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Agricultural Productivity: Concepts, measurement and factors driving it

— A perspective from the ABARES productivity analyses —

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Agricultural Productivity: Concepts, measurement and factors driving it

A perspective from the ABARES productivity analyses

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Foreword

Productivity growth has been an essential element of Australian agriculture's sustained international competitiveness. The emerging challenges facing the agriculture sector, including climate change, competition from overseas suppliers and rising input costs, mean that continued productivity growth above the long-term growth rate (currently 1.4 per cent a year) is likely to be required to maintain farm profits and living standards in the long term.

The Rural Industries Research and Development Corporation (RIRDC) invests in research and development (R&D) as a part of its strategy to create a globally competitive Australian agricultural sector. Given the imperative to improve productivity growth in agriculture, RIRDC has commissioned the ABARES report *Agricultural productivity: Concepts, measurement and factors driving it*. The report describes the productivity estimation methods used by ABARES and identifies the key factors that influence agricultural productivity at the farm and industry levels.

This report provides a non-technical guide to the concept, measurement and key drivers of agricultural productivity growth. A key objective of the report is to enable readers to understand and interpret productivity estimates and relevant statistics in an informed way.

Effective policy will require an understanding of the factors influencing productivity, which in turn requires an understanding of the constraints that affect producers' decision to adopt new technologies or make changes to management practices. This report identifies the factors that influence the diffusion of innovations through an industry in the context of the ABARES productivity estimates for the broadacre and dairy industries.

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 forms part of our Global Challenges R&D program, which aims to address, through R&D, emerging and current issues, including global competitiveness, market access and trade barriers, productivity and climate change, leading to a globally competitive Australian agricultural sector.

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.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

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Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
MFP	multifactor productivity
OECD	Organisation for Economic Co-operation and Development
R&D	research and development
RD&E	research, development and extension
RDC	Research and Development Corporation
PFP	partial factor productivity
PC	Productivity Commission
TFP	total factor productivity

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Executive summary

What the report is about

ABARES (formally ABARE) has released statistics and reports on the productivity performance of the broadacre sector (non-irrigated cropping and grazing) and the dairy industry since the early 1990s. This report provides a non-technical exposition of the concepts, theories and empirical methods underlying how ABARES measures productivity.

Who is the report targeted at?

The report is targeted at industry to improve the accessibility of the productivity estimates and reports ABARES produces annually. The report will assist non-technical readers of these analyses to interpret productivity estimates and trends, and to identify and understand the mechanisms of agricultural productivity growth.

Where are the relevant industries located in Australia?

ABARES produces estimates of productivity growth rates for Australia's broadacre and dairy industries, which account for almost 70 per cent of commercial-scale farm businesses in Australia, and the majority of family-owned and operated farms. The broadacre sector includes five industries:

- wheat and other crops industry (specialised producers of cereal grains, coarse grains, pulses and oilseeds)
- mixed livestock–crops industry (farms producing sheep and/or beef cattle as well as substantial activity in broadacre crops such as cereal grains, coarse grains, pulses and oilseeds)
- sheep industry (specialised producers of sheep meat and wool)
- beef industry (specialised producers of beef cattle)
- sheep–beef industry (farms running sheep and beef cattle).

Broadacre and dairy farms manage more than 90 per cent of the total area of agricultural land in Australia. Broadacre farms are located in all regions (Northern Territory broadacre farms consist only of beef-specialists). Dairy farms are located in all regions, excluding the Northern Territory.

Background

Productivity growth in agriculture, reflecting increases in the efficiency of production processes over time, is a key determinant of farm profitability and an important mechanism for maintaining the international competitiveness of Australian agriculture. Productivity growth in the broadacre sector has averaged 1.4 per cent a year because of a long-term decline in input use, averaging 0.6 per cent a year, and a long-term increase in output growth, averaging 0.8 per cent a year. The dairy industry achieved an average output growth of 4.7 per cent a year, but, in contrast with the broadacre sector, the dairy industry averaged only 0.8 per cent productivity growth over this period as input use also increased, averaging 3.9 per cent a year. Differences in the rates of input, output and productivity growth of these industries likely reflects differences in the technological advances, production cycles, input substitution possibilities and structural shocks they have experienced, as well as the effect of climate variability.

However, evidence of declining productivity growth rates is cause for concern given the current and emerging challenges of increasing competition in export markets, climate change and increasing pressure on the natural resource base. Moreover, Australian farmers face declining terms of trade (the ratio of prices received to price paid by farmers), which has required farmers to lift productivity to remain internationally competitive and increase farm incomes. Addressing these issues while maintaining the commercial viability of the sector requires continued agricultural productivity growth, in turn ensuring a globally competitive Australian agriculture sector.

Aims/objectives

This report's objective is to improve a non-technical audience's ability to understand, interpret and communicate productivity and relevant statistics. This objective is achieved by:

- providing a non-technical description of the concepts, theories and methodology underlying how ABARES estimates productivity
- outlining the factors that influence the changes in agricultural productivity over time and the differences between the productivity of farms or industries at a particular point in time.

Methods used

Following the introduction, chapters 1 and 2 provide a non-technical description of the concepts, theories and methodologies underlying productivity estimation. Chapter 1 describes the productivity measure and empirical method used by ABARES, discusses analytical issues associated with using index numbers to aggregate data on the quantities of inputs and outputs, discusses the distinction between the ABARES measure of productivity growth, total factor productivity (TFP) and commonly used partial factor productivity (PFP) measures, and notes the advantages of the TFP measure. Chapter 2 describes the farm financial and physical data obtained from the ABARES annual farm survey, which are used to estimate broadacre and dairy productivity.

Chapter 3 focuses on the mechanisms of agricultural productivity change. This chapter surveys the empirical literature on analyses of Australian and international agricultural productivity to identify the determinants of agricultural productivity growth.

Chapter 4 discusses some of the differences between the ABARES and Australian Bureau of Statistics (ABS) agricultural productivity estimates. The appendixes provide more detail on the analytical procedures associated with using index numbers to estimate productivity statistics, and list the data obtained from the ABARES annual farm surveys that are used to estimate productivity.

Results/key findings

ABARES produces estimates of productivity growth at the farm, region and industry level for the broadacre and dairy industries, using data collected through its farm survey program. The farm survey data, and accordingly the productivity estimates, cover the period 1977–78 to 2007–08 for the broadacre industries, and 1988–89 to 2007–08 for the dairy industry.

ABARES estimates productivity as the ratio of a measure of total outputs to a measure of total inputs used in production (aggregated at the farm, region or industry levels). Productivity growth compares changes in this ratio over time, and is the growth rate of outputs that is above and beyond the growth rate of inputs, removing as much as possible the effects of relative price changes. The productivity measure used by ABARES, TFP, relates growth in output to growth in a bundle of inputs, including capital, labour, land and materials and services (intermediate inputs), and can be interpreted as the effect on farm production of technological change embodied in new or improved inputs, new knowledge or scientific results, changes in technical and scale efficiency, input substitution, and the seasonal conditions prevailing in a given year. TFP is also called multifactor productivity (MFP).

In contrast, PFP measures estimate output growth relative to a single input such as land or labour. If productivity growth is estimated using PFP measures, the effects of technological and efficiency changes, input substitution, and technological improvements embodied in other inputs, can be incorrectly attributed to improvements in a particular factor, such as labour or land productivity. This can result in a misleading assessment of an industry's productivity performance. For example, reporting an increase in labour PFP may obscure the true source of productivity growth, which may be the substitution of other inputs such as capital or materials and services for labour.

ABARES calculates its annual estimates of broadacre and dairy TFP using the Fisher index method to aggregate farm-level data on the quantities and prices of inputs used and outputs produced by farms. However, because factors such as seasonal conditions (especially rainfall) can cause broadacre and dairy TFP estimates to fluctuate widely from year to year, ABARES also calculates average productivity growth rates for the broadacre and dairy industries over time. Long-term productivity growth trends provide a more reliable indicator of an industry's productivity performance and rate of technological progress.

The report also surveys the Australian and international literature to identify the key mechanisms of agricultural productivity growth. In the long term, productivity growth is driven by innovation and its diffusion throughout an industry. New knowledge and technology will increase productivity if it allows the quantity of output produced from a given quantity of inputs to rise, or for at least as much output to be produced when the quantity of inputs is reduced. New knowledge and technologies may be the output of publicly and privately funded R&D or a spillover productivity gain from borrowing and/or adapting the R&D output of other industries, regions or countries.

Agricultural productivity growth is also driven by efficiency improvements. Production decisions that improve efficiency may follow changes in the institutional environment and the organisation of production at the farm and industry level that reduce or remove constraints on production. The incentive to undertake innovative activities and/or adopt new technologies or management practices is provided by exposure to undistorted incentives. Consequently, agricultural productivity growth is also dependent on a regulatory and institutional environment that exposes farmers to market competition, while ensuring farmers have the flexibility and capability to respond to those incentives. If some farmers are unable to respond to market incentives, aggregate efficiency improvements (that is, at the industry level) may also occur as a consequence of structural change in agricultural industries.

The ABS also produces official productivity estimates for the agriculture, fishing and forestry sector. While both ABARES and the ABS use conventional index number methods to estimate productivity growth, the productivity estimates differ in several key respects:

- ABS productivity estimates cover fishery and forestry production and all agricultural outputs, including irrigated and intensive agriculture.

- The ABS produces value-added and gross-output MFP measures. Gross-output measures compare total outputs with total inputs (capital, labour, land and materials and services), while value-added measures consider only capital, land and labour inputs. Value-added TFP is more easily aggregated across industries and is a more reliable indication of the relative contribution of an industry's productivity performance to economy-wide TFP growth than gross-output TFP measures. However, gross-output TFP measures reflects how productively all inputs are combined to produce output. Given the importance of materials and services in agricultural production, ABARES uses the gross-output TFP measure.

- The ABS uses national accounts data to produce productivity estimates, which means agricultural MFP can be compared with other industries in the market sector. ABARES uses farm-level data to estimate TFP, which makes detailed analysis of the factors influencing agricultural productivity possible. However, data limitations mean estimates cannot be aggregated to the level of the agriculture sector or compared with other industries in the market sector.

Implications for relevant stakeholders

Understanding agricultural productivity trends and the mechanisms through which productivity growth is achieved is important if Australian agriculture is to address the challenges posed by increasing competition in export markets, climate change and increasing pressure on the natural resource base. This report will assist users of the productivity estimates and analyses produced by ABARES to identify and understand the measurement and mechanisms of agricultural productivity growth and the links between productivity growth and the agriculture sector's broader economic and institutional environment, including regulatory and policy frameworks.

Introduction

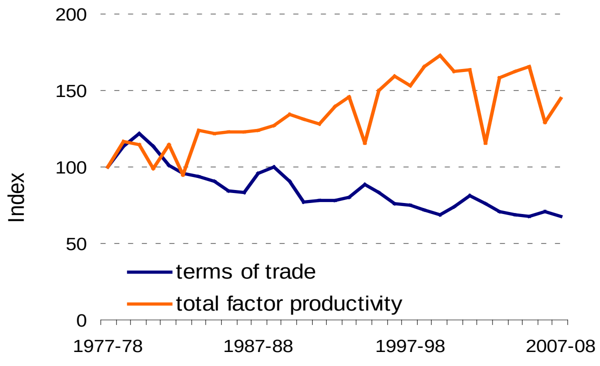
> Productivity isn't everything, but in the long run it is almost everything. … [T]he essential arithmetic says that long-term growth in living standards … depends almost entirely on productivity growth.
>
> Paul Krugman, *The Age of Diminished Expectations* (1990, p.11)

Productivity is a measure of how efficiently inputs are combined to produce outputs. Productivity growth reflects increases in the efficiency of production processes over time and is an important mechanism by which material living standards in an economy are improved. This is because productivity growth is the only way to grow aggregate income without also using up additional physical inputs (Productivity Commission 2008). Productivity growth accounted for the entire increase in Australian agricultural output over the 30-year period from 1974–75 to 2003–04, which has been calibrated as a productivity 'dividend' of $170 billion (Productivity Commission 2005). Over the longer period since 1952–53, during which productivity has grown at an average rate of 2 per cent a year, Sheng et al. (2010) estimate that about two-thirds of the current value of farm production can be attributed solely to productivity growth.

Productivity growth in the agriculture sector is also important for maintaining the international competitiveness of domestic agricultural industries (Productivity Commission 2005). Productivity and the 'terms of trade' (which is a measure of the relativity between the prices for farm outputs and inputs) are the twin determinants of farm profitability. Farm operators generally cannot control changes in their terms of trade. Hence, productivity growth becomes the main mechanism through which producers can influence farm profits and their living standards. When there is a prolonged decline in the terms of trade for farmers—that is, higher increases in prices of farm inputs relative to prices for farm output—productivity growth is the only way to maintain the commercial viability of the farm business.

Figure 1 shows the trend in the productivity and terms of trade of Australian broadacre farms. The terms of trade have declined continuously, while productivity has increased fairly consistently. Between 1977–78 and 2007–08, productivity in the broadacre sector increased from an index value of 100 to about 150, growing by 50 per cent over three decades. While there were fluctuations in this index, the sector achieved an average rate of productivity growth of 1.4 per cent a year. In the same period the index for the terms of trade faced by the agriculture sector declined substantially. The average rate of decline in the terms of trade in this period was 1.6 per cent a year. Hence, if there had not been an offsetting increase in the productivity of broadacre farms, farm cash income and living standards would have dropped considerably in this period.

Figure 1: Broadacre total factor productivity and the agricultural terms of trade



Source: Nossal and Sheng (2010)

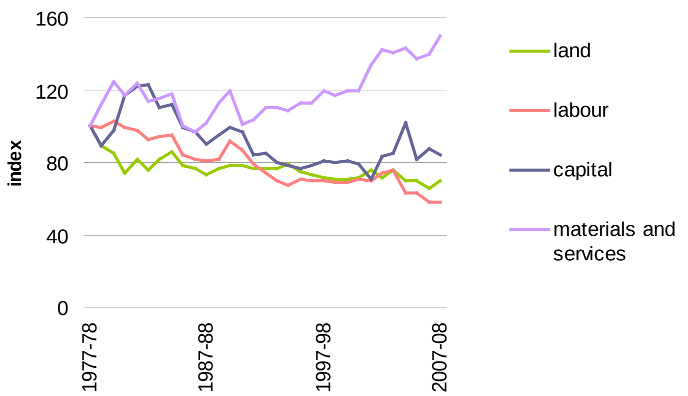
The agriculture sector also contributes to productivity growth in the economy as a whole. From 1974–75 to 2003–04, productivity growth in the agriculture, fishing and forestry sector accounted for around 16.4 per cent of productivity growth in the market sector of the Australian economy. Because productivity growth means that inputs are being used more efficiently in production, productivity growth in agriculture is also an important channel through which resources (such as labour) are freed up to be used more efficiently in other sectors of the economy. Further, agricultural productivity growth can lead to lower food prices for consumers (Productivity Commission 2005). Declining productivity growth rates in agriculture will also affect the productivity performance of the economy as a whole—more than half of the recent fall in Australia's market sector productivity growth below its long-term average rate can be attributed to the productivity slowdown in the agriculture and mining sectors since 2000 (Productivity Commission 2008).

Productivity is broadly measured as the ratio of a *volume* (or quantity) measure of output to a *volume* measure of inputs, and productivity growth measures the growth rate of outputs that is above and beyond the growth rate of inputs. Measures of productivity growth can be differentiated according to whether they are partial factor productivity (PFP) measures or total factor productivity (TFP) measures. PFP measures relate output growth to a single input such as capital or labour. For example, yield per hectare is a commonly used PFP measure in agriculture. TFP measures relate output to a bundle of inputs such as capital, labour, land and intermediate inputs (OECD 2001).

Although yield and labour productivity are commonly used measures of productivity in agriculture, these PFP measures (relating to land and labour, respectively) are of limited use for summarising the overall productivity performance of the sector. While PFP measures serve some interests (for example, estimates of labour PFP provide an indication of the wages of farm workers), PFP measures do not account for either improvements in other categories of inputs (for example, innovations that improve capital or intermediate inputs) or substitution among input categories. So if an increase in labour PFP is observed, it may not necessarily mean that farm labour alone has become more productive, with the productivity of other inputs remaining unchanged. In fact, other influences such as improvements in the capital input or substitution of capital for labour may be the source of the increased labour productivity. This means that the effects of technological and efficiency change and input substitution, as well as technological improvements embodied in other inputs, can be incorrectly attributed to improvements in a particular factor, such as labour or land productivity.

Figure 2 shows the pattern of change in the index of the four main input categories used in broadacre farming in Australia. During the period from 1977–78 to 2007–08, when farm productivity grew at an average rate of 1.4 per cent a year, the use of land, labour and capital inputs all declined substantially. The declines in the levels of these key inputs are the main cause of the productivity growth observed in this period. The fourth input, which is an aggregate measure of the materials and services purchased as intermediate inputs in farm production, increased substantially in this period (materials and services include inputs such as fuel, fertiliser and contracting services). The increase in the materials and services input is clearly related to the decline in the other three inputs, as producers were able to substitute materials and services for the land, labour and capital inputs. This suggests that farm operators regularly alter their input mix and substitute one input for another as technology and input prices change. Such a process of substitution among inputs can also be an important channel for productivity growth, and the substitution of materials and services for the other inputs in broadacre farming indicated in Figure 2 did increase productivity in this sector (Nossal et al. 2009).

Figure 2: Changes in input use among broadacre industries



Source: Nossal and Sheng (2010)

Relying only on PFP measures to analyse productivity trends may not only hide the underlying changes in the technology and use of other inputs, it can even lead to an erroneous interpretation of the direction of productivity changes. It is possible that a certain PFP measure may show a strong trend growth when in fact total productivity of all inputs has been declining because of dramatic increases in the levels of other inputs. In contrast, TFP measures capture the influence of improvements in all production-related inputs, including skills and management practices, as well as technological improvements that are not embodied in inputs.

In the short term, TFP estimates will also capture the effects of seasonal conditions such as drought. For this reason, long-term trends in productivity growth provide a more reliable indicator of an industry’s productivity performance, as the effects of year-to-year variability are softened.

Although long-term productivity growth largely reflects technological progress, movements in *technical*, *allocative* and *scale* efficiency will also affect productivity:

- Technical efficiency refers to farms using minimum inputs to produce a given level of outputs
- Allocative efficiency refers to farmers using inputs (and producing outputs) in optimal proportions, given the relative prices of inputs (and outputs)
- Scale efficiency refers to productivity gains from changing the size of the farm operation.

Improvements in technical efficiency will always increase productivity as well as farm profit. In contrast, allocative and scale efficiency movements may cause productivity and profitability to move in opposite directions in the short term. However, if improvements in the terms of trade induce rational producers to increase the scale of their enterprise in order to maximise profits, these production decisions may or may not increase productivity in the short term (O'Donnell 2009). For this reason, not all observed short-term falls in productivity should be viewed negatively, if the falls are a result of profit-maximising farmers changing their scale of operations in response to changes in the terms of trade.

Finally, the objective of improving productivity growth rates should not be equated with increasing production, as growth in output does not always imply higher productivity. Nor should it be an objective of the agriculture sector to identify a single best-practice farming system that will increase productivity for all farms in an industry. This is because the optimum production system for a particular farm depends on a number of characteristics, some of which will be specific to the region, the farm operator, or the farm itself.

ABARES productivity analyses

ABARES produces estimates of TFP growth for the broadacre and dairy industries using a unique dataset of farm-level records collected through its farm survey program. This dataset makes possible detailed estimates and analyses of productivity, and of the factors influencing productivity, at the farm, regional and industry levels.

Productivity growth in the broadacre sector has averaged 1.4 per cent a year between 1977–78 and 2007–08. Growth in productivity reflects a long-term decline in input use, averaging 0.6 per cent a year, and a long-term increase in output, averaging 0.8 per cent a year (Figure 3). Within the broadacre sector, the cropping industry has consistently achieved the highest long-term growth, followed by beef, mixed cropping–livestock and sheep (Figure 4).

Figure 3: Broadacre inputs, outputs and total factor productivity

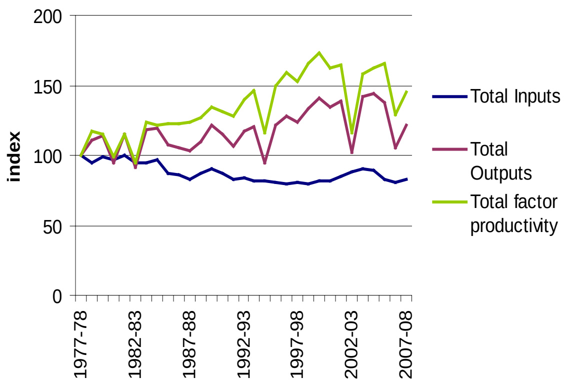
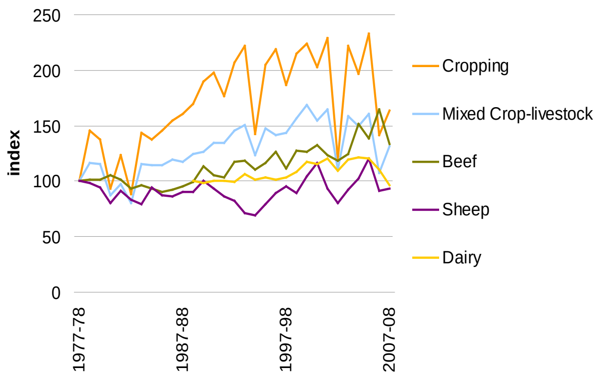


Figure 4: Broadacre total factor productivity

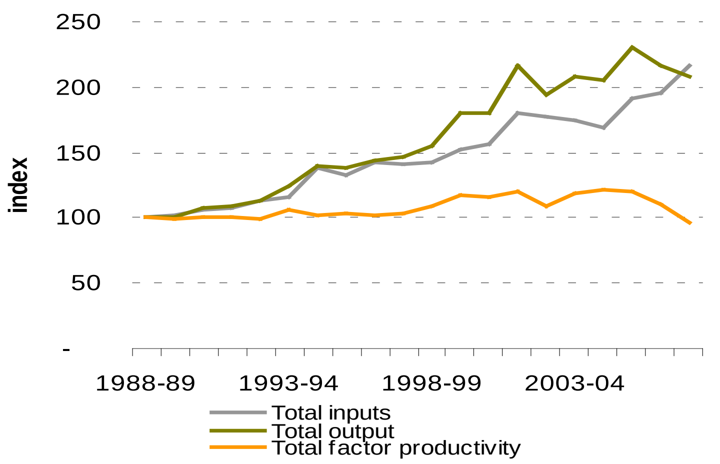


Source: Nossal and Sheng (2010)

In contrast, the dairy industry achieved an average output growth of 4.7 per cent a year between 1988–89 and 2007–08. However, the dairy industry averaged only 0.8 per cent productivity growth over this period as input use also increased, averaging 3.9 per cent a year (Figure 5). Nossal and Sheng (2010) suggest that productivity gains in the early 2000s were a result of a structural adjustment in the industry following deregulation (in 2000). Since then, a combination of factors, including increased supplementary feeding because of poor seasonal conditions, and high levels of investment in on-farm capital and farm improvements, have resulted in a severe fall in short-term productivity.

Much of the volatility in the broadacre sector's productivity growth rates in figures 2 and 3 can be attributed to seasonal conditions, with significant downturns in drought years (1994–95, 2002–03 and 2006–07). However, the differing productivity growth rates of the broadacre industries likely reflect differences in the technological advances, production cycles, input substitution possibilities and structural shocks experienced by those industries (see Nossal and Sheng 2010).

Figure 5: Dairy inputs, outputs and TFP



Source: Nossal and Sheng (2010)

Between 1977–78 and 2000–01, broadacre productivity grew at 2.0 per cent a year, but since 2000–01, growth has declined at a rate of 1.0 per cent a year. Sheng et al. (2010) have determined that the slowdown began in the mid 1990s, and investigated the contribution of climate, real investment in agricultural R&D, levels of education and the farmers' terms of trade to the decline in broadacre productivity growth. They found that the broadacre productivity slowdown was associated with drought and the slow growth in real public investment in agricultural R&D (extending back to the 1970s), although the relative contribution of climate and public investment in R&D to agricultural productivity growth is uncertain.

Productivity measurement

There is a range of empirical methods for estimating a farm, region or industry's productivity growth (as measured by TFP). These methods are briefly described in the following chapter (and interested readers are referred to Coelli et al. (2005)). The appropriate method will depend on the data that is available (for example, the number of observations and whether prices as well as quantities of input and outputs are available), whether farms are assumed to be technically efficient, whether it is important to accommodate data noise (for example, as a result of measurement error, unaccounted for differences in the quality of inputs or omitted inputs or outputs), and the end-use of the productivity estimates (whether TFP growth is estimated as part of an annually updated series).

ABARES calculates estimates of TFP growth using the conventional index method framework. Specifically, ABARES uses the Fisher index formula, which only requires the prices and quantities of each input and output used in production to aggregate the inputs and outputs of broadacre and dairy farms obtained from the annual broadacre and dairy surveys. While productivity is concerned with the relationship between input and output quantities, each item included in the input or output index is weighted by either its price or its value share in the total value of inputs or outputs. It is important to note that although prices or value shares are used as weights when productivity is measured using index numbers, the TFP index is not a financial measure. It remains a volume or quantity measure in a ratio form. Data on the prices or value shares of inputs and outputs are necessary to aggregate heterogeneous units of inputs and outputs in the index formula.

Factors driving productivity

In the long term, agricultural productivity improvements may be the result of new knowledge or technology that shifts the best-practice (or production) frontier, and/or improvements in efficiency, where the underlying drivers of efficiency improvements include changes to institutions and the organisation of production, and effects arising from changes in the structure of agricultural industries. In the short term, agricultural productivity movements are often caused by water availability, especially when drought causes water to be a limiting factor to production.

New technology may appear in either a disembodied or an embodied form. *Disembodied* technological change is not physically tied to any input (OECD 2001), and may take the form of new management practices or scientific results that improve the efficiency of production processes (for example, integrated pest management strategies). *Embodied* technological change is incorporated in new or improved inputs (for example, new farm machinery, improved agricultural chemicals and new crop varieties). Investment in R&D and extension has an important role in the creation of new embodied and disembodied technologies, its adoption by farm operators and diffusion through an industry. For example, the uptake of conservation-tillage farming systems is thought to have contributed to productivity growth in the cropping sector over the past 20 years. By reducing cultivation, these systems allowed producers to reduce inputs such as labour and fuel without reducing output, while also preserving soil structure and moisture. Development of the conservation-tillage farming system was possible because of technological progress in the form of improved inputs (machinery and agricultural chemicals), and better knowledge of how conservation-tillage farming systems work (and the extension of that knowledge to farm operators).

Public and private investments in agricultural R&D have been an important source of the innovations that have driven productivity growth in the broadacre sector (Mullen 2007), and there are concerns that slow growth in real public R&D investment may affect future Australian agricultural productivity growth. Adaptation of foreign knowledge and technology also contributes to productivity growth, especially when the technology is sourced from regions with similar crop-climates and agroecology.

Efficiency improvements following the reorganisation of production at the farm and/or industry level can enable agricultural productivity growth. Such a reorganisation of production may be influenced by changes to institutions and regulatory arrangements that reduce or remove constraints on production or increase an industry’s exposure to domestic and external competitive pressures. This includes spillover productivity gains from government investment in transportation and communication infrastructure (Parham 2004), and microeconomic reforms such as the removal of statutory marketing authorities and industry price-support schemes. The education level of farm operators is also recognised as an important factor influencing agricultural productivity (Mullen 2007). Skills obtained with higher levels of formal schooling increase farm operators’ ability to manage production and marketing risks, and to identify and adopt new technologies (Huffman and Evenson 2001). This is especially the case as increasing mechanisation, modern pest-control methods and the availability of information and communications technologies make agriculture more technology-intensive.

Productivity growth is also enabled by changes in the structure of farms and agricultural industries. Larger farms tend to have higher productivity growth than smaller farms. A possible explanation for this result is economies of scale (the cost advantages that a business obtains because of expansion), which may exist because on-farm infrastructure and capital (for example, sheds and machinery) are better utilised as farm size increases. Alternatively, larger farms may have a greater capacity to adopt a technology suited to their size, allowing them to use more efficient combinations of inputs than smaller farms. A change in the structure of an industry will also improve industry productivity growth rates if the share of production of high-efficiency farms increases as a result of consolidations and less-efficient farmers exiting the industry.

Role of government

The decline in productivity growth in the broadacre and dairy industries is a major concern as Australian agriculture faces the challenges of increasing competition in export markets, climate change and increasing pressure on the natural resource base. Increasing productivity growth can be an effective strategy for counteracting the expected adverse consequences of increased climate variability and the depletion of the natural resource base. Moreover, productivity growth is the primary mechanism for maintaining the international competitiveness of Australian agriculture. The nature of the agriculture sector suggests that there is a role for government in promoting future improvements in agricultural productivity.

At an aggregate level, the Productivity Commission (2008) notes that productivity is driven by innovation and its diffusion throughout an industry (via adoption and adaptation of technology and knowledge), and by the reallocation of resources from less productive to more productive firms and industries.

There is a well-established historical link between public R&D expenditure and agricultural productivity growth. An argument for continued, targeted public investment in agricultural R&D lies in the public good nature of some agricultural innovations, and the structural characteristics of the agriculture sector. Where R&D activities have public (spillover) benefits as well as private benefits, public funding may be justified if private benefits are not sufficiently large to encourage private investment in R&D, whether by individual farmers or by Research and Development Corporations (RDCs) funded by producer levies (Productivity Commission 2007).

If private innovators are unable to recoup fully the social value of their research through the prices charged for use of the innovation, so that the private returns to research are less than the social returns, this can lead to levels of investment in agricultural R&D that are less than what is socially optimal. This outcome may be more pronounced in agriculture because that sector is mostly made up of a large number of relatively small farms, each with only a small share of industry output. The structural characteristics of the sector make it difficult to enforce property rights to innovations, while the relatively small scale of farms means that for some R&D activities the required level of funding may be beyond the capacity of any farm. While this aspect may be addressed through industry levies, for cross-cutting issues where the social benefits to the wider community exceed the collective private benefits to industry, public investment in agricultural R&D may be justified.

Equally, government can facilitate innovation and its diffusion throughout an industry by ensuring the industry is exposed to market competition and external pressures. Market competition provides an incentive for organisations to absorb and apply new knowledge, both to improve profits and retain market share (Productivity Commission 2008). Regulations and institutions that reduce farm operators' flexibility in responding and adapting to external pressures and competition can impede productivity growth, especially where compliance with standards and regulations is associated with significant costs.

Innovative activity also requires that industry has the capability to respond to competition. This includes undertaking basic research, efficient regulation (through appropriate policy instruments, rather than using agricultural policy as an instrument to achieve environmental or social outcomes) and efficient economic infrastructure. For example, improving communication services and public infrastructure may enhance farmers' ability to adopt existing but under-utilised innovations, improving the industry's overall productivity performance by raising the efficiency of low-productivity farms. However, as with public investment in agricultural R&D, provision of public infrastructure should take place only if there are net benefits.

Correcting any distortions in the incentives faced by farmers and ensuring farm operators have the necessary capabilities to respond to market competition will also facilitate resource reallocation and the adjustment process, as poorly performing operations or operations that are unable respond to incentives lose market share or exit the industry. For example, business-support measures under drought-assistance programs can distort the decisions that farmers might otherwise make to pursue productivity gains, encouraging the accumulation of excessive levels of debt or delaying adjustment decisions (Elliston and Glyde 2008).

Objectives

The main objective of this report is to provide a brief guide to the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) productivity estimates and analysis. This report aims to improve a non-technical audience's ability to understand, interpret and communicate productivity and relevant statistics in an informed way. This objective is achieved by:

- providing an outline of the concepts, theories and methodology underlying how ABARES estimates productivity with minimum technicality
- outlining the factors that influence the changes in agricultural productivity over time and the differences between the productivity of farms or industries at a particular point in time.

ABARES (formally ABARE) has released agricultural productivity estimates since the early 1990s. This report provides non-technical users with a comprehensive description of the underlying theories and methodology for the first time. This report will also assist users of the productivity estimates reported by ABARES to better understand how they should be used and interpreted. The report also discusses the main factors driving agricultural productivity and provides a link with the broader economic and policy discussions about the agriculture sector and rural producers.

Methodology

This report consists of two parts. The first part (chapters 1 and 2) provides an outline of the concepts, theories and methodologies underlying productivity estimates. Chapter 1 describes the empirical method and measure of productivity used by ABARES, and discusses analytical issues associated with using index numbers to aggregate data on the quantities of inputs and outputs. Chapter 2 describes the farm financial and physical data obtained from the ABARES annual farm survey that are used to estimate broadacre and dairy productivity.

The second part of the report focuses on the factors driving agricultural productivity change. Chapter 3 surveys the empirical literature on analyses of Australian and international agricultural productivity to identify the determinants of agricultural productivity growth. Chapter 4 highlights some of the differences between the ABARES and Australian Bureau of Statistics agricultural productivity estimates.

Chapter 1: Methods for calculating total factor productivity

Although TFP growth is generally understood to capture the difference between the growth rate of total output and the growth rate of total input, there is no universally accepted method for its measurement. The four main empirical methods are: (i) econometric estimation of deterministic production frontiers; (ii) econometric estimation of stochastic production frontiers; (iii) data envelopment analysis; and (iv) conventional index methods.

Econometric techniques can be used to estimate the technical relationship that transforms the main categories of inputs into the technically efficient (or best-practice) levels of the main categories of outputs (that is, the production function—the level of technical efficiency that cannot be exceeded, and might not be attained). The residual of the regression equation—which represents the part of output not explained by the level of inputs—can then be used as an estimate of TFP. Stochastic frontier analysis (SFA) also uses econometric regression techniques to estimate the best-practice or technology frontier for a set of farms in an industry. However, while both of these methods accommodate data noise (as a symmetric error term) in defining the production frontier, in SFA a one-sided error term is included representing technical inefficiency (farm observations that are not on the production frontier because of the 'managerial ability' of farm operators, rather than measurement error).

Data envelopment analysis (DEA) also allows for farm technical inefficiency. However, because DEA uses linear programming techniques to locate the production frontier for a set of farms in an industry, it is unable to accommodate data noise. Conventional index methods use index formulas (such as the Laspeyres, Paasche, Fisher or Törnqvist indexes) to aggregate data on the quantities of outputs and inputs into measures of total output and total input (for farms, regions or industries). TFP growth is then calculated as the ratio of the output index to the input index, and changes in TFP reflect differing rates of growth in the quantities of inputs and outputs used in production.

There are advantages and disadvantages to using each of these methods (see Coelli et al. 2005 for a comparison of these methods). Broadly, methods that use econometric regression techniques allow the production function to be fully represented and can accommodate noise in the data, but econometric issues may reduce the robustness of estimates. Moreover, whenever TFP estimates are updated the entire system of equations must be re-estimated (OECD 2001). Both SFA and DEA methods allow the observed change in TFP to be decomposed into changes in technology (a shift of the production frontier) and changes in the degree of inefficiency (a movement towards or away from the production frontier). An advantage of these methods is that they can be used when price data are not available for some inputs or outputs (for example, environmental inputs or undesirable outputs such as pollution). However, because DEA (unlike SFA) does not take data noise into account, outliers because of measurement error may result in an erroneous production frontier (Hulten 2001).

Conventional index methods require data on the prices and quantities of each input and output used in production, but only two observations are needed (such as two farms in a single time period or one farm in two time periods). It is also unnecessary to make any assumptions about the parameters of the underlying production technology when using index methods. However, TFP growth estimated using the index number method includes the contributions of technological change, efficiency improvements, and other sources of productivity improvements such as economies of scale and more efficient use of existing capacity.

The following section explains the index method used by ABARES to calculate TFP. First, several conceptual features of the TFP measure and index number methods are explained in more detail.

Then, some of the analytical choices ABARES makes in constructing the index number measure of TFP are described.

Measures of total factor productivity

An important consideration when calculating TFP estimates is whether to use an output measure based on value added or on gross output. The difference between the gross-output and value-added TFP measures lies in how intermediate inputs—defined as materials and services in the ABARES farm survey—are included in the index.

TFP calculated as a measure of gross output $\left(TFP_{GO}\right)$ is given by equation (1):

$$TFP_{GO} = \frac{Gross\ Output}{Capital, Labour, Land, Materials\ \&\ Services}, \qquad (1)$$

and TFP calculated as a measure of value added $\left(TFP_{VA}\right)$ is given by equation (2):

$$TFP_{VA} = \frac{Value\ Added}{Capital, Labour, Land} = \frac{Gross\ Output - Materials\ \&\ Services}{Capital, Labour, Land}. \qquad (2)$$

Both gross output and value added are valid measures for estimating TFP, but they will produce different and non-comparable estimates of TFP. However, when the same dataset is used, the gross-output measure of an industry's TFP growth is less than the value-added measure by a factor equal to the ratio of the current value of the industry's value added to its current value of gross output (Zheng 2005), meaning that TFP growth is higher when calculated as a value-added measure. Because it is easier to aggregate across industries using TFP_{VA} (especially where the output of one industry is an input to another), the value-added TFP measure provides a more reliable indication of the relative contribution of an industry's productivity performance to economy-wide TFP growth than the gross-output measure (OECD 2001).

However, using TFP_{VA} in equation (2) to calculate productivity estimates assumes that materials and services—intermediate inputs such as fuel, fertiliser, chemicals, seed and contracting services—cannot be substituted in production for capital, labour or land. In other words, the value-added TFP measure reflects how efficiently capital, labour and land are combined to produce value-added output, while the gross-output TFP measure reflects how productively all inputs are combined to produce output. The value-added TFP measure also attributes all measured technological progress to capital and labour, implying intermediate inputs cannot be used more efficiently in production (Ball 2010). Because materials and services represent a significant proportion of total farm input, and technological change may improve these intermediate inputs in addition to capital and labour, or cause farmers to choose new combinations of capital, labour, land, and materials and services, ABARES uses the gross-output measure of TFP.

Conceptual features of the ABARES approach to measuring productivity

ABARES uses the conventional index method to measure TFP growth in the broadacre and dairy industries. This method evaluates TFP growth residually, by seeking to explain how much of the observed growth in total output is not accounted for by the growth in total input (OECD 2001).

Estimates of TFP growth are calculated using conventional index number formulas to aggregate data on the quantities of outputs and inputs into measures of total output and total input (for farms, regions or industries). TFP growth is then calculated as the ratio of the output index to the input index, and changes in TFP reflect differing rates of growth in the quantities of inputs used in production and outputs.

TFP growth is sometimes identified as the shift in the production function because of technological progress. However, this implicitly assumes that producers are price-takers, who can adjust quantities but not individually influence market prices (perfect competition), and that producers are technically and allocatively efficient (minimising costs and/or maximising revenues). As these assumptions may not always hold in the broadacre or dairy industries, it is important to reiterate that factors unrelated to technology also lead to changes in productivity and measured TFP. For this reason, the index number-based TFP framework can be complemented by further analysis—such as with econometric techniques—to decompose the TFP residual into variables corresponding to the factors driving productivity growth over time and/or differences in productivity levels (Hulten 2001). These factors are discussed in greater detail in Chapter 3.

To construct the aggregate quantity indexes, data are required on the prices and quantities of each input and output used in production. For most inputs and outputs, price and quantity data are available from the ABARES farm survey program, which collects data on the value and quantity of farm outputs and inputs. Alternatively, as long as quantity and value data are available, implicit prices can be calculated for most items. In cases where only value data are available (such as for some types of capital or categories of output), implicit quantities are calculated by dividing the value data by the appropriate industry prices-paid (inputs) or prices-received (outputs) index.

While productivity is concerned with the relationship between input and output quantities, each item included in the index is weighted by either its price or its value share in the total value of inputs or outputs. This does not mean that TFP is a financial measure; rather, this makes it possible to aggregate heterogeneous units of inputs and outputs in the index formula. For example, this allows inputs such as tonnes of fertiliser and litres of diesel to be aggregated consistently to produce an index of total materials and services used. Similarly, price or value weights allow different outputs such as canola and wheat to be aggregated consistently to produce an index of total crop outputs.

Calculating TFP measures: analytical issues

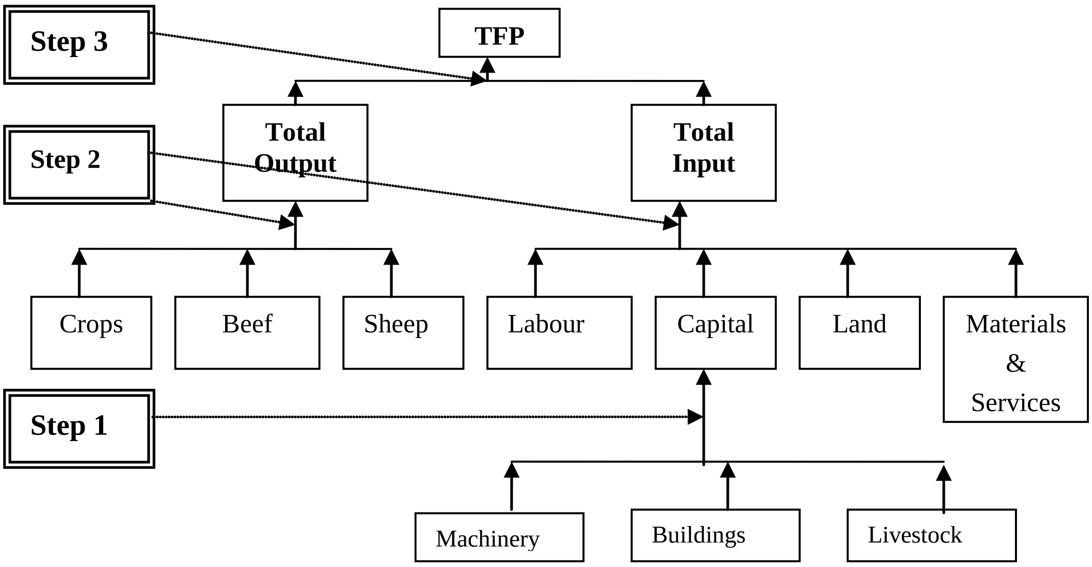
This section briefly examines some of the analytical issues associated with using index number methods to calculate TFP growth. Readers not interested in the technical aspects of calculating TFP indexes may proceed to Chapter 2, while readers requiring more detail are referred to Appendix 1 and Zhao et al. (2010) for a more technical exposition.

The choice of index number formula

The index aggregations of input and output quantities—and therefore the measure of TFP growth calculated—will depend on the index number formula used. The most commonly used index formulas are the Laspeyres, Paasche, Fisher and Törnqvist indexes. The Laspeyres and Paasche indexes are used by official statistical agencies to compute quantity and price indexes (including the consumer price index) and have the advantage of being easy to compute. Moreover, those indexes provide a lower (Laspeyres index) and upper (Paasche index) limit for the ‘true’ index defined using economic theory. This is because the Laspeyres index uses the price or value of inputs and outputs in the base year as weights, while the Paasche index uses the price or value of inputs and outputs in the current year as weights. However, if the economic theory of production is used to compare the properties of index numbers, the choice is essentially between the Törnqvist and Fisher indexes, which have more desirable economic properties. Appendix 1 outlines some of these properties in the context of the Fisher index, which is the geometric mean of the Laspeyres and Paasche indexes, and the index ABARES uses to aggregate inputs and outputs to derive estimates of TFP growth. The formula of the Fisher index is presented in Appendix 1, with a simple example in Table 1 outlining how productivity growth is calculated for a single farm using the Fisher index.

The process followed when calculating farm-level TFP estimates using the ABARES survey data is demonstrated in Figure 6, and the inputs and outputs pertaining to the broadacre and dairy industries are outlined in tables 2 and 3 in Appendix 2 (and other industries will have different input and output categories). In the first step, multiple inputs and outputs are aggregated via the Fisher index to form broad categories of inputs and outputs. In the second step, the input and output categories are aggregated (again using the Fisher index) to form indexes of total input and output. In the final step, a ratio of total output to total input is taken to calculate the estimate of TFP.

Figure 6: The ABARES farm-level TFP estimation process



Source: Zhao et al. (2010)

A similar procedure is followed when TFP estimates are calculated at aggregate levels, only specific outputs and inputs across farms are aggregated to the relevant level. However, the outputs and inputs of a particular farm are aggregated using sample structure weights that reflect how representative that farm is of other farms in the industry.

The direct versus chained Fisher index

As noted previously, the use of weights allows aggregation of quantities of heterogeneous inputs and outputs. If TFP growth is estimated between two consecutive periods (periods 1 and 2), whether the quantities of inputs and outputs are weighted using prices (or value shares) from period 1 or 2 will depend on the index number formula used. However, TFP estimates are usually calculated over longer periods (the ABARES farm survey data is available from 1977–78 for broadacre industries and 1988–89 for the dairy industry). This makes it necessary to choose between a direct and a chained index.

A direct index compares the current period (period *t*) to a fixed base period (quantities are weighted with prices or values from period *0*), whereas a chained index compares the current period to the previous period (quantities are weighted with prices or values from period *t–1*) for all observations. This process is summarised in Figure 7.

Figure 7: Comparing direct and chained indexes

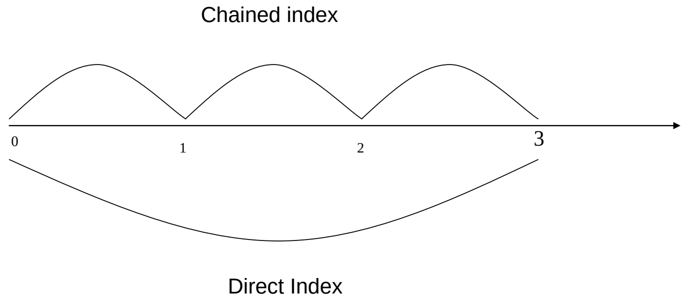


Figure 7 illustrates the choice between a direct and chained index. If there are four time periods (periods 0, 1, 2 and 3), then the change in productivity between periods 0 and 3 can be calculated as a direct Fisher index between period 0 and period 3. Alternatively, the change in productivity between periods 0 and 3 can be calculated *indirectly* as a chained index by calculating the Fisher indexes between periods 0 and 1, periods 1 and 2, and periods 2 and 3, which are then multiplied together to obtain the change in productivity between periods *0* and *t*.

Direct and chained indexes will result in different estimates of TFP growth between periods *0* and *t*, especially in longer time series, as the current period (*t*) moves further away from the base period (*0*). For this reason the chained index is considered to provide a better representation of the change in productivity, because comparisons are made between consecutive periods. If the direct index is used, the changes between consecutive periods are less directly observable, because the productivity change between periods 1, 2 and 3 are all compared with productivity in the base period (*0*). However, a disadvantage to using a chained index is that the weights need to be revised each year. There are other technical issues which apply to the choice between a direct and a chained index (see Zhao et al. (2010) for more details), and both are considered to be statistically valid. Which one is most suitable depends on the purpose of the estimates and the availability of price data to construct input and output quantity weights. ABARES uses the direct index method.

The multilateral Fisher index

In addition to estimating productivity *growth* in the broadacre and dairy industries over time, ABARES also compares the TFP estimates of farms in a period (that is, compares the relative productivity *levels* across different farms). However, the Fisher index is only suitable for estimating productivity changes over time. Therefore, to compare TFP estimates between a pair of farms (and between farms over time), the Fisher index must be transformed so that TFP estimates are consistent. If there are more than two farms, and the Fisher index is used to calculate TFP estimates, the resulting estimates will differ depending on whether farms are compared directly or indirectly, and on the order in which the farms are compared. For example, if there are three farms (farms A, B and C), then there are two ways to compare productivity between farms A and C. A direct comparison would simply be the Fisher index calculated between farms A and C. Alternatively, an indirect comparison would be to calculate the Fisher index between farms A and B, and between farms B and C, and then multiply the two indexes together to produce a Fisher index comparing farms A and C.

The estimated index between farms A and C should be the same regardless of whether farms A and C are compared directly or indirectly, but because the Fisher index is not transitive (a direct comparison of two farms does not produce the same estimate as an indirect comparison through a third farm), the indexes are not the same. To overcome this problem, ABARES extends the Fisher index and makes it transitive by applying the Elteto-Koves-Szulc (EKS) procedure (outlined in Appendix 1) to generate estimates of total input and total output (at Step 2 in Figure 6). Then, productivity estimates are calculated as in Step 3. The transitive Fisher index is also independent of the choice of the base farm. Using the EKS procedure allows any two farms to be compared by dividing their respective index numbers.

Calculating long-term productivity estimates

The preceding sections have outlined how ABARES derives its annual TFP estimates for the broadacre and dairy industries. ABARES also calculates average productivity growth rates for the broadacre and dairy industries over time, which provides an indication of technological progress in these industries. Factors such as seasonal conditions (especially rainfall) can cause broadacre and dairy TFP estimates to fluctuate widely from year to year (see Chapter 3 for a discussion of water availability as a determinant of productivity growth). For this reason, long-term trends in productivity growth provide a more reliable indicator of an industry's productivity performance, as the effects of year-to-year fluctuations are softened. ABARES derives estimates of the broadacre and dairy industries' long-term productivity trends econometrically by regressing the logarithm of the estimated TFP index against a constant and a time trend variable. The annual (average) growth rate is then the estimated coefficient on the time trend (see Nossal and Sheng 2010 for a more detailed discussion).

Chapter 2: Data

Detailed data are required on the inputs and outputs of farms in order to calculate estimates of TFP growth or to compare levels of TFP between farms. Farm financial and physical data are obtained from the ABARES farm surveys. This chapter outlines how the survey data are collected and outlines some issues that arise when the data are used to calculate measures of TFP. Readers are referred to Zhao et al. (2010) for more detail on general measurement issues, on how specific inputs and outputs are measured, and on how inputs and outputs are aggregated to produce productivity estimates for the industry, regional and national levels.

Sources of data

As noted in the introduction, ABARES produces estimates of TFP growth for the broadacre and dairy industries. Using ABARES farm survey data, productivity statistics for the broadacre industry can be calculated from 1977–78 to the present. Productivity statistics for the dairy industry can be calculated from 1988–89. Broadacre and dairy farms account for almost 70 per cent of commercial-scale farm businesses in Australia, and the majority of Australia's family owned and operated farms. Broadacre and dairy farms are responsible for managing more than 90 per cent of the total area of agricultural land in Australia (ABARE 2009).

The main source of data for the broadacre industry is the ABARES Australian Agricultural and Grazing Industry Survey (AAGIS). For the dairy industry, the main data source is the ABARES Australian Dairy Industry Survey (ADIS). The sample size of AAGIS in a given year is between 1200 and 1600 broadacre farms. ADIS collects data from approximately 300 dairy farms. Farms are generally retained in AAGIS or ADIS for three to five years, although some farms are included for longer and shorter time periods.

The sample of farms included in AAGIS and ADIS is not random. This is because one objective of the ABARES farm survey program is to provide a representation of Australia's agricultural industries in aggregate. To achieve this, farms are selected for inclusion in the surveys according to their classification by industry, size and geographic region. For the purpose of aggregation, farms are assigned weights that reflect the number of farms in the stratum, areas of crops and livestock numbers as recorded by the Australian Bureau of Statistics (ABS). These weights are also used when calculating industry-level estimates of productivity. The classification of farms and calculation of weights is based on data from the Agricultural Census conducted by the ABS, updated annually with data collected from the ABS agricultural commodity surveys.

Both AAGIS and ADIS collect quantity and value data on inputs and outputs wherever possible, and tables 2 and 3 in Appendix 2 contain lists of the inputs and outputs included in AAGIS and ADIS. Where possible, prices are taken at the farm gate. In cases where only value data is available, such as for capital items like farm machinery, quantities are derived by dividing the value data by an appropriate price index, as described in Chapter 1. Data are collected through face-to-face interviews between farm operators and experienced data collectors. Interviews generally take around three hours and information is drawn from a variety of sources, including farm accounts, record-keeping software and the farm operators' knowledge. Where necessary, non-farm survey data are also used, mainly on the prices of inputs and outputs. Sources include the ABARES corporate database, the ABS and the Reserve Bank of Australia.

Multiple-enterprise farms

Australian farms often operate multiple enterprises—for example, livestock and cropping. This has several implications for productivity analysis. This section contains a discussion of the implications of farms with multiple enterprises for farm-level and industry-level estimates.

Because the ABARES farm surveys collect data at the farm level, and not the enterprise level, the inputs and outputs of each enterprise operated by the farm are undifferentiated. The allocation of inputs to specific enterprises is particularly problematic. Often, records are not kept on input use by enterprise and, unlike outputs such as wool or wheat, inputs such as fuel and fertiliser are not easy to identify as belonging to a particular enterprise. This means that calculating productivity estimates at the enterprise level is often not possible.

Farm-level effects

Farms that produce multiple outputs often alter the amount of each output produced. Theoretically, this change in the enterprise mix will be accurately reflected in farm-level estimates of TFP. For example, if the cropping enterprise of a mixed crop–livestock farm is relatively more productive than the livestock enterprise, then a shift within the farm to a higher proportion of cropping will raise the aggregate productivity of that farm. A shift towards more cropping will make no difference to farm-level productivity only if there is no difference in productivity between the two enterprises.

Farm-level productivity estimates should also reflect the impact on TFP of a multi-enterprise farm using the output from one enterprise as an input to another. For a farm that is relatively more productive producing crops than livestock, feeding grain to livestock rather than selling it will cause the measured productivity of the farm to fall. However, the extent to which this is responsible for a given change in productivity will be hard to measure, because data are not collected on the volume and value of outputs used as intermediate inputs in other enterprises.

Industry-level effects

Just as farm-level estimates require data on the inputs and outputs of farms, estimation of productivity at the industry level requires data on the inputs and outputs of a particular industry (for example, cropping or livestock). If enterprise-level data were available, deriving industry-level data would be a relatively simple matter of aggregation. However, because enterprise-level data are not available, ABARES calculates industry-level productivity estimates by grouping farms into industries based on the proportion of total farm receipts that come from each enterprise operated, where the broadacre and dairy industries are defined according to the Australian and New Zealand Standard Industrial Classification (ANZSIC) (ABS 2006).

For example, a farm that earns 70 per cent of its receipts from a cropping enterprise and the remaining 30 per cent from a sheep enterprise would be classified as a cropping specialist, and all the inputs and outputs of that farm would be included when calculating productivity estimates for the cropping industry. Therefore, as measured by ABARES, TFP estimates for the cropping industry reflect the productivity of farms that are *mostly* involved in cropping, rather than the productivity of cropping enterprises in isolation. Furthermore, this system means that, as the enterprise mix changes, a given farm may switch from being a sheep specialist to a mixed crop–livestock farm to a crop specialist. Changes in the composition of farms in an industry may alter estimated productivity.

Accounting for quality

It can be difficult to account for the quality of inputs and outputs when calculating TFP estimates. If a farm improves the quality of wheat produced, this should be captured, to some extent, in the TFP estimates through the value weight used in the output index. Because higher-quality wheat has a higher unit value (price), the weight attached to wheat in the output index would increase (assuming world prices are constant). If the farm was at least as efficient when producing the higher-quality wheat, farm-level productivity would rise. However, the ABARES farm surveys do not collect data on wheat receipts by quality. Instead, the total value of wheat sold by the farm is collected, and this is influenced by a variety of factors, including (but not limited to) the quality of wheat, marketing arrangements and the farm operator's risk management strategies.

It is also important to consider input quality. In particular, land quality is difficult to capture accurately using a value weight. One possible method is to use the opportunity cost of land, calculated as the value of the property multiplied by a real interest rate. In this way, the weight attached to higher-quality (more expensive) land would be higher than that of lower-quality land. The problem with this method is that land prices reflect farmers' expectations about the future returns from land investment, and farmers' expectations are also influenced by factors not related to production, such as distance from markets and town centres and other non-productive amenities such as aesthetics and lifestyle factors (Martin et al. 2010).

Because land prices also reflect non-production factors, using the price of land to derive a value weight will result in too large a weight being placed on land in the input index, relative to when land is treated solely as an input to production (as is appropriate when calculating productivity estimates). To avoid this problem, ABARES uses the value of output produced plus any capital improvements as the weight applied to land in the input index. This provides an estimate of the per hectare value of services provided by land as an input to production.

Treatment of capital

For most inputs, measuring the quantities used in production is relatively straightforward. For example, the input of land is measured as the average of the area operated at the beginning and end of the financial year, and the input of labour is the number of weeks worked by hired workers, the owner-operator and family members. However, measuring the input of capital is more difficult. This is because productivity and the variables included in the input index are concerned with the *flow* of services provided by that input in the production of output.

Because flows of capital services are not directly observable, they are assumed to be proportional to the *wealth capital stock*. Wealth capital stock is the current market valuation of the productive capital stock (a measure of the productive capacity of a capital asset), adjusted for (economic) depreciation or the loss in value of the capital asset as it ages (OECD 2001). Accordingly, for capital items such as plant and equipment, the quantity variable used is the farm operator's estimate of the average value of each capital item, divided by the respective prices-paid index (see Zhao et al. 2010 for more detail).

If farm operators hire or rent their capital input, market rental prices can be used as weights. However, as farmers usually own the capital assets used in production, the prices of capital services are unobserved. Instead, ABARES approximates the 'user cost' of capital as the opportunity cost of capital plus depreciation, by multiplying the farm operator's estimate of the current market value of the asset by the sum of the market interest rate (The Reserve Bank of Australia's one-year loan rate that takes into account inflation) and the rate of depreciation. The user cost of capital is the implicit rent that the owners of capital assets 'pay themselves' to cover the cost of using the asset. To accurately reflect the flow of productive capital services to a particular farm, the value of leased capital items is included in this calculation.

Livestock are treated as a component of capital. The farm survey collects data using a livestock trading schedule to account for growth or reductions in total animal numbers (through natural replenishment, reproduction and mortality). In the livestock input index, the average of the opening and closing animal numbers is the quantity (or capital stock) variable, and the weight is the opportunity cost of investing in this capital. This is calculated as the average of the opening and closing values of the animals, multiplied by the market interest rate. For animals purchased in a production year, the value variable is the amount paid, plus the value of transfers in (such as livestock agisted on a farm). Volumes are derived by deflating the purchase values by an appropriate price index. An adjustment is made to account for operating gains from livestock growth during the course of a financial year. When livestock are sold, they are simply treated as an output. The value variable used is the receipts for livestock sold, plus transfers out and an adjustment for operating gains. Quantity variables are derived from the value of receipts, deflated by an appropriate price index.

Non-market inputs and outputs

Productivity estimates are calculated using data on ‘market’ inputs and outputs, which are inputs and outputs that are traded (in other words, priced) in the marketplace. However, there are some farm inputs and outputs that do not have market prices. For broadacre farms, water availability (including rainfall) is an important non-market input in the production process. Ecosystems services (such as habitat provision and conservation of native vegetation) and agricultural chemical leaching and runoff are examples of non-market outputs (both good and bad).

Because productivity measurement is concerned with how efficiently farm operators combine inputs to produce outputs, there is a case for broadening the definition of productivity to include non-market inputs and outputs. However, there are significant difficulties associated with constructing variables for non-market inputs and outputs, in part because non-market inputs and outputs (especially their prices) are difficult to measure. For example, a variable measuring water availability for farms must reflect not only the quantity and timing of rainfall, but also the rate of evapotranspiration, the location of the farm within a catchment, the nature of the soil, the extent and type of vegetation and the characteristics of the farming system, such as the tillage practice employed.

For this reason, productivity estimates measure how well operators combine chosen quantities of market inputs to produce market outputs, and the role of non-market inputs and outputs, which may or not be (indirectly) controlled by farm operators, is mainly a consideration when interpreting and comparing estimates of productivity (discussed in more detail in Chapter 3). Nevertheless, inclusion of water availability as an input to broadacre agriculture would make the relationship between TFP and technological progress clearer.

Chapter 3: Explaining productivity growth in broadacre agriculture

Productivity measurement (through calculation of TFP estimates) is not an explanation of the underlying causes of productivity growth. As noted previously, the TFP framework measures the remaining balance of output growth that cannot be explained by the growth in inputs, and should be complemented by further analysis to identify the factors driving productivity and their relative contribution to output growth. Estimates of TFP growth are likely to comprise the combined effects of technological change, economies of scale, efficiency change, variations in capacity utilisation and errors in the measurement of the components of total input and output. This chapter discusses the interpretation of TFP estimates, and outlines some of the factors driving agricultural productivity growth at the farm and aggregate levels.

Interpreting TFP estimates

Conceptually, TFP growth (when calculated as a gross-output measure) is equivalent to new knowledge and technological change that allow the quantity of output produced from a given quantity of inputs to rise, or for at least as much output to be produced when the quantity of inputs is reduced. However, as measured by ABARES, TFP estimates will also capture factors other than technological progress that cause productivity to change. These points are explored in this section.

In the context of productivity measurement, technological innovations may take the form of either *embodied* or *disembodied* technologies. Embodied technological change is apparent in new or improved inputs (for example, new farm machinery, improved agricultural chemicals and new crop varieties). In contrast, disembodied technological change is not physically tied to any input (OECD 2001), and may take the form of new management practices or scientific results that improve the efficiency of production processes.

Conceptually, the distinction between embodied and disembodied technology is important because only disembodied technological change will enter the TFP measure. This is because the TFP index attributes the effect of embodied technologies to the relevant input *so long as* the price used to weight the input reflects the change in the quality of the input (that is, the change in the value of the input to the farmer). This would be the case if the innovator was able to appropriate the value of the improved input to the farmer, so that the measured increase in the (weighted) input offset the increase in output. Alternatively, the greater weight will compensate for the decrease in the quantity of the input used. Conversely, disembodied technology is not generally paid for directly by the adopting farmer, but can be a consequence of imitation, 'learning by doing', or public investments in R&D (OECD 2001).

In practice, the adoption of embodied technologies increases TFP estimates (as measured by ABARES) because: (i) the new technology incorporates or enables the use of some disembodied technology; or (ii) the new technology is embodied in new inputs that are purchased at a price less than their full value, because the gains are not fully appropriated by the innovator (or seller) of the new inputs (Griliches 1992; OECD 2001). TFP estimates will also increase because data and resource constraints mean that inputs such as capital, labour, and materials and services cannot be differentiated according to their quality.

Reiterating a point that has been made in the earlier chapters of this report, the ABARES TFP estimates also capture the effect of factors that influence productivity other than technological progress. This includes the effect of institutional and organisational changes that reduce constraints on production, scale effects, improvements in technical efficiency (moving closer to 'best practice') and allocative efficiency (moving closer to profit-maximising behaviour), and measurement errors. TFP estimates will also capture spillover productivity gains, such as the benefits of improvements to public infrastructure (for example, transportation, information technology, and communication infrastructure).

Farm-level and industry-level productivity

Analysis of farm-level TFP estimates may provide an insight into the mechanisms through which broadacre industries adopt technology, and, more broadly, achieve productivity growth (OECD 2001). The productivity of farms within an industry will differ, and one source of productivity growth for an industry is the reallocation of resources—from less productive to more productive farms—associated with the expansion of some farms and the exiting of others from the industry. Industry-level productivity will also increase if the share of output of high-productivity farms increases. Further, the reallocation of outputs and inputs between farms, and between industries, contributes to the productivity of the broadacre sector as a whole.

Technological improvements in an industry may be associated with the staggered adoption of new technology by farms, rather than with a simultaneous uptake of technology by all farms in the industry (OECD 2001). Similarly, efficiency improvements in an industry may be a result of farms simultaneously moving closer to best practice, or an increase in the share of production of high-efficiency farms. Therefore, farm-level productivity analysis can help to identify the characteristics of higher-productivity farms. In contrast, industry-level productivity analysis allows the effect of macro-level factors, such as institutional changes and R&D funding, to be explored.

Factors driving agricultural productivity growth

This section discusses the factors that have been identified as drivers of farm-level and industry-level agricultural productivity. Following the Productivity Commission (2005), these factors can be characterised into three broad mechanisms of growth:

- new knowledge or technology
- changes to institutions and the organisation of production
- effects arising from changes in the structure of agricultural industries.

It should be noted that these mechanisms are not unique to agriculture. However, there are other factors that are specific to agriculture. For example, as noted in Chapter 2, broadacre and dairy productivity depends on water availability, and the effect of water availability on agricultural productivity is also discussed in this chapter.

New knowledge or technology

The distinction between the forms of technology (embodied versus disembodied) has already been discussed in the context of interpreting TFP estimates. A second issue concerns the role of R&D and extension in the creation of new knowledge and technology—key drivers of productivity growth—and its dissemination to producers. Public and private investments in agricultural R&D (used as proxies for the stock of knowledge available to farmers) have been important in driving long-run productivity growth in agriculture (Morrison Paul 2000; Mullen 2007). However, there are usually very long lags between expenditure on R&D and an appreciable change in productivity growth. This is partly because developing new technology or knowledge takes time, and also because the adoption of innovations across an industry can be slow, despite the best extension efforts. Accordingly, changes in TFP should not be used as an indicator of the success of recent investments in R&D. This is particularly the case for short-term fluctuations in TFP, because these changes are usually the result of factors such as seasonal conditions, which are beyond the control of governments, researchers or industries. However, if the rate of technological progress is rapid, in the short run the productivity gains arising from technical *change* may be partially offset by a decline in technical *efficiency*, if farmers are unable to adjust their input mix in line with the fast rate of technological progress (Brümmer et al. 2002).

Agricultural productivity (as measured by TFP) has generally been found to be more responsive to public than private R&D investment, although this may be because private-sector research more often takes the form of applied research and/or the development of embodied technologies. Patent protection provides the private sector with the incentive to focus on applied research with shorter term payoffs that can be appropriated during a patent life (Chavas et al. 1997). Similarly, private markets usually exist in embodied technologies, so that innovators are able to capture more of the benefits of their R&D activity. In contrast, basic research and disembodied technologies, having public good characteristics, are more likely to be funded by public investment in order to avoid suboptimal levels of investment in agricultural R&D. This division of public and private investment also means the long-term effects of private and public R&D on productivity differ. The effects of private research are often larger in the short term (five to 15 years) but small in the longer term. In contrast, the returns from public research are small in the short term, but larger in the longer term (15 to 25 years) (Chavas et al. 1997). Further, the impact of public investment in R&D may be overstated because productivity improvements resulting from extension activities, research spillovers and consumption of natural resources (among other things) can be incorrectly attributed to public R&D investments (Alston and Pardey 2001).

Sunding and Zilberman (2001) also draw attention to the political economy of public funding of agricultural R&D. Competitively-awarded public funding may have a lower productivity payoff than programmatic funding if there are substantial transaction costs associated with managing proposals and projects. Competitively awarded public funding may also shift the focus of R&D away from innovations that improve agricultural productivity in favour of cross-cutting issues such as natural resource management (Huffman and Just 1994; Huffman and Evenson 2006).

Research conducted overseas represents a source of spillover productivity gains, whether as ideas borrowed from the research of others or the adaptation of foreign technology to suit local conditions. The spillover productivity gains from external R&D will be greater if the technology or knowledge is sourced from regions (or countries) that have similar agroecological conditions, as less investment in adaptive research will be required (Sunding and Zilberman 2001; Gutierrez and Gutierrez 2003).

Changes to institutions and the organisation of production

Efficiency improvements following the reorganisation of production at the farm and/or industry level can also enable productivity growth. As noted previously, the reorganisation of production may be motivated by changes to institutions and regulatory arrangements that reduce or remove constraints on production or increase an industry's exposure to domestic and external competitive pressures.

The agricultural sector has benefited from spillover productivity gains because of government investment in transportation and communication infrastructure (Parham 2004). Improved infrastructure can reduce transportation costs, which may accelerate technology diffusion in an industry by reducing geographical barriers to adoption of new technologies and improving farmers' access to consultants (Sunding and Zilberman 2001; Yee et al. 2004; Chavas 2008). Access to private and public extension (for example, product demonstrations and institutional arrangements such as the National Variety Trials) reduces the risk associated with adoption of new technologies by signalling the appropriateness of a new technology for a particular farm. Another possibility is that the extent to which farmers are able to use new technologies depends on the benefits and costs of learning to use and using those technologies, where those benefits and costs depend on the stock of infrastructure capital and the costs of infrastructure services (Antle 1983).

The education level of farm operators is also recognised as an important factor influencing agricultural productivity (Mullen 2007). Skills obtained with higher levels of formal schooling increase farm operators' ability to manage production and marketing risks and to identify and adopt new technologies. This is especially the case as agriculture becomes more technology intensive—because of increasing mechanisation, modern pest-control methods, and the availability of new process technologies such as the internet and information and communications technologies (Makki et al. 1999; Huffman and Evenson 2001). Rigidities, such as slow capital adjustment, can prevent farm operators from reaching cost-minimising combinations of inputs and outputs, thereby acting as a constraint on agricultural productivity growth (Arnade and Gopinath 1998; Morrison Paul *et al.* 2000). However, farm operators' experience or 'learning by doing' can facilitate adjustment to a changing economic and technical environment. This is because experience with existing durable capital goods and 'learning' that improves farm operators' ability to organise and maintain complex production processes can facilitate the adoption of new technologies and improve productivity (Luh and Stefanou 1993).

Agricultural productivity is also influenced by the institutional environment within which farmers operate. For example, productivity growth may be affected by tradeable water rights, inheritance laws (Ball et al. 2001), intellectual property protection (Alston and Pardey 2001), land tenure and macroeconomic (for example, interest rate) policy (Sunding and Zilberman 2001). Productivity growth is also influenced by the terms of trade faced by farmers. In the short term, changes in the relative terms of trade may induce farmers in profit-maximising to choose combinations of inputs and outputs that reduce productivity (Productivity Commission 2008; O'Donnell 2009). Also, in the short term, favourable terms of trade may appear to reduce productivity if farmers increase spending on inputs while the relatively inelastic output supply is unaffected (Mullen and Cox 1995). However, if farmers are using high income periods to bring forward their purchases of inputs and add to their inventories, the change in estimated productivity may only reflect mismeasurement of the current periods input use, rather than an actual decline in the efficiency of production processes. Conversely, in the long term, productivity will increase if favourable terms of trade encourage farmers to substitute more efficient technologies for conventional inputs (Makki et al. 1999).

Regulatory controls or industry standards that determine farm management strategies will also influence productivity, and Sunding and Zilberman (2001) suggest that the induced innovation hypothesis (see the preceding section) can be expanded to state that investment in innovative activities is induced by the shadow prices implied by government policies and regulations. For example, environment-friendly techniques may be linked to the imposition of stringent environmental regulations. Davidson et al. (2006) found that controls on clearing native vegetation constrained broadacre productivity growth by inhibiting the introduction of new technologies, restricting changes in land use and reducing the efficiency of normal farm management practices. Standards that determine the range of management practices available to farm operators will also influence productivity growth. For example, comparisons of the performance of organic and conventional farms in Finland determined that even as organic crop and livestock farms used relatively less productive technology, organic farms had a relatively high level of technical efficiency. This was attributed to the imposition of standards ruling organic farming, which decrease the variation in management practices (Oude Lansink et al. 2002).

Finally, agricultural productivity will be affected by microeconomic reforms that expose farmers to competition in export markets. This includes the removal of statutory marketing authorities and industry price support schemes, and the removal of trade barriers. Reform may increase productivity by removing distortions so that resources are reallocated to more productive activities. However, Makki et al. (1999) suggest that farm payments may relax farmers' budgets so that they are able to purchase and substitute technologically improved inputs for conventional inputs, raising productivity. In the short run, sudden changes in the economic environment as a result of drastic reform may decrease efficiency, because of farmers' financial stress and resulting reduced capacity to adapt to the new economic conditions (Morrison Paul *et al.* 2000). However, in the long run, the same reforms can have a significant and positive effect on productivity (Hall and Scobie 2006). These benefits may be the result of improved allocative efficiency in response to price signals, especially in terms of output composition (Morrison Paul *et al.* 2000) or of inefficient farmers leaving the industry (Coelli 1996).

Hall and Scobie (2006) also suggest that foreign R&D is especially important for small, open economies, and the effect of foreign R&D on productivity can increase with the country's degree of openness to trade (Gutierrez and Gutierrez 2003). This is because trade is a mechanism through which knowledge and technical progress is transmitted across countries: (i) by assisting to spread new production methods and more efficient use of domestic resources; (ii) by reducing duplication of research by encouraging producers in each country to pursue distinctive ideas and technologies; (iii) by enlarging the size of the market and thereby influencing incentives to innovate; and (iv) by inducing patterns of specialisation when countries' research experience or the composition of their endowment bundle differ (Grossman and Helpman (1999) in Gutierrez and Gutierrez (2003)).

Effects arising from changes in the structure of agricultural industries

Changes in the structure of farms and of agricultural industries are also a source of aggregate productivity improvements. The determinants and enablers of productivity growth discussed in the preceding paragraphs (such as technology adoption, R&D and government policies and reforms) can also induce structural change, which may motivate farmers to make better use of available technologies and management practices, improving efficiency and thereby increasing the productivity of agricultural industries (Huffman and Evenson 2001). This suggests that policies intended to retard structural change may slow productivity growth.

There is a trend in Australia towards larger farms and a smaller number of farms (Productivity Commission 2005). Farm exits and consolidations (causing a change in the composition of farms in the industry) can lead to an increase in the share of production of high-efficiency farms, resulting in higher industry productivity overall. When a farmer exits the industry and sells his or her farm, the buyer typically has higher productivity than the exiting farmer. As the area of land controlled by producers with relatively high productivity rises (and consequently the share of production), industry productivity will increase. Other trends are also apparent, including increasing enterprise specialisation and participation in off-farm work (Productivity Commission 2005), which also have implications for productivity growth.

Farm-level analyses show that larger farms tend to have higher productivity growth than smaller farms (Huffman and Evenson 2001; Yee et al. 2004; Zhao et al. 2009). The reason for the generally higher productivity growth of larger farms is not clear. One possibility is economies of scale (that is, the cost advantages that a business obtains because of expansion). As farm size increases, on-farm infrastructure and capital (for example, sheds and machinery) will be better utilised, leading to higher productivity.

A second possibility is that different technologies are adapted to particular farm sizes, so that as farm size increases, farmers can switch to a technology better adapted to their size (see Chavas 2008). However, larger farms may have a greater capacity to adopt a technology suited to their size, allowing them to use more efficient combinations of inputs than smaller farms. This may be a result of larger farms having a greater capacity to invest in new technology and farm management practices because of their generally larger cash flow and greater access to finance. Equally, new technologies may be better suited to larger-scale farming.

Broadacre productivity growth is also influenced by a trend towards increasing enterprise specialisation (especially in the cropping industry) (Huffman and Evenson 2001; Alexander and Kokic 2005). Specialisation may reduce the complexity of farm management by allowing farmers to focus their skills on fewer enterprises, improving production control and efficiency, and allowing farm and food marketing firms to become better organised spatially, contributing to lower transportation and marketing costs (Chavas 2008).

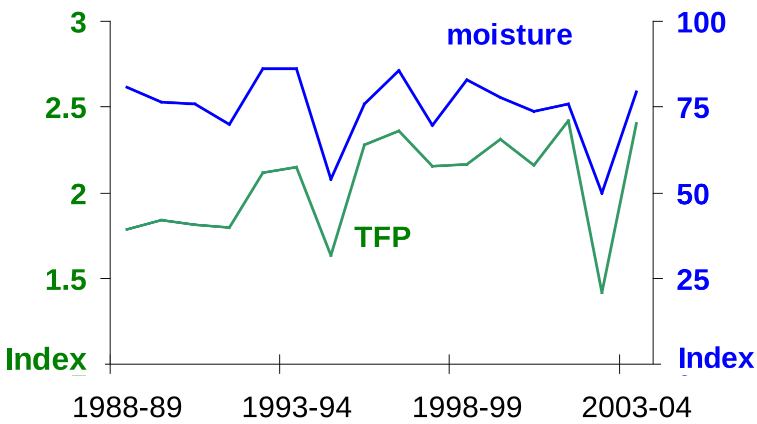
Participation in off-farm work tends to reduce productivity, possibly by changing the time lines of farming activities in ways that reduce agricultural productivity (Yee et al. 2004; Ahearn et al. 2005) or by reducing farmers' opportunities to research and implement more efficient farming practices and technologies (Alexander and Kokic 2005). Equally, a negative correlation between productivity and participation in off-farm work may actually arise because low-productivity farmers work off-farm out of necessity (Yee et al. 2004).

Water availability

Climate (usually approximated by a measure of water availability) is also an important determinant of broadacre productivity. Water availability explains a significant proportion of the short-run variability in TFP estimates over time. Water availability (often measured by pre-planting cumulative rainfall less than or greater than one standard deviation from normal, or by a moisture availability index as in previous ABARES productivity analyses) appears to mainly affect productivity when water is a limiting factor to production, with higher productivity associated with lower levels of water stress (Kokic et al. 2006). However, cumulative pre-planting rainfall also explains productivity growth (Huffman and Evenson 1992; Mullen and Cox 1996; Yee et al. 2004). If water is non-limiting in a given year, factors such as management skill and enterprise mix are more important determinants of productivity. The effect of moisture availability on Australian broadacre TFP is evident in Figure 8, which demonstrates that when water is a limiting factor to production—such as during a prolonged drought—the effect is reflected in TFP estimates.

The strong correlation between water availability (on the right axis) and the ABARES TFP estimates (on the left axis) in Figure 8 arises because water is not included as an input to production. This is because water (specifically, rainfall) is neither a market input nor under the control of farmers. This means that when drought causes water to be a limiting factor to production, the measured quantity of inputs generally falls, if at all, by less than the measured quantity of outputs, and so TFP falls.

Figure 8: Broadacre productivity and moisture availability in Australia



As discussed previously, water availability is not included as an input to broadacre production because, unlike capital or labour, producers generally do not have a choice of how much water to use in a given year. However, while rainfall cannot be influenced by farmers, management practices exist that can affect water availability on a given farm. These practices relate to tillage methods, stubble retention, soil carbon, paddock layout and compaction.

For this reason, ABARES is developing a measure of water availability to include in the input index when estimating productivity. Including a measure of water availability will reduce the variability of productivity growth from year to year and allow more accurate estimation of productivity, taking into account seasonal variation. For example, in a year with poor seasonal conditions, overall output and observed productivity of individual farms falls. At the same time, the proportion of output produced by farms with relatively high productivity rises, because those farms make the best use of the resources available to them. A farm-level measure of water availability (that incorporates the moderating effects of management practices) will allow the effect of different management practices on farm-level productivity to be explored in more detail.

However, there are a number of data challenges related to constructing a variable to measure a farm's water availability, and these must be overcome before a measure of water availability can be included in the input index. For example, a variable measuring water availability at the farm level might require information on the quantity and timing of rainfall, the evapotranspiration rate, the soil type, the extent and type of vegetation, and the characteristics of the farming system, such as the tillage practice employed. A second concern is the choice of an appropriate price to weight the quantity measure of water availability in the input index. Because rainfall is not a market input, there is no meaningful price which can be applied. Overcoming these data constraints and determining the appropriate weight are areas for further research.

It is also important to note that, to the extent that rainfall and water availability are not under the control of farmers, inclusion of this variable will change the interpretation of the estimates. By including water availability, TFP estimates will reflect the combined productivity of farmers and the seasonal conditions in a given year, rather than just the productivity of farmers.

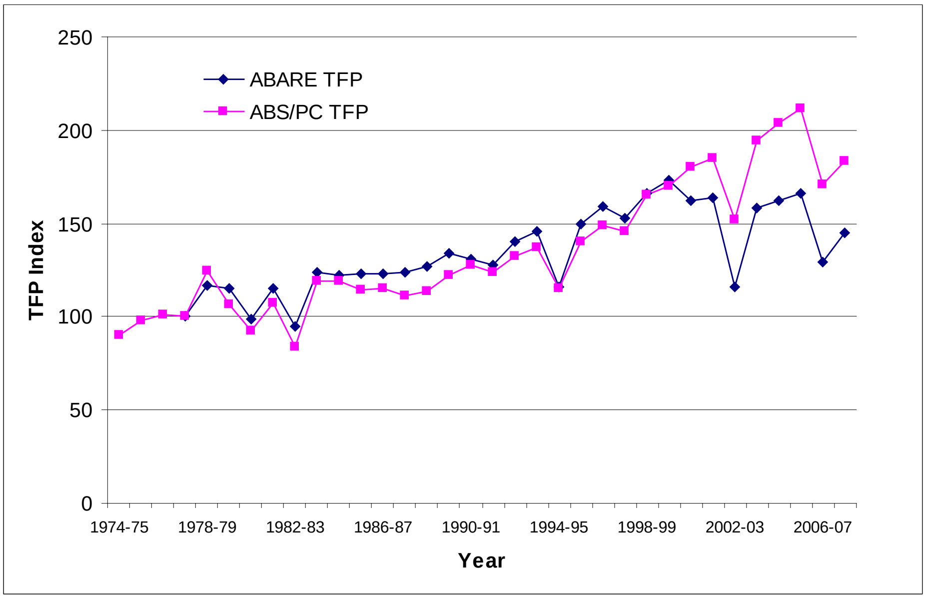
Chapter 4: Comparing the ABARES method with the ABS method

This chapter compares the key differences between the TFP estimates produced by ABARES for the broadacre and dairy industries with the TFP estimates for agriculture produced by the ABS. ABARES and the ABS both measure productivity growth within the growth accounting approach, and TFP estimates are calculated using conventional index number formulas. However, there are some differences which make it difficult to compare these organisations' estimates, and these differences are highlighted below. Interested readers may also refer to Zheng (2005) and ABS (2007) for more information.

The Australian Bureau of Statistics

The ABS produces Australia's official multifactor productivity estimates for the market sector, which includes the agriculture, fisheries and forestry industry. This is a key difference between the ABARES and the ABS productivity estimates, as ABARES only measures productivity growth in the broadacre and dairy industries. In contrast, the ABS measure includes fishery and forestry production, and other agricultural industries (including irrigated and intensive agriculture). The ABS estimates are not calculated at a level of disaggregation below this level—for example, there are not separate estimates available for the agriculture, fisheries and forestry sectors. Figure 9 compares ABARES and ABS productivity estimates, treating 1977–78 as the base period (both TFP indexes are set equal to 100 in 1977–78). Although the general patterns are similar, the ABARES and ABS TFP series diverge in early 2000. A possible reason for this divergence is the difference in industry coverage between the ABARES and the ABS productivity estimates. The ABS data cover some industries that are not as affected by drought (for example, intensive farms and the fishery and forestry sectors). In contrast, ABARES estimates productivity for the two industries (cropping and livestock) that are most sensitive to drought, and there has been a sustained dry period post-2000.

Figure 9: Comparing ABARES and ABS productivity estimates



The key differences between the ABARES and ABS productivity estimates may be summarised as follows:

- While ABARES uses the AAGIS and ADIS farm survey data to calculate farm, regional and industry-level estimates of productivity growth, the ABS produces sector-level multifactor productivity estimates using its national accounts data.

- ABARES estimates TFP using a gross-output measure. The ABS calculates multifactor productivity estimates using both the gross-output and the value-added measures (see ABS (2007) for a further discussion of these measures).

- ABARES uses the Fisher index to aggregate all categories of input and output, and also to aggregate input and output categories into indexes of total input and output. In contrast, the ABS uses several different index number formulas (ABS 2007)

  – the industry-level output (value added and gross output) and intermediate inputs are aggregated using chained Laspeyres indexes

  – the capital services index is derived using the Törnqvist index

  – the labour input is calculated as a simple elemental index of hours worked using data from the ABS Labour Force Survey

  – capital, labour and intermediate inputs are aggregated to form an index of total inputs using a chained Törnqvist index.

- the AAGIS and ADIS survey structure requires ABARES to measure the stock of capital as the average value of the capital stock, deflated by a real interest rate (see Zhao et al. 2010). The ABS uses the perpetual inventory method to estimate the stock of productive capital, which is based on a capital asset's pattern of decline in efficiency because of age and estimates of current and previous years' capital investments (see ABS 2007, p.6).

- ABARES measures the quantity of land used in agricultural production as the average of the area operated at the beginning and end of the financial year (from AAGIS and ADIS survey data). The ABS assumes that land used in agricultural production is constant over time.

Finally, because ABARES uses farm survey data to produce estimates of productivity growth, detailed analysis of the factors driving broadacre and dairy productivity are possible. However, estimates cannot be aggregated to the sectoral level because of data limitations and, unlike the ABS multifactor productivity estimates, productivity growth cannot be compared with other industries in the market sector (see ABS 2007, p.10).

Implications

This report provided a brief overview of the concepts and uses of productivity measurement and the methodology followed by ABARES in calculating TFP estimates for the broadacre industries. The ABARES measure of total factor productivity was described and compared to alternative PFP measures. This report also outlined some of the limitations of the ABARES methodology and data, which highlights the interpretation of the ABARES TFP estimates. Further opportunities to improve how ABARES measures the productivity of the broadacre and dairy industries were also identified.

Governments, research agencies and industry groups have increased their focus on the productivity of agricultural industries. Increasing productivity growth is an important element of the solution to a diverse range of issues facing agricultural industries, including climate change and increasing competition on world markets. TFP estimates illustrate productivity trends and can be used for further research into the drivers that influence productivity growth.

Appendix 1: Analytical issues in estimating TFP

The economic-theoretic properties of index formulas

The economic approach to evaluating input and output indexes (Diewert 1976) derives from some index number formulas having the desirable property of also corresponding to different functional representations of the underlying technology (the production function). This is advantageous as it establishes a link between the index formula used to aggregate inputs and outputs and the microeconomic theory of producers (OECD 2001). Assuming *technical and allocative efficiency* (optimising behaviour: producers minimise costs and/or maximise revenues) and *perfect competition* (producers are price-takers, who can adjust quantities but not individually influence market prices), the Fisher index has been shown to be *exact* for the quadratic flexible functional form of the production function (that is, the Fisher index can be *derived* from the quadratic flexible functional form) (Diewert 1976).

A *flexible functional form* provides a second-order approximation to an arbitrary, twice differentiable linear homogeneous function (Coelli et al. 2005). A *second-order approximation* means that it is possible to choose values for the parameters of the approximating function (the flexible functional form), so that the value of the approximating function and all its derivatives up to the second-order will equal those of the arbitrary function at any point. If a function is *twice differentiable*, calculus can be used to define a number of economic relationships of interest (for example, the marginal product of a production function). A *linearly homogeneous* function will exhibit constant returns to scale (if all inputs are increased (decreased) by a given proportion, output increases (decreases) by the *same* proportion).

Thus, if the production function can be reasonably represented by a quadratic specification, then under the standard assumptions about producer behaviour outlined above, the Fisher quantity index provides an exact formulation for an output quantity index. An index that is exact for a flexible functional form is called 'superlative' (Diewert 1976). The Törnqvist index is exact for the translog functional form, which has been widely used and tested in econometric analysis. However, the Fisher index satisfies more of the mathematical properties that have been identified as desirable for index formulas. These properties include positivity, proportionality, commensurability and the time reversal test (see Coelli et al. 2005 for more details). It also has the advantage of being able to handle zero quantities (of inputs or outputs).

The Fisher index

To demonstrate, a Fisher quantity index $\left(Q_{0t}^{F}\right)$, calculated for N inputs (or outputs) between the base period (period *0*) and the current period (period *t*), is calculated as the geometric mean of the Laspeyres $\left(Q_{0t}^{L}\right)$ and Paasche $\left(Q_{0t}^{P}\right)$ indexes as in equation (3):

$$Q_{0t}^{F} = \sqrt{Q_{0t}^{L} Q_{0t}^{P}} \ . \qquad (3)$$

The Laspeyres quantity index, calculated for N inputs (or outputs) between the base period (period *0*) and the current period (period *t*), is given by equation (4):

$$Q_{0t}^{L} = \frac{\sum_{i=1}^{N} p_{i0} q_{it}}{\sum_{i=1}^{N} p_{i0} q_{i0}} = \sum_{i=1}^{N} W_{i0} \frac{q_{it}}{q_{i0}}, \tag{4}$$

where q_{i0} and p_{i0} are the quantity and price of input (or output) *i* in the base period, q_{it} and p_{it} are the quantity and price of input (or output) *i* in the current period, and $W_{i0} = \frac{p_{i0} q_{i0}}{\sum_{i=1}^{N} p_{i0} q_{i0}}$ is the share of the *i*th item in the total value of inputs (or outputs) in the *base* period.

The Paasche quantity index, calculated for N inputs (or outputs) between the base period and current period, is given by equation (5):

$$Q_{0t}^{P} = \frac{\sum_{i=1}^{N} p_{it} q_{it}}{\sum_{i=1}^{N} p_{it} q_{i0}} = \left\{ \sum_{i=1}^{N} W_{it} \left(\frac{q_{i0}}{q_{it}} \right) \right\}^{-1}, \tag{5}$$

where $W_{it} = \frac{p_{it} q_{it}}{\sum_{i=1}^{N} p_{it} q_{it}}$ is the share of *i*th item in the total value of inputs (or outputs) in the *current* period and all other variables are as in equation (4).

To illustrate how productivity estimates are calculated, a simplistic example is presented of a farm that uses two inputs, capital and labour, to produce two outputs, wool and wheat. Using data on quantities and prices from Table 1, the farm's productivity levels and growth can be calculated.

Table 1: Input and output quantities and prices for a hypothetical farm

	Inputs				**Outputs**			
	Capital		**Labour**		**Wool**		**Wheat**	
	units	**\$/unit**	**hrs**	**\$/hr**	**kg**	**\$/kg**	**t**	**\$/t**
Year 1	**1.5**	**1**	**4**	**4**	**1.5**	**2**	**5**	**3**
Year 2	**2**	**1.5**	**3.75**	**4.5**	**1.5**	**1**	**5.25**	**3**

Beginning with inputs, the Laspeyres, $Q_{0t}^{L}(I)$, and Paasche, $Q_{0t}^{P}(I)$, indexes are calculated as in equation (6):

$$\begin{aligned} Q_{12}^{L}(I) &= \frac{\sum_{i=1}^{N} p_{i1} q_{i2}}{\sum_{i=1}^{N} p_{i1} q_{i1}} = \frac{[(1\times 2)+(4\times 3.75)]}{[(1\times 1.5)+(4\times 4)]} = \frac{17}{17.5} = 0.97 \\ Q_{12}^{P}(I) &= \frac{\sum_{i=1}^{N} p_{i2} q_{i2}}{\sum_{i=1}^{N} p_{i2} q_{i1}} = \frac{[(1.5\times 2)+(4.5\times 3.75)]}{[(1.5\times 1.5)+(4.5\times 4)]} = \frac{19.875}{20.25} = 0.98 \end{aligned} \tag{6}$$

Then, the Fisher index for inputs, $Q_{0t}^{F}(I)$, is calculated, as in equation (7):

$$Q_{12}^{F}(I) = \sqrt{Q_{12}^{L}(I) \times Q_{12}^{P}(I)} = 0.98\,. \tag{7}$$

Then, the process is repeated for outputs in equation (8):

$$Q_{12}^{L}(O)=\frac{\sum_{i=1}^{N}p_{i1}q_{i2}}{\sum_{i=1}^{N}p_{i1}q_{i1}}=\frac{[(2\times 1.5)+(3\times 5.25)]}{[(2\times 1.5)+(3\times 5)]}=\frac{18.75}{18}=1.04$$
$$Q_{12}^{P}(O)=\frac{\sum_{i=1}^{N}p_{i2}q_{i2}}{\sum_{i=1}^{N}p_{i2}q_{i1}}=\frac{[(1\times 1.5)+(3\times 5.25)]}{[(1\times 1.5)+(3\times 5)]}=\frac{17.25}{16.5}=1.05 \quad (8)$$

And the Fisher index for outputs is calculated in equation (9):

$$Q_{12}^{F}(O)=\sqrt{Q_{12}^{L}(O)\times Q_{12}^{P}(O)}=1.04\,. \quad (9)$$

Finally, the farm’s TFP growth between periods 1 and 2 is estimated by dividing the Fisher index for outputs by the Fisher index for inputs in equation (10):

$$TFP_{12}=\frac{Q_{12}^{F}(O)}{Q_{12}^{F}(I)}=\frac{1.04}{0.98}=1.06\,. \quad (10)$$

In this simplistic example, the farm’s TFP increased by 6 per cent between periods 1 and 2.

The EKS procedure

The formula to make the Fisher index transitive is given by equation (11):

$$Q_{st}^{EKS}=\left(\prod_{r=1}^{N}Q_{sr}^{F}Q_{rt}^{F}\right)^{1/N}, \quad (11)$$

where Q_{st}^{EKS} is the transitive Fisher index between farms *s* and *t* when there are *N* farms being compared. Q_{sr}^{F} is the Fisher index with farm *s* as the base farm, and Q_{rt}^{F} is the Fisher index with farm *r* as the base farm. Using the EKS procedure allows any two farms to be compared by dividing their respective index numbers.

Appendix 2: Inputs and outputs included in the ABARES TFP estimates

Table 2: Inputs for the estimation of TFP in broadacre and dairy industries

Input type	Specific inputs	Data items
Land	Land	Average area operated in the financial year
Capital	Buildings and other farm improvements	Farm buildings, excluding operator's house, water supply structure and fencing (real opportunity cost)
		Structural improvements, including water supply infrastructure, fencing and yards (real opportunity cost)
		Real depreciation cost of buildings and other farm improvements
	Plant and machinery	Plant and equipment owned by the operator (real opportunity cost)
		Plant and equipment leased by the operator (real opportunity cost)
		Real depreciation of plant and equipment
		Real depreciation of structural improvements
	Beef cattle	Real value of beef cattle
	Other livestock	Real value of dairy and other cattle
	Beef cattle purchased	Real costs of purchasing beef cattle
	Sheep purchased	Real costs of purchasing sheep and lambs
	Other livestock purchased	Real cost of purchasing other livestock
Labour	Hired labour	Weeks worked on farm by hired permanent and casual workers
	Owner-operator and family labour	Total weeks worked on farm by owner-operator and family members
	Services by shearers	Real costs of shearers
Materials	Seed	Real costs of seed
	Fodder	Real costs of fodder and purchase of non-tree and vine crops
	Crop chemicals	Real costs of crop and pasture chemicals such as pesticides and herbicides
	Fuel	Real costs of fuel, oil and grease
	Livestock materials	Real costs of livestock materials such as dips and drenches
	Other materials	Materials used to pack fruits
		Materials for packing crops other than tree and vine crops
		Tree and vine replacements

Input type	Specific inputs	Data items
		Purchase of water for livestock
		Wool packs
		Livestock agisted off-farm (excluding lot feeding costs off-farm)
		Materials not included elsewhere (for example, vermin control and protective clothing)
Services	Contract services	Real cost of plant hire and non-capital development contracts such as mustering, harvesting etc.
	Rates and taxes	Real costs of rates paid, including drainage and water
	Administrative services	Real costs of accountancy, banking and legal services
		Real costs of electricity
	Repair services	Real cost of repair for building and structure (for example, fences)
		Real costs of repair of motor vehicles, plant and equipment
	Motor vehicle	Real costs for vehicle registration and third party insurance etc.
	Other services (1)	Real costs of advisory services
		Real costs of artificial insemination, herd testing and stud fees
		Real costs of veterinary services
	Other services (2)	Real costs of crutching
		Real costs of stores and rations provided to workers
		Real costs of tree and vine crops packed off-farm for sale
		Real costs of packing crops other than tree and vine crops
		Real costs of (work-related) travelling and entertaining expenses
		Real costs of services not included elsewhere
	Insurance	Real (net) costs of insurance for crops, livestock, buildings, improvements, motor vehicles and workers compensation
Inputs specific to dairy farms	Dairy cattle	Dairy cattle (real opportunity cost), as capital
	Real value of gain on purchased dairy cattle	Dairy cattle operating gain (the change in the value of the herd, in real terms)
	Fertiliser	Real costs of fertiliser (for pastoral), as materials
	Dairy supplies	Real costs of dairy supplies, as services

Table 3: Outputs for the estimation of TFP in broadacre and dairy industries

Output type	Specific inputs	Data items
Crops	Wheat	Real receipts from the sale of wheat (net of marketing expenses)
	Barley	Real receipts from the sale of barley (net of marketing expenses)
	Oats	Real receipts from the sale of oats (net of marketing expenses)
	Grain sorghum	Real receipts from the sale of grain sorghum
	Oilseeds	Real receipts from the sale of oilseeds
	Other crops	Real receipts from the sale of other crops
Livestock	Beef	Real receipts from the sale of beef cattle
		Operating gain (changes in the value of the herd, in real terms)
	Sheep	Real receipts from the sale of sheep
		Operating gain (changes in the value of the flock, in real terms)
		Transfer out (net), in real terms
	Lamb	Real receipts from the sale of prime lambs
	Other livestock	Real receipts from the sale of other livestock
Wool	Wool	Real receipts from the sale of wool through broker
		Real receipts from the private sale of wool
Other outputs	Off-farm contracts	Real receipts of income from off-farm contracts
	Hire of plant	Real receipts from the hire of plant
	Private use of farm equipment	Value of private use of farm equipment (telephone and vehicles, in real terms)
	Rebates and refunds	Real rebates and refunds received on purchases of farm inputs
	Royalties	Real royalties received
	Government assistance	Real farm income received in the form of government payments
	Income from agistment	Real income of agistment of livestock on-farm
	Insurance recoveries	Real income received in the form of insurance recoveries
	Livestock compensation	Real livestock compensation received
	Other farm receipts not included elsewhere	Real other farm receipts not included elsewhere

Output type	**Specific inputs**	**Data items**
Outputs specific to dairy farms	Dairy cattle gain	Dairy cattle operating gain (the change in the value of the herd, in real terms)
	Dairy cattle sold	Real receipts from sale of dairy cattle sold
	Other livestock	Real receipts from the sale of other livestock

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Agricultural Productivity: Concepts, measurement and factors driving it

— A perspective from the ABARES productivity analyses —

by Emily Gray, Tom Jackson and Shiji Zhao

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Productivity growth has been an essential element of Australian agriculture's sustained international competitiveness. The emerging challenges facing the agriculture sector, including climate change, competition from overseas suppliers and rising input costs, mean that continued productivity growth above the long-term growth rate (currently 1.4 per cent a year) is likely to be required to maintain farm profits and living standards in the long term.

This report provides a non-technical guide to the concept, measurement and key drivers of agricultural productivity growth. A key objective of the report is to enable readers to understand and interpret productivity estimates and relevant statistics in an informed way.

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