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Productivity growth and the returns from public investment in R&D in Australian broadacre agriculture

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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 to 40 per cent 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.

Key words: productivity, research and development, research evaluation.

1. 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 per cent in 2000 (Pardey *et al.* 2006a). Likely as a consequence, there has been continuing interest in Australian policy regarding 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 accelerated in recent decades. Notable Australian institutional changes include the Research and Development Corporation (RDC) and Cooperative Research Centre (CRC) systems. These new institutions address different aspects of problems for research management arising from the non-rivalry and non-excludability characteristics of information often generated by research.

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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. 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 estimate empirically with precision.

Much of the previous econometric research in Australia was conducted in the early 1990s by Mullen and various coauthors. They estimated that the returns from public investment in agricultural research between 1953 and 1994 were in the order of 15–40 per cent. Productivity had been growing at about 2.5 per cent per annum and public investment in R&D had stabilised after a period of strong growth in the 1950s to 1970s. 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 co-integrating 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 renewed interest in the relationship between R&D and productivity growth. In an international context, Pardey *et al.* (2006b) noted 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.

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.

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, using a longer dataset than used in previous Australian analyses.

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.

2. Trends in productivity in Australian broadacre agriculture

Mullen and coauthors in their analysis of Total Factor Productivity (TFP) used a dataset derived from the Australian Bureau of Agricultural and Resource Economics’ (ABARE) broadacre agriculture survey extending from 1953 to

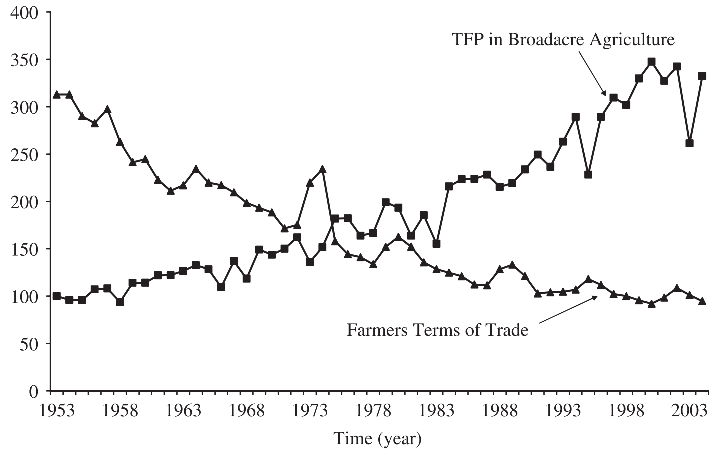

Figure 1 Productivity in Australian broadacre agriculture as measured by a Fisher ideal TFP index and the terms of trade facing farmers (1953–2004). Source: derived from ABARE data.

Table 1 Average growth in productivity (Fisher TFP index) for broadacre agriculture

	1953–2004	1953–1968	1969–1984	1985–1994	1995–2002[1]
Annual productivity growth (%)	2.5	1.9	1.8	2.5	2.7

Source: Wang (2006).

1988 and then to 1994 (see Mullen and Cox (1996) for more details). Wang (2006) 'spliced' an ABARE dataset for the years 1980–2003 to the original Mullen and Cox dataset. Because of the time series nature of the data, 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).

Using Wang's series, the Fisher TFP index for Australian broadacre agriculture rose almost 3.5 times from 100 in 1953, to 343 in 2002. It then declined to 261 in 2003, reflecting the drought in that year, before reaching 332 in 2004 (Figure 1 and Table 1). 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 per cent (estimated as the coefficient on a time trend in a regression against the log of TFP and a constant).

2.1 Has the rate of agricultural productivity growth changed?

Productivity in broadacre agriculture in Australia has not grown at a constant rate (see Table 1). Periods of atypical seasonal conditions and long investment cycles necessitate cautious interpretation of trends in productivity growth.

[1] The average annual growth rate for 1995–2003 was 0.1 per cent.

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 per cent per annum. Econometric analysis suggests that the annual growth rate from 1953 to 1968 was 2.0 per cent and from 1969 to 2004, 2.5 per cent. 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.

A current concern is that productivity growth in agriculture may be slowing. Pardey *et al.* (2006b) raised this prospect of a global slowdown in the growth of agricultural productivity with potential implications for food security in some developing countries.[2] Recent estimates from the Productivity Commission (Table 2) suggest productivity growth for both the Australian economy and the agricultural sector might have slowed since 2000. Has productivity growth in broadacre agriculture in Australia slowed?

Past studies of productivity growth in Australian agriculture were reviewed in Mullen and Crean (2007). Some of these studies are summarised in Table 3 where the observation period is in calendar year form but refers to the financial year ending in June that year (e.g. 2002 refers to the 2001/02 financial year). They are based on ABARE farm survey time series data. Comparisons of productivity growth are difficult to make because of differences in methods, data and observation periods. There is some consistency in approach in the studies reported in Table 3. Studies starting in the same year generally use the same dataset extended over a longer period. However, trends should be interpreted cautiously partly because they are influenced by seasonal conditions and partly because these TFP measures are non-parametric and hence observed differences may not be statistically significant.

Referring to Table 3, Males *et al.* (1990) reported productivity growth of 5.5 per cent per annum for specialist crop farmers for the period 1978–1989. Since then the two studies by Knopke *et al.* (1995, 2000) suggested that productivity growth for crop specialists slowed to 4.6 per cent per annum for the period 1978–1994 and to 3.6 per cent per annum for the period 1978–1999, while productivity growth in broadacre agriculture as a whole remained unchanged at 2.6 per cent per annum.

A study undertaken by ABARE for the Victorian DPI (ABARE 2006) found that productivity growth in broadacre agriculture had declined to 2.2 per cent per annum. 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.

[2] 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.

Table 2 Annual productivity growth (%) in sectors of the Australian economy: 1975–2005

	1975–1982	1982–1985	1985–1989	1989–1994	1994–1999	2000–2005
Agriculture	1.6	1.1	1.4	2.6	4.3	2.7
Mining	–1.7	0.5	2.6	2.5	1.2	–2.8
Manufacturing	2.1	1.8	1.7	1.6	1.3	1.3
Electricity, gas and water	2.0	3.2	4.2	3.7	1.8	–2.7
Construction	1.4	0.4	–0.3	–0.2	0.4	2.2
Wholesale trade	–0.7	–0.9	–0.5	1.2	3.2	1.5
Retail trade	1.0	0.6	–0.2	0.1	1.0	1.0
Accommodation, cafes and restaurants	–0.9	–1.3	–1.9	–1.6	–0.3	1.6
Transport and storage	2.2	1.2	1.0	1.4	1.9	2.1
Communication services	6.5	4.9	4.8	4.9	3.7	1.1
Finance and insurance	–2.0	–1.0	0.2	0.7	0.8	0.2
Comm. Rec. Services	–1.4	–2.2	–2.9	–3.1	–3.3	0.9
Market economy	1.1	0.8	0.4	0.7	1.8	0.9
Agriculture/market economy TFP	1.4	1.4	3.5	3.7	2.4	3.0

Source: adapted from Parham (2004) and the productivity commission website (http://www.pc.gov.au/commission/work/productivity/index.html).

Table 3 Estimates of productivity growth in Australian broadacre agriculture

Authors	Period	Annual input growth (%)	Annual output growth (%)	Annual productivity growth (%)
Lawrence and 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 and Lawrence (1996)	1983–1994	–	–	–
Sheep		–	–	≈ 1.0
Mullen and 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	–
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 *et al.* (2006)	1989–2004	–	–	–
Grains industry		–	–	1.9
Crops		–	–	1.8

Most recently, Kokic *et al.* (2006) using panel data found that from 1989 to 2004, annual productivity growth in the grains industry averaged 1.9 per cent and for specialist croppers, averaged 1.8 per cent. Annual growth for the grains industry increased to 2.6 per cent 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 per cent per annum 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 3 suggest that productivity in the beef sector may have been increasing. Productivity grew at the rate of 1.8 per cent per annum from 1978 to 2002 but the growth rate was 2.1 per cent per annum from 1989 to 2002, and 2.5 per cent per annum to 2004 for specialist beef producers.

Hence, although there is some evidence that productivity growth in the grains industry may be drifting down, while that for livestock specialists has been increasing,[3] evidence of a marked decline in the productivity of Australian broadacre agriculture generally is yet to emerge.

2.2 Agricultural productivity relative to other sectors of the Australian economy

The Productivity Commission (PC) has been estimating productivity growth in major sectors of the Australian economy such as agriculture (Table 2 adapted from Parham (2004) and from the PC website). These estimates are based on Australian Bureau of Statistics (ABS) data from the National Accounts for the sector using a value added approach to estimating productivity.[4] Note that this is a very different dataset from the ABARE broadacre farm survey data. The ABS estimates of productivity growth in agriculture fluctuate in a much broader range than do the ABARE estimates.

Parham (2004) estimated that the annual growth in agricultural productivity during the 1990s was 4.3 per cent, higher than for all other sectors. The surge in agricultural productivity growth in the 1990s coincided with a surge in productivity growth for the Australian economy generally. He estimated that annual productivity growth in the Australian economy during the 1990s (1994–1999) was 1.8 per cent, a percentage point higher than in previous periods. This placed Australia in a favourable position relative to other OECD countries. 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.

Factors thought to contribute to the surge in productivity 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

[3] 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 per cent) from these enterprises.

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

contributions of greater openness, R&D, and the adoption of ICT to an apparent increase of about 1 per cent per annum between 1989 and 1994, and 1994–1999 in the rate of productivity growth for Australia (market economy) may have been in the order of 0.5, 0.3 and 0.2, respectively, per cent per annum.

The most recent estimates from the PC for 2000–05 show a sharp drop in productivity for the economy as a whole and for the agricultural sector. However, agriculture fared better than other sectors, despite a series of droughts, and the ratio of agriculture's productivity growth to that in the rest of the economy rose to 3.0.

2.3 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. Further, the contribution of productivity differences to international competitiveness is difficult to separate from other factors. Results from two multicountry studies which include Australia (Bernard and Jones 1996; Rao *et al*. 2004) are reported below. The attraction of such studies is their internal consistency in methods, data and observation periods 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, Coelli and Rao (2003) for the period 1980–2000 found that Australian agriculture achieved a TFP growth rate of 2.6 per cent per annum – higher than the Rao *et al*. (2004) estimate of 2.0 per cent per annum for the period 1970–2001 and higher than estimates from earlier studies. This rate of growth is similar to that achieved by the USA and well above average for the group of OECD countries (Figure 2).

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 per cent per annum compares favourably with other countries which ranged from 1.4 to 2.8 per cent per annum. Livestock productivity appears to be low relative to the livestock sectors in other countries, although productivity in the Australian beef industry has risen.

2.4 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

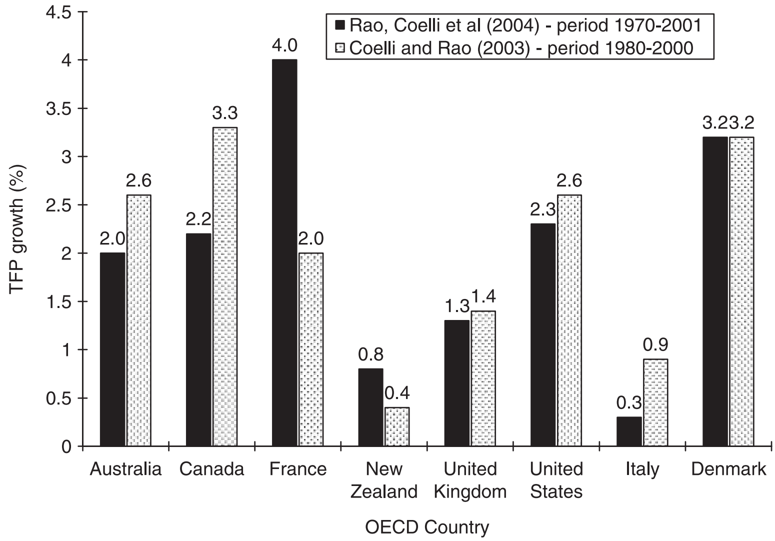

Figure 2 Agricultural productivity growth rates – selected OECD countries.
Source: Rao *et al.* (2004) and Coelli and Rao (2003).

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 TFP index grew from 100 in 1953 to almost 350 in 2004 while the terms of trade declined from about 320 to 100. The terms of trade declined at the rate of 2.3 per cent per annum over the period 1953–2004, similar to the rates of productivity growth in broadacre agriculture. However, the rate of decline was 2.7 per cent per annum from 1953 to 1990, and from 1991 to 2006, it was only 0.9 per cent per annum.[5]

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, p. 8) 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 2, 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

[5] From 1991 to 2004 (used in Figure 1) there was no trend in the terms of trade and this was reported in Mullen *et al.* (2006). Since then there has been a large downward revision to the terms of trade index in 2004 and data are now available to 2006 and have been used here.

Table 4 Annual productivity growth rates: agriculture vs other industries in selected OECD countries: 1970–1987

Country	Agriculture average TFP growth (%)	Total industry average TFP growth (%)	Ratio of agriculture TFP to non-agriculture TFP ratio
US	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
UK	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

Source: Bernard and Jones (1996).

and behind only two other countries, the US and the UK (Table 4), even though several countries had higher rates of growth in agricultural productivity.

Martin and Mitra (2000) similarly found evidence that productivity growth had been higher in agriculture than in manufacturing, for a larger sample of developed and developing countries over the period 1967–1992. They found 'strong evidence of convergence in levels and growth rates of TFP in agriculture, suggesting relatively rapid international dissemination of innovations (p. 417)'. With respect to Australia, they estimated that TFP in agriculture had been growing at the rate of 2.58 per cent per annum whereas for manufacturing the rate of growth was 2.01 per cent per annum, giving a ratio of 1.28, somewhat lower than that suggested by Bernard and Jones, and Parham, and perhaps explained by the focus of Martin and Mitra on TFP in manufacturing rather than in the economy as a whole.

Strong growth in agricultural productivity relative to the economy as a whole and a slowing in the decline in the terms of trade facing farmers may mean Australia's ability to compete on world markets may have improved over the last decade.

3. Trends in expenditure on R&D for Australia

In Australia, the public sector has always been the dominant provider of research services to the agricultural sector and remains so (Figure 3). The private sector generally has been responsible for less than 10 per cent of total agricultural R&D although its share in 2003 was 14 per cent. This contrasts sharply with other developed countries where agricultural R&D is shared

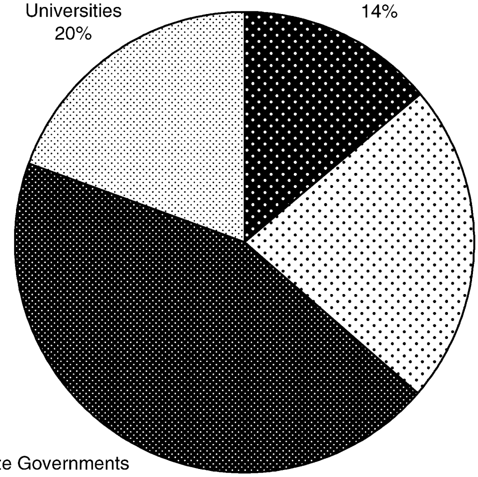

Figure 3 Expenditure shares of agricultural R&D in Australia by providers of research services (2002–2003).

approximately equally between public and private sectors (Pardey *et al.* 2006a). ABS data (various) suggest state organisations, presumably dominated by the state departments of agriculture or their equivalents, have been responsible for funding about half of all agricultural R&D in Australia, with the Commonwealth responsible for a quarter and universities, about 15 per cent. However, the 2003 ABS survey provided evidence that more research is being undertaken by universities and the business sector, and less by state and Federal organisations than was previously the case. The share undertaken by states was down to 44 per cent. The data used here are based on total expenditure by research providers from all sources. Important sources of funds to public research providers have been the RDCs.

The focus of this paper is on publicly funded agricultural research because of its dominant role.

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.* (1996b) on public investment in research and extension in Australia from 1953 to 1994. The second source is that collected in a biannual survey by the ABS which extends back in some form to 1968–1969 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 2002–2003.

Mullen *et al.* (1996b) 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)).

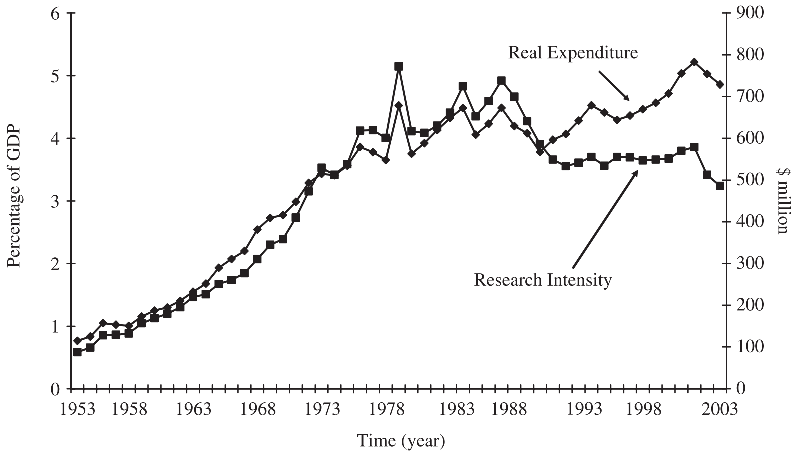

Figure 4 Real public expenditure and research intensity on agricultural R&D in Australia (in 2004 dollars): 1953–2003. Source: derived from public financial statements of public research institutions and the ABS.

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 gross domestic product (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 4 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 per cent. It has declined steadily from 20 per cent in 1982. Expenditure on environmental research has never exceeded 10 per cent of total expenditure and was 6.5 per cent in 2003.

Research intensity (Figure 4) is a measure of investment in research relative to the size of the agricultural sector normally measured in terms of GDP. In research intensity terms, public funding for agricultural research has been drifting down from about 5 per cent per annum of GDP in the period 1978–1986 to just over 3 per cent per annum in 2003. Intensity grew strongly in the 1950s and 1960s.[6]

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 per cent but by 2001 it had risen to 30 per cent before declining to 27 per cent in 2003–2004. The leading states in 2004 for the location of public

[6] Fisheries and Forestry have not been included in either R&D expenditure or in GVP and GDP.

agricultural R&D in 2003 were Victoria and Queensland (similar amounts), followed by NSW.

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 total RDC funds are raised (as levies generally based on the value of production) from producers (because of the predominant Federal funding of Land and Water Australia, and the Rural Industries RDC, for example). In the 1980s, RDC funding only amounted to about 15 per cent of total public expenditure on agricultural R&D.

A recent international review of agricultural R&D by Pardey *et al*. (2006c) 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 per cent 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 per cent per annum and total agricultural research intensity was about 5.2 per cent per annum. Research intensity in less developed countries was often very low such that average public research intensity in developing countries was 0.53 per cent per annum. 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.

4. 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 (Cox *et al*. 1997; Pannell 1999).

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. 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 and 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 per cent. Forty-three estimates were reported ranging from 2.5 to 562 per cent with a mean of 87.3. Mullen was one of four analysts whose median rate of return was 25 per cent or less.[7]

The findings of Mullen and coauthors 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 internal rate of return to Australia had been about 9.5 per cent and the internal rate of return to woolgrowers was in the order of 25 per cent.[8]
- Mullen and Cox (1995) estimated that the returns to public research in broadacre agriculture in Australia were 15–40 per cent from 1953 to 1988. 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 per cent for the 35 and 16 year models. However, they also found 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.* (1996a) attempted to incorporate research in a translog cost model of broadacre agriculture in Australia. While their preferred model

[7] The other three were Alston *et al.* (19.1 per cent), Pardey (22.3 per cent) and Scobie (22.6 per cent).

[8] 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.

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 per cent.

- Cox *et al.* (1997), using non-parametric methods, estimated marginal internal rates of returns to research and extension expenditures in the order of 12–20 per cent from 1953 to 1994. They found non-parametric evidence of lagged research and extension impacts on productivity in Australian broadacre agriculture out as far as 30 years.

More recently the PC (Shanks and Zheng 2006) analysed 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 per cent. Their preferred estimate of the rate of return to public investment in agriculture was 24 per cent, relatively precisely estimated in a range from 1 to 46 per cent.[9] The estimated rate of return in the manufacturing sector was 50 per cent and the returns to the mining, and wholesale and retail sectors were 159 and 438 per cent 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 per cent per annum 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 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 (KS) variable, a weather index, farmers' terms of trade and farmers' education, where all variables were in logs and the models were linear. The KS variables were assembled as weighted sums of past investments in research and extension over 16 and 35 years lag lengths using a procedure more fully described in the original Mullen and Cox paper. The data series on public research investment was backcast to 1918 based on a regression of the log of R&D against a time trend from 1953 to 1972 to allow the estimation of models with research lags of 35 years. 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 years lag models used by Mullen and Cox, and Wang over the 1953–2003 period. Neither model estimated using OLS performed well. For the 16 years model, the research coefficient was not significant and both the Durbin–Watson (D–W) and RESET statistics suggested evidence of mis-specification. For the 35 years model all coefficients

[9] 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 per cent.

Table 5 Econometric results and IRRs from the 35 and 16 years lag models

Period	35 years models									
	1953–1988		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	3.39
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

Period	16 years models									
	1968–1988		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

Coeff., coefficient; *t*-stat, *t*-statistic.

were significant but the specification diagnostics were similar to the 16 years model. Plots of the CUSUM statistic[10] showed a marked departure by the statistic from zero from the early 1980s for both models and it crossed the upper bound in the early 1990s (a bit later for the 35 years model), giving further evidence of mis-specification 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[11] as can

[10] The sum of normalised recursive residuals estimated by adding observations in a forward direction (Brown *et al.* 1975).

[11] As suggested by Garry Griffith.

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[12] and on this basis, attention focused on the 16 and 35 years 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 years quadratic models are strong. All coefficients are precisely estimated and have the expected sign (expectations about the signs on the KS variables are discussed further below). For the 35 years 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 years model suggested that specification remains a problem. Non-nested testing of these two models provided clear evidence in favour of the 35 years model and supported concerns about the specification of the 16 years model.[13]

Some preliminary testing for unit roots suggests that the explanatory variables are not integrated of the same order, as Mullen and Strappazzon (1996) also found. Hence there is a strong likelihood that there is not a co-integrating or stable long run relationship between productivity growth and the knowledge stock over the observation period. As Mullen and Strappazzon 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 KS, say through research investment, 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 from 1953 to 2003, the marginal impact of increments to research investment is still increasing

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

$$\partial \ln TFP / \partial \ln KS = \alpha + 2\beta \ln KS.$$

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

[13] The t-statistic on the introduced variable in the 16 years model associated with the 35 years model was over 3 for both the J and JA-tests, and the corresponding variable in the 35 years model was not significantly different from 0.

At its average level for 1953–2003, the marginal impact of a change in the KS (in logs) was 0.18 and 0.22, respectively, for the 16 and 35 years models. Using the same procedure as Mullen and Cox (1995), these marginal impacts translate into IRRs of 23 and 15 per cent for the 16 and 35 years models.[14] These IRRs are for a once only, unit ($1000) increase in the KS variable evaluated at the average levels 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.

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. However, 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. By themselves these results do not provide definitive evidence that Australia is underinvesting in agricultural research.

Alston *et al.* (2000) found no evidence that rates of return were declining over time. While I did not test this hypothesis formally, the estimates reported here for the 1953–2003 period are within the range first reported by Mullen and Cox.

In my view, these results indicate that investment in agricultural research, at least over the range in investment levels experienced from 1953 to 2003, has earned moderately high rates of return and that there is little evidence the rates of return are likely to decline markedly either as investment increases or over time because of diminished research opportunities. Hence a safe policy option is to maintain current levels of investment in 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 years models still had superior properties to the linear models. There was little change in the 35 years model. However, the IRR from the 16 years model, 39 per cent, is much larger than the IRR from the 35 years model, 16 per cent. This difference reflects the change in marginal impacts. The marginal impact of a change in KS for the 35 years model increased from 0.22 to 0.33 for the period since 1969 whereas the marginal impact for the 16 years model increased from 0.18 to 0.56, reversing their relative magnitudes. Non-nested testing was unable to discriminate between the 16 and 35 years alternatives, both models displaying little evidence of mis-specification.

Because of its assumption that the impacts of research are experienced over 16 years rather than 35 years, the 16 years model gives greater weight to

[14] Again using the same procedure as Mullen and Cox, the implied IRRs for extension are 7 and 13 per cent p.a. for the 16 and 35 years models.

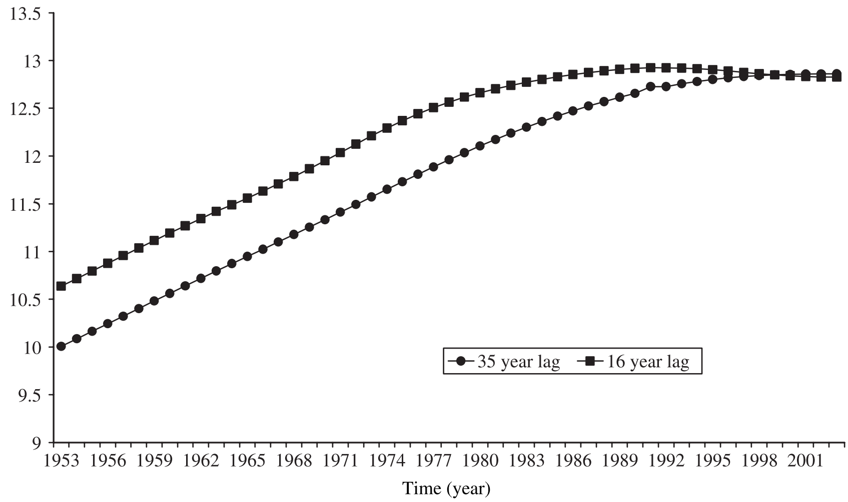

Figure 5 Knowledge stock for 16 and 35 years research lag profiles.

the more recent changes in research investment (Figure 5). 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.

5. 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 using standard benefit–cost techniques. The 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 (Alston *et al*. 1994; Mullen 2002; Mullen *et al*. 2006; Mullen and Crean 2007) 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 per cent per annum. 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 per cent per annum can be attributed to factors such as public infrastructure and the education levels of farmers. Perhaps the remaining 2 per cent can be attributed to technical change, arising from public and private investments in research and extension

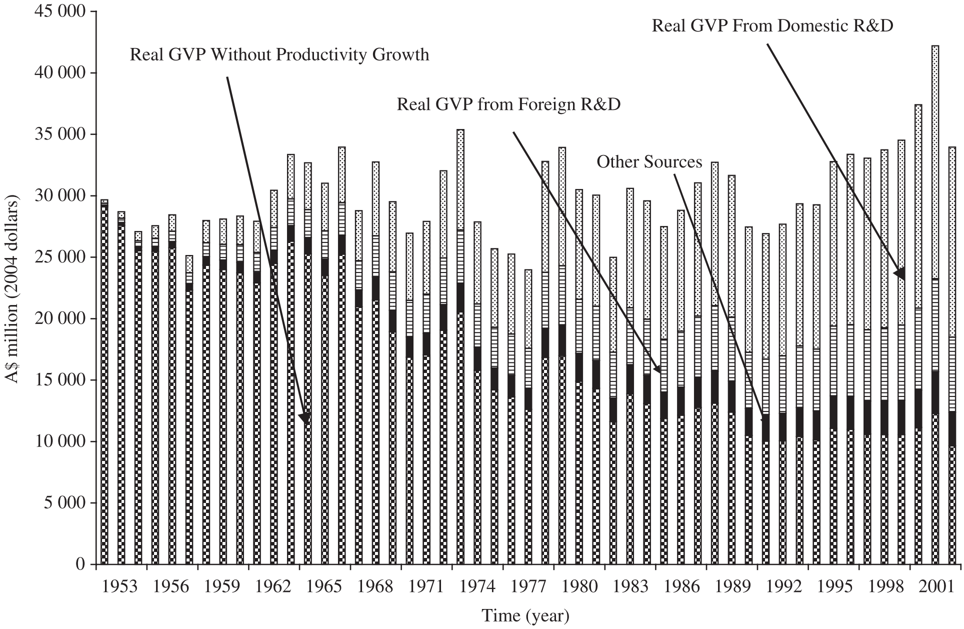

Figure 6 Sources of productivity growth in Australian agriculture (in 2004 dollars): 1953–2003.

where a significant component of both activities is related to the adaptation of foreign knowledge spill-ins. 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 directly responsible for productivity growth in the order of 1.2 per cent per annum and foreign spill-ins for 0.8 per cent per annum – 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 per cent (80 per cent of its current rate).

From Figure 6 it can be seen that the real value of agricultural output in Australia has risen from less than $30 billion in the early 1950s to about $35 billion in the years since 2000. Only since 1996 has it consistently exceeded $30 billion and perhaps these favourable trends in TFP and the terms of trade have contributed.

Holding technology at its 1953 state, less than 30 per cent of the value of output in 2003 can be accounted for by conventional inputs (represented by the bottom bars). Seventy per cent 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.

For the scenario presented here, the contribution of domestic research is particularly significant. Almost half the value of output in 2003 can be attributed to new technology generated by domestic research since 1953 (represented by the top bars). Were it not for domestic research, the real value of output would have contracted to less than $20 billion which serves to highlight the importance of domestic R&D in maintaining output levels. At a real rate of interest of 4 per cent, the compound value of the stream of benefits from domestic research (1.2 per cent) from 1953 to 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, some of whom are non-residents of Australia. On the basis of previous research into the distribution of the benefits from research, he speculated that perhaps Australian producers, processors and consumers retain 80 per cent of benefits or about A$700 billion in this case.

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 per cent to domestic R&D investment, giving a total of A$90.3 billion since 1953 and A$108 billion since 1918 (in 2004 dollars).

Two scenarios for investment analysis relate Australian R&D investment first, to productivity growth at the rate of 2.0 per cent per annum and second, to productivity growth at the rate of 1.2 per cent per annum. These scenarios 'bracket' the potential benefits from domestic research. Under the first scenario, domestic research generates productivity gains of only 1.2 per cent and some productivity gains, 0.8 per cent, 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 (Pannell 1999). 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 per cent 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 per cent are attributed to domestic research investments made since 1918, the internal rate of return (IRR) is 17 per cent and the benefit–cost ratio (discount rate of 4 per cent) is 17 : 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 per cent then the IRR is 15 per cent and the benefit–cost ratio is 8 : 1.

Table 6 Rates of return to research in Australian agriculture

Scenario	Benefit–cost ratio	IRR (%)
Productivity growth at 2.0%:		
(a) Public research only		
R&D from 1918 to 2003	17.0	17
R&D from 1953 to 2003	20.5	–
(b) Public + private research + extension		
R&D from 1918 to 2003	12.2	16
R&D from 1953 to 2003	14.6	–
(c) ((b) + gains to Australians only (80%))		
R&D from 1918 to 2003	9.7	15
R&D from 1953 to 2003	11.7	–
Productivity growth at 1.2%:		
(a) Public research only		
R&D from 1918 to 2003	11.3	16
R&D from 1953 to 2003	13.6	–
(b) Public + private research + extension		
R&D from 1918 to 2003	8.1	15
R&D from 1953 to 2003	9.7	–
(c) ((b) + gains to Australians only (80%))		
R&D from 1918 to 2003	6.5	14
R&D from 1953 to 2003	7.8	–

IRR, internal rate of return.

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.

6. 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 per cent per annum. It has been high relative to other sectors of the Australian economy and high relative to the agricultural sectors in other OECD countries. Further, 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 ($700 million in 2004 dollars) for two decades and its research intensity has declined. 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 is an emerging influence on agricultural research and its management. 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.[15] Within agricultural research institutions, some 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 50 per cent 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 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 per cent per annum range estimated by Mullen and Cox (1995). The lower returns are associated with a 35 years lag model and the higher returns with 16 years 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

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

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 KS variable restored good econometric properties.

More strongly, the results presented here suggest no evidence that the returns from agricultural research are likely to decline markedly either as investment increases or over time because of diminished research opportunities. In view of this, 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. In addition, there is not 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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