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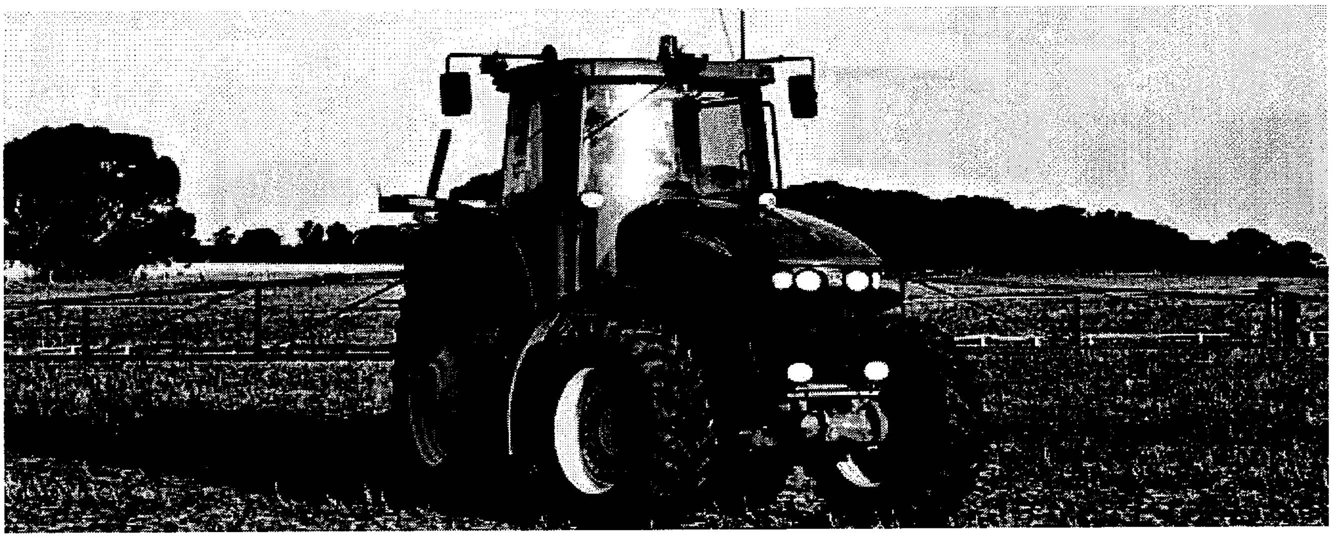

Rural Research and Development Corporations, Response to Draft Inquiry Report

ABARES submission to the Productivity Commission

December 2010

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The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), was formed following the merger of the Australian Bureau of Agricultural and Resource Economics (ABARE) and the Bureau of Rural Sciences (BRS) in 2010–11.

Contents

1 Introduction

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) is a professionally independent research organisation within the Australian Government Department of Agriculture, Fisheries and Forestry.

Among its roles and responsibilities, ABARES monitors productivity growth in Australia's agricultural industries. It regularly reports on trends in productivity growth for the broadacre and dairy industries using a unique dataset from its farm survey program.

In addition, the bureau's research program on productivity aims to understand the drivers of productivity growth, including the relationship between agricultural productivity and publicly-funded research and development (R&D). Its latest publication on Public investment in R&D and extension and productivity in Australian broadacre agriculture is attached to this submission and will be discussed later.

This submission responds to the Productivity Commission's Rural Research and Development Corporations, Draft Inquiry Report and addresses three areas of the draft report that underpin several recommendations proposed by the commission, which ABARES believes would benefit from further refinement, namely:

- the socially optimal level of public investment in R&D
- the comparison of various R&D support policies between rural and non-rural industries (draft report chapter 7)
- the effectiveness of the RDC model in improving agricultural productivity (draft report appendix B).

It is argued that there is insufficient empirical basis in the PC's draft report to justify its conclusion that government expenditure on rural R&D through a matching of industry levies up to a maximum of 0.5 per cent of industry gross value of production should be reduced. It is also argued that there is strong empirical evidence that there has been an under-investment in rural R&D and that this has led to diminishing growth in farm productivity.

2 Socially optimal level of public investment in R&D

The in-principle case for additional public expenditure on rural R&D, which is based on unpriced 'spillover' benefits to third parties, is well established and covered in the draft report.

Notwithstanding the in-principle role for government, the commission found that it is impossible to precisely determine the optimal level of government support (PC 2010, p. 159). In part, this is because many of the public benefits from rural research are largely intangible, non-market outcomes. While some of these benefits may be measurable, it is not feasible to calculate all the effects, both direct (such as healthier riparian ecosystems) and indirect (such as vibrant rural communities). This diminishes the value of the 'additionality' principles put forward by the commission (PC 2010, p. 61). In practice, it will not be possible to differentiate between projects that are 'additional' and those that have private benefits sufficient to justify investment. There is a considerable body of literature pointing to generally high rates of return to primary producers, and society more broadly, of public investment in rural R&D (for example, Fuglie and Heisey 2007; Sheng, Gray and Mullen 2010). As a recent Working Paper from the OECD concludes:

> *... we have amassed a persuasive body of evidence demonstrating that the world as a whole and individual nations have benefited enormously from productivity growth in agriculture, a substantial amount of which has been enabled by technological change resulting from public and private investments in agricultural R&D (Alston 2010, p. 19).*

While some commentators could view public investment in rural R&D as 'assistance' to the rural sector, at least to the extent that such public involvement crowds-out what would otherwise be private expenditure, there is little evidence to suggest the effects are particularly distortionary. And while not its principle aim, the outcomes of the current RDC funding arrangements would seemingly align reasonably closely with broader government policy objectives which are to maintain agricultural productivity and healthy regional economies.

However, were government funding reduced, as proposed in the draft report, there is a distinct likelihood that future broadacre productivity growth could be negatively affected. Despite the relatively attractive returns to R&D indicated above, there is a risk that decreasing public funding may not lead to an offsetting increase in private expenditure.

Moreover, the timing of this experiment, were the proposed funding cuts to be implemented, would most likely exacerbate the recent slowdown in productivity growth in some agricultural industries. This would increase the difficulty the sector has in meeting a number of emerging challenges, including adaptation to climate change and, more broadly, greater regulation of natural resource inputs. Therefore, the downside risk for agriculture seems significant.

3 Comparison of various R&D support policies between rural and non-rural industries

In the draft report, a key finding to support the case for lower government funding to RDCs is the extent to which R&D assistance to rural industries exceeds that available to non-rural industries, beyond the standard 100 per cent business tax deduction for expenditure on business inputs.

The extent to which the rural sector is shown to be 'advantaged' is heavily influenced by the choice of metric. For example, the PC has estimated that RDC support is around 11 times the support provided through basic (125 per cent) tax concessions available to non-rural industries (as focused on in the draft report). In contrast, comparing the rate of government contributions to RDCs per unit of rural value added is around six times what non-rural industries received (draft report, pp. 157–158).

A deficiency with the 'number of times greater' metric is that it is dependent on the basis on which the figures are derived—notably the more narrow the specification, the larger the metric is likely to be for a selected variable. This can create a significant distortion to the figures and may serve to mislead the reader, particularly as the link between the metric and the magnitude of the proposed cuts to RDC funding is not explicit in the draft report.

Given the government's underlying commitment to support R&D activities in all industries, a fundamental question should be: 'how much does it cost the government for rural or non-rural industries to lever an additional dollar of tax-payer funded R&D?' This alternative approach considers how much the additional (marginal) dollar of R&D assistance to rural and non-rural industries costs the government, principally through direct payments and forgone tax revenue (as described in box 1).

Under the current RDC funding arrangements, government has contributed no more than 0.5 per cent of GVP to RDCs. The commission estimates these contributions to have averaged $91 per $100 of industry contributions in recent years.

Were the GVP cap halved to 0.25 per cent, as proposed by the commission, the government contribution rate could be halved to around $46 per $100 of industry contributions. However, estimating the expected contribution rate is difficult because the government contribution to each RDC is capped three-ways (with the lower of the three caps binding) and, for some, includes appropriation funding. Nevertheless, this rough approximation should suffice for illustrative purposes.

Using this approach as a means of comparison, the current government contribution provides a benefit of between 0.8 to 2.2 times the benefit from the 125 / 175 per cent tax deduction—substantially less than that estimated by the commission. Once the proposed cuts are considered, the rural sector does not appear to maintain any clear advantage in terms of the cost to government to contribute an additional dollar of R&D (table 1). More specifically, were primary producers operating at an average marginal tax rate around 10 per cent, there would seemingly be no advantage to the rural sector despite the well-established case for additional public expenditure on rural R&D (table 1).

box 1 **How much does it cost government for rural or non-rural industries to lever an additional dollar of tax-payer funded R&D?**

Beyond direct appropriations and grants to various industries, government assists all industries to undertake approved R&D activities through tax concessions and, in the case of the rural RDCs, by adding to R&D funds contributed by primary producers themselves. Although the benefits to society from government R&D expenditure appear significant, particularly in the rural sector, it is important to know how much an additional (marginal) dollar of R&D assistance to rural and non-rural industries costs the government through matching contributions and forgone tax revenue. To keep the analysis simple, the cost associated with raising an additional dollar of tax revenue has been ignored.

For comparison purposes, the cost to government of contributing an additional R&D dollar to rural and non-rural industries may be expressed as a ratio (m) :

$$m = \frac{\textit{rural tax} + \textit{RDC funding}}{\textit{nonrural tax deduction}}$$

For all industries, the value of their tax deduction (*Deduct*) is equal to the difference between pre-tax expenditure (Exp_{preTax}) and post-tax expenditure ($Exp_{postTax}$):

$$Deduct = Exp_{preTax} - Exp_{postTax}$$

The value of the tax deduction reflects the permissible deduction rate (*DeductRate*) and the relevant marginal tax rate (*MTR*) for each $100 of post-tax R&D expenditure:

$$Exp_{preTax} \text{ x } DeductRate \text{ x } MTR = Exp_{preTax} - 100$$

which simplifies to:

$$Exp_{preTax} = 100/(1 - DeductRate \text{ x } MTR)$$

Substituting this equation into the first equation gives an expression of the value of the tax deduction in terms of the deduction rate and the relevant marginal tax rate:

$$DeductRate = 100/(1 - DeductRate \text{ x } MTR) - 100$$

For rural businesses, the deduction rate applicable to statutory levies claimed as a business tax deduction is 100 per cent, but the marginal tax rate varies according to individual farm business structures. For non-rural businesses, the full deduction rate for R&D expenditure could be either 125 per cent or 175 per cent, but the company tax rate of 30 per cent may be reasonably assumed for most businesses.

continued...

box 1 How much does it cost government for rural or non-rural industries to lever an additional dollar of tax-payer funded R&D? *continued...*

Substituting the tax deduction equations and the average RDC funding rate of $91 per $100 of industry contributions into the first equation gives:

$$= \frac{100/(1-100\% \times MTR_f) - 100 + 91}{100/(1-125\% \times 30\%) - 100} = \frac{100/(1-100\% \times MTR_f) - 100 + 91}{60}$$

where MTR_f is the marginal tax for all primary producers.

1 Estimated ratio of rural to non-rural industries' government R&D support per $100 of industry contributions by selected primary producer marginal tax rates

	selected primary producer marginal tax rates			
	30%	20%	10%	0%
Under the current RDC contribution arrangements				
Using additional 25% (basic) non-rural tax concession	11.2	11.2	11.2	11.2
Using additional 75% (premium) non-rural tax concession	3.1	3.1	3.1	3.1
Using additional 25% (basic) non-rural plus 100% (standard) tax concessions for rural and non-rural industries	2.2	1.9	1.7	1.5
Using additional 75% (basic) non-rural plus 100% (standard) tax concessions for rural and non-rural industries	1.2	1.0	0.9	0.8
With reduced government RDC contributions				
Using additional 25% (basic) non-rural tax concession	5.7	5.7	5.7	5.7
Using additional 75% (premium) non-rural tax concession	1.6	1.6	1.6	1.6
Using additional 25% (basic) non-rural plus 100% (standard) tax concessions for rural and non-rural industries	1.5	1.2	1.0	0.8
Using additional 75% (basic) non-rural plus 100% (standard) tax concessions for rural and non-rural industries	0.8	0.6	0.5	0.4

Notes: Under the current funding arrangements, Government contributions have averaged $91 per $100 of industry contributions. For the purposes of this analysis, it was assumed that halving the GVP cap to 0.25 per cent, as proposed by the Productivity Commission, would reduce the government contribution rate to $46 per $100 of industry contributions.

4 Effectiveness of the RDC model in improving agricultural productivity

Appendix B of the commission's draft report on Rural Research and Development Corporations discusses several studies that have investigated the influence of public R&D expenditure on agricultural productivity growth. The discussion focuses on various methodological issues and other factors that could complicate attempts to estimate the benefits of rural R&D.

In essence, the appendix questions whether public expenditure on rural R&D contributes to agricultural productivity growth and, in particular, casts doubt on the possible link between declining public investment in rural R&D (since the mid-1970s) and the current slowdown in agricultural productivity growth. The key issues raised by the commission are:

- The complexity of model specifications and estimation methods means that the findings of previous studies cannot be compared and so cannot shed light on the relationship between rural R&D and agricultural productivity in Australia.
- Project-specific assessments tend to overestimate the benefits of rural R&D since they usually focus on the successful projects and may suffer a selection bias problem.
- The measures of public rural R&D expenditure and total factor productivity might not be suitable due to practical issues such as data availability and industry specification.

However, the availability of quality data, together with the fact that all statistical models are a simplification of reality, almost always limits the extent to which analysts may confidently draw inferences for public policy purposes. While such issues (and others not raised in appendix B) are important, they should not unduly affect several broad conclusions that have emerged recently from various quantitative studies, in particular, that the long-run decline in the intensity of public investment in rural R&D has contributed to the slowing of agricultural productivity growth.

Importance of agricultural productivity growth

At any point in time, productivity reflects the efficiency with which producers combine market inputs to produce outputs (that is, goods and services). Over time, productivity growth points to efficiency gains because producers use fewer inputs to produce the same level of output or, alternatively, produce more output from the same inputs.

Productivity improvements are a key determinant of economic performance, international competitiveness and economic welfare. In particular, it is the dominant means by which living standards improve over the long term, through lower production costs and higher incomes. Consequently, productivity growth can mean higher returns on capital, higher wages, higher profits and increased tax revenue. It can also lead to lower prices for consumers and may benefit the environment, as less land, water and chemicals are required to produce the same amount of output (PC 2005). As Krugman (1992) explained, 'productivity isn't everything, but in the long run it is almost everything'. Productivity growth is valuable for maintaining and improving the international competitiveness of Australian firms.

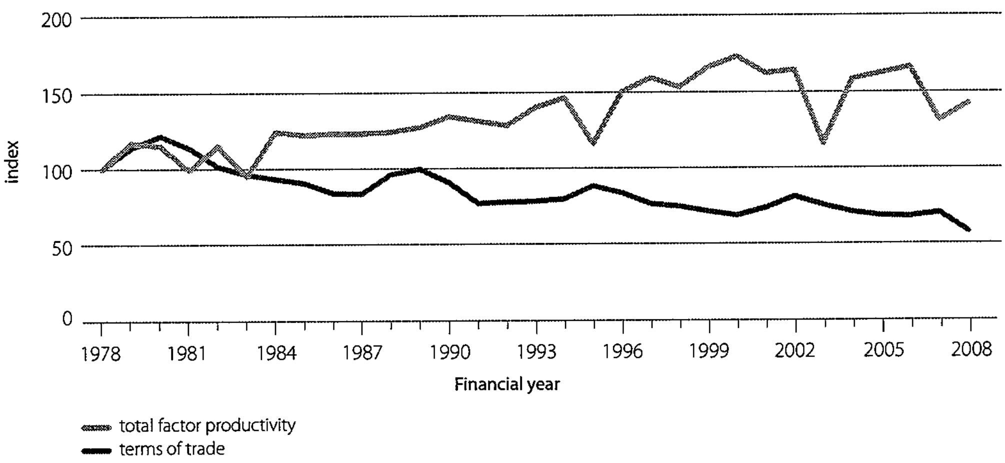
In agriculture, productivity gains have served to offset declining real prices received for farm commodities on global markets. In addition, farms have faced rising input costs which have also contributed to an overall decline in the farmer terms of trade in past decades (figure a). Finding ways to reduce costs by lifting productivity has been fundamental for the agriculture sector in remaining internationally competitive and sustaining farm incomes.

Productivity growth in agriculture (and the wider economy) can also serve to mitigate the adverse impacts on living standards of long-term challenges such as sustainable water use and climate change (PC 2008).

Broadacre productivity growth has slowed

Productivity growth has, in recent times, slowed in all sectors of the Australian economy, including services and manufacturing (PC 2008). Although the reasons differ between industries, drought events in recent years have had a major impact on agriculture.

a Broadacre total factor productivity and terms of trade 1977–78 to 2007–08



Note: The terms of trade index series is for all agriculture rather than for broadacre agriculture alone.

Productivity typically fluctuates through time. To avoid comparisons across inappropriate points of time, the ABS has identified 'productivity cycles'—periods over which growth in productivity may be compared most appropriately. These cycles have typically (though not always) coincided with the period between successive peaks in productivity. In recent decades, such cycles have tended to last around five years (PC 2009, p. 14).

However, to examine underlying agricultural productivity growth adequately, a much longer horizon is required. Although productivity cycles can provide useful timeframes for comparison in some circumstances, they do not suit analyses used to identify changes in trends and examining the contribution of possible causal factors. In addition, the highly aggregated (economy-wide) basis on which the official productivity cycles are defined may have little relevance to agriculture which, on a year-to-year basis, is substantially affected by seasonal conditions and price movements on world markets.

Over the past five decades (1953 to 2007), much of Australia's agriculture sector has experienced a slowing of its productivity growth. Detailed farm-level analysis by ABARES has found a significant departure from the historical productivity trend around 1994 (Sheng, Mullen and Zhao 2010a, b). Using 1994 as the turning point, annual TFP growth between 1953 and 1994 was estimated to be around 2.2 per cent, whereas it averaged just 0.4 per cent between 1994 and 2007. The statistical approach used by Sheng, Mullen and Zhao to identify and test the structural break is outlined in box 2.

box 2 **Testing for a slowdown in broadacre productivity growth**

A technique based on the cumulative sum of squared residuals from a regression model can be used to investigate the stability of the total factor productivity (TFP) data series over time. The technique calculates a cumulative sum index (CUSQ), which gives an out-of-control signal to indicate when the annual values of the TFP index become significantly different from their expected levels given past trends. This is a commonly used statistical technique for detecting a systematic change in time series data, usually referred to as a structural break, or turning point.

The key steps in the analysis are to determine how many structural breaks occur in the TFP series, if they are statistically significant and when they occurred. The magnitude of the CUSQ index determines the significance of the structural break. An index value exceeding a pre-specified critical value is considered fairly likely to mark a genuine turning point. For instance, an observed value of the CUSQ index of 1.36 or higher indicates in statistical terms that a structural break has occurred with a probability of 95 out of 100 (i.e. at the 5 per cent level of significance).

The timing of a structural break is usually identified as the year when the CUSQ index peaks after exceeding a threshold value.

The estimation procedure was then extended to allow 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 series are included in the regression model to generate a new series of cumulatively summed residuals. If the CUSQ persists above the critical level, then it is reasonable to conclude that the additional factors (or combinations of factors) are not the source of the structural break in the original TFP series.

Source: Sheng, Mullen and Zhao 2010b.

Factors likely to affect productivity growth

Seasonal conditions

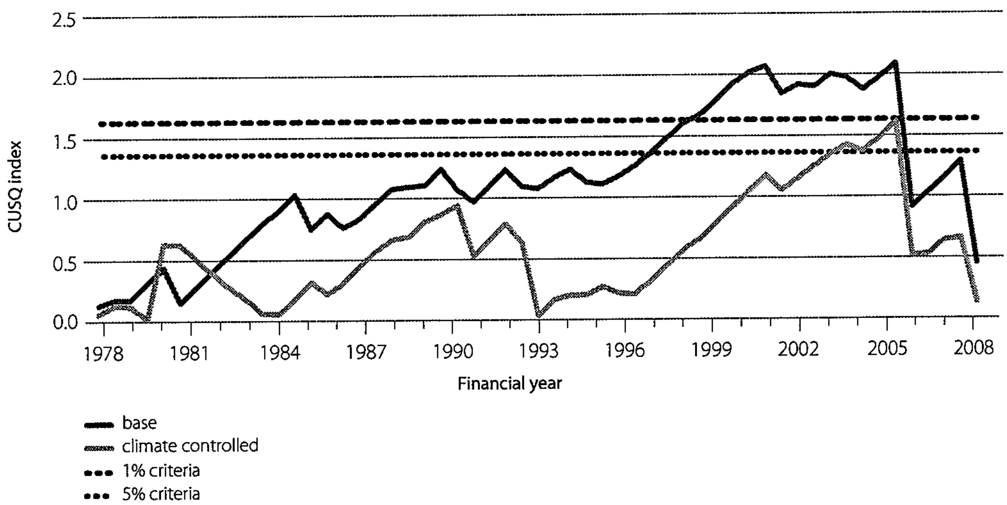
In considering the range of factors likely to have contributed to the slowdown in broadacre productivity growth, it is important to first examine the effect of seasonal conditions. Water availability can substantially depress broadacre TFP estimates in drought years because the component farming systems (grain, beef and sheep production) are predominately dryland (rainfed) activities. In recent years, most broadacre cropping areas have experienced seasonal conditions below 30-year averages.

ABARES has investigated the effects of adverse seasonal conditions on TFP growth using a measure of crop water stress (Sheng, Mullen and Zhao 2010b). This measure is based on a soil water balance model that takes into account factors such as rainfall, soil type, sunlight and temperature.

Not surprisingly, the study found that variable seasonal conditions can account for some of the volatility in productivity. However, the analysis also found that a structural break persisted in the productivity series even after allowing for seasonal conditions (figure b). In other words, factors other than seasonal conditions have contributed to the observed slowing in broadacre productivity growth.

Of course, in the long run, there could be a range of indirect effects induced by seasonal conditions. For example, seasonal conditions that are persistently below average could contribute to more risk-averse decision-making among farmers, such as skipping opportunities for double cropping that would have otherwise been taken in more normal years (this is an area of future ABARES research). Nevertheless, the statistical model indicates with a high degree of certainty (around the 1 per cent significance level) that a structural break remained that could not be fully explained by seasonal conditions.

b **Effect of climate on agricultural productivity structural change**

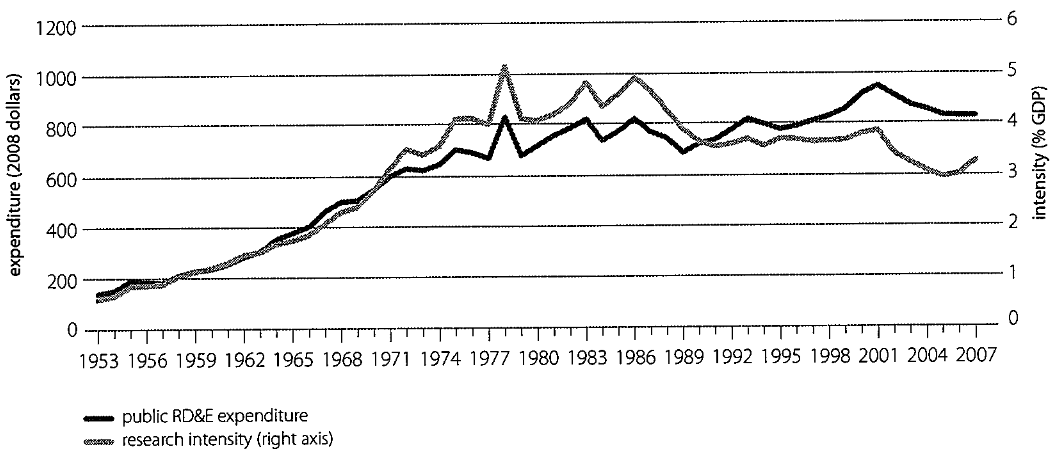


Source: Sheng, Mullen and Zhao 2010a.

Public expenditure on R&D

A second possible explanation for the slowdown is declining public agricultural 'research intensity'—that is, the level of public expenditure on research and development (R&D) and extension activities relative to the gross value of agricultural production. As highlighted in the commission's draft report, R&D plays an important role in enhancing the productivity and competitiveness of Australia's agriculture, fishing and forestry industries. It further notes that the bulk of this research has been directed at improving the productivity of the rural sector. However, data assembled by Mullen 2010 (p. 23) show a decline in research intensity in Australian broadacre agriculture in recent decades (figure c).

C Public research intensity in Australian broadacre agriculture: 1953–2007



Source: Sheng, Mullen and Zhao 2010a.

The link between public expenditure on R&D and extension (RD&E) and productivity is built by generating a 'stock of knowledge'. This is necessary because annual investment in R&D increases the stock of knowledge available to farmers which, in turn, yields a flow of benefits over many years (Alston, Norton and Pardey, 1995; Scobie and Jardine, 1988). Recognising the potentially long lag effects of RD&E expenditure, Sheng, Mullen and Zhao (2010b) incorporated knowledge stocks in the statistical model using 16-year and 35-year lags that followed gamma, trapezoidal and geometric distributions.

Further, to improve the statistical robustness of the test, the effect of public RD&E on productivity was examined in conjunction with climate effects. This was prudent because the stock of knowledge could, in part, depend on climate. For example, a proportion of recent RD&E expenditure in Australian agriculture has been directed at addressing drought and climate change at both the farm and national level.

ABARES found strong evidence that climate and real public agricultural RD&E investment have jointly influenced broadacre productivity growth in the past. Further, the addition of RD&E expenditure is sufficient to explain the recent slowing of broadacre productivity growth. In contrast to the model testing climate effects only, the CUSQ index remained below the critical threshold when RD&E expenditure was incorporated in the model (as explained in box 2).

Subsequent research by ABARES has concluded that the private returns from public investment in RD&E are significant (Sheng. Gray and Mullen, 2010). After accounting for technological 'spill-ins' from other countries (proxied by US R&D expenditure), the internal rate of return (IRR) for domestic public investment could be as high as 28 per cent for R&D and 47 per cent a year for extension activities.

Further, to the extent that such RD&E activities may benefit society more broadly (that is, beyond broadacre farmers), the flow of private plus social benefits would translate into even higher internal rates of return to public investments in agricultural RD&E, such as through applications outside the agriculture sector and/or incidental effects on environmental quality or human health and safety.

Other factors driving productivity growth

Apart from the key roles played by climate and RD&E, changes in a range of other factors that are widely accepted determinants of TFP may also have contributed to slower broadacre productivity growth. However, while changes in these other factors may have influenced TFP for individual years, they have seemingly contributed little to the slowdown in TFP growth.

While improvements in the level of education attainment of farmers (proxied by a national education attainment rate) appear to have slowed, its inclusion appears to have moderated rather than contributed to the observed slowdown in broadacre productivity growth (Sheng, Mullen and Zhao 2010b).

Although it is widely accepted that changes in the terms of trade facing farmers can affect productivity, the recent flattening in the farmer terms of trade has not contributed significantly to the overall slowdown (Sheng, Mullen and Zhao 2010b). In the short run, changes in the terms of trade may induce farmers, in profit-maximising, to choose combinations of inputs and outputs that reduce their overall productivity (O'Donnell 2009; PC 2008). For example, farmers may expand cropping into relatively marginal land in response to increases in expected output prices. However, in this example, were such a trading environment to persist, in the long term, productivity should increase to the extent that farmers can or do substitute more efficient technologies.

Additionally, there is no evidence that fewer research opportunities have contributed to the slowdown in productivity growth. Research agronomists seem confident that there are practical research opportunities (and opportunities for farmers to grow crops more efficiently) associated with, for example, greater understanding of soil biology and further development of precision agriculture to encompass variable-rate fertiliser technologies (Carberry, Keating, Bruce and Walcott 2010).

In contrast, foreign public R&D (along with domestic public R&D) has been a major contributor to TFP growth in Australia's broadacre sector over the long term, largely reflecting the similarity of US and Australian farming systems. For example, while broadacre TFP growth averaged around 1.96 per cent a year between 1953 and 2007, almost two thirds of this has been accounted for by domestic research and extension (0.6 per cent a year) and foreign research (0.63 per cent a year) (Sheng, Gray and Mullen 2010). Thus, any slowing in overseas productivity growth, particularly from the United States, would be expected to affect TFP growth here too—a point recognised in the draft report.

Nevertheless, despite the importance of foreign (public) R&D, the broad conclusion remains that contracting Australia's rural R&D program is likely to affect its agricultural productivity growth, all other things being equal.

Comments on various analytical techniques

The draft report (p. 252) points out a number of difficulties that may confound attempts to isolate the 'precise' effects of public investment in R&D. The commission (PC 2007) raised many of these issues as part of its inquiry into public support for science and innovation which examined, among other things, the economy-wide benefits from public support of science, including agricultural science. More broadly, issues around model specifications, data imperfections and sample selection bias are regularly faced by many policy analysts pursuing evidenced-based research.

Despite such constraints, an extensive body of research has been published over many decades that includes a variety of analytical techniques and which generally points to a significant positive relationship between R&D and productivity growth.

Further, the availability of relatively high quality data sets in agriculture, which are not generally available in such detail for most other industries or indeed for the economy as a whole, in part serve to moderate such concerns. Of course, this does not mean that such difficulties vanish altogether. What it does mean is that more headway can be made in analysing broadacre agriculture than might otherwise be possible at a highly aggregate or national level. In particular, these data allow the use of a suite of sophisticated statistical techniques designed to address the various methodological issues.

Excluding private R&D

The draft report (p. 254) suggests that research conclusions drawn about the role of public investment in R&D that don't take into account what has been happening to private funding could be incorrect.

Although private R&D expenditure clearly plays an important role in advancing farm productivity, its influence on the slowdown on broadacre total factor productivity has not been explicitly investigated. Apart from the lack of data, this approach can be justified for two reasons.

First, the public sector share has, for many years, been the dominant source of R&D funds in Australia, although the private sector share has increased to around 20 per cent in recent years (Mullen 2010).

Second, the outputs of private research are largely embodied in inputs. To the extent that private R&D firms, rather than farmers, are able to appropriate the benefits of various technical inputs through royalties and other payments, the benefits are already captured by the TFP index. Thus, private R&D may not have the same impact on measured productivity as public R&D which is generally available to farmers at little or no cost. Examples here include many of the advances in precision agriculture (including those using GPS guidance systems and spray technologies involving optical weed recognition) and biotechnologies (such as commercially available herbicide tolerant and insect resistant crop varieties).

Omitted variable bias

It is argued in the draft report (p. 255) that not accounting for particular factors in the structural-break analysis can introduce an omitted variable bias into the investigation of broadacre TFP trends. Not including industry rationalisation in the regression analysis has been used in the draft report as an example of this argument. However, in this case, the bias problem might only occur when industry rationalisation is correlated with the stock of public rural R&D knowledge. ABARES is not aware of any evidence that points to such a correlation.

More importantly, the ABARES structural-break analysis is unaffected by the potential 'omitted variable bias' insofar as the methodology used in the structural break analysis was based on a series of generalised method of moments / ordinary least squares estimations with adjustments for the endogeneity problem (correlation between each independent variable and the residuals) (Perron 2006).

Reverse causality

The above discussion on omitted variable bias also applies to another comment in appendix B regarding the 'reverse causality problem'. The draft report (p. 255) claims reduced productivity growth (induced by drought) could conceivably result in lower public investment in R&D (rather than the converse interpretation that reduced public investment has contributed to declining productivity) consequent on lower industry levy revenue and, in turn, matching government contributions. In this regard, the draft report acknowledges that this possibility could be offset by the three-year averaging arrangements that apply to levy collections and any flexibilities the RDCs may draw on (including reserve funds).

However, it is important to recognise that knowledge stocks drive productivity growth rather than rural R&D investments in any one year. Thus the potential decline in R&D expenditure associated with reduced output would only have a very minor impact on the knowledge stock because it is largely accumulated expenditure from past years. When the long lags between investment and productivity growth (as well as the analytical techniques used by ABARES to deal effectively with this problem) are also taken into account, such concerns would seem to be inconsequential for understanding the recent slowdown in TFP growth.

R&D spending not matching broadacre productivity data

A further concern raised in the draft report (p. 255) is the extent to which the RD&E expenditure data (which were used to construct the knowledge stock variables) correspond to the same industries comprising the productivity data. While RD&E expenditure data for broadacre agriculture alone are not available, Sheng, Mullen and Zhao (2010a) did attempt to address this issue by apportioning total RD&E expenditure between broadacre and non-broadacre industries on the basis of production value. Although this approach is arguably ad hoc, no better approach has so far been found.

In addition, most public RD&E for agriculture is directed at broadacre industries; only relatively small amounts flow to horticulture and other irrigated agriculture. Thus, changes in total agricultural public R&D expenditure are broadly consistent with those that would apply to broadacre agriculture.

5 Conclusions

As noted above and in the draft report, a fundamental reason to fund rural R&D is, among other objectives, to improve agricultural productivity. Despite ongoing public involvement in this area, there is an emerging body of research indicating that the underlying growth of broadacre agricultural TFP has slowed, most likely since the mid-1990s. While a range of factors are almost certainly at play, the statistical techniques employed by Sheng, Mullen and Zhao (2010) have singled out declining public agricultural 'research intensity' as being a key factor, once the effect of changing seasonal conditions has been taken into account.

To the extent that stagnant growth in public RD&E is a factor, a reduction in public investment is likely to exacerbate any slowdown in rural productivity growth and, in turn, would contribute to lower rural incomes (all other things being equal). While the scope of the inquiry covers all rural R&D, the results discussed above are, nevertheless, pertinent to the greater part of agricultural output. Broadacre agriculture, (that is, dryland cropping and livestock production) accounts for nearly two-thirds (62 per cent) of the gross value of agricultural production.

While there is no evidence to suggest the slowdown is necessarily permanent, changes that act to restrict productivity growth could materially affect livelihoods in rural and regional Australia. Moreover, although evidence of a similar slowdown in other developed countries (such as the United States, Germany and the Netherlands) could serve to dispel concerns regarding Australia's international competitiveness, some developing countries (such as Brazil) that are major agricultural exporters continue to realise strong agricultural productivity growth and, in turn, improve their competitiveness on world markets.

Given this evidence, and concerns presented above about the usefulness of the commission's 'number of times greater' metric to justify reduced government expenditure, as well as the downside risk to agriculture productivity growth and, in turn, rural communities, the case for a reduction in government expenditure on rural R&D appears weak.

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ABARES CONFERENCE PAPER 10.16a

Public investment in R&D and extension and productivity in Australian broadacre agriculture

Conference paper prepared for the 16th World Productivity Congress and 2010 European Productivity Conference at Antalya, Turkey, November 2010

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Abstract

This paper uses time series data to examine the relationship between public research and development (R&D) and extension investment and productivity growth in Australian broadacre agriculture. The results show that public R&D investment has significantly promoted productivity growth in Australia's broadacre sector over the past five decades (1953 to 2007). Moreover, the relative contributions of domestic and foreign R&D have been roughly equal, accounting for 0.6 per cent and 0.63 per cent of annual total factor productivity (TFP) growth in the broadacre sector, respectively. The estimated elasticity of TFP to knowledge stocks of research (both domestic and foreign) and extension were around 0.20–0.24 and 0.07–0.15, respectively; the ranges reflecting alternative distributions of benefits flowing from knowledge stocks. These elasticities translated into internal rates of return (IRRs) of around 15.4–38.2 per cent and 32.6–57.1 per cent a year, respectively. While such rates are less than the average IRR of 100 per cent reported in the international literature, they are consistent with previous estimates for Australian agriculture of around 15–40 per cent.

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Introduction

Increasing productivity in the agriculture sector continues to be a core policy objective of rural industries and Australian governments. Investment in research, development and extension (RD&E) is an important means of developing new technologies and management methods. Facilitating industry adoption drives long-term agricultural productivity growth. In recent decades there has also been a focus on developing technologies that are both profitable for farmers and deliver better environmental and human health outcomes.

There is an ongoing debate in Australia about the role that governments should play in funding agricultural RD&E and the returns to such public expenditure. These issues are especially relevant because agricultural productivity growth has slowed over the past decade or so, most notably in the cropping sector (Nossal and Sheng 2010; Nossal et al. 2009). Extended poor seasonal conditions explain some of this slowdown, but a long-term decline in the growth of public RD&E since the 1970s has also been shown to be a factor (Sheng et al. 2010).

The returns to public agricultural R&D as reported in the literature appear significant, with no evidence that the rate of return to public RD&E investments is declining over time. Alston et al. (1995) surveyed a large number of studies and found that the median return to public investment in agricultural research was 48 per cent (with an average of 100 per cent) across many different countries. Similar results have also been found in Australian studies that have focused on the broadacre sector. For example, Mullen and Cox (1995) estimated the internal rate of return (IRR) to publicly funded research in Australian broadacre agriculture (essentially, non-irrigated crops, beef cattle and sheep industries) to be around 15–40 per cent between 1953 and 1988. Mullen (2007) estimated similar rates of return for the period 1953–2003, suggesting high rates of return to public research have also persisted in Australia.

However, the extent to which technology and knowledge 'spill-ins' from research conducted in other countries influences agricultural productivity growth in Australia is not well understood. Research conducted interstate or overseas can be a source of spillover productivity gains, whether as ideas borrowed from the research of others or through foreign technology adapted to suit local conditions. The small number of studies that have considered foreign spillovers have found that foreign R&D is as important—if not more so—as domestic R&D (Alston 2002). Moreover, foreign R&D is likely to be especially important for small, open economies such as Australia.

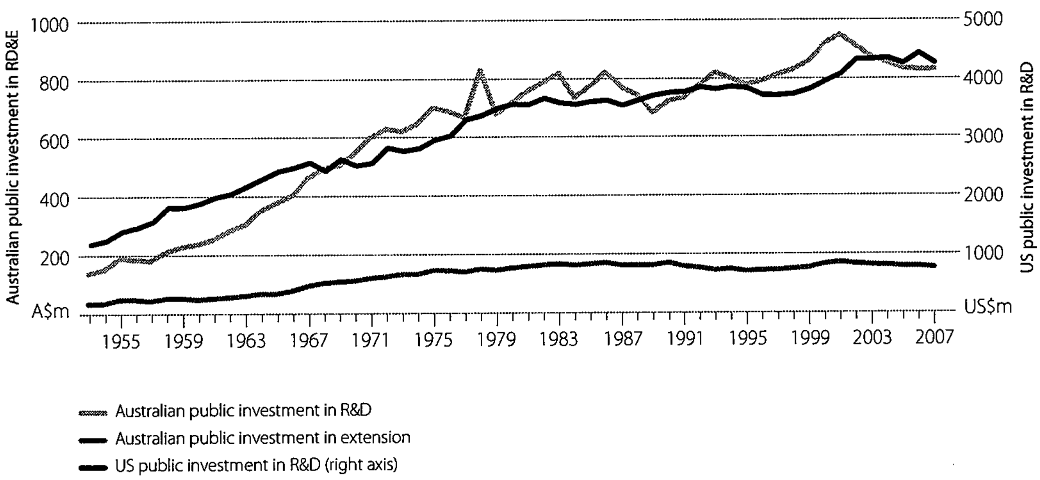
The objective of this paper is to re-examine the relationship between public agricultural RD&E investment in Australia and broadacre total factor productivity (TFP). The rate of return to public R&D is estimated using a research strategy similar to that used by Alston et al. (2010), and uses a range of econometric techniques and an extended dataset covering the period from 1953 to 2007. An important advance is to account for broadacre productivity gains arising from technology spill-ins from other countries and to distinguish between the relative contributions of foreign and domestic R&D and domestic extension activities to broadacre TFP growth. The results of several model specifications are presented. Thus, the results reflect a range of assumed benefit distributions of public RD&E over time and, in turn, a range of internal rates of return.

Public RD&E investment and agricultural productivity in Australia

In Australia the share of agricultural RD&E funded by the public sector has been much larger than that of the private sector—generally greater than 90 per cent of total agricultural R&D, although by 2007 this had decreased to 80 per cent (Mullen 2010). This contrasts strongly with other OECD countries where, on average, more than half of the total investment in agricultural research in 2000 came from the private sector. Not surprisingly, the extent of public investment in agricultural RD&E, and its effect on agricultural productivity, has consistently been an important policy issue in Australia.

Australian public investment in agricultural research has, in real terms, increased over the past 50 years, from A$140 million in 1953 (2008 dollars) to around A$829 million in 2007 (figure 1). However, while growth in public R&D expenditure was strong until the late 1970s, it has since slowed. Research intensity (defined as the ratio of public RD&E expenditure to agricultural GDP) peaked at 5 per cent in 1978, before declining to 3 per cent in 2007. The annual growth rate of public R&D expenditure for agriculture has declined from around 7 per cent a year between 1953 and 1978 to around 0.6 per cent a year from 1978 to 2007.

1 Real public RD&E investment in Australian broadacre and US agriculture: 1953–2007

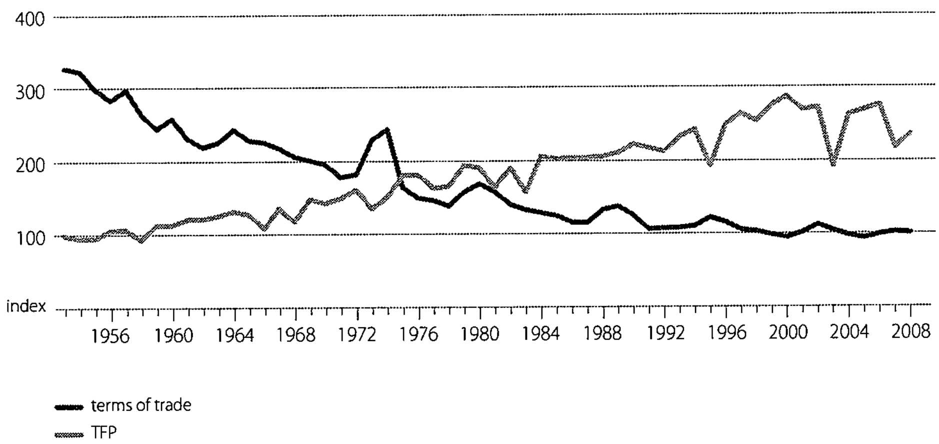


Sources: Estimated with data from Mullen 2010 and ERS-USDA.
Notes: In 2008 dollars. Australian public investment in R&D includes expenditure by state and Commonwealth research institutions and universities, including funds from the research and development corporations and other external funders for agriculture, excluding research in fisheries and forestry.

A key objective of agricultural RD&E is to improve farm performance, particularly in relation to farm productivity. TFP in broadacre agriculture in Australia generally grew for many decades, from an index value of 100 in 1953 to 218 in 2007, peaking at 288 in 2000 (figure 2). However, the slowdown in growth since the mid-1990s, particularly in the cropping industry, is concerning (figure 3). Broadacre TFP growth averaged around 2.2 per cent a year before 1994 (a turning point year determined by Sheng et al. 2010), but declined to 0.4 per cent a year thereafter.

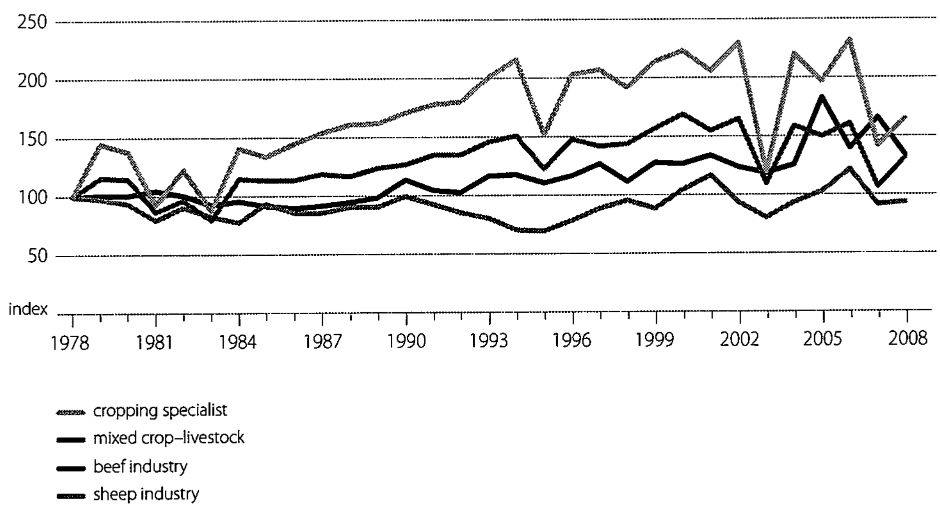
There is now evidence that stagnating public investment in RD&E since the late 1970s may have contributed to the slowdown in agricultural productivity growth (Sheng et al. 2010). Of course, there is a range of factors that could have contributed to the slowdown in broadacre TFP growth. Chief among these is drought, which has been a feature of agriculture for the past decade, but particularly in 2003 and 2007. However, that RD&E should be singled out as a contributing factor is not surprising given the underlying intent of such investment.

2 Broadacre TFP and terms of trade in Australia, 1953–2007



Notes: The terms of trade is the ratio of an index of prices received by farmers to an index of prices paid by farmers (ABARE 2009). TFP is the ratio of a quantity index of aggregate output to a quantity index of aggregate input (Gray et al. 2010).

3 TFP in Australian broadacre agricultural industries, 1978–2008



Source: Nossal and Sheng (2010).

Methodology and estimation strategy

For a variety of reasons, estimating a relationship between RD&E activities and agricultural TFP is complex. First, agricultural TFP in a given year does not depend on the current level of RD&E expenditures, but rather on the stock of usable knowledge derived from past RD&E expenditures (Alston and Pardey 2001). Second, there are usually long lags before investments can be converted into useful knowledge and technologies that are available for farmers to use (Alston et al. 2010). Thus, because it is unlikely that expenditure on R&D and, to a lesser extent, extension will be directly correlated with broadacre TFP in the same period, the unobserved knowledge stocks drawn on by farmers can be proxied by weighted aggregates of past expenditures on R&D and extension. In these matters, economic theory does not suggest an obvious estimation strategy, although past empirical studies do provide some guidance.

In the first instance, an unconstrained base model can be used to represent the relationship between RD&E knowledge stocks and TFP:

$$(1) \qquad TFP_t = f(KS_t^{DS}, KS_t^{PS}, KS_t^{EXT}{}_t, KS_t^{FS}, Z_t) + \varepsilon_t$$

where is the TFP index at time t and KS_t^{DS}, KS_t^{PS}, KS_t^{EXT} and KS_t^{FS} are knowledge stocks pertaining to expenditures on domestic public R&D, domestic private R&D, domestic extension and foreign public and private R&D, respectively. Z_t is a vector of other control variables cited in previous studies (namely, seasonal conditions, the terms of trade and farmers' highest level of education attainment). A specific functional form is denoted by $f(.)$ and ε_t is an error term.

A number of data limitations and various econometric issues mean it is not possible to directly estimate equation (1) without encountering a range of statistical limitations. The balance of this section outlines a less direct, but more robust four-step estimation strategy involving:

- construction of the R&D and extension knowledge stocks
- choice of model specification
- choice of estimation strategy
- estimation of impacts and internal rates of return.

Construction of knowledge stocks

The choice of the models for constructing the knowledge stock variables was based on the findings of previous international and domestic studies (Alston et al. 2010; Alston et al. 2000; 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):

$$(2) \qquad KS_t^i = g_i(R_t^i, R_{t-1}^i, \ldots, R_{t-L_R^i}^i)$$

where KS_t^i denotes the knowledge stocks corresponding to various RD&E activities $i = \{DS, PS, EXT, FS\}$ as in equation (1). The investment at time t is denoted by R_t^i and the maximum time lag for each knowledge stock variable is L_R^i. The distribution functions for alternative time-lag profiles of R&D 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, which is commonly used to construct knowledge stocks for the manufacturing sector (for example, Shank 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).

Choice of model specifications

To identify the relationship between the different types of knowledge stocks and TFP growth, past approaches have usually needed to impose two constraints on the way in which the model is specified. This is because of issues arising through multicollinearity (owing to the high correlation between the knowledge stocks) and endogeneity (arising from excluding private R&D).

First, following Mullen and Cox (1995), private R&D knowledge stocks were excluded from equation (1). Time series data on private R&D expenditure in Australian agriculture are not generally available. Not including private R&D (domestic and foreign) may result in biased estimates of the coefficients of public knowledge stock variables if private and public knowledge stocks are correlated. For example, were private R&D positively correlated with public R&D, its omission would bias the estimates of the coefficient on public R&D upwards (Alston and Pardey 2001).

Omitting private R&D knowledge stocks is, potentially, a significant limitation of this analysis. However, there are reasons to believe that any such bias may be less than would otherwise be expected. To the extent that farmers pay for the outputs of private sector research and services, the benefits of private R&D will be captured as an input in the TFP index. Conceptually, this would be the case if the private sector is able to appropriate some of the value of improved inputs, including consultancies to farmers. In other words, the productivity effect of an increase in output would be at least partially offset by the measured increase in higher quality inputs.

Furthermore, in the case of Australia, the private share of agricultural R&D has been small relative to public investment, exceeding 10 per cent only in recent years. Given the longs lags between research investments and their eventual contributions to the stock of knowledge, it is likely that domestic private R&D has had a relatively limited impact on broadacre TFP to date. However, excluding foreign private R&D remains a potentially significant source of bias and an area for future research.

Second, rather than estimate the individual effects of domestic and foreign public knowledge stocks (equation 1), it was necessary to form a total public research knowledge stock variable (TS_t^{kj}) to deal with the high correlation between foreign and domestic public R&D knowledge stocks. Foreign (public and private) R&D is expected to contribute directly to TFP growth in Australia through cross-country technology spillovers. Not controlling for the impact of foreign public knowledge stocks may also result in omitted variable bias, leading to over or underestimation of the contribution of domestic public R&D and extension knowledge stocks to productivity.

Two assumptions guided construction of the total public R&D knowledge stock variable. First, domestic and foreign public R&D were assumed to have the same lag profiles. Second, the foreign public R&D knowledge stock was assumed to have a smaller effect on broadacre TFP than the domestic public R&D knowledge stock. This was to take into account possible differences in agricultural production techniques, the focus of public R&D investment and possible trade and non-trade barriers to agricultural knowledge transfers across countries. It is likely that spillover productivity gains from external R&D are greater when the technology or knowledge is sourced from regions (or countries) that have similar agroecological conditions, as less investment in adaptive research is required (Sunding and Zilberman 2001). Similarly, openness to trade and investment increases the transfer of knowledge and technology between countries and, in effect, facilitates access to the outputs of foreign R&D. In contrast, the jurisdictional pattern of intellectual property rights may act as a non-trade barrier to international technology flows (Alston and Pardey 2001).

The total public research knowledge stock variable (TS_t^{kj}) was constructed as a weighted sum of domestic and foreign public R&D knowledge stocks. The value of the weight for foreign public R&D knowledge stocks (π) was informed by an approach used by Alston et al. (2010), which was based on the degree of similarity in production patterns in the US and Australia and by Australia's openness to trade (Shank and Zheng 2006). The choice of the value of foreign spill-ins was also heavily influenced by the performance of the weighting factor in the Ramsey RESET and CUSUM specifications tests when π was set to 0.1. This yielded the total public research knowledge stock variable, TS_t^{kj}, such that $\ln TS_t^{kj} = \ln KS_t^{DS} + 0.1 \ln KS_t^{FS}$.

Regression method and estimation strategy

Given the methodology, the base model for examining the relationship between public research and extension knowledge stocks and broadacre TFP became:

$$\text{(3)} \qquad \ln(TFP_t) = \alpha + \beta_1 \ln(TS_t^{kj}) + \beta_2 \ln(EXT_t) + \gamma_1 \ln(WEA_t) + \gamma_2 \ln(EDUC_t) + \gamma_3 \ln(TOT_t) + \varepsilon_t$$

where the superscripts k and j denote the lag duration (length) and distribution (shape) of the research benefit profiles.

Following Mullen and Cox (1995), equation (3) also included three control variables: a measure of seasonal conditions (WEA_t), farmers' level of education attainment as a proxy for the unobserved human capital of broadacre farmers ($EDUC_t$) and the farmers' terms of trade for Australian agriculture at time t (TOT_t). These variables are included because they could have an effect on productivity, but are not reflected in the TFP index.

Water availability can substantially depress TFP estimates in drought years because the broadacre industries (grain, beef and sheep production) are predominately dryland (rain-fed) enterprises.

Human capital formation is a driver of agricultural productivity growth, which may be proxied by the education level of farmers. If labour can be differentiated in the TFP index according to education and weighted by prices that are indicative of labour quality, then improvements in human capital are effectively embodied in the labour input and will not be reflected in TFP estimates. However, ABARES only differentiates labour according to whether it is hired labour, services provided by shearers, or owner-operator and family members. Therefore, the effect of human capital formation on agricultural productivity will not be captured by the TFP index, but will be reflected in TFP estimates.

Changes in the terms of trade may, in the short run, induce farmers in profit-maximising to choose combinations of inputs and outputs that reduce their overall productivity (O'Donnell 2010; Productivity Commission 2008). For example, farmers may expand cropping into relatively marginal land in response to increases in expected output prices.

There are other factors that could influence agricultural productivity that are not included in equation (3). For example, the agriculture sector has experienced spillover productivity gains from government investment in transportation and communication infrastructure, and changes in the structure of the farm sector are likely to be sources of productivity growth. However, it can be difficult to identify suitable proxies for these variables and, to the extent that these variables are not correlated with the independent variables in equation (3), excluding them from the analysis should not introduce bias in the time series regression model.

A time series regression technique—the autoregressive integrated moving average (ARIMA) model—was used to estimate equation (3) which assumes the residuals (ε_t) follow a random normal distribution. Although the model can be estimated using ordinary least squares (OLS), the estimates may be biased and inefficient because OLS fails to take into account the time series properties of the data. For example, if $\ln(TFP_t)$ and $\ln(TS_t^{kj})$ are positively correlated with time (that is, they have time-trend unit roots), then OLS may estimate a spurious relationship between $\ln(TFP_t)$ and $\ln(TS_t^{kj})$ (Greene 2007).

Data sources and variable definitions

The measure of productivity used in the regression analyses is the ABARES broadacre TFP index, which is defined as the ratio of a Fisher quantity index of total output to a Fisher quantity index of total input. An exposition of the concepts, theories and empirical methods underlying the ABARES TFP estimates for the broadacre (and dairy) industries can be found in Gray et al. (2010). All related data were collected through the ABARES (formerly ABARE) broadacre farm surveys, which cover the period from 1953 to 2007, and were aggregated to the national level.

Domestic public R&D investment is defined by total public R&D expenditure on plants and animals and excludes fish and forestry R&D. Data were obtained from two sources:

- Raw data for 1995–2007 were sourced from the Australian Bureau of Statistics (ABS) biannual Australian Research and Innovation Survey (ABS 2008).
- Data before 1994 were drawn from Mullen et al. (1996), who sourced data from the Commonwealth Department of Science and the published financial statements of the state departments of agriculture and counterparts.

For the period before 1953, investment in extension was estimated as one-third of the state departments' investment in research. This proportion was derived based on staff surveys about time spent on research, extension and regulation. The share of extension in total research expenditure for the period from 1953 to 1994 ranged from 27.4 per cent (in 1965) to 39 per cent (in 1958), with no apparent trend.

R&D investment in broadacre agriculture alone was derived by applying broadacre agriculture's share of the total value of production in agriculture to total public investment in agricultural R&D. The GDP deflator was used to derive real public R&D and extension expenditure.

Foreign public R&D expenditure was proxied by US public R&D expenditure on agricultural production related research. The United States has had a pivotal role in global agricultural R&D, not only in terms of its investment compared with the rest of the world, but also in terms of 'know-how' and new technology spillovers arising from research conducted in the United States. The raw data for the period from 1970 to 2007 were obtained from the Economic Research Service of the US Department of Agriculture. The pre-1970 data are aggregated state-level data from Huffman and Evenson (2006).

Seasonal conditions (WEA_t) are approximated by an index of moisture availability for broadacre agriculture. Moisture availability—more precisely, the annual wheat water stress index (Potgieter et al. 2002)—is a measure of the relative water stress of the crop accumulated throughout the growing season. The index was simulated using daily rainfall and average weekly radiation data, maximum and minimum temperatures, location specific soil data and crop-specific water requirements. The index reflects the cumulative stress endured by the crop throughout the season relative to its initial value of 100 at the start of the season.

Broadacre farmers' level of education attainment ($EDUC_t$) was proxied using ABS data by the proportion of school-age students in the total population enrolled in schools (see Mullen and Cox 1995). Enrolment is defined as 'school attendance' or 'the number of school students at the national level'. The education index is a crude proxy for the real variable of interest, the human capital stock of broadacre farmers, because farmers' education attainment is likely to differ from that of the total population. The farmers' terms of trade (TOT_t) is the ratio of the average price received by farmers for their output to the average price paid for farm inputs. It covers all agriculture (not just broadacre) and was derived from data in *Australian commodity statistics* (ABARE 2009).

Estimation results: effects of R&D on productivity

A range of model specifications for equation (3) were investigated to identify a preferred model and to establish the robustness of the main results. These investigations produced a large set of results that cannot be usefully summarised here. However, the statistical tests suggested that:

- a 35-year lag period for capturing the effects of past R&D expenditure was preferable to a 16-year period (the models with 16-year lags did not pass the RMSE specification test and are not discussed further)
- the log-linear function form for equation (3) was preferable to linear and quadratic functional forms
- aggregating domestic and foreign R&D to construct a total public research knowledge stock variable was preferred to the past practice of omitting foreign R&D (as in Mullen and Cox 1995).

In addition, a standard gamma distribution with peak impact occurring after seven years was preferred over alternative distributions (gamma_T, gamma _P, trapezoid and PIM).

Effects of R&D and extension knowledge stocks on agricultural TFP

The estimated elasticity of TFP with respect to public R&D knowledge stocks was positive and significant for all distribution profiles (table 1). In the preferred gamma specification, the coefficient on public R&D knowledge stocks was 0.23, implying that a 1 per cent increase in the public R&D knowledge stock led to a 0.23 per cent increase in broadacre productivity.

Similarly, increases in public extension knowledge stocks have a significant and positive effect on productivity, with an elasticity of around 0.1 per cent. The marginal impact of the extension knowledge stock on TFP was, on average, around half that of the public R&D knowledge stock, where R&D and extension knowledge stocks both increased at the same rate.

The relative contributions of public R&D and extension knowledge stocks to annual TFP growth between 1953 and 2007 can also be calculated by multiplying the elasticities (from table 1) by the annual growth rates of the corresponding knowledge stocks. The elasticity of TFP to the foreign public R&D knowledge stock is the coefficient on total public R&D knowledge stocks deflated by π, which is the weight on foreign public R&D knowledge stocks used to construct the total public R&D knowledge stock variable.

Growth in public R&D and extension knowledge stocks has accounted for more than half of annual TFP growth in the broadacre sector between 1953 and 2007. Broadacre TFP growth averaged around 1.96 per cent a year between 1953 and 2007. Over this period public R&D knowledge stocks increased by an average 5.8 per cent a year, accounting for approximately half of annual broadacre TFP growth a year (around 0.96 per cent). This

1 Elasticities of TFP to public RD&E knowledge stocks and other explanatory factors

	Gamma	Gamma_T	Trapezoid	Gamma_P	PIM
Dependent variable: ln(TFP)					
Public R&D knowledge stock (log)	0.23***	0.23***	0.20***	0.24***	0.20***
	(0.05)	(0.05)	(0.05)	(0.06)	(0.05)
Extension knowledge stock (log)	0.10***	0.10***	0.14***	0.07**	0.15***
	(0.04)	(0.03)	(0.03)	(0.04)	(0.03)
Water stress indicator (log)	0.28***	0.27***	0.28***	0.26***	0.28***
	(0.05)	(0.06)	(0.06)	(0.06)	(0.06)
Education (log)	0.56	0.66*	0.02	0.85**	0.29
	(0.37)	(0.38)	(0.40)	(0.39)	(0.39)
Terms of trade (log)	−0.27***	−0.24**	−0.26***	−0.26***	−0.26***
	(0.08)	(0.10)	(0.08)	(0.10)	(0.09)
Constant	−0.33	−0.85	1.84	−1.37	0.61
	(1.69)	(1.82)	(1.57)	(1.91)	(1.65)
Number of observations	55	55	55	55	55

Notes: ***, ** and * represent statistical significance at 1 per cent, 5 per cent and 10 per cent levels, respectively. ARIMA model with 35-year lag. The values in parentheses are standard errors. 'Gamma' refers to the preferred model specification in which a standard gamma distribution was used to construct knowledge stocks, with a peak impact occurring seven years after investment.

comprised 0.33 per cent a year from the accumulation of domestic public R&D knowledge stocks and 0.63 per cent a year from the accumulation of foreign public R&D knowledge stocks. Growth in public extension knowledge stocks, which increased by an average 3.2 per cent a year, contributed around 0.27 per cent to TFP growth a year. This suggested that, between 1953 and 2007, the relative contribution to broadacre TFP growth of domestic and foreign research activities and domestic extension activities was in the ratio of 1:2:1.

Of the three control variables, seasonal conditions and the farmers' terms of trade had significant effects on broadacre TFP. The estimated elasticities of TFP with respect to seasonal conditions ranged from 0.26 to 0.28 for all distributions, indicating that a 1 per cent increase in moisture availability over the growing season would increase productivity in that year by 0.28 per cent, all other things being constant.

In contrast, the farmers' terms of trade had a negative effect on broadacre TFP. The elasticity of TFP with respect to the terms of trade was −0.27 in the preferred gamma distribution (ranging from −0.24 to −0.27), indicating that a 1 per cent improvement in the farmers' terms of trade would, on average, lead to a 0.27 per cent fall in productivity, all other things being constant. As indicated earlier, a possible explanation is that improvements in the terms of trade may induce farmers in profit-maximising to choose combinations of inputs and outputs that, in the short term, reduce their overall productivity.

The elasticity of TFP with respect to the level of education attainment was positive but insignificant. To some extent this is unexpected since human capital can facilitate technology adoption and improve farmers' ability to organise and maintain complex production processes. As suggested earlier, the national education attainment index used in the analysis may not be a good proxy for the human capital stock of broadacre farmers.

Return to public investment in RD&E: a cost-benefit analysis

The above analysis provides evidence of the positive impact of R&D and extension knowledge stocks on TFP in the Australian broadacre sector. However, of further interest from a policy perspective is the return from public R&D and extension. The internal rates of return (IRRs) to public investment were calculated using the elasticities of TFP to the R&D and extension knowledge stocks. Estimates of the IRR to public investment provide a measure of the benefits from a one-off increase in public expenditure on agricultural R&D and extension, which can be used *ex post* as a measure of the returns achieved and *ex ante* to assist in resource allocation.

Over the period from 1953 to 2007, the IRR to public investment in agricultural R&D was 28.4 per cent a year in the preferred model, and ranged from 15.4 to 38.2 per cent in the other specifications (table 2). The differences in IRRs across the distributions arose from the different weights assigned to the lagged years, since the estimated elasticities are quite similar in magnitude. Generally, distributions that assigned greater weights to more recent years generated higher IRRs.

Public extension generated significantly higher IRRs than those for public R&D. Over the period from 1953 to 2007, the IRR estimated from the preferred gamma specification for public extension was 47.5 per cent, but ranged from 32.6 per cent to 57.1 per cent. The higher rates of return to extension than R&D may be because of the relatively quicker (although still lagged) effect on productivity of extension activities (Huffman and Evenson 2006). In addition, public extension may facilitate adoption of spill-in technology from foreign public R&D investment. However, the IRRs should be viewed with caution, given the source and approach taken in constructing the extension dataset (as outlined previously). Despite these qualifications, the estimated IRRs for R&D and extension were consistent with the median rates of return in the international literature reported in Alston et al. (2000).

2 IRR from domestic public investment in agricultural R&D and extension activities (%)

	Gamma	Gamma_T	Trapezoid	Gamma_P	PIM
Public R&D	28.4	14	15.4	38.2	51.9
Extension	47.5	35	32.6	57.1	79.5

To determine if the IRR to public R&D has changed over time, the estimation procedure was repeated for the period 1978–2007. Growth in public R&D expenditure has slowed since the late 1970s, with research intensity peaking at 5 per cent in 1978 before declining to 3 per cent in 2007.

The estimated IRR from public agricultural R&D over the period from 1978 to 2007 was 45 per cent in the preferred model (table 3). This is significantly higher than the IRR estimated for the period from 1953 to 2007. Since the model specification used to estimate IRRs for the period from 1978 to 2007 is the same as previously reported, the larger IRRs in the more recent period were because of an increase in the elasticity of TFP to public R&D knowledge stocks (from 0.20–0.23 to 0.31–0.45). Compared with the IRR estimated for the period from 1953 to 2007, these results suggest that the returns to public agricultural R&D may be increasing, possibly because growth in public R&D has been falling since the 1970s.

3 Comparison of return to domestic public R&D investment in agricultural R&D

	Gamma	Gamma_T	Trapezoid	Gamma_P	PIM
Elasticity					
1978–2007	0.45	0.35	0.41	0.31	0.34
1953–2007	0.23	0.23	0.20	0.24	0.20
IRR (%)					
1978–2007	45.3	21.0	24.1	69.2	81.0
1953–2007	28.4	14.0	15.4	38.2	51.9

In contrast, the estimated elasticities of TFP to the public extension knowledge stocks were not significant (even at the 10 per cent level) for all distribution scenarios over the period from 1978 to 2007, possibly because of the limited time series. Consequently, an IRR could not be estimated for public investment in extension over the period from 1978 to 2007.

Conclusions

Public and private sector investment in agricultural RD&E has been an important source of agricultural innovations, enabling productivity growth in the Australian broadacre sector. In this paper, the relationship between public agricultural RD&E investment in Australia and broadacre TFP over the period 1953 to 2007 was re-examined taking into account technology spill-ins from overseas research.

Public investment in broadacre R&D and extension has generated rates of return that could be as high as 28 per cent and 47 per cent a year, respectively. While little is known about the opportunity cost of public investment in RD&E, this rate of return is comparable to rates of return estimated for other developed countries (Alston et al. 2010). Further, the growth in domestic public R&D and extension knowledge stocks arising from this investment has accounted for 0.33 per cent and 0.27 per cent, respectively, of TFP growth annually in the broadacre sector (an aggregate of 0.6 per cent).

An important contribution of this analysis was to identify the influence of foreign R&D relative to domestic public RD&E for broadacre productivity growth. Growth in foreign public R&D knowledge stocks has accounted for 0.63 per cent TFP growth annually in the broadacre sector. This suggests that the relative contributions of foreign and domestic research activities (including domestic extension) to broadacre TFP growth have been roughly equal.

Statistical diagnostic tests indicated that the preferred model specification in an Australian context was a log-linear regression function with a lag profile for past R&D investment characterised by the gamma distribution (with peak impact at seven years) and maximum lag length of 35 years. Using this model, the long lags between public investment in R&D and appreciable effects on productivity can be taken into account.

However, data constraints in this analysis suggested that opportunities remain for further research into the relationship between agricultural productivity growth and investment in RD&E. This includes further consideration of the contribution of domestic and foreign private research knowledge stocks and the magnitude of social returns to public investment in broadacre RD&E. These constraints mean that the estimated elasticities and IRRs to public investment in R&D and extension are subject to several qualifications.

First, not including private R&D (domestic and foreign) may result in biased estimates of the coefficients of public knowledge stock variables if private and public knowledge stocks are correlated. For example, were private R&D positively correlated with public R&D, its omission would bias the estimates of the coefficient on public R&D upwards (Alston and Pardey 2001). In turn, this suggests that the marginal impact of public R&D knowledge stocks on broadacre TFP and the internal rate of return to public investment would be less than reported in tables 1 and 2.

Second, the analysis necessarily focused on quantifying the private returns to public investment in RD&E activities. However, a range of social benefits from publicly funded research may arise through the application of rural R&D outputs beyond the broadacre sector and/or incidental effects on environmental quality or human health and safety. In recent decades, agricultural research has increasingly focused on developing technologies that are not only profitable but that also deliver better environmental and human health outcomes. These benefits have largely not been captured in the broadacre TFP index. To the extent that public investment in agricultural RD&E activities benefit society more broadly (that is, beyond broadacre farmers), accounting for such social benefits would translate into higher internal rates of return to public investments in agricultural RD&E than those estimated in this paper.

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