Productivity Growth and the Returns from Public Investment in R&D in Australian Broadacre Agriculture

John Mullen

President of the *Australian Agricultural and Resource Economics Society*,
Principal Research Scientist, NSW DPI
Adjunct Professor, CSU and University of Sydney

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Abstract

Investment in R&D has long been regarded as an important source of productivity growth in Australian agriculture. Perhaps because research lags are long, current investment in R&D is monitored closely. Investment in R&D has been flat while productivity growth has remained strong, relative both to other sectors of the Australian economy and to the agricultural sectors of other countries. Such productivity growth, at a time when the decline in terms of trade facing Australian farmers has slowed, may have enhanced the competitiveness of Australian agriculture. The econometric results presented here suggest no evidence of a decline in the returns from research from the 15- 40 percent per annum range estimated by Mullen and Cox. In fact the marginal impact of research increases with research over the range of investment levels experienced from 1953 to 2000, a finding which lends support to the view that there is underinvestment in agricultural research. These results were obtained from econometric models which maintain strong assumptions about how investments in research and extension translate into changes in TFP. Hence some caution in interpreting the results is warranted.

Keywords:
Productivity, research and development, research evaluation

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Introduction

Public sector investment in agricultural research in Australia has been much larger than that by the private sector, contrasting strongly with the experience in OECD countries where the private share averaged 55 percent in 2000 (Pardey, Alston and Beintema, 2006). Likely as a consequence, there has been continuing interest in research policy related to the funding and management of research and in the contribution of research investments to productivity growth. There have been three enquiries by the Productivity Commission since 1976 and most public providers of research services to agriculture have been engaged in a process of 'evolution' that seems to have been accelerating in recent decades. Notable institutional changes include the Research and Development Corporation (RDC) and Cooperative Research Centre (CRC) systems in Australia. These new institutions address different aspects of problems for research management arising from elements of non-rivalry and non-excludability that often characterise the information generated by research.

The long lags between the generation of new information through research investments and efficiency gains in agriculture make it difficult to monitor the performance of the public agricultural research sector[1]. Benefit cost analysis has been applied at a project level both ex post, as a measure of accountability, and ex ante, to assist in resource allocation. At a sector level, trends in productivity growth and in research investment are often monitored as proxies for knowledge about their causal relationship which has proved difficult to empirically estimate with precision.

Much of the previous econometric research in Australia was conducted in the early 90s by Mullen and various co-authors. They estimated that the returns from public investment in agricultural research between 1953 and 1994 were in the order of 15 – 40 percent. Productivity had been growing at about 2.5 percent per annum and public investment in R&D had stabilised after a period of strong growth in the 50s – 70s. Highlighting the difficulties of this empirical work, Mullen and Strappazzon (1996) found that the models they were working with had poor time series properties, raising doubts about the existence of a stable long-term cointegrating relationship between research and productivity growth.

It is now opportune to revisit this work. Changes in the agricultural research sector both domestically and internationally have seen renewed interest in productivity growth and in its relationship with R&D. In an international context, Pardey, Alston and Piggott (2006) note concerns that both productivity growth and investment in agricultural R&D are falling, particularly in developed economies, with implications for food security in developing countries reliant on technology 'spillovers' whose populations will continue to increase for several decades.

[1] Perhaps other sectors face similar uncertainties about returns from public sector investment.

In Australia there is concern by governments to more closely align the large public investment in agricultural research with community goals and concern by the RDCs to earn adequate returns to farmers from the funds they invest. Except for organisations like ACIAR, technology spillover to developing countries is not a high priority.

The objectives here are to assess whether there has been a slowdown in productivity growth given the stagnation in public investment in research in recent decades and whether there has been any associated change in the returns earned from investment in research. I had hoped that a longer dataset (than used by Mullen and Cox) would allow a more thorough and rewarding econometric analysis of this relationship.

In the next section of the paper, the trend in productivity growth in broadacre agriculture in Australia relative to other sectors of the economy and to agricultural productivity in other countries is reviewed. Then follows a review of trends in the funding of agricultural R&D in Australia. Finally, recent econometric analyses and productivity decomposition approaches are reviewed and updated for evidence about the returns from public investment in agricultural R&D.

Trends in Productivity in Australian Broadacre Agriculture

Past studies of productivity growth in Australian agriculture based on ABARE farm survey data are reviewed in and Mullen and Crean (2007). Estimates from studies conducted in the 70s suggested that productivity growth in broadacre Australian agriculture ranged from 0.6 to 1.7% p.a. The first study using a 'modern' index measure of total factor productivity (TFP[2]) in Australia was that by Lawrence and McKay (1980)[3]. They used a Tornqvist-Thiel TFP index[4]. Studies using these techniques are summarised in Table 1 where the observation period is in calendar year form but refers to the last half of the preceding financial year. These studies are based on time series data which generally means that changes in technical efficiency and scale economies cannot be isolated from the contribution of technical change to productivity growth. Nor do these standard measures reflect current theory about how producers make decisions under risk, particularly climate risk (O'Donnell et al. 2006).

Mullen and coauthors in their analysis of TFP used a dataset extending from 1953 to 1988 and then to 1994, derived from ABARE's broadacre agriculture survey (see Mullen and Cox (1996) for more detail). Wang (2006) 'spliced' an ABARE dataset for the years 1978 to 2003 to the original Mullen and Cox dataset. Wang used the original dataset to 1979 and the more recent dataset from then.

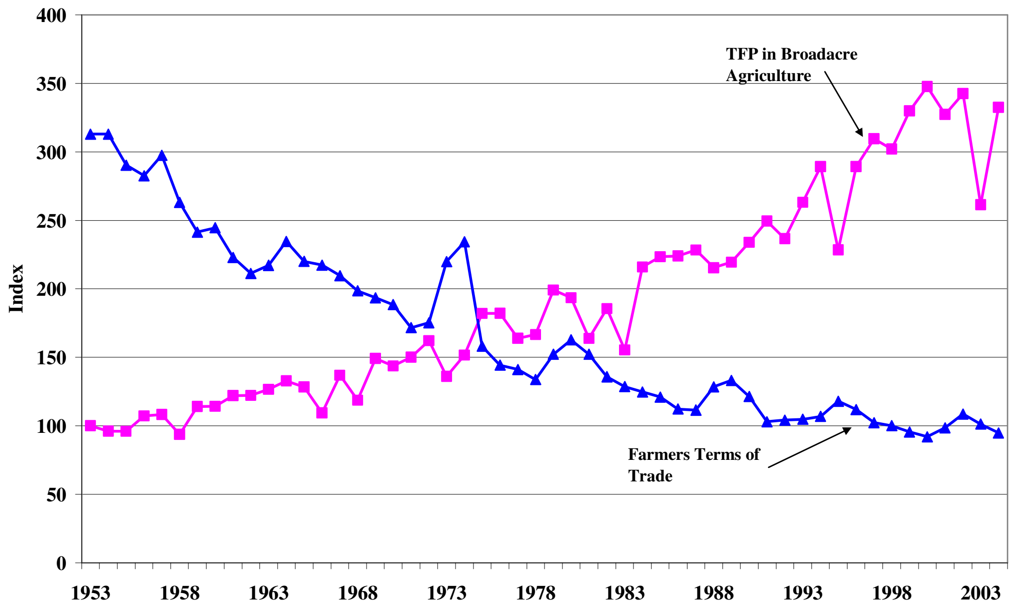
[2] I follow much of the literature in using the term total factor productivity but recognise that not all inputs are accounted for. Other use the term multi factor productivity (MFP) to recognise this 'error'.
[3] Modern in the sense of being based on a locally flexible functional form that can be interpreted as giving a second order approximation to an arbitrary production function.
[4] This remained the standard approach in Australia until Mullen and Cox (1996), following Diewert's (1992) recommendation, used the Fisher index to measure productivity.

Table 1: Estimates of productivity growth in Australian broadacre agriculture.

Authors	Period	Annual Input Growth (%)	Annual Output Growth (%)	Annual Productivity Growth (%)
Lawrence & McKay (1980)	1953–1977	1.5	4.4	2.9
Lawrence (1980)	1960–1977			3.1
Paul (1984)	1968–1982	1.5	2.7	1.1
Beck et al. (1985)	1953–1983	1.3	4.0	2.7
Males et al. (1990)	1978–1989			
• All agriculture				2.0
• All Broadacre		1.4	3.6	2.2
• Crops		-1.8	3.7	5.5
• Sheep		1.3	1.5	0.2
Zeitsch & Lawrence (1993)	1983–1994			
• Sheep				≈ 1.0
Mullen & Cox (1995)	1953–1994	0.1	2.6	2.5
Knopke et al. (1995)	1978–1994			
• All broadacre		0.2	2.9	2.7
• Crops		0.4	5.0	4.6
• Sheep		0.5	1.5	1.0
• Beef		0.3	1.9	1.6
• Sheep-Beef		-2.1	0	2.1
Knopke et al. (2000)	1978–1999			
• Grains industry		0.7	3.3	2.6
• Crops		1.3	4.8	3.6
• Sheep		0.6	1.2	0.6
• Beef		0.3	2.4	2.1
• Sheep-Beef		-0.9	0.4	1.4
ABARE (2004)	1989-2002			
• All broadacre				
• Crops				1.8
• Beef				2.1
• Beef - crops				2.4
ABARE (for Vic. DPI) (2006)	1989–2004			
• All broadacre		-0.9	1.3	2.2
• Crops		7.7	10.1	2.4
• Sheep		-5.4	-5.0	0.4
• Beef		-0.3	2.2	2.5
Kokic, Davidson and Rodriguez (2006)	1989 - 2004			
• Grains industry				1.9
• Crops				1.8

Wang's estimate of the Fisher TFP index in Australian broadacre agriculture is shown in Figure 1 and Table 2. The Fisher TFP index rose almost 3.5 times from 100 in year 1953 to 343 in 2002, declined to 261 in 2003, reflecting the drought in that year before reaching 332 in 2004. The index is highly variable, falling in 18 of the 50 years, reflecting seasonal conditions. The average annual rate of growth over the entire period was 2.5 percent[5].

Figure 1: Productivity in Australian Broadacre Agriculture as measured by a Fisher ideal index and the Terms of Trade facing Farmers (1953 – 2004)



Source: Derived from ABARE data

Table 2: Average Growth in Productivity (Fisher Index) for Broadacre Agriculture

period	1953-2004	1953-1968	1969-1984	1985-1994	1995-2002[6]
Productivity growth (%)	2.5	1.9	1.8	2.5	2.7

Source: Wang (2006)

[5] Estimated as the coefficient on a time trend in a regression against the log of TFP and a constant.
[6] The average annual growth rate for 1995-2003 was 0.1 percent

Has the rate of agricultural productivity growth changed?

From Table 2, it can be seen productivity in broadacre agriculture in Australia has not grown at a constant rate. However, periods of atypical seasonal conditions and long investment cycles necessitate cautious interpretation of trends in productivity growth.

Stoeckel and Miller (1982) argued that productivity growth in Australian agriculture increased after 1969 – a 'watershed' year for agriculture. After this, output continued to grow but inputs actually declined. Their study only extended as far as 1980 and inputs have grown since, but at a rate that has rarely exceeded 1% p.a. Parham (2004) using ABS data also observed a surge in agricultural productivity from the late 80s. Mullen (2002) adopted the Stoeckel and Miller (1982) view, that 1969 was a 'watershed' year. Econometric analysis suggests that the growth rate from 1953 to 1968 was 2.0 percent and from 1969 to 2004, 2.5 percent. These estimates have been used in several papers by Mullen and coauthors to estimate the benefits from productivity gains in broadacre agriculture and are applied again below.

Presently there is concern that productivity growth in agriculture may be slowing. Pardey, Alston and Beintema (2006) raised the prospect of a global slowdown in the growth of agricultural productivity with potential implications for food security in some developing countries[7]. Eslake noted that productivity growth for Australia as a whole this decade is lower to date that that experienced in the 90s. Has productivity growth in broadacre agriculture in Australia slowed?

There is some evidence that productivity growth in the grains industry may be drifting down[8] while that for livestock specialists has been increasing[9]. However evidence of a marked decline in the productivity of Australian broadacre agriculture generally is yet to emerge.

Males et al. (1990) reported productivity growth of 5.5% p.a. for specialist crop farmers for the period 1978 to 1989. Since then the two studies by Knopke et al. (1995; 2000) suggested that productivity growth for crop specialists slowed to 4.6% p.a. for the period from 1978–94 and to 3.6% p.a. for the period from 1978–99, while productivity growth in broadacre agriculture as a whole remained unchanged at 2.6% p.a.

A study undertaken by ABARE for the Victorian DPI (ABARE) found that productivity growth in broadacre agriculture had declined to 2.2% p.a.. However, the analysis was conducted over a relatively short period from 1989 to 2004 and drought was a major influence in latter years of this period.

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[7] The tenor of a symposium at the 2006 IAAE Conference titled 'Global Agricultural Productivity Slowdown—Measurement, Trends and Forces' was that growth was likely to fall in some countries but empirical evidence confirming this is yet to be published.

[8] Some ABARE reports are prepared from the perspective of broadacre agriculture while the more recent reports take the perspective of the grains industry and hence it is not always clear that the same classifications are being used over time.

[9] Generally ABARE farm survey data are not used to estimate productivity trends at an enterprise level. Rather from the broadacre survey population, subsets of farms with particular characteristics can be drawn to study productivity performance. Crop, wool and beef specialists for example are those farmers who receive most of their income (usually greater than 75%) from these enterprises.

Most recently, Kokic et al. (2006) using panel data found that for the 1989-2004 period, productivity growth in the grains industry averaged 1.9% and for specialist croppers, averaged 1.8%. The rate of growth for the grains industry increased to 2.6% when adjusted for the poor seasonal conditions over this period.

Productivity growth in the sheep industry, at least as estimated using ABARE survey data, has always been disappointing, at 1% p.a. or less in recent decades. The productivity of beef specialists has been better than that of sheep specialists but less than that of those predominantly involved in crop production. The estimates from Table 1 suggest that productivity in the beef sector has been increasing. Productivity grew at the rate of 1.8% p.a. from 1978 to 2002 but the growth rate was 2.1% p.a. for the 1989 to 2002 period and 2.5 % to 2004 for specialist beef producers.

It is somewhat puzzling that productivity on crop farms has consistently exceeded that on livestock farms and the issue is not explored in any depth in the literature. Some studies suggest that this might arise from a more rapid development of cropping technologies in recent decades (minimum tillage, crop varieties, improvements to fertilisers and pesticides etc) compared to livestock technologies, the longer breeding cycles for livestock, and perhaps the labour intensive nature of some livestock handling operations. As noted later, expenditure on plant research in Australia has grown more rapidly than expenditure on livestock research in recent years. Whether this is a cause of, or a response to, higher rates of productivity growth in the crop sector is unclear.

What is also puzzling is the apparent ambiguity as to whether there are gains in farm productivity from economies of scope. It would seem that there are gains for specialist livestock producers to diversify towards more cropping but the rate of productivity growth of specialist croppers is higher than that of mixed farms.

Hailu and Islam (2004) using a multilateral measure and ABARE farm survey data from 1977 to 1999 found that while the *level* of productivity in agriculture was still higher in NSW (2.07% p.a.) and Victoria (1.45% p.a.) than the other states, the gap has narrowed considerably because WA (3.73% p.a.) and SA (3.19% p.a.) in particular, have enjoyed higher *rates* of productivity growth in recent years, perhaps because of their greater reliance on cropping.

Agricultural productivity relative to other sectors of the Australian economy

The Productivity Commission has been estimating productivity growth in major sectors of the Australian economy such as agriculture (Table 3 adapted from Parham (2004)). These estimates are based on ABS data from the National Accounts using a value added approach to estimating productivity[10].

[10] In the value added approach, the value of intermediate inputs are deducted from the gross value of output and inputs are a correspondingly reduced set – often only labour and capital used in the sector.

Table 3: Productivity growth in sectors of the Australian economy: 1975–99.

	1975–82	1982–85	1985–89	1989–94	1994-99
Agriculture	1.6	1.1	1.4	2.6	4.3
Mining	-1.7	0.5	2.6	2.5	1.2
Manufacturing	2.1	1.8	1.7	1.6	1.3
Electricity, gas & water	2.0	3.2	4.2	3.7	1.8
Construction	1.4	0.4	-0.3	-0.2	0.4
Wholesale trade	-0.7	-0.9	-0.5	1.2	3.2
Retail trade	1.0	0.6	-0.2	0.1	1.0
Accom., cafes & restaurants	-0.9	-1.3	-1.9	-1.6	-0.3
Transport & storage	2.2	1.2	1.0	1.4	1.9
Communication services	6.5	4.9	4.8	4.9	3.7
Finance & insurance	-2.0	-1.0	0.2	0.7	0.8
Comm. Rec. Services	-1.4	-2.2	-2.9	-3.1	-3.3
Market Economy	1.1	0.8	0.4	0.7	1.8
Agriculture/Market economy TFP	1.4	1.4	3.5	3.7	2.4

Source: adapted from Parham 2004

Parham (2004) estimated that productivity growth in the Australian economy during the 1990s (1994–99) was 1.8% p.a., a percentage point higher than in previous periods. This placed Australia in a favourable position relative to other OECD countries. He estimated that the growth in agricultural productivity during the 1990s has been 4.3% p.a., higher than all other sectors and higher than for previous decades. The growth rate in the wholesale trade sector was 3.2% p.a., much improved on previous periods, and 3.7% p.a. in the communications services sector – down on previous periods. Up to 1994, productivity growth in the electricity, gas and water sector and in the communications sector, generally exceeded that in agriculture and so did the growth rate in manufacturing although to a lesser extent.

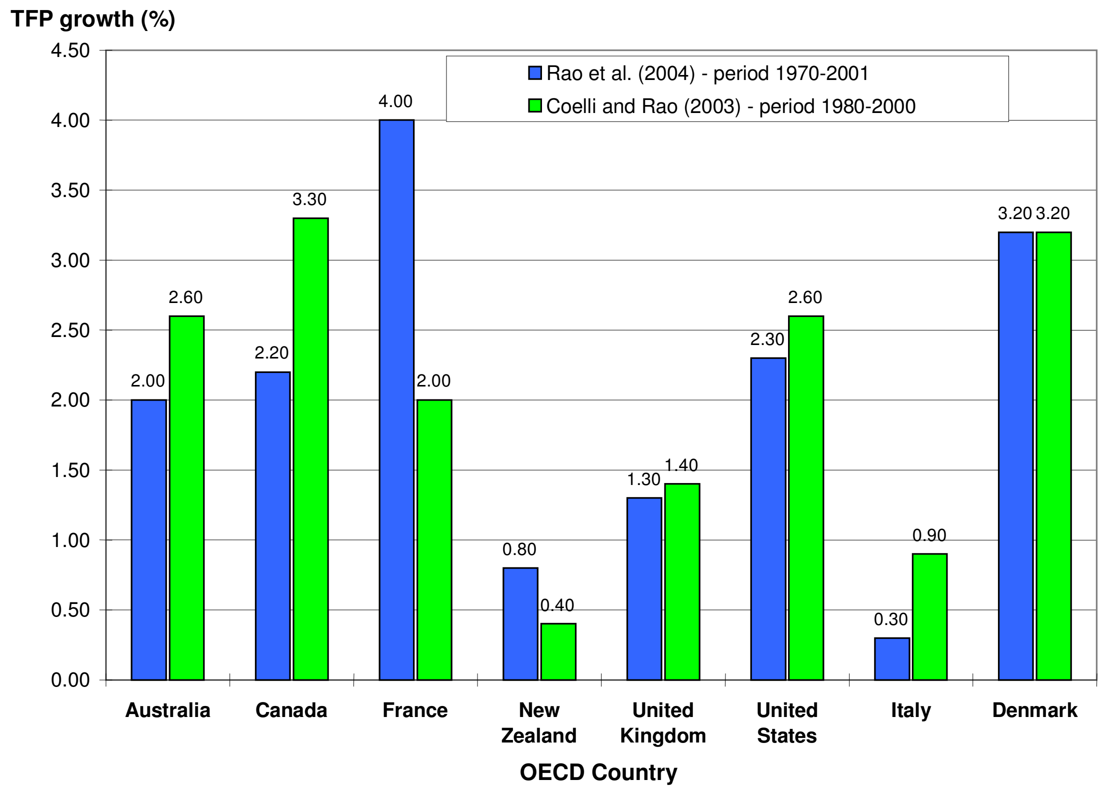
The surge in productivity growth in the 1990s coincided with a surge in productivity growth for the Australian economy generally. Factors thought to contribute to this surge included the greater openness of the economy to trade and investment, the continuing deregulation of markets and institutions, and efficiency gains from the computer, telecommunications and transport sectors. R&D made a significant ongoing contribution to productivity growth both in agriculture and the economy generally. Parham (2004) tentatively speculated that the relative contributions of greater openness, R&D, and the adoption of ICT to an apparent increase of about 1% p.a. in the rate of productivity growth in the 1990s may have been in the order of 0.5, 0.3 and 0.2% p.a.

Australian agricultural productivity relative to other agricultural sectors

International comparisons of productivity are difficult to make because of differences in methods, data, and observation periods and the contribution of productivity differences to international competitiveness is difficult to separate from other factors. I have reported below results from two multi-country studies which include Australia (Rao et al. (2004) and Bernard and Jones (1996). The attraction of such studies is some consistency in methods, data and observation period which may give an indication of Australia’s relative performance. However between studies, this consistency is often lost. There are marked differences in productivity estimates between the two studies used here for example. Furthermore, single country studies such as those for America by Acquaye et al. (2003) and Ball et al. (1999) may give a more accurate analysis because they exploit more fully data sources peculiar to the country of study. International comparisons are reviewed in Mullen and Crean (2007).

With these qualifications in mind, Australia's recent performance compares favourably with other countries. For example, Rao et al. (2004) for the 1980–2000 period found that Australian agriculture achieved a TFP growth rate of 2.6% p.a. – higher than their estimate of 2.0% p.a. for the period 1970–2001 and higher than estimates from earlier studies. This rate of growth is similar to that achieved by the US and well above average for the group of OECD countries (Figure 2).

Figure 2: Agricultural Productivity growth rates – selected OECD countries.



Source: Rao et al. 2004; Coelli & Rao 2003

The lack of international farm survey data comparable to that collected by ABARE appears to be the main reason for the lack of comparative international studies of particular agricultural industries. However, there appears to be some evidence to suggest that Australia's rate of crop productivity growth of 3.6% p.a. compares favourably with other countries which ranged from 1.4–2.8% p.a. Livestock productivity appears to be low relative to the livestock sectors in other countries, although productivity in the Australian beef industry has risen.

Implications for Competitiveness

Most commonly, productivity growth has been compared with the terms of trade as a partial indicator of whether Australian agriculture is becoming more competitive.

The conventional wisdom has been that the terms of trade for Australian agriculture have been declining inexorably. However, while the trend in the terms of trade did decline for about 40 years from 1953 (Figure 1), since the early 1990s, the rate of decline has been much slower, at least for the sector as a whole. The terms of trade declined at the rate of 2.3% p.a. over the whole period 1953–2004, similar to the rates of productivity growth in broadacre agriculture. However, the rate of decline was 2.7% p.a. from 1953–1990, and from 1991 to 2006, it was only 0.9%[11].

The TFP index grew from 100 in 1953 to almost 350 in 2004 (fig 1) while the terms of trade declined from about 320 to 100. From Figure 6 it can be seen that only in recent years has the real value of agricultural output in Australia consistently exceeded $30 billion and perhaps these favourable trends in TFP and the terms of trade have contributed.

An important indicator of the agricultural sector's competitiveness is the rate of its productivity growth relative to that achieved by other sectors of the economy. Shane et al. (1998) argued: 'the assessment of changes in comparative advantage in two countries entails a comparison of the ratio of growth in agriculture to growth in the rest of the economy'.

Agricultural productivity growth in Australia has been up to four times higher than the average productivity growth for the economy as a whole (Table 3, last row). Bernard and Jones (1996) reported that Australia's ratio of productivity growth in agriculture to that in the rest of the economy was 3.6, significantly higher than the 2.17 average reported for the OECD group and only behind two other countries, the US and the United Kingdom (Table 4), even though several countries had higher rates of growth in agricultural productivity. Australia's ability to compete on world markets may have improved over the period.

[11] For the period 1991 – 2004 (used in Figure 1) there was no trend in the terms of trade and this was reported in Mullen and Crean (2006). Since then there has been a large downward revision to the terms of trade index in 2004 and data is now available to 2006.

Table 4: Productivity growth rates – agriculture versus other industries (selected OECD countries): 1970–87.

Country	**Agriculture** Average TFP growth	**Total Industry** Average TFP growth	**Ratio of Agriculture TFP to Non-Agriculture TFP** Ratio
United States	1.50	0.30	5.00
Canada	0.90	0.40	2.25
Japan	-0.20	1.50	-0.13
Germany	4.30	1.30	3.31
France	4.00	1.70	2.35
Italy	2.00	1.00	2.00
United Kingdom	3.60	0.90	4.00
Australia	**1.80**	**0.50**	**3.60**
Netherlands	4.40	1.30	3.38
Belgium	3.70	1.60	2.31
Denmark	4.10	1.40	2.93
Norway	2.10	1.50	1.40
Sweden	2.00	1.20	1.67
Finland	2.20	1.70	1.29
Average	**2.60**	**1.20**	**2.17**

Trends in Expenditure on R&D for Australia

There are two important sources of data on public investment in agricultural R&D in Australia. The first of these is the dataset assembled by Mullen et al. (1996a) on public investment in research and extension in Australia from 1953–94. The second source is that collected in a biannual survey by the ABS which extends back in some form to 1968–69 where total public expenditure on agricultural R&D was estimated as the sum of expenditure on R&D in the plant and animal socioeconomic objective classes (from which expenditure on fisheries and forestry was deducted for the purposes here). The most recently reported ABS survey year was 2002–03

Mullen et al. (1996a) advised that in view of the availability of ABS data, it was no longer sensible to update their series. Instead the two series have been 'spliced' to give a perspective on investment in R&D from 1953 to the present (detailed in Mullen and Crean, 2007 and Wang 2006). Since the ABS census is only conducted every second year, R&D expenditure was linearly interpolated for the intervening years. All expenditure data have been expressed in 2004 dollars using a GDP deflator.

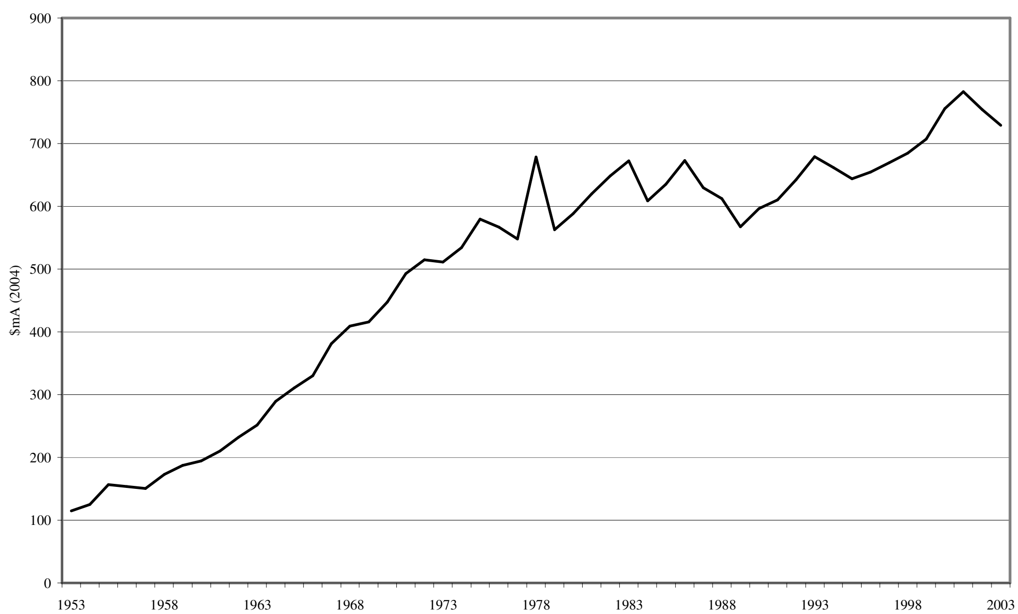
Total public expenditure on agricultural R&D has grown from A$115 million in 1953 to almost A$730 million in 2003 (in 2004 dollars). Figure 3 shows that growth was strong to the mid 1970s. There has been little growth since, although in recent years there is some evidence of renewed growth. As a percentage of total expenditure on

R&D, expenditure on agricultural R&D in 2003 was 8%. It has declined steadily from 20% in 1982. Expenditure on environmental research has never exceeded 10% of total expenditure and was 6.5% in 2003.

In Australia, the public sector has always been the dominant provider of research services to the agricultural sector (Figure 4)[12]. The business sector has generally been responsible for less than 10% of total agricultural R&D although its share in 2003 was 14%. This contrasts sharply with other developed countries where agricultural R&D is roughly shared between public and private sectors (Pardey & Beintema 2001). From ABS data, state organisations, presumably dominated by the state departments of agriculture or their equivalents, have been responsible for about half of all agricultural R&D in Australia, with the Commonwealth responsible for a quarter and universities, about 15%. From the 2003 ABS survey, there was evidence that more research is being undertaken by universities and the business sector and less by state and Federal organisations. The share undertaken by states was down to 44%.

The focus of this paper is on publicly funded agricultural research.

Figure 3: Real public expenditure on agricultural R&D in Australia (in 2004 dollars): 1953-2003.



[12] The data here are based on total expenditure by research providers from all sources. Important sources of funds to public research providers have been the RDCs.

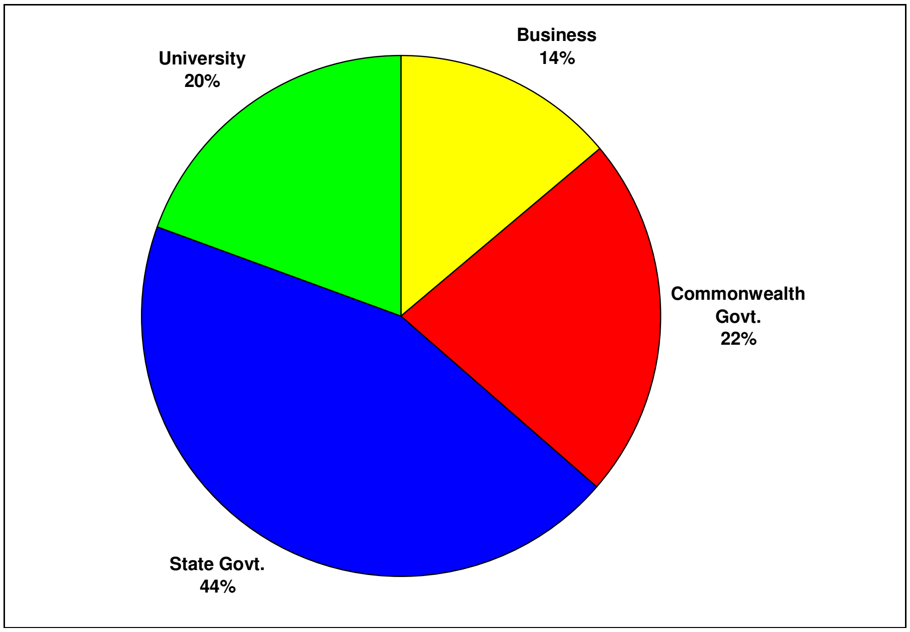


Figure 4: Expenditure shares of agricultural R&D in Australia by providers of research services (2002–03).

Research intensity is a measure of investment in research relative to the size of the agricultural sector. In Figure 5 two measures of public research intensity are presented, one relative to agricultural GVP and one relative to agricultural GDP[13]. The latter measure is the one most frequently used in international comparisons. In research intensity terms, public funding for agricultural research has been drifting down from about 5% p.a. of GDP in the period from 1978–86 to just over 3% p.a. in 2003. Intensity grew strongly in the 1950s and 1960s[14].

For most of the 1990s, expenditure on plant and animal research was similar but by 2003 expenditure on plant research was half as much again as that on animal research. Perhaps this partly reflects the growing importance of the Grains Research and Development Corporation (GRDC) as a source of funds. During the 1980s, the share of the GRDC in total RDC funding was under 20% but by 2001 it had risen to 30% before declining to 27% in 2003–04[15]. The leading states in 2004 for the location of public agricultural R&D in 2003 were Victoria and Queensland (similar amounts), followed by NSW.

[13] Both GDP and GVP were expressed as five year moving averages to remove trends purely related to seasonal conditions.
[14] Fisheries and Forestry have not been included in either R&D expenditure or in GVP and GDP.
[15] RDC levies are generally based on the value of production.

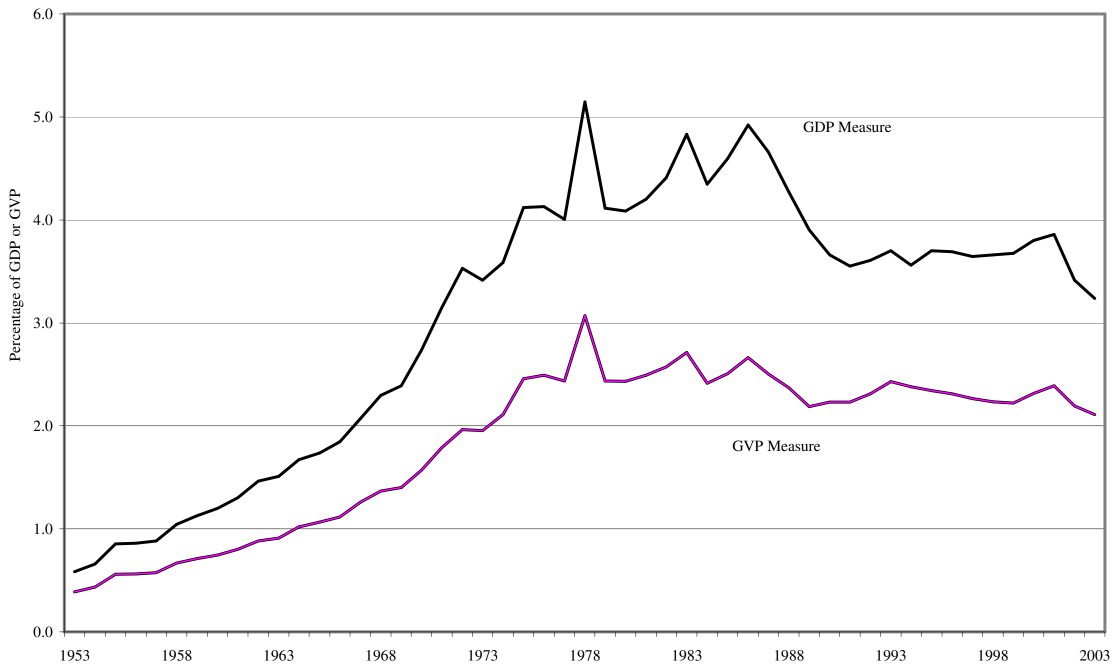


Figure 5: Public agricultural research intensity in Australia (R&D expenditure as proportion of agricultural GDP or GVP).

A feature of the agricultural research sector in Australia has been the prominent role played by the RDCs. In 2003, total expenditure by the RDCs was A$461 million (nominal) which is approaching half the total public expenditure on agricultural R&D, although it probably overstates RDC funding for agricultural production research because some of these funds were used to fund research of a non-production nature, such as research in processing or environmental areas. Recall also that less than half of RDC funds are raised from producers (because of the predominant Federal funding of Land and Water Australia for example). In the 1980s, RDC funding only amounted to about 15% of total public expenditure on agricultural R&D.

A recent international review of agricultural R&D by Pardey, Beintema, Dehmer and Wood (2006) found that public investment in agricultural research in real dollars (2000 international dollars) had only risen from A$15.2 billion in 1981 to about A$23 billion in 2000. Expenditure on agricultural research in 2000 in developing countries (55.7% share of total) exceeded that in developed countries with China, India and Brazil emerging as major investors. Public research intensity in developed countries was 2.4% p.a. and total agricultural research intensity was about 5.2% p.a. Research intensity in less developed countries was often very low such that average public research intensity in developing countries was 0.53% p.a. The world's poorest countries are still dependent on technology spillovers from rich countries both directly and through organisations such as the CGIAR system and Australia's ACIAR.

Econometric Analyses of the Contribution of R&D to Agricultural Productivity

Establishing econometrically a significant relationship between investment in research and productivity growth remains a challenging task. Econometric analyses are often based on a structural model where the product of investment in research is a lagged increase in the stock of technology or knowledge-in-use by producers. The lags over which this process occurs may be up to 35 years or more.

Other explanatory variables include the level of education of farmers, the terms of trade, seasonal conditions and investment in extension, which comprise the set of variables used by Mullen and Cox. Additionally TFP in agriculture is likely to be influenced by 'spillovers' of technology from other countries and by improvements in public infrastructure in the form of communications and transport within Australia. There are real difficulties in assembling suitable proxies for these variables and I have not yet attempted this. A further difficulty in econometric research in this area is the high degree of collinearity between explanatory variables, making precise estimation of all coefficients unlikely.

A common view (Shanks & Zheng 2006) is that econometric techniques used to date are not powerful enough to fully resolve some important issues such as the length and shape of the research lag profile and the separate contributions of domestic and international research and extension to productivity growth. Despite these misgivings, because of consistent findings from a range of peer reviewed analyses across several countries, the conventional wisdom remains that investment in research does lead to productivity growth in agriculture.

Alston et al. (2000) conducted a meta-analysis of 292 studies of the rates of return to agricultural research, about one third of which were published in scientific journals. Their main findings included:

- there was no evidence that returns from research investments were declining
- the returns from research appear higher in developed countries
- estimated rates of return from research were lower for enterprises with longer production cycles.

According to Alston et al. (2000) the median rate of return reported in the Mullen papers was 25%[16]. Mullen was one of four analysts whose median rate of return was 25% or less[17].

The findings of Mullen and co-authors can be summarised as follows:

- In an alternative to the econometric approach, Scobie et al. (1991) synthesised a production function linking expenditure on research with productivity growth in the Australian wool industry. They estimated that the average

[16] Forty three estimates were reported ranging from 2.5–562% with a mean of 87.3.
[17] The other three were Alston et al. (19.1%), Pardey (22.3%) and Scobie (22.6%).

internal rate of return to Australia had been about 9.5% and the internal rate of return to woolgrowers was in the order of 25%[18].

- Mullen and Cox (1995) estimated that the returns to public research in broadacre agriculture in Australia were 15–40% over the 1953-1988 period. The low rate was associated with a 35-year research profile and the high rate with a 16-year research profile.

- Mullen and Strappazzon (1996) using a dataset extended to 1994 estimated that the rate of return to public investment in broadacre research was between 18 and 39% for the 35- and 16-year models. However they also found that there was no strong evidence of a stable long run equilibrium relationship between expenditure on research and productivity. This does not imply that research has no effect on productivity. Rather it suggests that the impact of research may vary through time in response say, to changes in research management or to research opportunities.

- Mullen et al. (1996) attempted to incorporate research in a translog cost model of broadacre agriculture in Australia. While their preferred model did not satisfy all the conditions of a well behaved cost model, they found that research did have a significant impact in reducing costs in broadacre agriculture and that the rate of return to research was as high as 86%.

- Cox et al. (1997) using nonparametric methods estimated the marginal internal rates of returns to research and extension expenditures in the order of 12–20% over the 1953–94 period. They found nonparametric evidence of lagged research and extension impacts on productivity in Australian broadacre agriculture out as far as 30 years.

More recently the Productivity Commission (Shanks & Zheng 2006) undertook a analysis of the relationship between investment in research, particularly by the business sector, and productivity growth in the Australian economy. They estimated that the return to business investment at the level of the entire market economy was 50%. Their preferred estimate of the rate of return to public investment in agriculture was 24%, relatively precisely estimated in a range of from 1–46%[19]. The estimated rate of return in the manufacturing sector was 50% and the returns to the mining, and wholesale and retail sectors were 159% and 438% with very wide confidence intervals.

Wang (2006) attempted to 'replicate' the analysis of Mullen and Cox (1995) using a dataset extended to 2003. His estimates of the rates for return (IRR) to R&D in Australian broadacre agriculture ranged from 11 to 35 percent with some evidence that the research coefficient may have increased. However there was also evidence of structural change in the relationship between TFP and R&D investment because the

[18] These rates of return are low relative to past studies but they accounted for the leakage of research benefits to non-residents of Australia and the excess burden of raising taxes to fund research.
[19] There was a problem of double counting capital and labour in estimating the returns to the other industry sectors. This does not appear to be a problem for the agricultural sector where the control variable was public rather than business investment in research. They estimated that without this seemingly unnecessary adjustment the rate of return to public investment in agriculture was 32%.

Mullen and Cox models did not have strong econometric properties over the extended dataset.

Mullen and Cox and Wang regressed TFP against a knowledge stock variable and a weather index, farmers' terms of trade and farmers' education where all variables were in logs and the models were linear. The knowledge stock variables were assembled as weighted sums of past investments in research and extension over 16 and 35 year lag lengths using a procedure more fully described in the original Mullen and Cox paper. Some of the estimated models can be found in Table 5, as well as Mullen and Cox's original models.

Initially, I estimated the linear 16 and 35 year lag models used by Mullen and Cox and Wang over the 1953-2003 period[20]. Neither model estimated using OLS performed well. For the 16 year model, the research coefficient was not significant and both the Durbin-Watson and RESET statistics suggested evidence of misspecification. For the 35 year model all coefficients were significant but the specification diagnostics were similar to the 16 year model. Plots of the CUSUM statistic[21] show a marked departure by the statistic from zero from the early 80s for both models and it crossed the upper bound in the early 90s (a bit later for the 35 year model), further evidence of misspecification or structural change over this long period.

Various techniques were used without success to address these specification problems including the addition of a time trend, correction for serial correlation and the use of dummy variables both as an intercept and interactively with research.

The RESET test provides some guidance as to whether quadratic or interaction terms are missing from the model. Adding a quadratic knowledge stock term led to a marked improvement in the properties of both models[22] as can be seen in Table 5. Models including a variable allowing interaction between the knowledge stock and farmers' education also performed well. There was some evidence from non-nested testing (Doran, 1993) that the introduction of a quadratic term added to the explanatory powers of the models more than the interaction term[23] and on this basis attention focussed on the 16 and 35 year models with quadratic knowledge stock terms. Adding a trend term to either of these models to isolate the contribution of the omitted variables noted above proved unsatisfactory.

The econometric properties of both the 16 and 35 year quadratic models are strong. All coefficients are precisely estimated and have the expected sign (expectations about the signs on the knowledge stock variables are discussed further below). For the 35 year model, the D-W and RESET statistics and the plot of the CUSUM values all suggest few problems with the specification of this model. These same specification statistics for the 16 year model suggested that specification might remain a problem.

[20] 35 year lag knowledge stocks from 1953 were constructed by backcasting R&D expenditure to 1918 based on a regression of the log of R&D against a time trend from 1953 to 1972.

[21] The sum of normalised recursive residuals estimated by adding observations in a forward direction (Brown, Durbin and Evans, 1975).

[22] As suggested by Garry Griffith.

[23] The t-statistic for the introduced variable associated with the interaction term was larger for both the 16 and 35 year models.

Non-nested testing of these two models provided clear evidence in favour of the 35 year model and supported concerns about the specification of the 16 year model[24].

I have not yet undertaken a comprehensive analysis of the time series properties of the extended dataset. However some preliminary testing for unit roots suggests that the explanatory variables are not integrated of the same order, as Mullen and Strappazzon (1996) found. Hence there is a strong likelihood that there is not a cointegrating or stable long run relationship between productivity growth and the knowledge stock over the observation period. As Strappazzon and Mullen pointed out this may imply that the impact of research may vary through time

The equations below represent the total and marginal impact of the knowledge stock, KS, on TFP where the other explanatory variables, evaluated at their means, are subsumed in the constant term. The implication of a quadratic knowledge stock is that the impact on TFP of a change in the knowledge stock, through research investment say, is not a constant as in a linear model but depends on the level of research investment. Our expectation is that as investment in research continues to increase, holding other explanatory variables constant, eventually the changes in TFP will become smaller. For this to happen, typically the coefficient on the linear term is positive and that on the quadratic term is negative. As can be seen from Table 5, the signs are reversed here, suggesting that over the range of research investment experienced in the 1953- 2003 period, the marginal impact of increments to research investment is still increasing.

$$\ln TFP = c + \alpha \ln KS + \beta (\ln KS)^2$$
$$\partial \ln TFP / \partial \ln KS = \alpha + 2\beta \ln KS$$

At its average level for 1953-2003, the marginal impact of a change in the knowledge stock (in logs) was 0.18 and 0.22 for the 16 and 35 year models. Using the same procedure as Mullen and Cox (1995), these marginal impacts translate into IRRs of 23 and 15 percent for the 16 and 35 year models[25]. These IRRs are for a once only, unit ($1000) increase in the knowledge stock variable evaluated at the average level of TFP, research investment and output price and scaled up from farm level by the ratio of the value of broadacre agriculture in Australia to the value of output from the farm survey data.

These results were obtained from econometric models which maintain strong assumptions about how investments in research and extension translate into changes in TFP and from which some variables expected to influence TFP have been omitted . Nor is there much information available about the opportunity cost of alternative uses of public funds. Hence some caution in interpreting the results is warranted. Nevertheless they indicate that investment in agricultural research, at least over the range in investment levels experienced from 1953 to 2003, has earned good rates of return. There is no evidence that the returns from public research are declining, a

[24] The t-statistic on the introduced variable in the 16 year model associated with the 35 year model was over 3 for both the J – and JA – tests and the corresponding variable in the 35 year model was not significantly different from zero.

[25] Again using the same procedure as Mullen and Cox, the implied IRRs for extension are 7 and 13 percent per annum for the 16 and 35 year models.

finding consistent with Alston et al. (2000). In fact this finding, that the marginal impact of research is increasing, lends some support to a view recurring in the literature that there is underinvestment in agricultural research.

In response to the possibility of structural change, the models were estimated from 1969, Stoeckel and Miller's 'watershed' year. From Table 5, it can be seen that the quadratic version of the 16 and 35 year models still had superior properties to the linear models. There was little change in the 35 year model. However the IRR from

Table 5: Econometric Results and IRRs from the 35 and 16 year lag models

	35 year models									
Period	**1953-1988 (Mullen & Cox)**		**1953-2003**		**1953-2003**		**1969-2003**		**1969-2003**	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Knowledge stock:										
Linear	0.16	3.44	0.14	2.58	-1.9	-5.53	-3.05	-1.68	0.25	3.93
quadratic					0.08	5.96	0.13	1.82		
Weather	0.04	5.19	0.3	5.48	0.24	5.67	0.3	3.76	0.31	3.84
Education	2.22	3.05	2.35	2.72	3.7	5.36	3.33	2.87	4.42	4.31
Terms of Trade	-0.27	-2.52	-0.49	-3.58	-0.29	-2.71	-0.27	-2.09	-0.30	-2.25
R^2	0.95		0.95		0.97		0.94		0.93	
D-W	2.02		1.13		1.96		1.92		1.74	
Reset	na		38.1		3.72		1.93		5.24	
IRR%	17		10		15		16		13	

	16 year models									
Period	**1968-1988 (Mullen & Cox)**		**1953-2003**		**1953-2003**		**1969-2003**		**1969-2003**	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Knowledge stock:										
Linear	0.22	2.22	0.001	0.25	-4.39	-5.45	-13.8	-3.11	0.22	2.49
quadratic					0.17	5.46	0.52	3.16		
Weather	0.26	3.22	0.3	5.01	0.24	5.06	0.3	3.75	0.3	3.24
Education	2.11	0.98	2.94	3.24	6.08	6.65	6.89	6.71	6.01	5.34
Terms of Trade	-0.27	-1.92	-0.8	-7.24	-0.43	-3.88	-0.3	-2.30	-0.49	-3.72
R^2	0.83		0.95		0.97		0.94		0.92	
D-W	1.73		1.23		1.69		1.86		1.53	
Reset	na		32.4		11.2		5.72		10.4	
IRR%	30		0		23		39		21	

the 16 year model, 39 percent, is much larger than the IRR from the 35 year model, 16 percent. This difference reflects the change in marginal impacts. The marginal impact of a change in knowledge stock for the 35 year model increased from 0.22 to 0.33 for the period since 1969 whereas the marginal impact for the 16 year model increased from 0.18 to 0.56, reversing their relative magnitudes. Non-nested testing was unable to discriminate between the 16 and 35 year alternatives, both models displaying little evidence of misspecification.

Because of its assumption that the impacts of research are experienced over 16 years rather than 35 years, the 16 year model is gives greater weight to the more recent changes in research investment. In particular, the slowdown in research investment over recent decades is fully reflected in this model. Perhaps this explains the higher marginal impact and IRR associated with this model estimated since 1969. Perhaps the focus of research institutions such as the RDCs on applied research and practice change by farmers is shortening the lag profile. Perhaps there have been efficiency gains by the sharing of human and physical capital between research institutions. If however, research lags do extend over 35 years, then perhaps the consequences of this stagnation in research funding are yet to be fully reflected in productivity trends and IRRs.

Benefit Cost Analysis of Some Productivity Decomposition Scenarios

In this section, some scenarios are developed about sources of productivity growth in agriculture and estimates are made of the rates of return from domestic R&D that these scenarios imply using standard benefit-cost techniques. These estimated rates of return are not statistically based 'results' but rather the rates of return implied by a set of plausible assumptions which are subject to sensitivity analysis. This decomposition approach has been used in other studies (Mullen, 2002, Mullen and Crean, 2007, Mullen, Scobie and Crean, 2006, Alston, 1994) and hence a detailed explanation is not presented here.

The long-term trend in productivity for broadacre agriculture in Australia is in the vicinity of 2.5% p.a.. Acknowledging its speculative nature, some assessment can be made of how this underlying rate of productivity growth may be decomposed. Perhaps up to 0.5% p.a. can be attributed to factors such as public infrastructure and the education levels of farms. Perhaps the remaining 2% can be attributed to technical change, arising from public and private investments in research and extension where a significant component of both activities is related to the adaptation of foreign knowledge spillins. This scenario attributes none of the productivity growth to scale economies or gains in technical efficiency.

Alston (2002) has argued that, certainly between states, but even between nations, foreign research may be as important as domestic research. I have assumed that for Australian broadacre agriculture, domestic R&D activities may be responsible for productivity growth in the order of 1.2% p.a. and foreign spillins for 0.8% p.a. – a 60:40 split.

Based on these assumptions, Figure 6 decomposes the value of all productivity gains in Australian agriculture since 1953 into those attributable to domestic R&D and those attributable to other sources of productivity including foreign knowledge and domestic sources such as public infrastructure and farmers' education. It has been assumed that prior to 1969, productivity grew at 2.0% (80% of its current rate).

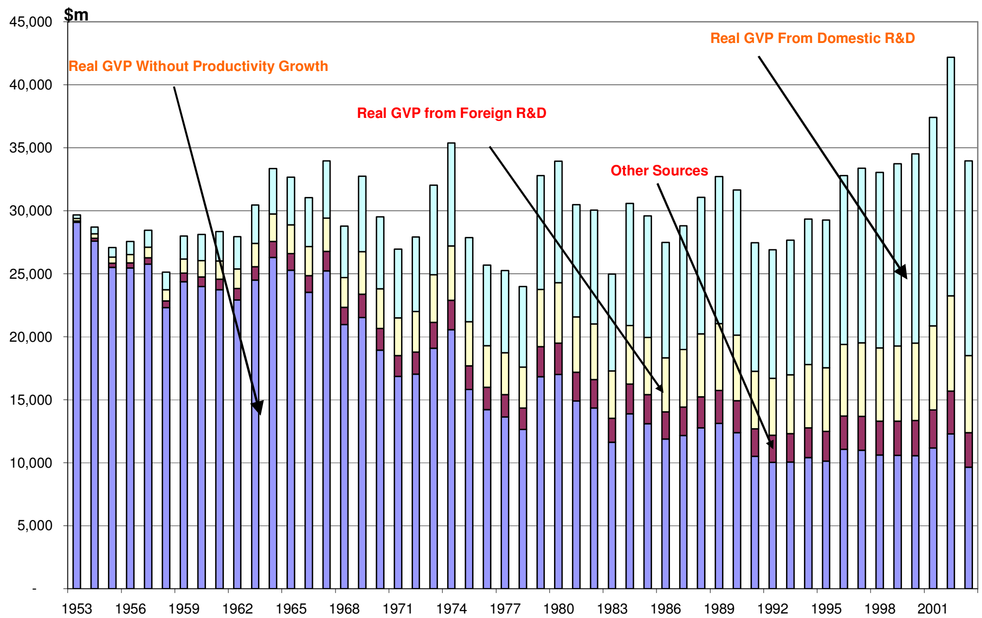


Figure 6: Sources of productivity growth in Australian agriculture (in 2004 dollars): 1953–2003.

Holding technology at its 1953 state, less than 30% of the value of output in 2004 can be accounted for by conventional inputs (represented by the blue or bottom bars). Seventy percent of the value of farm output arises from the various sources of productivity growth such as improvements in infrastructure and communications, higher quality inputs, and new technologies from research and extension activities. Almost half the value of output in 2003 can be attributed to new technology generated by domestic research since 1953 (represented by the aqua or top bars). At a real rate of interest of 4%, the compound value of the stream of benefits from domestic research (1.2%) from 1953–2003 is A$878 billion (in 2004 dollars).

As pointed out in Mullen (2002) the benefits from new technology in Australian agriculture are shared with producers, processors and consumers who are non-residents of Australia. On the basis of previous research into the distribution of the benefits from research, he estimated that perhaps Australian producers, processors and consumers retain 80% of benefits or about A$700 billion in this case.

The data series on public research investment presented above was backcast to 1918 to allow the estimation of models with research lags of 35 years. The compound value of public investment in research between 1953 and 2003 was A$64.5 billion and the estimated total back to 1918 was A$77.4 billion (in 2004 dollars). Mullen (2002) estimated that private R&D in Australia and public extension expenditure might add a further 40% to domestic R&D investment, giving a total of A$90.3 billion since 1953 and A$108 billion since 1918 (in 2004 dollars).

Table 6: Rates of return to research in Australian agriculture.

Scenario:	Benefit-Cost Ratio	IRR
Productivity growth @ 2.0%:		
(a) Public research only		
R&D from 1918-2003	17.0	17%
R&D from 1953-2003	20.5	
(b) Public + private research + extension		
R&D from 1918-2003	12.2	16%
R&D from 1953-2003	14.6	
(c) [(b) + Gains to Australians only (80%)]		
R&D from 1918-2003	9.7	15%
R&D from 1953-2003	11.7	
Productivity growth @ 1.2%:		
(a) Public research only		
R&D from 1918-2003	11.3	16%
R&D from 1953-2003	13.6	
(b) Public + private research + extension		
R&D from 1918-2003	8.1	15%
R&D from 1953-2003	9.7	
(c) [(b) + Gains to Australians only (80%)]		
R&D from 1918-2003	6.5	14%
R&D from 1953-2003	7.8	

Two scenarios for investment analysis relate Australian R&D investment first, to productivity growth at the rate of 2.0% p.a. and second, to productivity growth at the rate of 1.2% p.a. These scenarios ‘bracket’ the potential benefits from domestic research. Under the first scenario, domestic research generates productivity gains of at least 1.2% but some productivity gains, 0.8%, are picked up from foreign sources without any domestic mediation. It is more likely the case that some domestic research is required to capture the benefits from foreign spillovers. Hence under the second scenario, domestic research is required to capture any of these foreign benefits, and domestic R&D can lay claim to the whole 2.0% gain.

Note that for these benefit cost scenarios, only benefits between 1953 and 2003 were recognised, a conservative approach particularly with respect to the flow of future benefits. Costs between 1918 and 2003 were recognised to allow the estimation of IRRs. Results are sensitive to this assumption.

Under the most optimistic scenario where all productivity gains at the rate of 2.0% are attributed to domestic research investments made since 1918, the internal rate of return (IRR) is 17% and the benefit-cost ratio (discount rate of 4%) is 17.0:1 (Table 6). If it is assumed that productivity gains from domestic public and private research and extension result in productivity gains of 1.2% then the IRR is 15% and the benefit-cost ratio is 8.1:1.

Table 6 also reports IRRs and benefit-cost ratios for scenarios in which the leakage of benefits to non-residents of Australia is recognised and which are a little lower.

All estimated IRRs are within the range suggested by Mullen and Cox (1995), although at the lower end of this range.

Conclusions

While some evidence indicates that productivity growth in the cropping sector has declined in the past decade, for Australian broadacre agriculture as a whole, productivity growth has remained at around 2.5 percent per year. It has been high relative to other sectors of the Australian economy and relative to the agricultural sectors in other OECD countries. In particular, the ratio of productivity growth in Australian agriculture to productivity growth in the Australian economy as a whole has been high relative to other countries. Over the past decade, the terms of trade facing Australian farmers has declined at a much slower rate. Hence it is likely that productivity growth has improved the competitive position of Australian agriculture. Despite a series of poor seasons, the real value of output from Australian agriculture has remained consistently above $30 billion for the first time since the early 1960s.

While productivity growth has remained high, public investment in agricultural research in Australia has been static ($700m in 2004 $s) for two decades and has declined in research intensity terms. Meanwhile the research sector has continued to evolve both in terms of where investments are made and how they are managed. The ABS statistics reveal a shift in research resources to plant industries from animal industries which may underpin average broadacre productivity growth given the observed higher rates of productivity growth in the cropping industries. The increasing importance of funding through RDCs and CRCs may well mean that a greater proportion of research investment is of an applied nature, boosting productivity growth in the short run but perhaps at the expense of growth in the longer term.

The pursuit of environmental outcomes through agricultural research is a more dominant influence in the management of public research than previously. While investment in research in ABS Socio-Economic Objective Classification categories related to agriculture has grown little, it is likely that investments in research by traditional agricultural research agencies, now classified as having environmental objectives, has grown[26]. Within agricultural research institutions, much of this environmental research is focused on developing technologies to ameliorate or accommodate degradation in a manner profitable to farmers. Hence, some investment in environmental research is likely to be underpinning continued productivity growth in agriculture.

The joint nature of agricultural and environmental outcomes and the inadequate accounting for environmental outcomes is a source of bias in the measurement of productivity, research investment and returns to research, particularly from society's perspective. A common view is that traditional measures overstate productivity growth because they ignore resource degradation. The focus on improved environmental outcomes from agricultural technologies, still unmeasured, means that this bias is at least smaller and in some agricultural systems may be negative.

The share of research conducted in the public sector funded by RDCs now approaches fifty percent and the growth of the CRC system has fostered greater cooperation and sharing of both human and physical capital by public research institutions not just

[26] Published ABS data on environmental research do not identify where the research is undertaken.

though CRC partnerships. The role of the public sector in funding agricultural research remans under scrutiny.

Given the long lags noted above, the impacts of neither the decline in investment nor the offsetting changes in the research portfolio and its management are likely to be exhausted yet. Hence, even though productivity growth has remained healthy, concern about current rates of investment in research is understandable.

In this paper, both econometric and productivity decomposition techniques were applied to assess the likely rates of return from public investment in research in broadacre agriculture. The least that can be said is that the returns on investment are likely to have remained within the 15- 40 percent per annum range estimated by Mullen and Cox (1995). Again the lower returns are associated with the 35 year lag model and the higher returns with a 16 year lag model estimated for the period since 1969. The substantive change from Mullen and Cox's work was the finding that for the extended dataset, a linear-in-logs specification was no longer adequate in explaining the relationship between research and TFP but that introducing a quadratic term associated with the knowledge stock variable restored good econometric properties.

More strongly, the results presented here suggest no evidence of a decline in the returns from research. In fact the marginal impact of research, now related to the level of research investment (through the quadratic term), increases with research over the range of investment levels experienced from 1953 to 2003, a finding which lends support to the view that there is underinvestment in agricultural research. As there is no evidence that the returns from investment in agricultural research are falling, every effort should be made to preserve the current rate of investment, irrespective of how the ongoing debate about the extent of public funding is resolved.

These results were obtained from econometric models which maintain strong assumptions about how investments in research and extension translate into changes in TFP and from which some variables expected to influence TFP have been omitted. Nor is there much information available about the opportunity cost of alternative uses of public funds. Hence some caution in interpreting the results is warranted.

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