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Cross-country Comparisons of Agricultural Productivity

An Australian perspective

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Foreword

Australian agriculture has evolved over many decades in response to both pressures and opportunities for innovation and adaptation. This process has shaped the size and composition of the agriculture sector and led to productivity improvements, without which, profitability would have declined. Unable to draw more land and natural resources into production, future growth in output will rely increasingly on the ability of Australian agriculture to secure productivity gains.

The benefits of productivity growth are well-acknowledged. For export-oriented industries such as agriculture, improving productivity is fundamental to maintaining competitiveness. Agricultural productivity gains also determine, in part, the benefits to Australia from growth in global food demand. These motivations demand an understanding of the sources and likely challenges to future productivity improvements and a coordinated response from the public and private sectors.

This project has enabled ABARES to partake in a cross-country initiative to develop comparable measures of agricultural productivity for major agriculture producing countries — Australia, Canada and the United States. ABARES has worked closely with the United States Department of Agriculture, and Agriculture and Agri-food Canada to prepare a comprehensive database suitable for productivity measurement and analysis. This project has taken the initial step towards developing a global picture of agricultural productivity trends.

The results provide Rural Research and Development Corporations, government and other industry stakeholders with a guide to how Australian agriculture has been tracking since the 1960s. The ability to compare the sector with its counterparts in North America provides new insights into the drivers of productivity growth, including those most relevant to Australia's performance.

The study finds that agricultural productivity has been maintained relative to the United States and improved relative to Canada, despite inherent challenges such as higher climate variability, remoteness from global markets and a smaller capacity for rural R&D. Given these domestic challenges alongside new developments in the global economy, ongoing improvements in agricultural productivity will depend heavily on the economic and policy environment. ABARES have noted several areas of policy reform with the potential to increase innovativeness and incentives for adaptation in Australian agriculture.

This project was funded from RIRDC Core Funds which are provided by the Australian Government.

This report is an addition to RIRDC's diverse range of over 2000 research publications and it forms part of our Global Challenges R&D program, which aims to address impediments and opportunities to Australian agriculture associated with trade, productivity growth, food security, climate change and other emerging rural issues.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

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Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACIAR	Australian Centre for International Agricultural Research
ACS	Agricultural Commodity Statistics (previously Australian Commodity Statistics)
ASEAN	Association of Southeast Asian Nations
AusAID	Australian Agency for International Development
CGIAR	Consultative Group on International Agricultural Research
COAG	Council of Australian Governments
DAFF	Department of Agriculture, Fisheries and Forestry
FAO	Food and Agriculture Organization of the United Nations
OECD	Organisation for Economic Co-operation and Development
PFP	Partial Factor Productivity
PPP	Purchasing Power Parity
RRDC	Rural Research and Development Corporations
R&D	Research and Development
TFP	Total Factor Productivity
USDA	United States Department of Agriculture
WTO	World Trade Organization

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Executive Summary

What the report is about

Australian agricultural productivity is compared against two key competitors on global agricultural markets—Canada and the United States. The comparisons draw on new comparable agricultural productivity data developed as part of an international initiative. The analysis evaluates how Australian agriculture has performed over the past five decades and considers implications for maintaining competitiveness on global food markets and for contributing to global food security.

Background

While several countries, including Australia, have maintained national systems for measuring agricultural productivity, cross-country comparisons have remained an ongoing challenge. International agricultural output and input data (such as that maintained by the FAO) have been incomplete and domestic data have contained too many inconsistencies in data and methodology to allow for productivity comparisons.

A global network of researchers was established in 2010 to collaboratively address data gaps and methodological differences to facilitate cross-country comparisons using an analytical framework developed by the USDA Economic Research Services. With the support of RIRDC, ABARES participated in this network to develop an internationally-consistent dataset for Australian agriculture.

Australia, along with Canada and the United States were first to successfully develop a panel data series of agricultural outputs and inputs for 1961 to 2006. These data have been used by ABARES to develop the first comparable cross-country estimates of agricultural productivity for Australia.

Aims/objectives

The study develops an internationally consistent data series for agricultural productivity in Australia to enable cross-country comparisons. These data are analysed to:

- identify ‘productivity gaps’ that might exist between Australia and its competitors
- evaluate potential reasons for global disparities in agricultural productivity growth and levels
- understand the implications of Australian productivity growth for global food supply and food security.

Methods used

Various data sources were used to develop a database of inputs and outputs for the Australian agriculture sector, including the Australian National Accounts (ABS) and the Agricultural Commodities Statistics (ABARES). Similar databases were compiled for the United States and Canada. Key outputs included crops and livestock, while key inputs included land, capital, labour and intermediate inputs.

Two types of productivity statistics are estimated—productivity levels and productivity growth. While both statistics are used to assess performance they have different interpretations. Productivity levels are estimated as a ratio of aggregate outputs to aggregate inputs for each country, and productivity growth is estimated as the change in outputs relative to the change in inputs. Productivity levels measure how efficiently inputs are used to produce outputs, while productivity growth measures changes in production efficiency over time. Unlike traditional productivity statistics, methodological advances are employed to enable comparability of both productivity levels and growth rates between countries.

Comparisons of agricultural productivity trends in Australia, Canada and the United States are used to identify key factors that may explain the productivity gap between Australia and other countries. Importantly, some factors are beyond the control of landholders and policy-makers, while others may be influenced to improve Australia's performance. The capacity for Australia to maintain its international competitiveness and to play a greater role on global food markets is considered.

Key findings

The productivity level of Australian agriculture has been below that in Canada and the United States over the past five decades. Lower productivity suggests that, in aggregate, Australian agriculture has faced relatively higher production costs and has been less competitive on world markets.

In spite of this, Australian agriculture has maintained its relative productivity at around 70 per cent of the United States, which is seen as a global leader in agriculture. Notwithstanding international factors that have also influenced competitiveness on world markets (such as exchange rate fluctuations and shifts in global demand), these results suggest that the competitiveness of Australian agriculture has been maintained relative to these two key competitors.

Long-term productivity growth in Australian agriculture has averaged 1.6 per cent a year, behind the United States (1.8 per cent a year) but above Canadian agriculture (1.2 per cent a year) for 1961 to 2006. This growth has accounted for most of the increase in agricultural output, which has tripled over the period in Australia and Canada, and doubled in the United States. Less than 25 per cent of Australian output growth has been driven by additional use of market inputs.

There are many similarities between Australian agriculture and that in other developed countries. Australia, Canada and the United States each export a significant share of their agricultural production and have experienced, over time, a trend towards fewer, larger and more capital intensive farms. Key drivers of productivity growth are also common, including:

- continued investment in research, development and extension
- increased adoption of advanced technologies and practice innovations
- improvements in human capital
- reallocation of resources and enhanced specialisation
- greater trade openness and market competition.

However, there are also country-specific factors that have influenced productivity levels and growth rates. Physical, climatic, geographic, economic and policy factors have shaped industry composition and inherent comparative advantages in agricultural production. For example, Australian agriculture has faced challenges associated with a small, remote sector with a highly variable climate.

Many of these factors are beyond the control of industry or governments. Others, such as the removal of distorting price supports and marketing schemes, have improved Australian agricultural productivity, but their payoffs have already been realised. Nonetheless, there are some areas where further reform could assist in maintaining and enhancing agricultural productivity and competitiveness in Australian agriculture. Two such areas identified in this study include:

- *Increasing agricultural innovation spillovers* to overcome Australia's small domestic capacity for agricultural R&D and to better leverage international technological advances
- *Reducing policy and regulatory constraints* that inhibit structural adjustment and efficient resource allocation towards more productive farm enterprises. In particular, improvements in labour market flexibility could yield productivity improvements for many rural

businesses. In addition, improving access to skilled labour could serve to improve productivity.

Implications for stakeholders

Increasing agricultural productivity is a critical challenge for Australian agriculture. It is the main mechanism for the sector to maintain and improve its international competitiveness and to contribute to global food supplies.

Australian agriculture’s productivity improvements, at 1.6 per cent a year, have continued to increase Australian food production. Given Australia’s small domestic population, increases in agricultural production generally increase the surplus available for agricultural export. However, this is only a small part of Australia’s food security role. Mostly, it is through providing technical assistance to food-deficient countries—including advice and training to improve their productivity growth—that Australia is likely to make it largest contribution.

Monitoring and evaluating trends in agricultural productivity, including through cross-country comparisons, provides relevant insights into how Australian agriculture has performed over the long-term. The analysis presented here serves to assist rural R&D managers, policy-makers and other stakeholders in understanding the issues and opportunities for improving agricultural productivity and competitiveness in Australia in order to make strategic investment and policy decisions.

Introduction

Productivity growth has underpinned Australia's agricultural performance and remains imperative to future growth prospects. Over the past five decades, around four-fifths of the increase in agricultural output can be explained by productivity improvements—the contribution from additional input use being minor. Looking ahead, productivity growth is the main mechanism by which Australian farmers can remain competitive in international markets and benefit from the expected growth in global food demand. In addition, productivity growth is an effective solution to key challenges for the agriculture sector: climate change, declining access to natural resources, ageing workforces and the declining terms of trade.

Worldwide interest in measuring and comparing agricultural productivity across countries has continued to strengthen. Such comparisons create an opportunity to understand how policy settings may influence productivity growth and competitiveness. More specifically, the knowledge gained by industry and government can assist them in responding strategically to local and global challenges.

Although productivity is a relatively simply notion, the measurement of agricultural productivity and subsequent analysis of trends and likely drivers have been hampered by data and methodological constraints. In particular, inconsistent data sets across countries have made it difficult to evaluate Australia's agricultural performance and competitiveness. It has also made it difficult to assess the extent of any potential deterioration in productivity growth.

This report offers the first results from an international initiative to develop comparable agricultural productivity data for major producing countries. It compares the agricultural productivity trends of Australia, Canada and the United States over the past 50 years. The estimates provide a useful addition to ABS estimates for the Australian 'Agriculture, Forestry and Fishing' industry and ABARES estimates, which cover broadacre agriculture and dairy industries only. Cross-country comparisons of agricultural productivity enable Australia's agricultural performance to be benchmarked relative to Canada and the United States—two key competitors on world food markets. Most evidence has pointed towards strong long-term productivity growth in Australian agriculture, notwithstanding short-term variability coinciding with poor seasons. But, whether this productivity growth has been sufficient to maintain competitiveness depends on how others have been tracking.

There are two key motivations for comparing Australian agriculture and evaluating opportunities for achieving higher productivity: maintaining international competitiveness and contributing to global food security.

- Productivity growth is the most important factor determining international competitiveness for a country's agricultural sector (Ball et al. 2010). The analysis considers the implications for Australian agriculture's competitiveness of domestic and international productivity patterns.

- Growth in global population and incomes could increase demand for food consumption by 77 per cent between 2007 and 2050 (Linehan et al. 2012). The extent to which Australia, and other countries, are able to increase agricultural productivity will determine, in part, their ability to increase global food supply directly and to provide technical assistance to increase agricultural production and support economic development in food insecure countries.

Background to the project

Several countries have, for many years, maintained national systems for measuring agricultural productivity. Australia has two such systems: one for estimating productivity trends in key agricultural industries (broadacre cropping, livestock and dairy) using ABARES farm-level data and another for estimating aggregate trends in agriculture, fisheries and forestry productivity using ABS data from the national accounts. Some countries, such as the United States and Canada, monitor agricultural productivity on a regular basis; while other countries have been the subject of occasional studies (see, for example, Alston et al. 2010b).

Despite the prevalence of national studies, cross-country comparisons of agricultural productivity are an ongoing challenge for economists. Where established productivity measurement systems are available, differences in definitions and units of measurement limit the comparability of input and output panel data (Capalbo et al. 1990). Some economists have warned of 'insurmountable data constraints' in producing an internationally consistent data set (Craig et al. 1997; Fuglie 2010). For example, researchers attempting cross-country comparisons have often drawn on FAO datasets as the main evidence base. However, these data only partially cover agricultural outputs and inputs and do not include the input price data necessary to construct superlative index numbers (Alston 2010). These limitations have precluded definitive comparisons and evaluations of agricultural productivity.

To advance research on agricultural productivity and to collaboratively address these known data gaps, the Global Agricultural Productivity Network was established in 2010 following a conference on the Causes and Consequences of Global Agricultural Productivity Growth, in Washington D.C. As a first step toward a consistent panel data for estimating agricultural productivity, Australia and several other members with relatively comprehensive national data agreed to develop internationally-comparable indicators of agricultural productivity. Led by the Economic Research Service (ERS) of the United States Department of Agriculture, the collaborators are using a common methodology to develop consistent quantity, price and value share data. The methodology is based on that suggested in the OECD Manual for estimating industry-level productivity growth (OECD 2001), but has been adapted to suit the agriculture sector (see Capalbo et al. 1990; Ball et al. 2001; Ball et al. 2010).

RIRDC's funding of this project has enabled ABARES to participate in the global initiative and to develop a complete, internationally-comparable index of agricultural productivity for Australia.

Objectives

The primary objective of this study is to develop a long-term data series on agricultural productivity for Australia using an internationally consistent methodology to enable comparisons of Australia's agricultural productivity performance with other countries.

The analysis of these data will:

- identify 'productivity gaps' that might exist between Australia and its competitors
- evaluate potential reasons for global disparities in agricultural productivity growth and levels
- understand the implications of Australian productivity growth for global food supply and food security.

Project scope and overview

This report includes the findings from a collaborative research project between the economic research agencies of DAFF (ABARES), the USDA (ERS) and Agriculture and Agri-food Canada that aimed to develop an internationally consistent set of agricultural productivity data. The collaboration is ongoing and other countries (including China, Argentina and Brazil) have made some initial progress towards developing their datasets. The project builds on an earlier comparison of agricultural productivity between the United States and European Union undertaken by the ERS (Ball et al. 2001; Ball et al. 2010).

The body of the report is divided into four chapters. Chapter 1 reviews the relevance of productivity in maintaining the international competitiveness of Australian agriculture and in contributing to global food supplies. Chapter 2 describes the consistent approach used in measuring agricultural productivity across countries and reviews its strengths and sensitivities. Chapter 3 compares trends in agricultural productivity for Australia, Canada and the United States to evaluate factors likely to explain any 'productivity gap' between Australia and its competitors. Importantly, it makes a distinction between circumstantial factors (which are largely inherent or beyond the control of landholders or policy-makers) and factors that may be influenced by changes in policy or institutional settings. Finally, chapter 4 considers the implications for Australian agriculture, highlighting reform areas that could facilitate future productivity gains.

Why compare agricultural productivity?

Cross-country comparisons of agricultural productivity serve two purposes: to evaluate changes in the relative competitiveness of Australian agriculture on world markets and to evaluate changes in Australia's contribution to global food supplies.

Productivity, along with prices, is a major determinant of international competitiveness. Measuring agricultural productivity serves to indicate how Australian agriculture is performing relative to its competitors on global markets. Given that Australia exports the majority of its agricultural production, and has little influence over prices received, achieving productivity growth that maintains competitiveness is particularly important. Without continued increases in productivity and competitiveness, the agriculture sector in Australia would not maintain sufficient income to remain viable.

Given limited natural resources to draw into agricultural production and increasing input costs, agricultural productivity growth also determines Australia's direct contribution to global food supplies. Increasing global food supplies is one part of the solution to achieving global food security. While increased domestic productivity growth will increase the surplus available for international export, Australia remains a relatively small contributor to global food consumption. Nevertheless, there are significant opportunities for Australia to take advantage of growing demand for agricultural exports as populations and incomes increase.

Productivity and international competitiveness

International competitiveness in agriculture can be considered from the perspective of comparative advantage or absolute advantage. The former refers to the efficiency of agriculture relative to other sectors within a country while the latter refers to the efficiency of agriculture relative to other countries. These concepts are both relevant and hold implications for the future of Australia's agriculture sector.

It is often considered that Australia holds a comparative advantage in agriculture. A comparative advantage means that the opportunity costs of agricultural production are less than that faced by other countries[1]. While difficult to measure, researchers have concluded that Australia holds a comparative advantage in several agricultural products (Wonder and Fisher 1990; Sanderson and Ahmadi-Esfahani 2009). Although the extent of this comparative advantage may diminish over time, such as in response to climate change, it is unlikely to disappear all together (Sanderson and Ahmadi-Esfahani 2011).

Holding a comparative advantage in agriculture implies that the farm sector will remain an important component of the Australian economy. While labour used in agriculture may continue to fall, the sector is likely to remain the most productive user of land and some capital assets. This suggests there are economic benefits from continuing to specialise in some agricultural activities.

However, the extent to which the agriculture sector contributes to the Australian economy depends on its absolute advantage. An absolute advantage means that a country is able to produce the same amount of goods and services using fewer inputs (such as labour, land and capital) than another country. A country holding an absolute advantage has lower cost producers and is therefore more competitive on world markets. The strength of returns to agriculture largely depends on this absolute advantage.

[1] Opportunity costs are the forgone returns of the next highly valued activity to which resources could have been used.

For Australia, an absolute advantage in agriculture is particularly important given the sector's export-orientation. More than 70 per cent of all agricultural production is currently exported, and any future increases in production will likely need to be exported making the sector even more export-dependent (Andrews et al. 2003). In addition, the ability to maintain international competitiveness is essential for farmers to sell their product as they are usually price-takers in the world market. If farmers' production costs were to increase, many would be unable to sustain supply at world market prices. Farm incomes would decline and consequently the economic viability of agriculture would diminish. While some resources would be reallocated to more productive uses, resources remaining in agriculture (particularly land) are likely to realise declining returns, with flow on impacts for the economy more broadly.

Maintaining international competitiveness requires Australian farmers to uphold an absolute advantage in agricultural production. As farmers are price-takers on global markets, the returns they receive and their future viability depends on maintaining an absolute advantage relative to producers in other countries.

Measuring international competitiveness

This study uses productivity growth to evaluate the international competitiveness of Australian agriculture in terms of its absolute advantage. While comparative advantage can be measured by comparing agricultural productivity relative to non-agricultural productivity with other countries, a lack of comparable data has precluded any testing of this kind. On the other hand, absolute advantage can be measured using direct comparisons of agricultural productivity between countries.

In practice, however, various price factors also influence international competitiveness. In the short-term, supply shocks or changes in exchange rates can cause price fluctuations that shift international competitiveness. For example, a spike in the wheat price due to drought in the northern hemisphere improves the price competitiveness and returns to Australian growers while a strengthening of the Australian dollar weakens the price competitiveness of Australian farms. In the longer term, changes in world demand (such as increased demand for meat from middle-income Asia) or changes in trade policy (such as a reduction in tariff rate quotas) can shift international competitiveness. For example, Australian agriculture's competitiveness would improve were competitors to remove distorting policies that have enabled them to supply export markets at lower costs or remain protected from import competition (Ludena et al. 2007; Nair et al. 2007; Anderson et al. 2010).

There are valid reasons for focusing on productivity as an indicator of international competitiveness rather than other determinants. For the most part, shifts in global prices, demand, exchange rates and trade policies are likely beyond the influence of Australian decision-makers. And while Australia continues to pursue further agricultural trade liberalisation, the agriculture sector's main tool for maintaining agricultural competitiveness is through productivity growth. Farmers can improve productivity by selecting, adapting and adopting innovations that are well suited to their production system (Nossal and Lim 2011). Policy-makers can also promote agricultural productivity growth by improving farmers' capacity for innovation and through providing appropriate incentives for innovation and structural adjustment. Agricultural productivity is therefore the most useful indicator for tracking international competitiveness.

Cross-country comparisons of agricultural productivity can provide an indicator of changes in Australian agriculture's absolute advantage. While only two other countries are included in this analysis, Canada and the United States have remained key competitors over the long-term. Because Australian agriculture relies heavily on export markets, a sustained fall in productivity growth below many of its competitors will lead to a loss of farm incomes and viability. Given the apparent fixity of many of Australia's resources devoted to agriculture, any change could have implications for rural living standards in particular and the economy more broadly.

Productivity and global food security

The global challenge of food security requires achieving two goals: an increased food supply and reduced poverty (that is, an increased ability of people to purchase food). The FAO (1996) defines food security as 'ensuring all people, at all times, have physical and economic access to sufficient, safe and nutritious food to maintain a healthy and active life'. While Australia has the income to adequately feed its population from domestically produced food and imports, the Australian Government holds a humanitarian interest in improving food security among developing countries.

Increasing the domestic agricultural surplus available for export by improving productivity is one mechanism by which Australia can contribute to global food supplies. However, it is only a small part of Australia's food security role. It is through other mechanisms, such as reducing barriers to trade and providing technical assistance to food-deficient countries, that Australia is likely to make its largest contribution.

Improving domestic agricultural productivity growth

Australia's large arable landmass and small population enables it to produce food in excess to its consumption requirements; a large majority being exported. During the 2000s, the quantity of wheat production averaged 3.5 times domestic consumption, while beef and veal production averaged 2.8 times (Moir and Morris 2011). The total value of farm exports averaged 72 per cent of farm production between 2003-04 and 2009-10 (ABARES 2012).

Any increases in agricultural productivity in Australia will contribute to increased global food supplies. Productivity growth will enable Australia to produce more output for a given level of resource use. As Australia's domestic requirements are sufficiently met, most additional increases in agricultural output will be exported.

However, Australia's surplus agricultural production meets only a tiny fraction of global food consumption needs. Two of Australia's largest agricultural exports, wheat and beef, contribute only 2 per cent and 1.5 per cent respectively of global wheat and beef consumption (Moir and Morris 2011). In addition, despite a significant rise in the real value of Australia's exports expected between 2007 and 2050, this is likely to contribute to only 3 per cent of the growth in global exports (Linehan et al. 2012).

In addition, Australia's agricultural exports are mostly directed to high value markets, rather than countries with high food deficiencies (Moir and Morris 2011). For Australian producers and exporters, the incentive is to target markets where they receive the highest returns. In most cases this means middle and higher income consumers in developing economies that can afford Australian food exports.

An increasing share of Australian exports is destined for developing countries with a rapidly growing middle class, including China and ASEAN countries. Around 52 per cent of Australian agricultural exports are destined to developing countries, although this share is expected to significantly increase by 2030 with growth in trade with Asia (Anderson and Strutt 2012). As their incomes rise, consumers in these countries will hold greater purchasing power and demand a greater variety of food products. In particular, these consumers are increasingly able to afford more livestock and dairy products in their diets. This economic development creates opportunity for Australia where livestock product exports already make up around half of all agricultural exports (Linehan et al. 2012) and where proximity with Asia provides transport cost advantages from growth in these export markets.

Maintaining, if not improving, agricultural productivity, is important to ensuring that Australia can contribute to, and benefit from, increased global food demand. This growth is the only means of increasing agricultural output without drawing additional resources into production.

Supporting global agricultural productivity growth

Australia's main contribution to global food security has, and will continue to be, through the provision of technical assistance to food insecure countries. Assistance to agricultural production—including advice, assistance and training—builds domestic capacity to improve agricultural productivity and rural incomes. More broadly, it can drive economic development, leading to improved national food security. In addition, assistance that supports the development of improved governance and institutions is fundamental.

Australia's advanced experience in agricultural research, production, economics and policy development makes it well equipped to contribute technical assistance towards improving agricultural productivity in developing countries. Australia is a leader in agricultural research and shares many similar challenges with developing countries, including drought and disease. For example, technological innovations such as modern seed varieties, soil management practices and drip irrigation, widely used in Australian agriculture, are underutilised in developing countries. In addition, there is significant potential for more widespread use of technologies and expertise to better manage soil fertility, weather and risk. Increased awareness and uptake of such innovations can improve agricultural productivity, contributing to food production and availability in low-income countries.

Box 1 provides an overview of Australia's technical assistance program to support agricultural productivity growth, poverty reduction and improved food security among developing countries.

Box 1: An overview of Australia's technical assistance program to improve global food security

Australia contributes to global food security among developing countries through three mechanisms: 1) lifting agricultural productivity through agricultural research and development; 2) improving rural livelihoods by strengthening markets and market access; and 3) building community resilience by supporting the establishment and improvement of social protection programs (AusAID 2012).

Lifting agricultural productivity

There are several pathways through which Australia provides research, expertise and new technology to support productivity growth among developing country farmers through several pathways. For instance, the Australian Centre for International Agricultural Research (ACIAR) supports collaborative research and innovation within around thirty countries, mostly in the Asia-Pacific Region. The Centre's central mission is to lift agricultural productivity. ACIAR enables Australian agricultural scientists to use their expertise to benefit developing countries and Australia. Recent research and extension has helped to improve soil fertility in Kiribati, Fiji and Samoa, develop new rice varieties suited to Cambodia and introduce mechanised tractors to increase uptake of minimum tillage in Bangladesh (ACIAR 2012).

Australia also supports agricultural research specific to developing counties by supporting the Consultative Group on International Agricultural Research (CGIAR) and its international research centres. Further, the Australian Agency for International Development (AusAID) has contributed funding towards the Global Agriculture and Food Security Program administered by the World Bank that provides grants to developing countries to enable them to boost agricultural productivity, among other objectives.

Improving market access

Trade distortions for agriculture tend to be greater than for other goods, which is an impediment to increasing food production and incomes in developing countries. The most costly distortions are import market access restrictions, but also include trade-distorting domestic supports and remaining export subsidies (Anderson 2007). For example, domestic support measures in developed countries, especially the European Union and United States, distort trade by drawing resources into agricultural production in developed countries and away from production in developing countries.

Australia has been a global leader in pursuing agricultural trade liberalisation. It has actively pursued reduced agricultural trade barriers in multilateral and bilateral negotiations and reduced its support to agricultural producers, which is now second lowest among OECD countries (2.9 per cent) and well below the OECD average (18.8 per cent) (OECD 2012). Further liberalising agricultural markets would have significant benefits for agricultural production in developing countries and Australia (Anderson 2007).

Through AusAID, Australia also assists developing countries in improving their trade policy skills, quarantine regimes and enhancing their trade promotion (AusAID 2007). Improving these underlying policies and institutions is essential to ensure that countries may actively participate in trade negotiations and benefit from increased global food trade. In addition, Australia can play a role in assisting developing countries in adjusting to changes in markets associated with trade liberalisation. This is because many developing countries have inappropriate governance and institutional arrangements for dealing with transitional adjustment pressures associated with trade reform (Nair et al. 2007).

Building community resilience

Australia also targets AusAID resources towards building community resilience to expand the capacity of poor people to purchase or access sufficient, nutritious food, including during price shocks. For example, Australia is supporting the development of financial services (including savings, loans, payment services, insurance and money transfers) as an effective way to reduce poverty. More generally, AusAID assists in providing health, sanitation, housing and productive assets (such as livestock or equipment) to sustain rural livelihoods and strengthen economic growth over the medium to longer term (AusAID 2011).

Australia also contributes indirectly to technical assistance and poverty alleviation through support for United Nations institutions such as the Food and Agriculture Organization (FAO), the World Food Program (WFP) and the World Bank. As part of the G20 initiative in 2012, Australia has also supported sustainable improvements in agricultural production and productivity, particularly in the poorest countries, through public and private investment in agricultural research and development (Interagency Report to the Mexican G20 Presidency 2012).

Measuring and interpreting agricultural productivity

This chapter summarises the approach used to estimate comparable agricultural productivity growth and levels between countries. Unless otherwise specified, productivity in this chapter refers to total factor productivity, that is, aggregate market outputs relative to aggregate market inputs used in production. An increase in productivity indicates that inputs are being used more efficiently—that is, fewer inputs are required to produce the same output or, alternatively, that additional output is possible from a given level of input use.

ABARES has developed a database of inputs and outputs for the Australian agriculture sector for the period 1950 to 2010. These data have been drawn from the Australian National Accounts supplied by the Australian Bureau of Statistics (ABS) (ABS 2011b) and supplemented with data from ABARES commodity statistics, ABARES farm surveys and other sources to develop a complete and detailed series for Australian agriculture (while excluding fisheries, forestry and hunting activities).

Key outputs include crops (including grains, oilseeds and horticulture) and livestock (including livestock products). Key inputs include land, labour, capital and other intermediate inputs. Land is quality-adjusted to account for variation in soil quality, moisture and other characteristics.

Similar databases compiled by the USDA ERS and by Agriculture and Agri-Food Canada were provided to ABARES. These databases extend from 1949 to 2010 for the United States and 1961 to 2006 for Canada. It should be noted that international collaboration is ongoing and that these databases will be updated over time in response to advances in data availability or methodology.

These data have enabled the development of internationally comparable indexes of agricultural productivity for Australia, Canada and the United States for 1961 to 2006. Unlike traditional estimates of agricultural productivity, these estimates use an approach developed by the USDA for the purpose of international comparisons. The theoretical underpinnings and technical details of this approach are outlined in appendix 2.

In brief, productivity measurement was conducted in four major stages.

- Data on input and output prices for each country were adjusted to form comparable series using a real price index. This price index reflects 'purchasing power parity' (PPP) across Australia, Canada and the United States, estimated in each year from the price of a basket of all inputs and outputs relative to the real United States price for an equivalent basket (in 2005 US dollars).

- These comparable input and output prices were aggregated to a total input price index and a total output price index using a chained, Törnqvist index number approach with weights derived from data on cost or revenue share of each input and output. These aggregate indexes were adjusted for transitivity to ensure comparability between countries and years using a procedure recommended by Caves et al. (1982).

- Data for total input and output values were divided by the aggregate input and output price indexes, respectively, to derive consistent input and output quantity indexes.

- The ratio of the total output quantity index to the total input quantity index was used to measure total factor productivity.

Comparison and compatibility with other estimates

Several estimates of agricultural productivity growth for Australia have already been published (Productivity Commission 2005; ABS 2011a; Gray et al. 2012). ABARES produces annual productivity estimates for selected agricultural activities. These estimates enable detailed analysis of the performance of major farming activities and regions. The ABS produces annual estimates for industry sectors including agriculture fisheries and forestry. These estimates enable productivity comparisons between sectors of the economy.

These existing estimates are not comparable with each other or with estimates of productivity across other countries due to many methodological and data related differences. For example, while ABARES uses farm-level data, the ABS uses aggregate national accounts data. In addition, each approach uses different time periods, industry mixes, index number methods and variable definitions. For these reasons, estimates from ABARES and the ABS are not comparable.

Some international comparisons of agricultural productivity growth have also been undertaken, some of which include Australia. Two that compare total factor productivity (rather than partial factor productivity of land and labour) are Coelli and Rao (2005) and Fuglie (2010). Coelli and Rao (2005) used FAO data and Malmquist distance functions to estimate productivity growth for 93 countries, including Australia. More recently, Fuglie (2010) estimated productivity growth for several country groups, including 'Australia and New Zealand' as a residual of output growth minus input growth using FAO data. To address the lack of price data necessary for international comparisons, country-level case studies on productivity typically use derived fixed input cost-shares. While a conscious effort has been made in these studies to address data and measurement limitations, there are acknowledged biases within the results (Alston et al. 2010a). Further, as these methods preclude estimating productivity levels, they cannot be used to evaluate relative competitiveness.

While developing another agricultural productivity series for Australia may, at first glance, seem questionable, the estimates produced through this study address several research gaps. First, they allow for total Australian agricultural productivity to be estimated separately from fisheries and forestry activities, which rely on dissimilar inputs, outputs and production processes. Second, they contain more detailed, sector-specific data than the aggregate ABS statistics allow for. Third, they enable Australian agriculture to be directly compared with the agriculture sectors of its competitors in terms of both productivity growth and level.

Productivity growth and productivity levels

Both the level and growth rates of total factor productivity were estimated and compared for the countries included in this analysis. These estimates can both be useful for analysing international competitiveness.

Productivity growth is the most common productivity measure. In this study, it is estimated residually as the rate of change in output not explained by the rate of change in input use. Productivity growth suggests more efficient ways of production have been identified, typically through adopting new technologies, processes or production organisation. As a result, more output can be produced from the same or fewer inputs.

Productivity growth is best measured using long-term rates of growth, especially for agriculture where output is highly variable. Long-run growth rates are useful for mitigating the effect of short-term factors on performance measurement, particularly when these are beyond the control of farm managers. For example, seasonal variability can lead to sharp fluctuations in agricultural output and may also influence input decisions in the short-term. By minimising these influences, underlying improvements in performance are better captured.

While measuring productivity growth over at least ten years is a general rule of thumb, caution is required in selecting start and end years. Misleading growth rates may be presented if an atypical start or end year is selected, for example, a drought year.

Productivity levels are also useful in comparing performance over time or entities. Productivity levels are measured as a ratio of outputs to inputs. Generally speaking, comparing productivity levels is less reliable than comparing growth rates, particularly where the methodology has not been designed for this purpose. However, the methodology employed in this paper allows for productivity levels to be compared between countries. A consistent framework has been used and a transitivity condition has been imposed (as detailed in appendix 2).

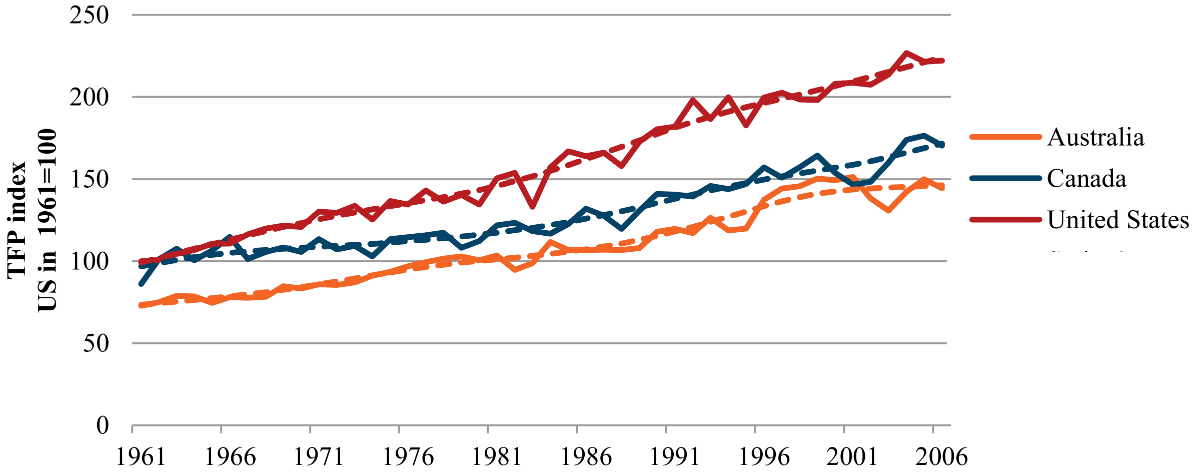
Estimates of productivity levels assist in understanding reasons behind productivity growth differences. For example, countries with faster agricultural productivity growth may be starting from a lower base. If so, faster growth in productivity may have helped in catching up to the frontier, even though they may still lag in performance and competitiveness. Developing countries are commonly observed to have faster productivity growth rates through adoption of technologies already in use by developed country counterparts, suggesting a convergence in productivity levels (Ludena et al. 2007).

Cross-country comparisons of agricultural productivity

Trends in agricultural productivity and competitiveness

Compared with Canada and the United States, the level of agricultural productivity in Australia has been relatively low over the past five decades (Figure 1). While Australian agriculture briefly became as productive as Canada in 2001, this corresponded with a severe drought in Canada. Comparatively, agriculture in the United States has been the most productive over the long-term.

Figure 1: Agricultural TFP levels, 1961–2006



Note: Trend smoothed using a Hodrick-Prescott filter with a parameter of 100

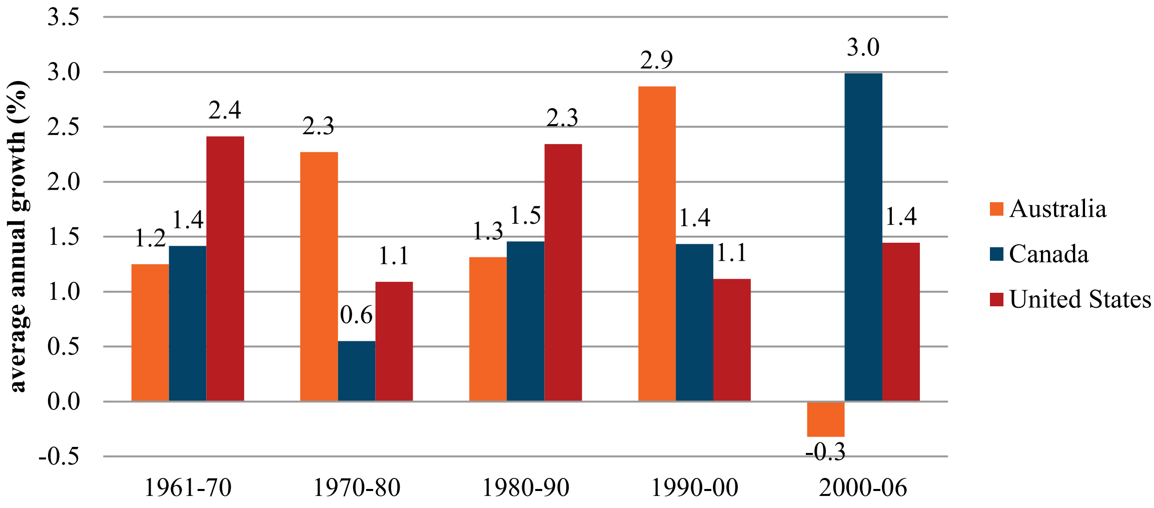
Productivity growth has been most rapid in the United States agriculture sector (1.8 per cent a year), exceeding that realised in Australian agriculture (1.6 per cent) and Canadian agriculture (1.2 per cent) between 1961 and 2006 (Table 1). Notwithstanding Australia's higher growth rate has yet to consistently exceed agricultural productivity levels in Canada.

Beyond these broader trends, productivity growth rates have varied considerably between the three countries over this period. Australia achieved more rapid agricultural productivity growth than both the United States and Canada during the 1970s and the 1990s (Figure 2), while United States growth surged during the 1960s and 1980s. From 2000 to 2006, average annual productivity growth in Australian agriculture was negative. Although negative agricultural productivity growth is far from desirable, it is acknowledged that such short-term estimates can be misleading indicators of underlying technological progress because they may indicate a random deviation rather than a fundamental shift (OECD 2001). For example, while Australia experienced drought over much of the 2000s, there is little evidence to suggest that the downturn in productivity growth reflects an ongoing trend.

The results suggest Australian agriculture has been less competitive than the United States and Canada in terms of absolute advantage. Lower productivity implies that, in aggregate, Australian agriculture has faced higher per-unit production costs, which have disadvantaged it on world markets.

In spite of this, Australian agriculture has maintained its relative productivity and, in turn, its competitiveness, at around 70 per cent of United States, which is seen as a global leader in agriculture. Of course, it is difficult to interpret the overall competitiveness of Australian agriculture given only two other countries are in this comparison. However, it is encouraging that Australian agriculture has maintained productivity as a constant proportion of the levels realised by the United States, and improved relative to Canada over the long-term.

Figure 2: Agricultural TFP growth, 1961–2006



Impacts on agricultural production and input use

Agricultural output increased more rapidly in Australia and Canada (at 2.1 per cent and 2.0 per cent a year, respectively) than in the United States (1.6 per cent) between 1961 and 2006 (Table 1). As a result, total agricultural production in Australia (and Canada) has almost tripled over the past four decades in contrast to production doubling in the United States.

Table 1: Average annual output, input and TFP growth, 1961–2006

	TFP growth %	Output growth %	Input growth %	Land PFP %	Labour PFP %	Capital PFP %	Intermediate PFP %
Australia	**1.6**	2.1	0.4	2.4	4.6	0.2	1.5
Canada	**1.2**	2.0	0.8	2.2	3.7	1.6	-0.3
United States	**1.8**	1.6	-0.2	2.1	3.8	2.2	0.6

Note: Any discrepancies between totals and sums of components are due to rounding

For all three countries, productivity growth has been the main driver of agricultural output growth over the long-term (Figure 3). Nonetheless, both Australia and Canada have, in part, relied on input expansion to increase agricultural output. Over the study period, input use increased by 0.4 per cent a year in Australia and by 0.8 per cent a year in Canada. In comparison, the United States agriculture sector has operated at a significantly larger scale (producing around 10 times more than Australian agriculture) (Figure 4). Over the long-term, productivity growth in the United States enabled increased output using fewer inputs on aggregate. In other words, productivity growth has more than offset the reduction in input use.

Australia's increased input use was mostly composed of additional capital and intermediate inputs (Figure 5). Australian agriculture accumulated capital during the 1970s when a global increase in commodity prices and a relative decline in the cost of capital accelerated investment in capital inputs. The sector took the opportunity to expand farm size and adopt new machinery, stimulated by government policies including accelerated rates of depreciation and an investment allowance (Ockwell 1990). After 1983, higher interest rates and a fall in the price of labour saw the rate of capital accumulation fall. However, it has, again, increased over the most recent decade.

In contrast, the labour employed in agriculture in Australia has declined by 2.5 per cent a year on average and land use has declined by 0.3 per cent a year over the same period. This trend has mirrored the experience of Canada and the United States where the agriculture sector has, in part, shifted away from land and labour inputs. Capital deepening and improvements in labour quality, through a larger share of more educated and more experienced workers, are reflected in these trends, as are improvements in the productive capacity of farm land made possible through innovations in fertilisers, pesticides and crop and pasture varieties.

Figure 3: Relative contributions to output growth, average (1961–2006)

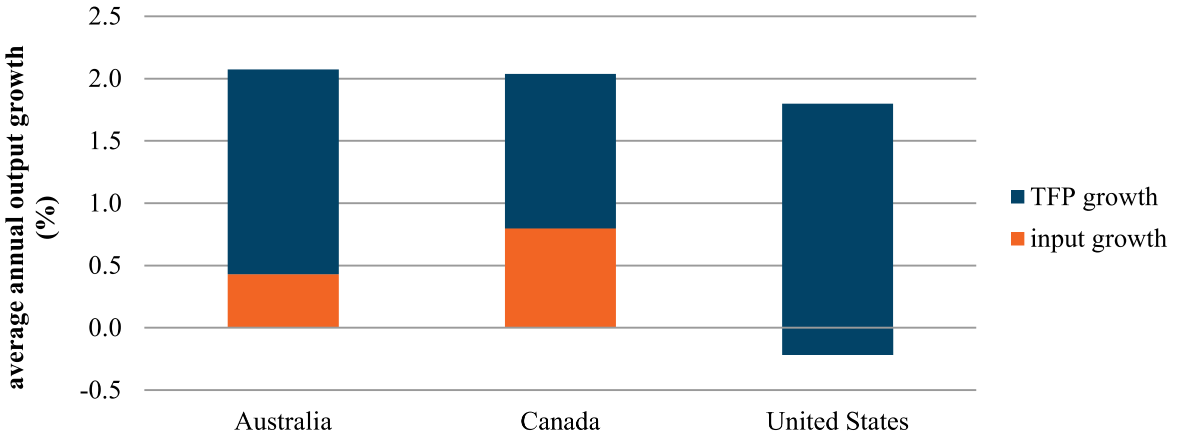


Figure 4: Agricultural output levels, 1961–2006

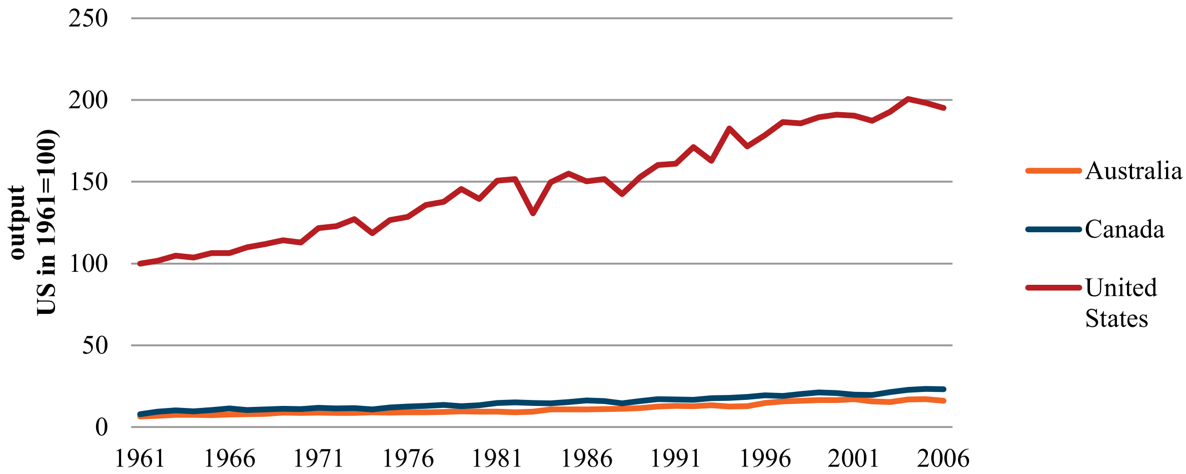
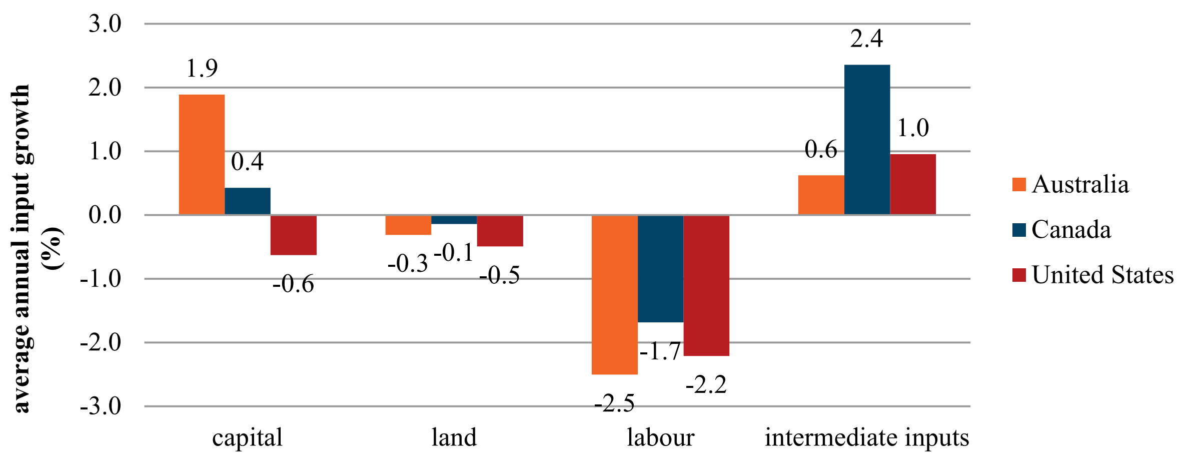


Figure 5: Input growth, by type, 1961–2006



Box 2: Testing for a slowdown in agricultural productivity growth

Recent research has pointed towards a slowdown in agricultural productivity growth in Australia, the United States and globally (Alston et al. 2009a; James et al. 2009; Sheng et al. 2011b), despite mixed evidence within and between countries (Fuglie 2010).

Whether or not total factor productivity has slowed is difficult to determine from observing productivity trends and growth rates. A common approach is to compare growth rates over shorter term periods or before and after a particular year. However, the choice of start and end years is somewhat arbitrary and may inadvertently identify or miss a turning point (Ball et al. 2012). Also problematic have been studies that focus on yield to identify productivity slowdowns, thereby overlooking the possible impacts of intensification of other inputs.

Recently, more advanced methods have been used to test for structural breaks in agricultural productivity growth trends.

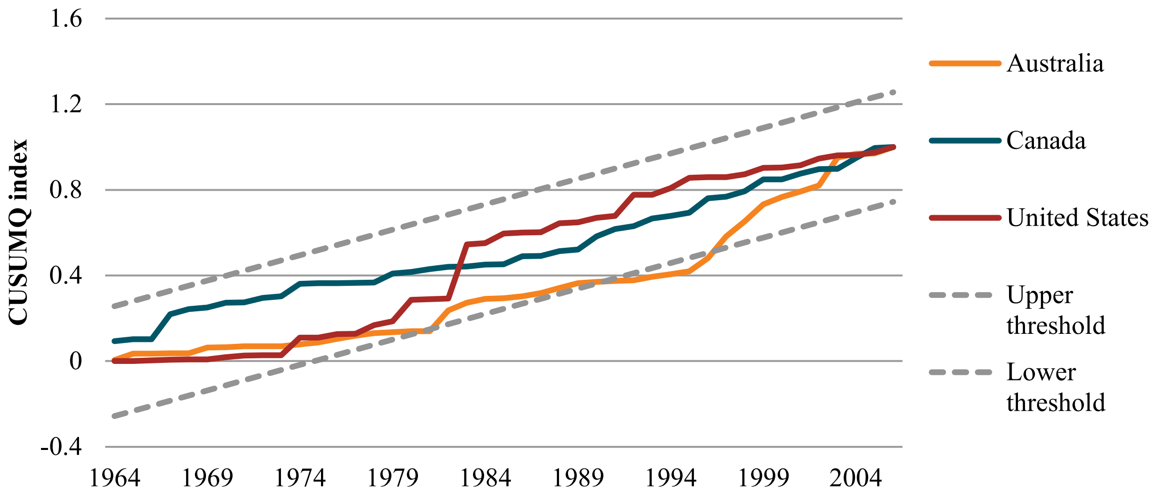
- Sheng et al. (2011b) used a cumulative sum of squares (CUSUMQ) test to investigate whether there had been a structural break in broadacre productivity growth in Australia and therefore a turning point in the productivity growth trend. The analysis identified a turning point in broadacre productivity in 1994, after which productivity growth slowed.
- Ball et al. (2012) analysed agricultural productivity growth in the United States using a 'quasi-Local Level' test to identify structural breaks followed by various unit root tests with and without structural breaks to identify the timing of these breaks. Significant breaks were identified in 1974 and 1985. While 1974 signalled a slowdown in agricultural productivity growth, the 1985 break was a one-time upward shift in the level of productivity coinciding with significant liberalisation of farm policy

The slowdown hypothesis was tested for the agricultural productivity estimates for Australia, Canada and the United States using a simple CUSUMQ test to accompany the international comparison analysis of this study. The test was used to identify significant structural breaks in productivity series outside a five per cent significance threshold. Short-term climatic shocks and possible cross-country interactions were not considered.

The data indicate a significant structural break in the agricultural productivity trend in Australia in 1998 (Figure 6). Comparing productivity growth before and after this period finds that productivity growth slowed from 1.66 per cent a year from 1961 to 1998 to –0.47 per cent a year from 1998 to 2006.

In comparison, no significant turning point in agricultural productivity was observed in the United States and Canada.

Figure 6: Structural break in agricultural TFP trend



What is behind Australian agriculture's performance?

There are many reasons to expect Australia's agricultural productivity to be on par with that of other developed countries. Like Canada and the United States, Australia is a well-developed economy with agriculture accounting for only a small share of GDP and employment. All three export a significant share of their agricultural production and, over time, have experienced similar trends towards fewer farms and a smaller agricultural labour force as farms have become larger and more capital intensive.

The drivers of agricultural productivity growth identified in country-specific analyses have been similar between countries. Domestic analyses of productivity in Australian agriculture (Productivity Commission 2005; Gray et al. 2012), Canadian agriculture (Veeman and Gray 2010) and the United States (Alston et al. 2010b; Ball et al. 2011) have highlighted key drivers in common, including:

- continued investment in research, development and extension
- increased adoption of advanced technologies and practice innovations
- improvements in human capital
- reallocation of resources and enhanced specialisation
- greater trade openness and market competition.

However, while these drivers may be similar, there are many country-specific factors that have influenced productivity levels and growth rates. For example, physical, geographic, economic and policy related factors can shape the industry composition and inherent comparative advantages in agricultural production. Importantly, although many are beyond the influence of industry and governments, influencing some may offer opportunities for the future. These factors also provide insights into why Australian agriculture lags Canada and the United States, as well as highlighting where industry and government may be under utilising opportunities to improve productivity and competitiveness.

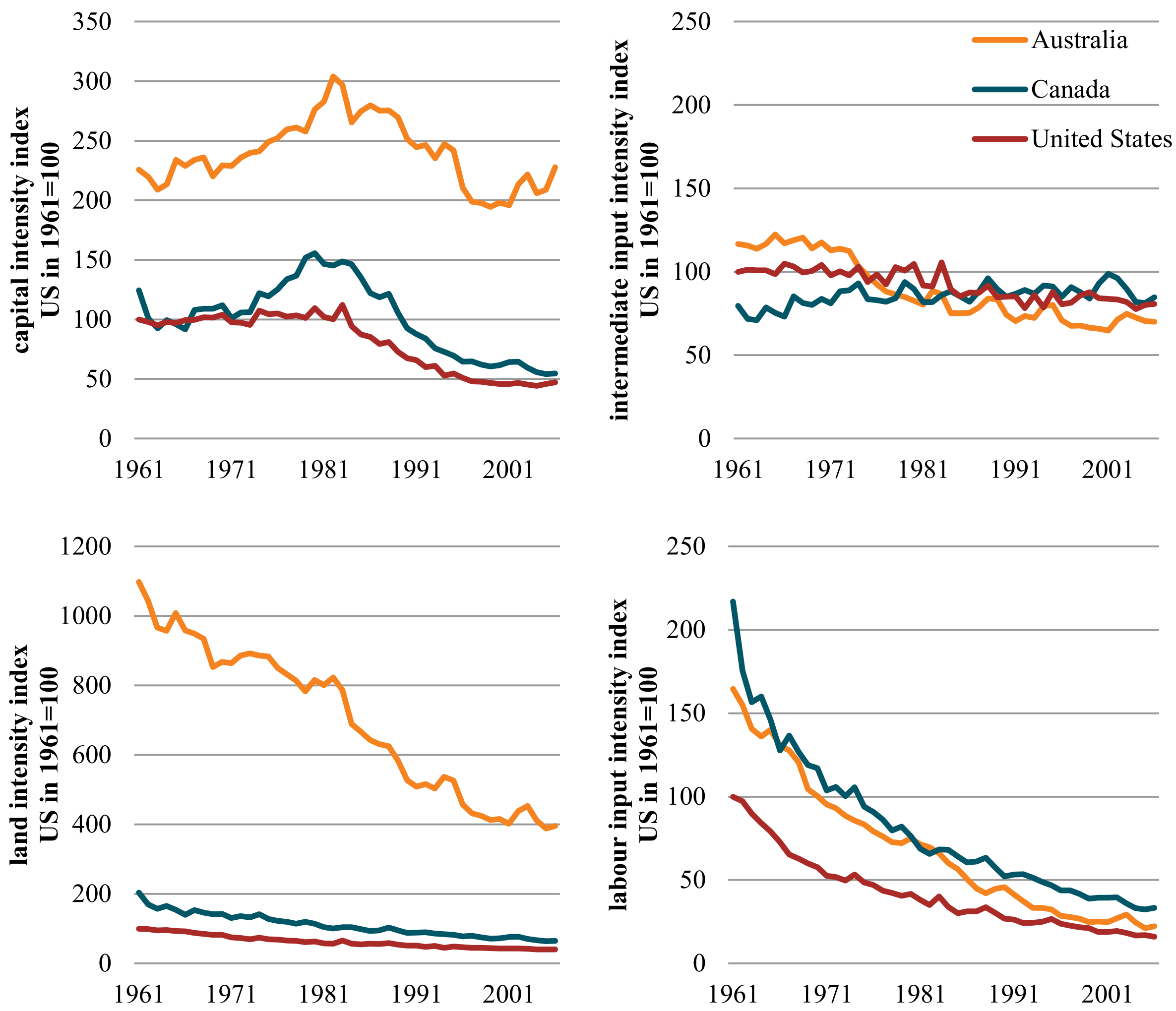
Physical characteristics

Agricultural land use decisions are, for the most part, dictated by resource characteristics such as soil type, topography, vegetation and rainfall. Australia, like other countries, has distinct regions suited to particular agricultural activities. For example, vast arid and semi-arid regions are best suited to livestock grazing on native pasture. Beef and sheep production makes up 55 per cent of total land use in Australia and 43 per cent per cent of total agricultural production (in value terms).

The specialisation of Australian agriculture towards extensive grazing may constrain its ability to match the productivity levels achieved by Canada and the United States. Grazing properties in Australia have historically achieved slower rates of productivity growth than cropping farms reflecting fewer technological advances and limited substitutes for land (Gray et al. 2012). In contrast, intensive non-ruminant livestock farm (mostly pigs and poultry) have achieved more rapid productivity growth than ruminant livestock because of technological advances such as improved feed efficiency (Ludena et al. 2007). All other things equal, a country with more resources allocated to high productivity activities will, on average, exhibit higher productivity.

Australian agriculture is relatively more land intensive than both Canada and the United States, using around ten times as much land per unit of output over the most recent decade (Figure 7). Although Australia has been using land more productively over time, increasing land partial factor productivity by 2.4 per cent a year, the nature of its resource characteristics suggest a comparative advantage in livestock grazing. Consequently, Australian agriculture is likely to remain more land intensive than North America.

Figure 7: Input intensity (input per unit output), 1961–2006



Climate

The considerable within year climate variability experienced in Australia has had a significant effect on agricultural productivity (Hughes et al. 2011). While some agriculture is irrigated, the vast majority is dryland and relies on low rainfall and as a result is highly vulnerable to climate. El Niño events are associated with widespread and severe drought, and increased temperatures, particularly across eastern Australia. These have occurred in 1982–83, 1994–95, 2002–03 and 2006–07 (ABS 2012).These droughts caused notable downturns in agricultural output and productivity (Figure 1).

Canada and the United States are not immune to drought, but in general, their droughts have been less widespread and less frequent. The widespread drought conditions that affected Canada in 2001–02 and the United States in 2012 were both the most extensive droughts experienced in over 50 years (USDA ERS 2012). These droughts had notable impacts on farm production. For example, the productivity downturn in Canada that enabled Australia to surpass its productivity level was likely driven largely by poor seasonal conditions. Notwithstanding these impacts, in general, North American droughts have had a lesser impact on long-term agricultural performance.

Climate change is also projected to affect agricultural productivity in Australia by more than that in North America. Given other conditions constant and relative to what otherwise would have been the case, agricultural productivity is projected to fall by 17 per cent in Australia by 2050, compared with declines of four per cent in the United States and one per cent fall in Canada (Table 2)[2] (Gunasekera et al. 2007). These productivity impacts largely stem from changes in water availability, water quality, temperatures and pests and diseases. While these impacts are likely to vary across different industries and regions, Australia is likely to need adaptation technologies and appropriate policies that facilitate structure adjustment in Australia to enable ongoing productivity growth.

Table 2: Projected changes in agricultural productivity from climate change at 2050

	%
Australia	–17
Canada	–1
United States	–4
China	–4
Japan	–4
New Zealand	1
ASEAN	–12
India	–25
Argentina	–7
Brazil	–10
European Union	–4
Rest of Europe	–4
Least developed countries	–18
Rest of the world	–13

Based on Cline (2007)

Geography

Australia's relative remoteness from global economic centres may also affect its productivity levels relative to other countries. While Canada exports 49 per cent of its production to the United States, Australia's is relatively remote from large markets[3]. Firms geographically distanced from centres of world economic activity tend to pay more for capital equipment, face higher transport costs in reaching foreign consumers and have lower productivity than more economically proximate firms (Battersby 2006; Dolman et al. 2007). As such, it is possible that Canada draws part of its competitive advantage over Australia because of its geographical closeness to the United States.

Domestic geography may also impede agricultural productivity in Australia given the long distances from regional Australia to ports and domestic market centres. Australia's population is concentrated in dispersed capital cities. While Canada is a similar geographic size and population, close to 1 in 5 Canadians live in rural areas compared with 1 in 9 Australians. The population density of the United States is much greater than either Australia or Canada (Table 3).

Australia's population dispersion may partially explain its relatively higher capital intensity and lower productivity (Table 3). For example, a disperse population reduces the efficiency with which infrastructure may be used and is associated with fewer gains from economies of scale, reduced competitive pressure on producers and a lesser ability to access agglomeration economies (Dolman et al. 2007).

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[2] These ABARE (now ABARES) estimates followed the assumptions of Cline (2007) and assume no carbon fertilisation effects (whereby increased carbon dioxide concentrations increase plant photosynthesis). Carbon fertilisation is expected to reduce the severity of climate change impacts on agricultural productivity. Projected changes are relative to a 2005 base year. ABARES is updating these projections for release in 2013.

[3] 'Remoteness' is the weighted average of a country's distance to all potential trading partners (that is, all other countries in the world) where weights are determined by the potential trading partners' GDP (RBA 2005).

Table 3: Population distribution and infrastructure

	Population density (people per sq. km of land area)	Urban population (% of total)	Road (km per '000 people)	Rail (km per '000 people)
Australia	3	89	37	0.4
Brazil	23	84	na	0.2
Canada	4	81	41	1.7
China	143	49	3	na
New Zealand	17	86	22	na
United States	34	82	21	0.7
OECD	36	79	na	0.5

Source: World Development Indicators Database, World Bank

Note: Data for 2010, or closest year available

Economy

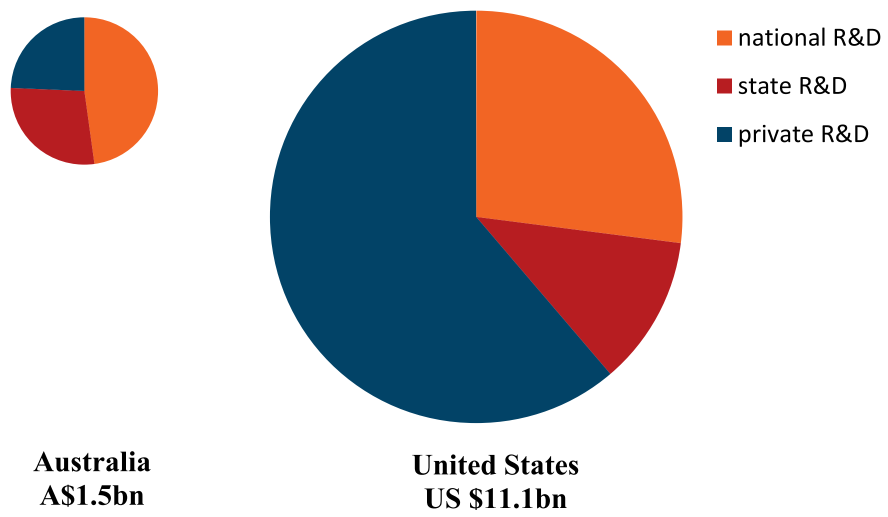
The large size of the United States economy gives it a number of competitive advantages over Australia and Canada. The gross domestic product of the United States is around US$15 Trillion, more than 10 times that of Australia. In addition, the value of agricultural production in the United States was more than seven times that in Australia in 2010. The size of the United States agriculture sector enables greater gains from specialisation and scale, greater domestic competition and a greater capacity for R&D than afforded to Australia.

Gains from specialisation and scale associated with a large sector have enabled the United States to achieve lower costs per unit of production. The reduction in average costs of production as the sector expands and shifts towards larger farms, coupled with an aggregate reduction in overall input use, has improved the competitiveness of United States agriculture. Australia and Canada have also seen a trend toward fewer larger farms over time, albeit to a lesser extent.

The United States also holds significantly more capacity for R&D and innovation. Most recent estimates for both public and private agricultural R&D expenditure indicate the United States has a much greater capacity for generating new technologies and practices than Australia (Figure 8). Many of the world's largest chemical, machinery and plant breeding companies are located in the United States. As a result, intermediate inputs have been cheaper in the United States relative to other countries, at least over the past two decades.

In comparison, Australia relies heavily on international research spillovers. For example, Sheng et al. (2011a) found that public agricultural R&D expenditure in the United States could account for up to one-third of long-term productivity growth in Australian broadacre agriculture. While Australian agriculture has a well-established domestic R&D sector, largely funded by public investment, its small domestic capacity makes it relatively difficult to attract large scale private investors.

Figure 8: Public and private R&D expenditure

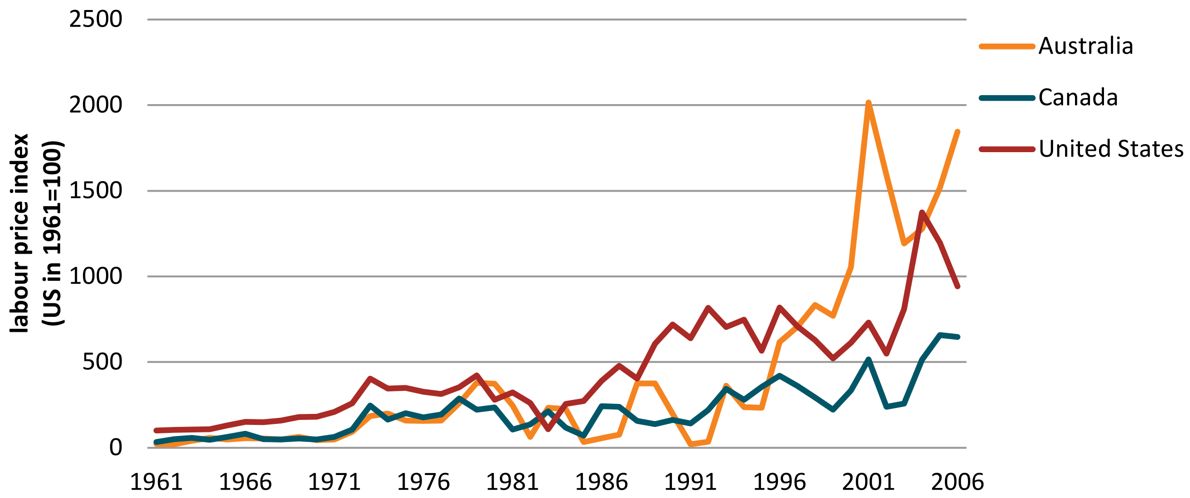


Source: PC (2011) and USDA (2012)
Note: All data in own currency for most recent year (Australia in 2008-09 and the United States in 2006)

Australia's small labour force and high demand for labour across the economy has provided strong incentives for Australian agriculture to become more efficient in its use of labour. Labour productivity growth for Australian agriculture averaged 4.6 per cent a year from 1961 to 2006, higher than both the United States (3.8 per cent) and Canada (3.7 per cent) (Table 1). This made a significant contribution to Australia's agricultural productivity growth.

However, Australian farm labour inputs have become relatively more costly than those in Canada and the United States, which are likely to impede productivity and competitiveness (Figure 9). With two-thirds of Canada's population, but four-fifths of its GDP, Australia's labour market is relatively tight. In addition, Australia does not have access to a large migrant labour force as available to the United States and, to a lesser extent Canada, particularly since the North American Free Trade Agreement (NAFTA) was signed in 1994.

Figure 9: Agricultural labour price index, 1961–2006



Policy

Over time, changes in agricultural and other economic policies have influenced productivity trends in Australia, Canada and the United States. In Australia, rural R&D policy and trade policy have been two major drivers of agricultural productivity growth. Over the long-term, changes in R&D and trade policy lead to shifts in input and output prices driving innovation, resource reallocation and productivity growth. Broader macroeconomic management and microeconomic policy reforms, including competition policy reforms, have led to more flexibility and innovation in agricultural production.

R&D policy

Governments account for more than 75 per cent of agricultural R&D in Australia and Canada, but less than 50 per cent of agricultural R&D in the United States. While the appropriate amount of government intervention is difficult to estimate, it is likely that the net benefits for private investors are insufficient to motivate an optimal level of private investment in agricultural R&D, because of the existence of significant public spillovers. Accordingly, public investment can help to mitigate underinvestment in rural research.

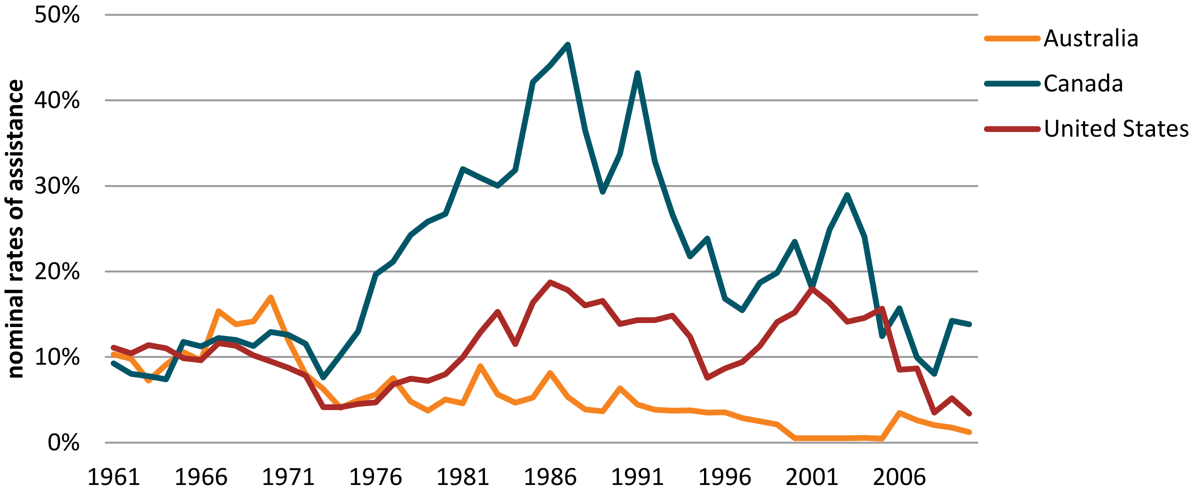
The Australian Government implements a range of rural R&D programs, the largest of which is the Rural Research and Development Corporations (RDC) program. Fifteen RDCs are jointly funded by government and primary producers via statutory and voluntary levy-based contributions. The RDCs procure research from public and private institutions, including state governments, universities and CSIRO. Around 30 per cent of Australian Government funding for agricultural R&D is allocated to the RDCs, with the remainder allocated to Cooperative Research Centres, CSIRO, universities and other departmental programs. A small amount of support is through uptake of R&D tax concessions.

While it is not possible to infer whether public investments in rural R&D have been adequate, most analyses suggest that such investments have contributed significantly to agricultural productivity growth. Estimates for the Australian broadacre industry suggest that domestic public R&D investment has contributed to around 17 per cent of productivity improvements, with domestic extension investment contributing to another 14 per cent (Sheng et al. 2011a). Globally, estimates of the rates of return to agricultural R&D have been wide ranging, with a median return of 48 per cent a year (Alston et al. 2000).

Trade policy

Australian agriculture has benefited from more open trade policies characterised by low levels of government intervention. And, importantly, Australian agricultural productivity has continued to improve without agricultural subsidies (Anderson et al. 2007). Agricultural tariff reduction began in Australia in the early 1970s and was accelerated during the 1980s and 1990s. Other assistance measures, including price supports, input subsidies, tax incentives and credit measure were also scaled back. Nominal rates of assistance for Australian agriculture fell from a peak of 16 per cent in 1970 to less than 3 per cent in the 2000s (with the exception of 2006 when exceptional circumstances payments were widely employed due to drought) (Figure 10). In comparison, government assistance to agriculture in Canada and the United States increased during the 1970s and early 1980s but was subsequently scaled back during the 2000s. Support in the United States and Canada remains higher than that in Australia.

Figure 10: Nominal rates of assistance to agriculture, 1961–2009



Source: Anderson and Nelsen (2012)

Competitive pressure on agricultural producers associated with open trade policies is likely to have been a driver of productivity growth in Australian and international agriculture. Open trade and increased market access increases opportunities for farmers to use resources more efficiently or alternatively, to release resources for more productive use elsewhere in the economy. As such, trade is associated with a shift in industry composition towards more efficient farms. Also, research has demonstrated that competition associated with increased trade induces innovation among farmers by providing an incentive to become more efficient (Kiriyama 2012).

As well as low levels of agricultural support, Australian agriculture has benefited from broader trade liberalisation, such as that achieved through free trade agreements with ASEAN, New Zealand, Singapore, Thailand, Chile and the United States. This has enabled the sector to access both cheaper farm inputs (for example, vehicles and machinery) and a greater variety of inputs (such as crop varieties).

Concluding comments

Implications for Australian agriculture

Projected growth in global food demand presents agricultural exporting countries with favourable opportunities. As with many other countries, Australia's supply response is likely to depend more on productivity growth than input growth, given natural resource constraints and competing demands for inputs, in particular, labour. However, countries differ in their capacity to respond through productivity improvements. As discussed, key differences include: industry composition, endowments (climate, physical geography), capacity for R&D, and policy and institutional settings.

Australia's agricultural productivity performance has been consistent over many years. Although it has historically been lower than that achieved by Canada and the United States, the results from this study are encouraging for two reasons. First, Australia's productivity has improved relative to Canada. Second, it has stayed constant (around 0.7) relative to the United States. In the latter instance, this is despite a significantly smaller production and research capacity; fewer scale advantages, greater geographic remoteness and a highly variable climate.

However, Australian agriculture faces several emerging productivity challenges which may affect its ability to enhance international competitiveness. Globally, competition in agriculture is likely to increase as middle income countries (importantly, China, India and Brazil) achieve rapid productivity growth by investing heavily in public R&D and by adopting technologies prevalent in developed countries (Pardey 2012). In Australia, natural resource pressures associated with climate change, increased societal expectations regarding environmental outcomes and an ageing rural population are likely to weaken the capacity of agriculture to maintain productivity growth.

Against this backdrop, the ability of Australian agriculture to realise further improvements will depend on an operating environment that promotes innovativeness and sharpens price incentives that facilitate structural adjustment. More specifically, this depends on broader economic and policy settings, including investments in R&D, innovation, infrastructure and human capital and in policy reforms that enhance farmers' flexibility to respond to market signals.

Towards a policy reform agenda

Analysts have identified many opportunities for microeconomic policy reform in Australia. The Productivity Commission has compiled a raft of potential initiatives based on past inquiries over the past decade or so (Banks 2012). In addition, ABARES has also identified several areas specific to agricultural productivity (see, for example, Gray et al. 2012). Common themes include, for example, drought support, fragmented infrastructure and native vegetation regulations that impose restrictions or additional costs on farm businesses.

This study's comparison of Australia, Canada and the United States also points to reform areas that could facilitate productivity growth in Australian agriculture, in particular, rural R&D and labour market policies.

- R&D efficiency and effectiveness could, among other ways, be improved by leveraging Australia's small domestic capacity for rural R&D through harvesting greater international knowledge spill-ins. This includes accelerating access to advanced farm inputs and operating practices that can be adapted or directly applied. This could complement efforts to improve the efficiency of Australia's rural R&D system by avoiding duplication and better utilising existing innovations (Alston 2002; Productivity Commission 2011).

- In addition, labour market reforms are potentially a high priority—labour is significantly more costly for Australian agriculture than for North America. In this regard, various commentators have highlighted labour market rigidities as constraining Australian businesses (Banks 2010; Eslake and Walsh 2011). Reforms that improve flexibility in wage determination and recruitment and enable businesses to readily make organisational changes could yield productivity improvements for many rural businesses. In addition, improving access to skilled labour, including temporary and permanent migrant workers could also serve to improve agricultural productivity.

Future research

The data series developed in this analysis has contributed to a better understanding of how Australian agriculture has performed relative to two key competitors. For the first time, trends in Australian agricultural productivity can be considered independent of the fishing and forestry sectors.

There is considerable scope to broaden the analysis to involve additional countries, to improve measurement methodologies and to further analyse drivers of agricultural productivity, such as foreign innovation spill-ins.

- Including additional countries within the comparison would provide further insight into the relative competitiveness of Australian agriculture. Towards this, several countries have commenced work towards developing a consistent dataset, including Brazil, China and the European Union.

- Improving the quality adjustments for land and other inputs (such as labour) would better capture productivity gains attributable to the sector. For example, improvements in human capital over time, through education, experience and informal training, have improved the quality of labour such that residual-based or hours-based measures may underestimate the contribution of labour to output growth.

- Increasing supplementary data collection (such as innovation survey data) to support analysis of productivity determinants is required to develop a comprehensive agenda for enhancing long-term agricultural productivity. Productivity indicators alone are insufficient for understanding drivers of industry performance.

In addition, further research could assist in developing strategies for Australia’s rural innovation system to take advantage of agricultural innovation spill-ins. In the first instance, this could involve identifying the sources and channels by which Australian agricultural industries access R&D spill-ins and reviewing their capacity to make efficient use of these. Evaluating the potential impacts of harnessing external spill-ins for Australia’s rural R&D capacity and long-term agricultural productivity growth would also provide relevant information for refining specific initiatives.

Appendix 1: Literature review

Measurement of agricultural productivity between countries

Past studies have highlighted the challenge of developing reliable international comparisons of agricultural productivity. Obtaining the data required for cross-country comparisons remains difficult, with some economists warning of 'insurmountable data constraints' in producing an international data set (Craig et al. 1997; Fuglie 2010). Even where reliable data are available, there are often limitations to the comparability of input and output groups and difficulties in developing consistent units of measurement (Capalbo et al. 1990).

Under the growth accounting approach, both price and quantity data are required for estimating productivity. In past comparisons of agricultural productivity, aggregation of diverse outputs has been made possible by using a fixed set of average global prices. Aggregation of inputs is more difficult due to limited data and wide price disparities between countries. For example, transactions of land and labour inputs may not be reported, particularly in developing countries (Fuglie 2010).

Most commonly, FAO data have been employed for agricultural productivity comparisons, (for example Rao et al. 2002; Coelli and Rao 2005; Alston et al. 2009b; Fuglie 2010) even though it only partially covers agricultural outputs and inputs and does not include the necessary input price data (Alston 2010). For example:

- Coelli and Rao (2005) compared productivity between 93 countries between 1980 and 2000 using FAO data. The study avoided the need for price data by using a Malmquist index formula which relies on distance functions. The use of Malmquist index formula is widespread for such comparisons, but the implicit cost shares derived can be unrealistic and the estimates can be highly sensitive to the set of countries included and the number of variables in the model (Coelli and Rao 2005; Headey et al. 2010). The main implication is the need for a large cross-section of observations to produce valid TFP estimates.
- Ludena et al. (2007) used the same approach but disaggregated outputs and inputs according to crops, ruminant livestock and non-ruminant livestock.
- Fuglie (2010) used a traditional index number approach to estimate productivity growth for 171 countries between 1961 and 2007. FAO data were supplemented with input cost-share data from country level case studies of agricultural productivity and average cost-share estimates applied to other countries with similar agriculture sectors. While the approach could not be used to compare productivity levels, it provided a useful starting point for international productivity analysis.

To address the main challenge facing international comparisons of agricultural productivity—a lack of reliable input price data—Ball et al. (2001) sought to define a new production account framework for data collection that could be applied consistently between countries. The approach was applied to comparisons of agricultural productivity between the United States and nine countries within the European Union for the period 1973 to 1993. Output (and input) price indexes were developed for each country and made comparable using purchasing power parities. An implicit output (and input) quantity index was derived by dividing total agricultural output value (and input costs) by a corresponding output (and input) price index. The indexes were estimated using a Fisher index formula coupled with the EKS procedure (Eltetö and Köves 1964; Szulc 1964) to achieve transitivity.

Later, Ball et al. (2010) revised and extended these estimates to include 11 European Union countries and the United States for 1973 to 2002. To simplify the computational requirements, Ball et al. (2010) moved to a translog index formula adjusted using the CCD procedure (Caves et al. 1982) for transitivity. Under this approach, output (and input) price indexes were made comparable using purchasing power parities for a reference period (in this case, equal to 100 in the United States in 1996) with time-series indexes derived by chain-linking these with the reference period. Output data were improved by the inclusion of output services, such as machinery hire. Input data were improved through including capital input subsidies (to develop improved estimates of user costs) and, in particular, land prices were improved through the use of a hedonic price index that captured land quality differences between countries.

Agricultural productivity trends

The findings from past analyses have been mixed, but generally point towards a convergence in productivity growth between developed and developing countries.

Coelli and Rao (2005) found that agricultural productivity growth across 93 countries averaged 2.1 per cent a year between 1980 and 2000. They identified a degree of catch-up between developed countries and developing countries, at least in Asia. However, both South America and Africa experienced below average productivity growth (0.6 and 1.3 per cent respectively).

Focusing on major agriculture sectors, Ludena et al. (2007) found diverging productivity growth for ruminant production between developed and developing countries from 1961 to 2001, but convergence in productivity growth for crops and non-ruminant production. In particular, the productivity growth rate for non-ruminants was much higher for developing countries.

Fuglie's (2010) cross-country analysis showed that global productivity growth had become more rapid over the past 20 years or so, increasing from 0.9 per cent between 1970 and 1989 to 1.6 per cent from 1990 to 2006. As a result, global agricultural output had increased by around 2 per cent a year, while aggregate input use had declined. Fuglie (2010) also found that productivity growth in developing countries (in particular, China and Brazil) had been more rapid than productivity growth in developed countries over the most recent decade. However, Alston et al. (2010c) argued that FAO data limitations preclude reliable cross-country comparisons of agricultural productivity growth.

Estimates following from the country-level data and comparisons framework developed by Ball et al. (2001) suggest that agricultural productivity converged between the United States and European Union countries between 1973 and 1993. Countries with a lower productivity growth in 1973 were more likely to experience faster productivity growth. Relative to the United States, the Netherlands, Belgium, Denmark and France had higher productivity levels in 1993, while Germany, Ireland, Italy and Greece had lower productivity levels.

After improving the data series and extending the analysis to 2002, the findings changed substantially (Ball et al. 2010). Only Spain and Sweden achieved faster productivity growth than the United States. Within the exception of The Netherlands during the 1970s and most of the 1980s, the United States achieved higher productivity that European Union countries. Notably, slower productivity growth in most European countries eroded their international competitiveness from 1984 onwards.

While it is widely agreed that the FAO data have a number of limitations, there are also constraints to a more widespread application of the Ball et al. (2010) approach. Collecting the required input and output variables for long time series in a consistent manner with other countries requires substantial effort in terms of both time and resources. Most countries do not have the capacity to participate in this kind of analysis. In these instances, using the Ball et al. (2010) approach for detailed comparisons and for cross-checking of the productivity trends identified using the FAO dataset is likely to provide the best opportunity to improve understanding of disparities and possible convergences in agricultural productivity between countries.

Appendix 2: Constructing internationally comparable agricultural productivity estimates

A common methodology for agricultural productivity measurement

The methodology used in this paper was developed at the USDA ERS and has been described in detail by Ball et al. (2010).

Productivity was estimated in this study using a traditional growth accounting index number approach. The approach relies on a neoclassical production framework to estimate productivity change residually, that is, as the difference between the rate of change in output and the rate of change in inputs used in production. The growth accounting method for productivity estimation is described in OECD (2001).

The growth rate of the productivity index over time is a measure of Hicks-neutral technological change. This index implicitly assumes a constant return to scale production function with all market inputs and outputs accounted for. It is measured for the agricultural industry represented as a single entity that maximises output for each input level.

Following Ball et al. (2010), the Törnqvist index number formula was used in estimation. This index is exact for a translog function (Diewert 1976). Specifically, given that price data were less volatile and more widely available than quantity data, the study developed a translog price index to indirectly estimate productivity in quantity terms. Because the Törnqvist formula does not have the property of self-duality, the quantity index differs from that which might be estimated directly. The theoretical debate about whether a direct or indirect quantity index is more reliable has been overviewed by Coelli et al (2005). For agricultural productivity, where prices are more stable than quantities over time, an indirect quantity approach may be more reliable as it can better stabilise high variability in inputs and outputs (Allen and Diewert 1981).

Input and output prices were used to construct purchasing power parities to ensure comparability between countries and aggregated using the Törnqvist index number formula. In this instance, price index series were converted to 2005 US dollars and chain linked. As such, the purchasing power parity of Australian agricultural output (inputs) was defined as the units of Australian dollars required to purchase the same amount of output (inputs) as one US dollar in 2005. The estimates are thus independent of currency exchange rates.

In addition, to enable comparisons across a number of countries (more than two), it is necessary to impose a transitivity condition to the Törnqvist indexes. This condition ensures that a direct comparison between country *a* and *b* yields the same productivity index as a comparison of country *a* and *b* through country *c*. Similarly, a comparison of country *a* between period *r* and *s* is the same as an indirect comparison through period *t*.

The transitivity condition was imposed to the output and input price indexes following the approach defined by Caves, Christensen and Diewert (1982). Letting p_{mj} represent the price of the m^{th} output (input) in the j^{th} country ($j = 1,2,\dots,I$) and I_{ij} represent a general index for current country, with i as the base country, a transitive CCD index in log-change form can be defined as:

$$\ln P_{ij}^{CCD} = \frac{1}{I}\sum_{k=1}^{I}[\ln P_{ik}^{T} + \ln P_{kj}^{T}]$$

$$= \frac{1}{2}\sum_{m=1}^{M}(c_{mi} + \bar{c}_m)(\ln p_{mj} - \overline{\ln p_m}) - \frac{1}{2}\sum_{m=1}^{M}(c_{mj} + \bar{c}_m)(\ln p_{mj} - \overline{\ln p_m})$$

Where P_{ij}^T are Tornqvist price index numbers for all pairs i, j, c_m is the revenue (cost) share of the m-th commodity output (input), $\bar{c}_m = \frac{1}{I}\sum_{k=1}^{C} c_{mk}$ and $\overline{\ln p_m} = \frac{1}{I}\sum_{k=1}^{C} \ln p_{mk}$., and $\overline{\ln p_m}$ is their mean. These price indexes are used to derive implicit quantity indexes.

Table 4 shows estimates of the output quantity indexes. National currency values were divided by the price index to develop consistent quantities in purchasing power parity terms. Relative productivity for each country was then calculated as the ratio of the translog output quantity index and the translog input quantity index.

Table 4: Agricultural output, 2005

	Units	**Australia**	**Canada**	**United States**
Value in national currency	(billions)	38	36	262
Purchasing power parity*	(National currency per US dollar)	1.70	1.16	1.00
Value in US dollars	(billions)	22	31	262
Implicit quantity	(index)	0.086	0.118	1.000

* translog price index

Growth rates throughout this analysis were estimated using a log-linear trend. Therefore, the estimates are sensitive to changes in the choice of start of end years. Short-term estimates can be useful in examining changes in the long run productivity trend, but should not be interpreted as reflections of technical change (OECD 2001).

Variable construction

This study was part of a collaborative project between ABARES, Agriculture and Agri-Food Canada and USDA ERS. Each agency collected output and input data for their country using a consistent framework, defined by the USDA ERS. As described above, ABARES then used these data to consistently estimate aggregate output, aggregate input and total factor productivity levels and growth rates for each country.

The full list of variables is included in this section.

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

- **Input variables** were collected under four categories: capital, land, labour and intermediate inputs. For each input and output, quantity, prices and value data were collected or imputed.

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.

All prices are in terms of real prices received and prices paid. In most cases, these prices were imputed implicitly as the total value of production divided by the real quantity. All prices are producer prices, that is, subsidies are added and indirect taxes subtracted from market values.

Outputs

The construction of output quantities and prices are described for each output category in the database (Table 5).

Agricultural crops and livestock outputs were measured using implicit quantities. Outputs include both final and intermediate demand. For example, output allocated to on-farm production and consumption activities are included.

Other agricultural outputs, including on-farm processing and farm services provision (such as land lease), were also estimated as implicit quantities. An approximate price index, estimated by an aggregate agricultural commodity output price index, was used to deflate total income from these activities.

Inputs

The construction of input quantities and prices are described for each input category in the database: capital, land, labour and intermediate inputs (Table 5). Capital and land inputs were estimated using capital service flows. Labour was estimated residually, as described in more detail below. Intermediate inputs were estimated using an equivalent approach to output estimation—as implicit quantities.

Capital

Capital is measured in terms of capital service flows. Capital service flows are measured as the stock of capital multiplied by the rental price.

Capital stocks

Following the perpetual inventory method, the stock of capital at each point in time (K_t) is first determined using a weighted sum of past capital investments (I) at constant prices. These weights are determined by the assets' relative efficiency (S_τ), measured as a function of the assets' age.

$$K_t = \sum_{\tau=0}^{\infty} S_\tau I_{t-\tau}$$

The decline in efficiency of an asset of τ years of age is given by:

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

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

where L is the service life of the asset and β is a selected decay parameter.

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.

The decay parameter β 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). 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 price

The rental price of each capital asset, c⍰, was estimated following Ball et al. (2001) as a function of the opportunity cost of the initial investment and the present value of all future replacements required to maintain the productive capacity of the capital stock:

$$c = \frac{rw}{1 - F}$$

where rw is the real discount rate times the price paid for the capital asset (in constant 2005 US dollars) and F is the rate of capital depreciation on one unit of capital according to a mortality distribution m⍰. That is,

$$F = \sum\nolimits_{t-1}^{\infty} m_t (1 + r)^{-t}$$

The real discount rate r was estimated as the nominal yield of one-year government bonds less inflation, where inflation was measured by the implicit deflator for gross domestic product. Observed real rates were expressed as ex-ante rates using an ARIMA process.

Land

Land was also estimated by the stock of land multiplied by its rental price.

The stock of land was estimated implicitly by the total value of agricultural land divided by a quality-adjusted land price index. The total value of agricultural land was estimated using agricultural census and farm survey data. The quality-adjusted land price index was a chained Törnqvist index estimated using a hedonic regression model. Under this method, the price of land was a function of the value of each characteristic that determines the land's productive capacity.

Following Ball et al. (2010), the hedonic price function followed a generalised linear functional form, where each dependent and continuous independent variable was represented by the Box-Cox transformation:

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

where $W_L(\lambda_0)$ is the Box-Cox transformation of the dependent price variable, $X_n(\lambda_n)$ is the Box-Cox transformation of the continuous quality variables, D_d are country dummy variables, λ, α and γ are unknown parameter vectors and ε is a stochastic error term. It is to be noted that, 'market accessibility' is not incorporated in the hedonic regression due to data constraints. Including 'market accessibility' in the hedonic regression tends to reduce the quality and quantity of land input.

The hedonic regression model was used to estimate a quality-adjusted price index for 2005 given the availability of land quality data for all countries this year. These data were then used to adjust time series prices, estimated by total value of agricultural land divided by total quantity of agricultural land (measured in million hectares).

The quality-adjusted land quantity index was measured by total value of land divided by the estimated quality-adjusted price index.

Estimating the rental price of land followed the same approach as for the rental price of capital where the replacement value was assumed to be zero.

Labour

Labour quantity was measured by total hours worked, estimated by the total number of rural workers multiplied by the average hours worked by hired workers. The price of labour was estimated as total wages paid divided by total hours worked.

Given a lack of data on farmers' wages and the difficulty in capturing total compensation allocated to farm workers (including in-kind payments), total wages paid was estimated as an accounting residual. That is, total wages equals the total value of production minus the total value of capital, land and intermediate inputs. As a result, total output values equal total input values such that economic profit is assumed zero.

Intermediate inputs

Intermediate inputs include all materials and services consumed during the calendar year. For most intermediate inputs, quantity was estimated implicitly by the value of expenditure divided by a price index. Consistent with the treatment of output, the value of expenditure was estimated at farm gate prices paid, including direct taxes and excluding subsidies.

For fertiliser and chemicals, quality-adjusted price indexes were sourced to reflect quality differences between fertiliser and chemical types. These price indexes were sourced directly from the World Bank WDI database (WB) for pesticides and from the FAO for chemicals for 2005 and used to adjust original time series. Although this accounted for some quality differences between countries, some differences may still remain where input qualities and compositions have followed differing trends.

Table 5: Production account for Australian agriculture, outputs and inputs

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	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	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
Other crops				*Services*				*Services*
Cotton lint Tobacco Horticulture Floriculture Greenhouse nursery Sugar beet Sugar cane Mushrooms Other crops not included elsewhere				Contract services Machinery hire Land lease Other services				Marketing Plant and machinery hire Repairs and maintenance Veterinary services Other services

Data

A brief description of input and output data for Australia, Canada and the United States are included in this section.

All countries faced a limited series for some variables, which necessitated using imputation techniques to develop a complete dataset for the period 1961 to 2006. In most cases, values were extrapolated backwards using a time trend or using constant value shares with assumed weights. For intra-census years, a moving average was used to fit missing values.

Australian agricultural data

Australian agricultural data were collected from four core sources. These were**:**

- Australian National Accounts: National Income, Expenditure and Product (ABS Cat. 5204.0 and ABS Cat. 5206.0)
- Australian Agricultural census and surveys (ABS)
- Australian population and housing census (ABS)
- Agricultural Commodity Statistics (ABARES)

Where data sets were incomplete (either a lack of required detail or a historical time series being too short), additional data were sourced from:

- Australian Agricultural and Grazing Industry survey (AAGIS) and Australian Dairy Industry Survey (ADIS)
- Powell (1974), Butlin (1977) and various ABS Production Bulletins (1901 to 1960)

For Australia, capital stocks were estimated using a gross investment series dating back to 1900. Gross investment data for 1900-01 to 1960 were sourced from Powell (1974) and from 1960 onwards from the ABS National Accounts database. Price indexes were sourced from the ABS and backcast using data from Butlin (1977).

While the USDA framework was readily transferable to Australian agriculture there remain some limitations that could not be addressed with the data and resources available. Specifically, capital services from forestry and fishery activities were inseparable within the National Accounts. Further, some capital asset categories were excluded because of a lack of data: livestock, biomass and natural resources and intangible assets. These items are expected to be a small share of total capital investment.

Canadian and Untied States agricultural data

The Canadian database was developed by Agriculture and Agri-food Canada. The main data sources include the Statistics Canada’s National Accounts, Agricultural Censuses, Population censuses and supply and disposition balance sheets. The series had limited data on output values and several intermediate inputs which may diminish the reliability of the estimates for Canada.

The United States database was developed by the USDA ERS. The ERS developed the approach to match the definitions within the United States National Income and Product Accounts. Some supplementary data were sourced from the US Agriculture Censuses, Agriculture and Resource Management Surveys (ARMS) and other USDA surveys.

Appendix 3: Data tables

Table 6: Agricultural output, input and TFP indexes (relative to the United States in 1961)

	Output			Input			TFP		
	Australia	Canada	United States	Australia	Canada	United States	Australia	Canada	United States
1961	6.52	7.80	100.00	8.94	9.06	100.00	72.87	86.06	100.00
1962	6.88	9.40	101.61	9.17	9.29	100.91	74.94	101.13	100.69
1963	7.41	10.19	104.84	9.40	9.47	100.45	78.86	107.65	104.37
1964	7.56	9.68	103.65	9.63	9.62	97.13	78.45	100.57	106.70
1965	7.25	10.38	106.43	9.72	9.74	96.22	74.52	106.61	110.61
1966	7.70	11.47	106.43	9.86	9.98	96.19	78.08	114.86	110.65
1967	7.80	10.39	109.93	10.05	10.26	94.52	77.65	101.25	116.30
1968	8.01	10.83	111.93	10.25	10.25	93.33	78.22	105.71	119.93
1969	8.89	11.12	114.26	10.48	10.26	93.92	84.82	108.36	121.65
1970	8.75	10.93	112.81	10.49	10.35	93.33	83.45	105.68	120.86
1971	8.86	11.89	121.61	10.31	10.48	93.39	85.92	113.47	130.23
1972	8.67	11.37	122.76	10.14	10.60	94.92	85.48	107.22	129.34
1973	8.71	11.68	127.25	10.00	10.67	95.20	87.06	109.40	133.67
1974	8.97	10.88	118.48	9.84	10.58	94.58	91.11	102.85	125.28
1975	8.93	12.05	126.61	9.56	10.62	92.70	93.46	113.48	136.58
1976	9.05	12.61	128.51	9.34	11.01	95.58	96.92	114.54	134.46
1977	9.10	12.92	135.74	9.15	11.15	94.86	99.42	115.82	143.10
1978	9.31	13.51	137.64	9.16	11.51	100.95	101.60	117.37	136.35
1979	9.72	12.88	145.64	9.44	11.90	103.80	102.93	108.19	140.30
1980	9.42	13.42	139.49	9.37	11.95	103.73	100.51	112.32	134.48
1981	9.53	14.67	150.66	9.21	12.05	100.08	103.43	121.79	150.53
1982	9.14	15.17	151.60	9.65	12.30	98.55	94.69	123.32	153.82
1983	9.54	14.68	130.67	9.67	12.40	98.19	98.71	118.39	133.08
1984	10.87	14.55	149.59	9.74	12.47	95.17	111.57	116.71	157.18
1985	10.81	15.36	154.94	10.13	12.52	92.80	106.76	122.66	166.96
1986	10.83	16.25	150.24	10.14	12.32	91.64	106.83	131.91	163.95
1987	11.07	15.84	151.72	10.36	12.41	91.32	106.88	127.62	166.13
1988	11.12	14.61	142.52	10.41	12.22	90.29	106.85	119.59	157.85
1989	11.54	15.86	152.88	10.70	12.13	88.50	107.86	130.73	172.73
1990	12.55	17.10	160.26	10.64	12.13	88.90	117.92	141.01	180.27
1991	12.96	16.97	160.98	10.83	12.07	88.52	119.69	140.61	181.85
1992	12.82	16.74	171.30	10.94	12.01	86.42	117.20	139.37	198.21
1993	13.32	17.59	162.74	10.53	12.06	87.22	126.43	145.78	186.58
1994	12.55	17.96	182.52	10.58	12.48	91.35	118.60	143.92	199.80
1995	12.78	18.37	171.67	10.67	12.50	93.97	119.78	146.92	182.70
1996	14.75	19.49	178.56	10.73	12.40	89.47	137.37	157.12	199.58
1997	15.75	19.03	186.46	10.91	12.60	92.00	144.33	150.96	202.67
1998	16.05	20.24	185.64	11.02	12.88	93.50	145.66	157.10	198.54
1999	16.60	21.23	189.43	11.04	12.91	95.58	150.30	164.39	198.19
2000	16.59	20.78	191.08	11.11	13.51	91.87	149.35	153.84	207.99
2001	17.01	19.90	190.49	11.24	13.57	91.26	151.33	146.67	208.75
2002	15.75	19.62	187.31	11.40	13.22	90.29	138.22	148.33	207.44
2003	15.34	21.32	192.81	11.72	13.32	90.24	130.87	160.02	213.67
2004	16.81	22.69	200.51	11.81	13.05	88.44	142.31	173.82	226.72
2005	17.02	23.42	198.31	11.36	13.27	89.56	149.83	176.42	221.44
2006	16.09	23.11	195.19	11.14	13.56	87.86	144.47	170.50	222.16
Average annual growth (%)	2.07	2.04	1.58	0.43	0.80	-0.22	1.64	1.24	1.80

Table 7: Agricultural input quantity indexes (relative to the United States in 1961)

	Capital			Land			Intermediate inputs			Labour		
	Australia	Canada	United States	Australia	Canada	United States	Australia	Canada	United States	Australia	Canada	United States
1961	14.72	9.70	100.00	71.54	15.89	100.00	7.61	6.21	100.00	10.73	16.91	100.00
1962	15.09	9.47	99.29	71.75	15.95	99.93	7.95	6.75	102.96	10.65	16.48	98.82
1963	15.48	9.42	99.83	71.65	16.00	99.79	8.44	7.24	105.76	10.42	15.97	94.18
1964	16.14	9.61	101.30	72.37	16.03	99.46	8.82	7.61	104.55	10.28	15.50	87.24
1965	16.95	9.97	103.13	73.04	16.04	98.87	8.86	7.82	105.00	10.14	15.17	84.28
1966	17.61	10.51	105.84	73.75	16.01	98.03	9.00	8.38	111.70	10.06	14.64	77.32
1967	18.26	11.21	109.45	74.09	15.94	96.94	9.28	8.85	113.37	9.96	14.19	71.70
1968	18.93	11.81	113.80	74.90	15.84	95.64	9.65	8.81	111.43	9.65	13.73	70.26
1969	19.57	12.12	115.88	75.83	15.73	94.16	10.14	8.91	114.70	9.30	13.22	68.45
1970	20.07	12.25	117.16	75.93	15.62	92.57	10.29	9.16	117.37	8.78	12.79	65.01
1971	20.28	12.02	118.65	76.55	15.53	91.01	10.00	9.64	118.88	8.45	12.34	63.80
1972	20.43	12.01	119.44	76.80	15.47	89.65	9.87	10.05	123.14	8.07	12.03	63.55
1973	20.87	12.39	121.38	77.67	15.44	88.65	9.79	10.37	124.36	7.71	11.72	63.12
1974	21.61	13.29	127.13	79.41	15.43	88.16	9.25	10.12	121.87	7.67	11.48	63.11
1975	22.25	14.38	132.08	78.91	15.43	88.25	8.73	10.07	118.78	7.44	11.34	61.36
1976	22.84	15.78	135.04	77.03	15.42	88.68	8.38	10.46	126.39	7.17	11.44	60.46
1977	23.61	17.29	139.02	75.72	15.41	89.14	8.02	10.60	125.59	6.92	11.14	59.20
1978	24.30	18.47	142.40	75.76	15.39	89.30	8.04	11.36	141.48	6.76	10.76	58.06
1979	25.05	19.58	147.30	76.08	15.37	88.96	8.25	12.08	146.75	7.01	10.56	58.93
1980	26.03	20.88	152.90	76.80	15.34	88.25	7.78	12.04	146.09	7.06	10.26	58.18
1981	26.95	21.52	153.59	76.37	15.30	87.38	7.66	12.00	138.07	6.80	10.07	57.49
1982	27.79	22.01	151.88	75.20	15.27	86.56	8.09	12.40	138.28	6.37	9.96	53.06
1983	28.31	21.80	146.50	74.99	15.23	85.95	8.27	12.62	138.12	6.30	10.02	52.37
1984	28.84	21.30	141.01	74.86	15.20	85.51	8.17	12.86	133.86	6.54	9.91	50.62
1985	29.70	20.77	135.46	72.11	15.16	85.14	8.12	13.10	132.07	6.12	9.85	46.73
1986	30.29	19.81	128.09	69.65	15.13	84.78	8.17	13.33	131.39	5.47	9.82	46.93
1987	30.45	18.77	120.63	69.90	15.08	84.33	8.69	13.96	132.49	4.97	9.67	47.39
1988	30.64	17.75	115.58	69.46	15.04	83.77	9.32	14.03	130.73	4.67	9.25	47.90
1989	31.11	16.75	111.32	67.40	15.01	83.14	9.64	14.21	129.44	5.16	9.11	46.18
1990	31.57	15.82	108.22	66.18	14.99	82.54	9.32	14.56	136.41	5.73	8.93	43.12
1991	31.70	14.89	105.83	65.97	14.99	82.09	9.12	14.73	137.31	5.35	9.06	42.36
1992	31.59	14.06	102.67	66.16	15.02	81.88	9.42	14.92	133.83	4.79	8.97	41.36
1993	31.34	13.32	99.21	67.01	15.08	81.98	9.64	15.27	139.92	4.44	9.02	39.78
1994	31.03	13.06	96.27	67.35	15.13	82.29	9.95	16.48	143.38	4.17	8.78	45.39
1995	30.92	12.77	93.63	67.19	15.18	82.66	10.23	16.75	150.91	4.13	8.60	45.77
1996	31.04	12.55	90.99	67.41	15.20	82.98	10.45	16.59	143.81	4.22	8.55	42.38
1997	31.29	12.34	89.31	67.99	15.20	83.13	10.63	17.26	151.95	4.37	8.31	42.19
1998	31.71	12.55	88.46	68.15	15.17	83.05	10.88	17.74	159.43	4.30	8.45	40.24
1999	32.30	12.82	88.22	68.60	15.13	82.73	11.02	17.82	166.04	4.11	8.24	39.94
2000	32.85	12.79	87.57	68.98	15.09	82.23	10.92	19.30	160.78	4.18	8.18	35.94
2001	33.33	12.80	87.14	68.33	15.06	81.64	11.01	19.63	159.39	4.20	7.83	35.91
2002	33.63	12.65	87.31	69.06	15.04	81.02	11.24	18.84	156.20	4.25	7.77	36.29
2003	34.02	12.65	87.58	69.54	15.05	80.45	11.48	19.09	157.93	4.49	7.66	35.08
2004	34.63	12.64	88.66	69.10	15.06	79.93	12.19	18.56	155.63	4.13	7.53	33.52
2005	35.54	12.64	90.87	66.12	15.08	79.41	11.98	19.02	158.87	3.59	7.60	33.47
2006	36.63	12.62	91.91	63.63	15.11	78.89	11.28	19.57	157.66	3.57	7.72	31.38
Average annual growth (%)	1.89	0.42	-0.63	-0.31	-0.14	-0.50	0.62	2.36	0.96	-2.51	-1.69	-2.21

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Cross-country Comparisons of Agricultural Productivity

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By Katarina Nossal and Yu Sheng

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