worked by hired, self-employed and unpaid family workers. Because data was 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 land inputs. This is because hourly wages do not capture total compensation to farm workers given the likelihood of 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 inputs. This enabled real wages to be estimated as the real labour compensation divided by the total hours worked.

**Purchasing power parity adjustment**

To enable cross-country comparisons, price variables measured in local currencies are converted to a common ‘international’ currency. While variations in exchange rates are accessible, movements in agricultural output and input prices do not necessarily coincide with variations in exchange rates. As such, we constructed relative price indexes for agricultural output and inputs using the assumption of 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.

Assuming that the same commodity across countries share the relative prices of agricultural outputs in the base year (2005), prices were be normalized using their purchasing power parities. Then, to enable comparability, the transitive CCD index in log-change form was defined as:

\[
lnP_{CCD}^{ij} = \frac{1}{2} \sum_{n=1}^{N} \left( s_i + \frac{1}{c} \sum_{k=1}^{c} s_k \right) \left( lnP_n^i - \overline{lnP_n^k} \right) - \frac{1}{2} \sum_{n=1}^{N} \left( s_j + \frac{1}{c} \sum_{k=1}^{c} s_k \right) \left( lnP_n^j - \overline{lnP_n^k} \right)
\]

(13)

where \( s_f = p_f y_n^f / \sum_{m=1}^{M} p_n^f y_n^f \), \( f = i, j, k \) and \( \overline{lnP_n^k} = \frac{1}{c} \sum_{n=1}^{N} P_n^k \).

With \( p_{mj} \) representing the price of the m-th output (input) in the j-th country (\( j = 1, 2, ..., I \)) and I_{ij} represent a general index for current country j, with i as the base country and where where \( c_m \) is the revenue (cost) share of the m-th commodity output (input), \( c_m = \frac{1}{I} \sum_{k=1}^{c} c_{mk} \), and \( \overline{lnP_m} = \frac{1}{I} \sum_{k=1}^{c} \overline{lnP_{mk}} \), and \( \overline{lnP_m} \) is their mean.
Data sources

Data were sourced from the production accounts for agriculture complied for Australia (ABARES), Canada (Agriculture and Agri-food Canada) and the United States (ERS USDA). A brief description on the data source from each individual country is made as below and a complete variable list is provided in Appendix A.

Australia

Agricultural output data were sourced from ABARES Agricultural Commodities statistics compiled using data from Australian Agricultural Census among other sources. For smaller commodity items, where price data were not available, a general ABARES farm receipt price index was used.

Capital investment data were from the ABS National Accounts Database and backcast to 1900 using data from Butlin (1977) and Powell (1974). Since there is no data available, the deflator for transportation vehicle between 1920 and 1960 is assumed to be same as that for plants and machinery.

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

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

Labour input was 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 ABS 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 1926 and 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 service was measured with rental income from land lease. These data were sourced from Statistics Canada, as part of the Agricultural Value-Added Account. All used 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 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 were data were unavailable, their values are estimated to be 1 to 3 per cent of total costs and have been 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 161 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.

**The United States**

Most data is sourced from the US Census of Agriculture and the US Agricultural Resource and Management Survey (ARMS) data. The ERS USDA 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 from the Bureau of Economic Analysis (BEA) and deflators for transport vehicles from the Bureau of Labour Statistics (BLS). For non-dwelling building and structures, the implicit price deflator from the US National Accounts was used.

State-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 from the US Census of Population and the US Current Population Survey.

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

**Empirical results**

*Relative productivity level among Australia, Canada and the United States*

Australian agricultural TFP has been below the level achieved by the United States and Canada. Between 1961 and 2006, the annual growth rate of agricultural TFP in Australia is 1.6 per cent a year, higher than that in Canada (1.2 per cent a year) in Canada but below that in the United States (1.8 per cent a year). Over the period, Australian agriculture had improved its TFP relative to Canada, and maintained its TFP at around 70 per cent of United States levels (Figure 2).

While Canada and the United States had similar levels of agricultural TFP during the 1960s, they have since diverged. Canada’s agricultural productivity, as its growth rate has not kept pace. As a consequence, the level of agricultural productivity in Canada fell to 75 per cent of the United States level on average over the past decade.
While Canada experienced a downturn in agricultural productivity associated with drought in the early 2000s, it has not experienced a sustained slowdown. In contrast, Australian agriculture experienced a significant slowdown since 1998. This downturn has enlarged the gap between Australian agriculture and its North American competitors. The finding is consistent with Sheng et al. (2011b) who identified a turning point in broadacre agricultural productivity in Australia 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 between countries. In the literature, these factors include technology progress and innovation, capital deepening, market competition and policy reforms aimed at reducing factor market distortions.

Investments in research and development (R&D) are widely believed to be the most important source of technology 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 and 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 from the private sector. In 2000, the United States accounted for a 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 has been publicly funded, despite an increase in private sector investments (Table 1). International spillovers are also recognized as an important source of agricultural productivity growth. As an example, Sheng et al. (2011a) found foreign agricultural spillovers (measured by United States public R&D investment) had accounted for around one-third of TFP growth in Australian broadacre industry between 1952–53 and 2006–07.

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 as suggested by the output similarity index (detailed in Appendix C). Absorptive capacity associated with increased education and knowledge may also increase the uptake of international spillovers.

Table 1: Share of public expenditure in total agricultural R&D investment

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>50.7</td>
<td>49.0</td>
<td>48.5</td>
</tr>
<tr>
<td>Canada</td>
<td>82.7</td>
<td>78.5</td>
<td>66.0</td>
</tr>
<tr>
<td>Australia</td>
<td>94.1</td>
<td>78.0</td>
<td>75.2</td>
</tr>
</tbody>
</table>
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 years, capital services inputs used in Australian agriculture increased by an average of 1.9 per cent a year, compared with 0.4 per cent a year for Canadian agriculture (Figure 6). This shift towards capital deepening through the adoption of labour augmenting technology has been a driver of agricultural productivity in Australia. In contrast, Canada and the United States have reduced their capital services inputs since the mid 1980s.
Australia’s rapidly increasing capital intensity may reflect a number of factors, including an land abundance of land and remoteness to major export markets. Given an abundance of land, Australian agriculture is specialized in extensive grazing. On average, Australian agriculture uses around ten times more land per unit of output than the United States and around six times more land per unit of output than Canada (after adjusting for land quality differences) (Figure 6). Therefore, although land input requirements per unit of output have reduced to one-third of those that were used in the 1960s, Australian agriculture is likely to remain relatively land-intensive. Given vast land areas, Australian agriculture may rely more heavily on capital inputs (such as vehicles and machinery).

Figure 5 Capital-labour ratio in agriculture

![Graph of capital-labour ratio in agriculture]

Figure 6: Land partial factor productivity

![Graph of land partial factor productivity]
Other factors, such as lack of irrigation water, climate variability and higher transport costs associated with disperse and remote agricultural sectors, make it difficult for Australian agriculture to make more efficient use of physical capitals and intermediate inputs. For example, 1 in 8 Australians reside in rural areas compared to 1 in 4 Canadians and 1 in 5 Americans. Disperse populations require more resources for efficient transportation and communication and realize fewer gains from economies of scale, competitive pressure on producers and access agglomeration economies (Dolman et al. 2007).

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

Table 2: Population distribution and transport infrastructure, 2010

<table>
<thead>
<tr>
<th></th>
<th>Population density (persons per sq km)</th>
<th>Urban population (% of total population)</th>
<th>Road length (km per '000 persons)</th>
<th>Rail length (km per '000 persons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>34</td>
<td>82</td>
<td>21</td>
<td>0.7</td>
</tr>
<tr>
<td>Canada</td>
<td>4</td>
<td>81</td>
<td>41</td>
<td>1.7</td>
</tr>
<tr>
<td>Australia</td>
<td>3</td>
<td>89</td>
<td>37</td>
<td>0.4</td>
</tr>
</tbody>
</table>


Structural changes and associated resource reallocation have also improved agricultural productivity between countries. It is widely observed that larger farms are more productive than smaller farms (Sheng et al. 2011c). Significant increase in average farm size in Australia over the 1990s and that in Canada after 2000 are consistent with periods of rapid agricultural productivity growth in the two countries.

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) have significantly increased. In output terms, average farm size increased from US $34,536 to US $123,454 (in 2005 dollars) in the United States. While average farm size in Australia is similar, the share of resources allocated to large farms is significantly lower. Recent OECD data suggest that the average output concentration (defined as the ratio of output to input values for the top 25 per cent farms relative to the bottom 25 per cent farms) in Australia is 2.0 and 1.2, compared to 13.2 and 3.0 in the United States (Table 3). This suggests the
relatively higher average farm size in Australia is reflects the nature of production and the large share of land extensive grazing operations. As such, the United States has been able to take advantage of structural changes associated with resource reallocation more so than Australia, possibly explaining in part its productivity advantage.

Figure 7: Number of farms

![Figure 7: Number of farms](image)

Figure 8: Average farm size (output per farm)

![Figure 8: Average farm size (output per farm)](image)

Table 3: Output and asset concentration ratios

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Output Concentration Ratio</th>
<th>Total Assets Concentration Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US</td>
<td>CA</td>
</tr>
<tr>
<td>2004</td>
<td>13.7</td>
<td>1.4</td>
</tr>
<tr>
<td>2006</td>
<td>13.2</td>
<td>1.3</td>
</tr>
<tr>
<td>2007</td>
<td>14.3</td>
<td>1.0</td>
</tr>
<tr>
<td>2009</td>
<td>13.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Average 13.2 1.2 2.0 3.0 1.2 1.2

Note: The concentration ratio is defined as the sum of total output or total assets in top 25 per cent farms over bottom 25 per cent farms in terms of “output/input ratio”.
Source: (OECD 2012).

Agricultural Productivity, Input Prices and International Competitiveness

Output prices are a useful indicator of international competitiveness since, under the assumption of perfect competition and zero-profit, they reflect comparable unit costs of production. By comparing trends in 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. Agricultural productivity, along with changes in relative input prices, are both major determinants of international competitiveness of agricultural products on world markets.

The relative competitiveness of Australian agriculture has declined since the 1980s (Figure 9). The decline mostly reflects increasing cost of production for cropping outputs (Figure 10). While 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, the costs of Australian livestock production have increased again, although this is likely to be heavily driven by increased feed costs associated with drought.

Figure 9: Relative output prices

Most of this decline is likely to relate to increasing real input prices in Australia relative to the United States and Canada, rather than agricultural productivity. Before 1985, inputs were
relatively cheap in Australia, particularly for 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 5). In particular, the price of labour and intermediate inputs has increased relative to Canada and the United States (Figure 6 and Figure 7). Over the past decade, the slowdown in agricultural productivity growth is likely to have exacerbated differences in agricultural competitiveness.

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

Figure 10: Crop output price index
Figure 11: Livestock output price index

Figure 5: Relative input price index

Figure 6: Relative labour prices
Conclusions

Agricultural productivity is compared between Australia, Canada and the United States between 1961 and 2006 using the growth accounting-based index numbers. Consistent production account for each country’s agriculture was developed and a multilateral index applied to construct comparable aggregate output, input and total factor productivity indexes.

The results find that Australian agricultural productivity has been below that of the United States and Canada. Australian agriculture has maintained is productivity relative to the United States and improved relative to Canada, but a productivity gap 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 towards larger, more efficient enterprises.

Although agricultural productivity growth has helped to 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. Given that input prices are typically beyond the control of farm decision-makers, pursuing productivity growth through the adoption of input-saving technologies and practices is required to maintain the competitiveness of Australian agriculture.
## Appendix A Agriculture Production account

<table>
<thead>
<tr>
<th>Crops</th>
<th>Fruits and Nuts</th>
<th>Vegetables and Melons</th>
<th>Livestock</th>
<th>Other outputs</th>
<th>Land</th>
<th>Capital</th>
<th>Labour</th>
<th>Intermediate inputs</th>
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</thead>
<tbody>
<tr>
<td>Grains and oilseeds</td>
<td>Barley</td>
<td>Almonds</td>
<td>Asparagus</td>
<td>Marketing</td>
<td>Land</td>
<td>Buildings</td>
<td>Operator</td>
<td>Chemicals</td>
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<tr>
<td></td>
<td>Canola</td>
<td>Apples</td>
<td>Crops</td>
<td>packaging</td>
<td></td>
<td>services</td>
<td>labour/hired</td>
<td>Electricity</td>
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<tr>
<td></td>
<td>Caster</td>
<td>Apricots</td>
<td>On farm</td>
<td>Processing</td>
<td></td>
<td>Services</td>
<td>workers</td>
<td>Fertiliser</td>
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<td>Cottonseed</td>
<td>Avocados</td>
<td>activities</td>
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<td>Pharming</td>
<td></td>
<td>Fodder and seed</td>
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<td>Flaxseed</td>
<td>Bananas</td>
<td></td>
<td></td>
<td></td>
<td>Transport</td>
<td></td>
<td>Fuel and lubricant</td>
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<td></td>
<td>Hay and silage</td>
<td>Cherries (sweet)</td>
<td></td>
<td></td>
<td></td>
<td>Plant</td>
<td></td>
<td>Livestock purchases</td>
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<td>Maize</td>
<td>Cherries (tart)</td>
<td></td>
<td></td>
<td></td>
<td>machinery</td>
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<td>Water purchases</td>
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<td>Oats</td>
<td>Cranberry</td>
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<td></td>
<td>Services</td>
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<td></td>
<td>Peanut</td>
<td>Dates</td>
<td></td>
<td></td>
<td></td>
<td>Services</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Rice</td>
<td>Figs</td>
<td></td>
<td></td>
<td></td>
<td>Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rye</td>
<td>Grapefruit</td>
<td></td>
<td></td>
<td></td>
<td>Services</td>
<td></td>
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<td>Safflower</td>
<td>Hazelnuts</td>
<td></td>
<td></td>
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<td>Services</td>
<td></td>
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<td>Sorghum</td>
<td>Lemons and limes</td>
<td></td>
<td></td>
<td></td>
<td>Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean</td>
<td>Asparagus</td>
<td>Lentils</td>
<td></td>
<td></td>
<td></td>
<td>Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunflower</td>
<td>Crops</td>
<td>Lentils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triticale</td>
<td>Other crops</td>
<td>Nectarines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>Onions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Livestock Services
- Cattle and Calves
- Ducks
- Chickens and broilers
- Eggs
- Hogs
- Milk, butter, cheese
- Sheep
- Turkey
- Wool

### Other Services
- Marketing services
- Machinery hire
- Land lease
- Other services
<table>
<thead>
<tr>
<th>Cotton lint</th>
<th>Tobacco</th>
<th>Horticulture</th>
<th>Floriculture</th>
<th>Greenhouse nursery</th>
<th>Sugar beet</th>
<th>Sugar cane</th>
<th>Mushrooms</th>
<th>Other crops not included elsewhere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olives</td>
<td>Oranges</td>
<td>Peaches</td>
<td>Pears</td>
<td>Pecans</td>
<td>Plums</td>
<td>Strawberries</td>
<td>Tangelos</td>
<td>Pecans</td>
</tr>
<tr>
<td>Peas (dry, green)</td>
<td>Potatoes</td>
<td>Rock melon</td>
<td>Spinach (fresh, processing), Sweet Potatoes</td>
<td>Tomatoes fresh, processing), Watermelon</td>
<td>Other fruit and nuts</td>
<td>Other vegetables</td>
<td>Veterinary services</td>
<td>Other services</td>
</tr>
</tbody>
</table>
Appendix B Comparison of agricultural productivity levels in Australia, Canada and the United States, 1961–2006

<table>
<thead>
<tr>
<th>Year</th>
<th>Australia</th>
<th>Canada</th>
<th>United States</th>
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<tr>
<td>1961</td>
<td>0.329</td>
<td>0.389</td>
<td>0.452</td>
</tr>
<tr>
<td>1962</td>
<td>0.338</td>
<td>0.457</td>
<td>0.455</td>
</tr>
<tr>
<td>1963</td>
<td>0.356</td>
<td>0.486</td>
<td>0.471</td>
</tr>
<tr>
<td>1964</td>
<td>0.354</td>
<td>0.454</td>
<td>0.482</td>
</tr>
<tr>
<td>1965</td>
<td>0.337</td>
<td>0.481</td>
<td>0.499</td>
</tr>
<tr>
<td>1966</td>
<td>0.353</td>
<td>0.519</td>
<td>0.500</td>
</tr>
<tr>
<td>1967</td>
<td>0.351</td>
<td>0.457</td>
<td>0.525</td>
</tr>
<tr>
<td>1968</td>
<td>0.353</td>
<td>0.477</td>
<td>0.542</td>
</tr>
<tr>
<td>1969</td>
<td>0.383</td>
<td>0.489</td>
<td>0.549</td>
</tr>
<tr>
<td>1970</td>
<td>0.377</td>
<td>0.477</td>
<td>0.546</td>
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<tr>
<td>1971</td>
<td>0.388</td>
<td>0.512</td>
<td>0.588</td>
</tr>
<tr>
<td>1972</td>
<td>0.386</td>
<td>0.484</td>
<td>0.584</td>
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<tr>
<td>1973</td>
<td>0.393</td>
<td>0.494</td>
<td>0.604</td>
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<td>1974</td>
<td>0.411</td>
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<tr>
<td>1975</td>
<td>0.422</td>
<td>0.512</td>
<td>0.617</td>
</tr>
<tr>
<td>1976</td>
<td>0.438</td>
<td>0.517</td>
<td>0.607</td>
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<tr>
<td>1977</td>
<td>0.449</td>
<td>0.523</td>
<td>0.646</td>
</tr>
<tr>
<td>1978</td>
<td>0.459</td>
<td>0.530</td>
<td>0.616</td>
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<tr>
<td>1979</td>
<td>0.465</td>
<td>0.489</td>
<td>0.634</td>
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<tr>
<td>1980</td>
<td>0.454</td>
<td>0.507</td>
<td>0.607</td>
</tr>
<tr>
<td>1981</td>
<td>0.467</td>
<td>0.550</td>
<td>0.680</td>
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<tr>
<td>1982</td>
<td>0.428</td>
<td>0.557</td>
<td>0.695</td>
</tr>
<tr>
<td>1983</td>
<td>0.446</td>
<td>0.535</td>
<td>0.601</td>
</tr>
<tr>
<td>1984</td>
<td>0.504</td>
<td>0.527</td>
<td>0.710</td>
</tr>
<tr>
<td>1985</td>
<td>0.482</td>
<td>0.554</td>
<td>0.754</td>
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<tr>
<td>1986</td>
<td>0.482</td>
<td>0.596</td>
<td>0.740</td>
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<tr>
<td>1987</td>
<td>0.483</td>
<td>0.576</td>
<td>0.750</td>
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<tr>
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<td>0.483</td>
<td>0.540</td>
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<tr>
<td>1989</td>
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<td>0.637</td>
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<tr>
<td>1991</td>
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<td>0.571</td>
<td>0.658</td>
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<td>1994</td>
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<td>1996</td>
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<td>1997</td>
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<tr>
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<td>0.742</td>
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<td>0.674</td>
<td>0.695</td>
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</tr>
<tr>
<td>2001</td>
<td>0.683</td>
<td>0.662</td>
<td>0.943</td>
</tr>
<tr>
<td>2002</td>
<td>0.624</td>
<td>0.670</td>
<td>0.937</td>
</tr>
<tr>
<td>2003</td>
<td>0.591</td>
<td>0.723</td>
<td>0.965</td>
</tr>
<tr>
<td>2004</td>
<td>0.643</td>
<td>0.785</td>
<td>1.024</td>
</tr>
<tr>
<td>2005</td>
<td>0.677</td>
<td>0.797</td>
<td>1.000</td>
</tr>
<tr>
<td>2006</td>
<td>0.652</td>
<td>0.770</td>
<td>1.003</td>
</tr>
</tbody>
</table>

Note: United States agricultural TFP in 2005 is normalized 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 ($\omega$) is given by:

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

(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, please refer to Alston et al. (2010a).
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