A turning point in agricultural productivity: consideration of the causes

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Foreword

Agricultural productivity growth is a major priority for industry and the Australian Government. For more than 50 years, productivity growth has been the main driver of agricultural output in Australia, contributing to around two-thirds of the gross value of agricultural production. Continued productivity growth is vital for maintaining the competitiveness of Australia’s agricultural exports on world markets.

However, broadacre agricultural productivity growth has been slowing in recent years. This study, commissioned by the Grains Research and Development Corporation as part of the GRDC–ABARES Harvesting Productivity Initiative, indicates that the slowdown since the mid-1990s was due largely to a combination of adverse seasonal conditions and stagnating investment in public agricultural R&D since the late 1970s.

This research lends support to the arguments that public investment in agricultural R&D has been critical in boosting agricultural productivity in the past and is likely to be an important driver over the long term. In particular, ongoing investment in R&D is likely to be necessary for maintaining and improving productivity under changing climate and resource constraints. Moreover, given the long lags between R&D investment and subsequent improvements in productivity growth, the innovations needed to meet the needs of the next generation and beyond are likely to result from investments made in agricultural R&D today.

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Summary

Productivity growth has been a key factor driving agricultural output in Australia. More than two-thirds of the current real value of Australian agricultural output can be attributed to productivity growth that has occurred since the early 1950s (Mullen and Crean 2007; Sheng et al. 2010). One important source of productivity growth is new technology from investment in research. However, observers are increasingly concerned that agricultural productivity growth in Australia, as in some other developed countries, has been slowing.

The objective of this study was to test whether any slowdown in Australian broadacre productivity growth has occurred and, if so, to determine when it occurred and the likely causes. A well-known statistical method based on an analysis of recursive residuals from regression models (the CUSQ method) was used to examine the systematic deviation from trend in current total factor productivity in Australian broadacre agriculture between 1952–53 and 2006–07. As a measure of productivity in Australian broadacre agriculture, total factor productivity is highly variable due, in part, to unstable seasonal effects. Therefore, detecting fundamental shifts in the long-term trend requires suitable statistical methods.

The report concludes that a significant structural change, or turning point, occurred in the total factor productivity series in the mid-1990s. Further, it suggests that the slowdown was likely due to a combination of adverse seasonal conditions and stagnant public research and development expenditure since the late 1970s.

This study lends support to the argument that public investment in agricultural research and development has been critical in driving agricultural productivity growth in the past and highlights the important role it could play in countering the expected adverse effects on broadacre farm productivity of changing climate, increasing water scarcity and other resource constraints, and to meet the demand for food from a growing world population.
Agricultural productivity growth in Australia has been strong relative to other sectors of the economy and to the agricultural sectors of other OECD countries (Mullen and Crean 2007; Nossal and Gooday 2009). Between 1952–53 and 2006–07, the growth rate of total factor productivity (TFP) in Australian broadacre agriculture was around 2.0 per cent a year. This growth has helped offset, among other negative influences, the impact of adverse seasonal conditions and declining terms of trade, thereby enabling Australian producers to remain internationally competitive during the past half century.

However, recent research suggests that productivity growth in Australian agriculture—and that of other developed countries—has slowed, particularly in the grains industries (Alston et al. 2010; Fuglie 2010; Gray et al. 2011; Veeman and Gray 2010). This is of particular concern for the competitiveness of Australia’s agricultural exports on world markets and, in turn, for returns to agricultural investments. Thus, it is important to monitor the trend in agricultural productivity growth and, in particular, to identify the likely causes of any slowdown with a view to informing public policy making.

During the past two decades, Australia has experienced higher than average temperatures and reduced rainfall, which have had a negative effect on crop yields and livestock production. Observers widely believed that adverse seasonal conditions alone had caused the slowdown in productivity growth, but it is also likely that the decline in public investment in research and development (R&D) since the late 1970s could have contributed.

This report seeks to examine the changing trend of productivity growth of Australian broadacre industry by using the ABARES long time-series estimates of TFP. Two research questions are posed. First, has Australian broadacre productivity growth slowed and, if so, when did it commence? Second, what are some of the likely causes of the slowdown?
Productivity growth in Australian broadacre agriculture

ABARES has conducted farm surveys since 1952–53 for broadacre agriculture, that is, for non-irrigated cropping and extensive livestock industries. Data from these surveys are used to analyse trends in broadacre total factor productivity (TFP). Box 1 contains details of the methodology ABARES used to measure agricultural productivity. The TFP index for Australian broadacre agriculture shows a persistent growing trend from 1952–53 to the late 1990s, with significant fluctuations in some years, typically coinciding with drought (figure 1).

Box 1  What is productivity and how is it measured in ABARES?

Productivity is a key determinant of economic performance, international competitiveness, economic welfare and living standards. An increase in productivity indicates that inputs are being used more efficiently—that is, fewer inputs are required to produce the same output or, alternatively, that additional output is possible from a given level of input use.

ABARES productivity estimates for the broadacre industry are derived using an index method similar to that used by official statistical agencies (the Australian Bureau of Statistics and the US Bureau of Labor Statistics). Two types of measures of productivity are typically calculated:

* **Total factor productivity** (TFP), also known as multifactor productivity, which is a ratio of a measure of total output to a measure of multiple inputs used in the production process.

* **Partial factor productivity** (PFP), which is a ratio of a measure of total output to a measure of a single input category.

ABARES calculates total output for the broadacre sector using the Fisher index approach across four outputs, namely: crops, livestock, wool and other on-farm outputs (itself an aggregate of 13 other outputs). Similarly, total input is calculated across four major inputs, namely: land, labour, capital, and materials (intermediate inputs) and services (the latter category combining 26 other inputs). Prices or values of each input and output are used as weights for the aggregation process. The Fisher approach is also applied to the estimation of a single individual input category for use in estimating a PFP index.

Compared with TFP measures, PFP measures (such as labour productivity and yield) are of limited use for summarising the overall productivity performance of the sector. This is partly because PFP measures can result in a misleading assessment of an industry’s productivity performance if the effects of technological and efficiency changes, input substitution and technological improvements embodied in other inputs are (incorrectly) attributed to changes in only one particular input.

Source: Gray et al. 2011
Over the past 50 years, Australian broadacre farms have consistently produced more farm output relative to the volume of inputs used. Between 1952–53 and 2006–07, broadacre TFP growth averaged around 2.0 per cent a year, reflecting average output growth of 2.7 per cent a year that more than offset average input growth of around 0.7 per cent a year. Total input use has been declining since the late 1970s (figure 1).

1 Input, output and TFP indexes in broadacre agriculture, 1952–53 to 2006–07

box 2 What has been happening to agricultural productivity growth in other countries?

Evidence is emerging of a global slowdown in agricultural productivity growth. Using partial productivity measures, Beddow et al. (2009) report slower global growth in yields for maize, rice, wheat and soybeans between 1990 and 2007 compared with 1961 and 1990. Similarly, with the notable exception of China, land and labour productivity growth was also slower between 1990 and 2005 compared with 1961 to 1990.

While global agricultural productivity may be slowing, marked country differences are evident. According to Fuglie (2010), Food and Agriculture Organization data suggest that agricultural productivity growth has slowed in developed economies and accelerated in developing economies. Specifically, average annual TFP growth for all developed economies declined from 1.5 per cent between 1961 and 2007 to 0.9 per cent between 2000 and 2007. In contrast, average annual TFP growth for developing and transitional economies increased from 1.0 per cent to 3.8 per cent over the same period.
However, while estimated TFP has generally trended up, it has fluctuated considerably over time (figure 2). Estimated TFP index dropped substantially in the four years marked as drought periods (1982–83, 1994–95, 2002–03 and 2006–07), but recovered strongly in subsequent years.

In addition, some notable differences in TFP growth have been evident in recent years compared with the average long-term trend rate, of around 2.0 per cent a year. For example, from the peak value of broadacre productivity observed in 1999–2000, TFP declined by an average annual rate of 1.7 per cent in the eight years to 2007–08. In contrast, in the preceding eight years from 1991–92 to 1999–2000, TFP grew strongly at an average annual rate of 2.3 per cent.

The divergent trends of 1999–2000 are not, however, sufficient to identify it as a turning-point year in productivity growth trends as estimates of short-term trends can be sensitive to annual fluctuations, as well as start and end years. For example, the broadacre TFP index fell in 20 of the 55 years between 1953 and 2008 (figure 3), reflecting adverse seasonal conditions as well as other unobserved factors not captured in the TFP calculation (or ‘input and output’) framework. Further, the increased volatility in recent years could reflect the cumulative effects of a run of adverse seasons.

The highly variable nature of Australia’s broadacre TFP index makes it difficult for farmers to discern trends in the underlying rate of growth through visual inspection or descriptive statistics. Further, such statistics could not determine the possible causes of any slowdown. Therefore, more complex analyses are required to investigate when productivity growth began to slow and what factors could have contributed to the slowdown.
3 Year-to-year fluctuation of estimated broadacre TFP, 1952–53 to 2006–07
Identifying the turning point in Australian broadacre productivity growth

An estimation procedure based on residuals from a series of regression models (run repeatedly and extended over the period 1952–53 to 2006–07) was used to test for significant departure of productivity from its historical trend (box 3).

**box 3  Description of the statistical model and estimation procedure**

The adjusted cumulative sum of squared index approach (CUSQ) (Deng and Perron 2008) was used to investigate the stability of the TFP data series over time by determining how many structural breaks occurred in the TFP series, when they occurred and what factors were likely to have been involved. The technique calculates an adjusted index of the cumulative sum of squared residuals, based on a series of regressions of TFP index against a time trend and/or its determinants. It compares the index with preset criteria at different significance levels and gives an out-of-control signal to indicate when the annual values of the TFP index differ significantly from their expected levels, given past trends.

Structural breaks were deemed to have occurred in years when the adjusted CUSQ index reached a peak after having exceeded a threshold value. A genuine turning point is considered likely when the index exceeds a pre-specified statistically-critical value. For instance, an observed value of the adjusted CUSQ index of 1.36 or higher indicates that, in statistical terms, a structural break has occurred with a probability of 95 out of 100 (that is, at the 5 per cent level of significance).

The estimation procedure was then extended to account for possible effects from climate, real investment in agricultural R&D, education levels and the agricultural terms of trade. In successive iterations, these sources of variation in the TFP index were included in the regression model to generate a new series of the cumulative sum of squared residuals. The tests were repeated to identify if structural breaks were still present in the data. If a structural break persisted, it was reasonable to conclude that the additional explanatory factors, or combinations of factors, were not the source of the structural break in the original unadjusted productivity data.

*Source: Sheng et al. 2010*

The results of the test for a structural break in the estimated TFP series for broadacre agriculture (unadjusted for any factors that could be behind it) are reported in figure 4. Consistent with the shifts observed in figure 2, the empirical evidence suggests that the trend in broadacre TFP growth changed significantly during the 1990s. Specifically, the turning point for broadacre productivity growth was identified as having occurred in 1993–94, when the adjusted CUSQ index reached its first peak.
Using 1993–94 as the turning point, annual productivity growth between 1952–53 and 1993–94 was estimated to be around 2.2 per cent (figure 4). Between 1993–94 and 2006–07 annual productivity growth has averaged just 0.4 per cent. This is the key evidence for the slowing of broadacre productivity growth in recent decades.
Although adverse climate conditions are widely believed to have slowed broadacre productivity growth, a number of commentators have argued that, among other factors, stagnant public R&D investment since the late 1970s has played a role (Mullen and Crean 2007; Mullen 2010; Nossal and Sheng 2010). Beyond these studies, the strong link between public R&D and agricultural productivity growth has been widely established in Australia (Salim and Islam 2010) and internationally (Alston 2010). To investigate this proposition, the adjusted CUSQ model was extended to explore the contribution of climate, real public investment in agricultural R&D, farmers’ levels of education and farmers’ terms of trade.

Changing climate

It is widely appreciated that adverse seasonal conditions have contributed to reduced agricultural output in recent years. Bureau of Meteorology data on rainfall anomalies in the Murray–Darling Basin, for example, show eight consecutive years after 2000 where rainfall was below the average rainfall between 1960 and 1990 (figure 5). Similar patterns were evident in Bureau of Meteorology data for most of southern Australia, although northern Australia experienced above average rainfall in six of the past eight years.
Although the annual rainfall data are useful for differentiating between good and bad years, they are poor indicators of the impact of seasonal conditions on agricultural production. This is because farmers’ production is more likely to be affected by soil moisture availability which is determined by a wide range of factors beyond total rainfall.

In this report, a measure of moisture availability, produced by the Agricultural Production Systems Research Unit, was used to capture the possible effects of adverse climatic conditions (figure 6). Although it is technically a crop water-stress index, for convenience, this report refers to it as moisture availability. It differs from total rainfall (figure 5) insofar as it compares the supply of water in the soil with the moisture requirements of a crop by taking into account factors such as soil water-holding capacity, timing of rainfall within a growing season and temperature.

Climate conditions in recent years, in particular drought, were found to be an important factor contributing to volatility and trend change in the TFP index. When climate variability was taken into account, the values of the adjusted CUSQ index were generally lower, indicating more stability in the climate-adjusted TFP series (figure 7). However, the adjusted CUSQ index still crossed the critical value level, indicating a structural break at the 5 per cent significance level.

Soil moisture availability index for the broadacre industry, 1952–53 to 2006–07

TFP can fall between successive years for a variety of climate-related reasons. In some years, use of inputs may be too high because, although farmers expected an average season, a dry season eventuated which led to lower than expected output. In other instances, TFP may fall because farmers’ seasonal outlook was too pessimistic, resulting in suboptimal use of inputs.

However, the effects of changing climate conditions alone did not completely account for the observed structural change in the broadacre TFP trend. The statistical model indicated that a statistically significant structural break remained in the TFP series, although its timing shifted from 1993–94 to 2001–02 (figure 7).
A turning point in agricultural productivity: consideration of the causes

The analysis suggests first that, if there had not been a run of poor climate conditions (including severe droughts) since the mid-1990s, broadacre TFP would have kept growing at its trend rate until 2002. Second, climate alone does not account for the change in trend in TFP because, after accounting for climate, there remains a change in structure in 2002.

Stagnating real public investment in agricultural R&D

In Australia, public investment in agricultural R&D (excluding fisheries and forestry) increased from $140 million in 1952–53 to $829 million in 2006–07 (in 2008 dollars) (figure 8). Despite a spike in investment in 2001, Australia has experienced little growth in real public R&D investment since the mid 1970s. Agricultural research intensity, measured as the ratio of agricultural R&D investment to the gross value of agricultural production, has also declined from a high of 5 per cent in the late 1970s to around 3 per cent in recent years (figure 8).

A knowledge stock variable was constructed to investigate the cumulative effect of public investment in R&D on broadacre productivity growth, following the method Mullen and Cox (1995) used (see appendix). Public investment in R&D is known to have a long lagged effect on agricultural productivity, with the maximum effects not being observed in agricultural productivity for several decades (Alston et al. 2010; Alston et al. 2008; Mullen 2007). Thus, the knowledge stock from research available to Australian broadacre farmers at any given time was estimated as the weighted sum of past expenditure on public sector–funded R&D over 35 years.
A turning point in agricultural productivity: consideration of the causes

From a statistical perspective, it is more robust to test for a turning point after controlling for the joint effects of knowledge stock and climate if the R&D expenditures behind the knowledge stock variable are likely to be affected by climate variability. It was possible to only look at the effect of climate variability on the turning point because it can be reasonably assumed that climate has not been affected by expenditure on agricultural R&D, or other underlying factors behind productivity growth not incorporated in the model.

When the joint effects of climate and knowledge stocks were included in the model, the structural break was no longer apparent—the adjusted CUSQ index remained below the critical threshold (figure 9). This suggested that climate and real public investment in agricultural R&D have jointly affected the stability of broadacre TFP growth in the past two decades. In particular, they have both contributed to explaining the recent slowdown of broadacre productivity growth.

An alternative model with a 16-year time lag for R&D investments was also explored, but it did not produce a better fit of the data or improve the stability of the adjusted CUSQ index by shifting it below the 5 per cent threshold. This result lends support to the view that the lag between public investment in agricultural R&D and subsequent productivity growth is likely to be long; in the order of 35 years rather than 16 years. It is also consistent with recent analysis on the length of time lags for agricultural R&D in the United States (Alston et al. 2010).

This study also examined the effects of other factors, such as farmers’ education and terms of trade, on the slowdown in Australian broadacre productivity. However, compared with the model only accounting for climate and real agriculture R&D investment, the estimated CUSQ indexes from the model that includes the education and terms of trade indexes are less
stable, especially since the mid-1980s. This result, combined with improving education levels and flattening terms of trade over the past two decades, suggests that changes in education and terms of trade contributed to weakening structural change in productivity and favouring broadacre productivity growth in recent years. However, since the estimated CUSQ indexes were not out of the 5 per cent and 1 per cent threshold criteria, it can be concluded that, statistically, they were not as important as climate and real agricultural R&D investment in affecting broadacre productivity.

While a range of other factors may have contributed to the decline in public R&D investment intensity, there is no evidence to suggest this is because of fewer research opportunities.

Research agronomists seem confident that there are more practical research opportunities and prospects for farmers to grow crops more efficiently in the current era. For example, an improved understanding of the soil biology and further developments in precision agriculture offer opportunities to capture further gains in productivity (Carberry et al. 2010). In addition, further development and adoption of biotechnology may serve to increase agricultural output under the higher temperatures and lower rainfall conditions associated with climate change.
As in some other developed countries, Australia’s broadacre industry (especially the cropping industries) has experienced a significant slowdown in productivity growth over the past decade. Initially, the cause was thought to be the potential impact of changing climate conditions, in particular three severe droughts after 2000, as the cause of this slowdown. However, the empirical analysis in this report suggests that the structural break in broadacre productivity trend occurred earlier—in the mid 1990s—and cannot therefore be entirely attributed to adverse climatic conditions.

The adjusted CUSQ analysis highlighted the importance of the combined effects of adverse climatic conditions and the decline in public investment in agricultural R&D in explaining the recent structural change in broadacre productivity growth.

Stagnating investment in agricultural R&D—which is actually declining when expressed as a percentage of agricultural gross value of production—is likely to concern many stakeholders given the long lags (35 or more years) observed between public R&D investment and subsequent improvement in productivity growth. This research lends support to the argument that public investment in agricultural R&D has been critical in boosting agricultural productivity in the past and is likely to be just as important in the future. Notably, the innovations needed to address changing climate conditions and future resource constraints in 2050 and beyond are likely to result from investments made in agricultural R&D today.

More work is needed to better understand the relative influences of climate change and R&D investment on agricultural productivity growth. Other ABARES research is using econometric methods to quantify the importance of public investment in R&D on productivity growth and to estimate the rate of return to public R&D and extension investment. Insofar as this related research shows high rates of return and no evidence of declining returns, it supports the case to at least maintain investment levels in agricultural R&D and to evaluate the scope for further public sector and industry involvement.

If additional investment is warranted, further work is needed to identify the options most likely to improve future productivity growth in Australia. ABARES research decomposing productivity growth into innovations that expand the technological frontier (technical change) versus those that increase the proportion of farmers close to the technological frontier (technical efficiency change) will aid in this endeavour. Insights into the relative balance of investments between research that leads to new innovations and knowledge, and extension activities that increase the number of farmers adopting best practices, offer the potential to significantly increase the return to public or private R&D investments.
While R&D is likely to be important to enabling agricultural productivity growth, it is by no means the only factor. In addition to technological advancements, increased innovative capacity in the agricultural sector is also needed through higher levels of skill and education, removal of unnecessary regulation that impedes structural adjustment, and improvements to market access and public infrastructure. Continued efforts are needed in all these areas to enable the sector to respond positively to changing conditions.

Without well-aligned policy incentives to encourage adoption of new management practices and technologies, the rate of farm innovation may be impeded. As Hilmer (2010) has recently underscored, incentives are what matter most in understanding actions and outcomes that lead to efficiency gains. In this regard, some government interventions may be distorting farmers’ incentives to pursue such improvements including, for example, statutory marketing arrangements that persist in some industries (such as rice and potatoes).

From a global perspective, the challenge for agricultural production in the twenty-first century is still to produce sufficient food to feed the growing population. In addition, observers, such as Gray (2008), are expecting that improving incomes in developing countries will result in greater demand for protein, while growing incomes in developed countries will result in increased demand for a greater variety of high quality food. Sustainable productivity growth in agriculture is the most important mechanism that can be relied upon to achieve these goals.

The slowdown in agricultural productivity growth observed across several developed countries raises significant concerns, particularly insofar as it correlates with a general decline in public agricultural R&D investment and stagnant institutional reforms in those countries (Alston et al. 2010; Beddow et al. 2009). A decline in new technologies generated by developing countries could well have spill-over affects for agricultural productivity in developing countries. This will affect their ability to meet growing food production needs.
The choice of the models for constructing the knowledge stock variables was based on the findings of previous international and domestic studies (Alston 2010; Alston et al. 2010; Mullen and Cox 1995) and econometric experimentation with similar models by the authors. A small group of models was selected that had sound statistical properties and economic implications, based on a series of econometric tests including the Ramsey RESET test and the root mean square error (RMSE) test. Knowledge stock variables were derived as the weighted average of past expenditure, using weights based on a suite of specific distributions (determined by an assumed duration and distribution shape of the impact of research over time):

\[ K_{Si} = g_i(R_i, R_{i-1}, ..., R_{i-L_i}) \]

where \( K_{Si} \) denotes the knowledge stocks corresponding to various research, development and extension activities; \( i = \{DS, PS, EXT, FS\} \) as in equation. The investment at time \( t \) is denoted by \( R_i \) and the maximum time lag for each knowledge stock variable is \( L_i^R \).

The distribution functions for alternative time-lag profiles of research and development and extension are denoted by \( g_i(.) \). The time profile (that is, the duration and distribution of the lag profile) used to construct knowledge stock variables was based on the likely features of the relationship between the flow of research investments and the stock of usable knowledge. There are usually long but uncertain lags between research investments and their eventual contributions to the stock of useful knowledge. To reflect this, R&D lags of 16 and 35 years were considered in constructing the R&D knowledge stock variables (following Mullen and Cox 1995). To describe the shape of the lag profile, three distribution functions were considered: gamma, trapezoid and geometric distributions. The geometric distribution was included because it reflects the perpetual inventory method (PIM) approach that is commonly used to construct knowledge stocks for the manufacturing sector (for example, Shanks and Zheng 2006). However, results obtained with the geometric distribution are not discussed as the PIM approach is inconsistent with the expectation that agricultural R&D investment will have little effect in its early years because of long lags in adoption (Alston et al. 2010).

In total, knowledge stocks were constructed using 10 different distribution functions: three gamma distributions (one with the peak impact occurring after seven years and two gamma distributions that mimic the trapezoid (gamma_T) and geometric (gamma_P) distributions) and the trapezoid and geometric distributions for both 16-year and 35-year lags.

In contrast to the relatively long R&D lag profiles, extension activities were expected to have a much quicker, but still lagged, effect on productivity. The domestic extension knowledge stock was assumed to follow a geometric distribution with a maximum lag length of four years (Huffman and Evenson 2006).
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