Trends in Research, Productivity Growth and Competitiveness in Agriculture in New Zealand and Australia

Invited Paper

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Abstract
Investment in R&D has long been regarded as an important source of productivity growth in New Zealand and Australian agriculture. Perhaps because research lags are long, current investment in R&D is monitored closely. In this paper trends in public investment in R&D and in productivity growth are reviewed. Investment in R&D has been flat in both countries although in recent years investment in New Zealand has increased. Nevertheless research intensity in Australia has been significantly higher than that in New Zealand. Productivity growth is also likely to have been higher. Econometric evidence about the sources of productivity growth is rarely clear. We develop some scenarios about the importance of domestic and foreign R&D and other sources of productivity growth and find that returns to investments in domestic research in both countries are likely to have been in the order of 15 – 20 percent.

Keywords:
Productivity, research and development, research evaluation

With the usual caveat, we are grateful for advice from colleagues in various State Departments, ABARE, the Productivity Commission and ABS. The project has been partly funded by the Australian Farm Institute.

1. Introduction

There is renewed interest on both sides of the Tasman about the contribution of research and other elements of science policy to productivity growth in agriculture, a source of economic growth and higher living standards for farmers, processors and consumers of farm products.

Mullen and Crean (2006a) estimated that the real value of productivity growth in agriculture to the Australian economy from 1953 to 2003 has been of the order of $1,580b (2004$). The gross value of agricultural production in Australia in real terms has grown slowly from just under $30b in the early 50s to about $35b around 2003 but without productivity growth, it may have only been about $10b in 2003. Holding technology at its 1953 state, less than thirty percent of the value of output in 2004 can be accounted for by conventional inputs. 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.

In this paper New Zealand agriculture is described in value added or GDP terms rather than gross value terms. The real GDP of agriculture was about $7b (NZ 2004$) from the mid 50s to the early 80s. It has since fallen to about $5b except for a spike back to $7b in 2001. Without productivity growth, GDP in recent years may have been about $2b. Almost 60 percent of GDP in now accounted for by productivity growth since 1953.

In this paper we compare and contrast trends in the growth in productivity in agriculture in New Zealand and Australia and in investment in research, particularly by the public sector. We then review recent econometric analyses of the relationship between research and productivity growth. We conclude by making some judgments about key drivers of productivity in agriculture, returns from research investments and consider their implications for science policy.

2. Productivity Growth in Australia and New Zealand Agriculture

Methodologies for measuring productivity, broadly comprising index number, malmquist (DEA) and econometric stochastic frontier approaches, are described in many places (Coelli et al. 2005 for example) and are not reviewed in detail here. Productivity is a physical measure conventionally defined as the growth in outputs less the growth in inputs. We use the terms total factor productivity (TFP) or multi-factor productivity (MFP) interchangeably but distinguish them from measures of partial productivity such as output per unit of labour or water.

Nor do we follow Mullen and Crean (2006b) in exhaustively reviewing empirical analyses of productivity growth in agriculture. Here we report trends in productivity in agriculture in Australia and New Zealand and briefly provide some qualifications to the interpretation of TFP measures as measures of technical change arising at least in part from investment in R&D.

2.1 Agriculture in the New Zealand and Australian Economies

The primary sector continues to play an important role in the New Zealand economy. It directly contributed $8 billion (to the year ended March 2005 in 95/96 prices), or 6.6%, to the country's real GDP. Of this, the agricultural sector contributed 77% to the primary sector, or approximately $6 billion (95/96 prices) to whole economy real GDP.

In Australia, the primary sector contributed 3.4% of total GDP, with the agricultural sector accounting for 93% of the total primary sector.

Table 1: GDP Growth Performance in Australia and New Zealand: 1988 – 2004

Sector	Australia	New Zealand
	Annual average growth rates	
Whole Economy	3.4%	2.5%
Primary Sector	2.9%	2.5%
Made up of:		
Agriculture	2.8%	2.1%
Fishing*	3.6%	1.7%
Forestry and logging*	3.6%	5.0%

Data Source: Statistics New Zealand and ABS
*Sectors not disaggregated in ABS data

Over the 1988 – 2004 period, the Australian economy (3.4%) has been growing faster than the New Zealand economy (2.5%) and similarly GDP in the agricultural sector in Australia (2.8%) has been growing faster than in its New Zealand counterpart (2.1%) (Table 1).

2.2 Productivity Growth in New Zealand Agriculture

In New Zealand, multifactor productivity in the primary sector (comprising agriculture, forestry, hunting and fishing) grew at an annual average rate of 1.5% from 1988 to 2004 (see Table 2), a distant third to the transport and communications sector (5.5 percent) and the personal and community services sector (1.6 percent). MFP for the market sector as a whole was 1.8 percent. Hence in New Zealand productivity in the agricultural sector grew at a rate 0.8 times that of the market sector as a whole for this period.

Hall and Scobie (2006) constructed a multifactor productivity series using a value added approach back to 1926-27 (see Figure 1). In this paper we have made some minor modifications to their analysis of productivity growth. We have estimated TFP growth rates as the coefficient on a time trend in a regression of the log of TFP against a constant and the time trend. Over the entire 1927 – 2001 period, TFP grew at the rate of 1.6 percent per year. The growth rates by subperiod were 0.6% (1927-56), 1.6% (1957-83) and 2.2% (1984-2001)

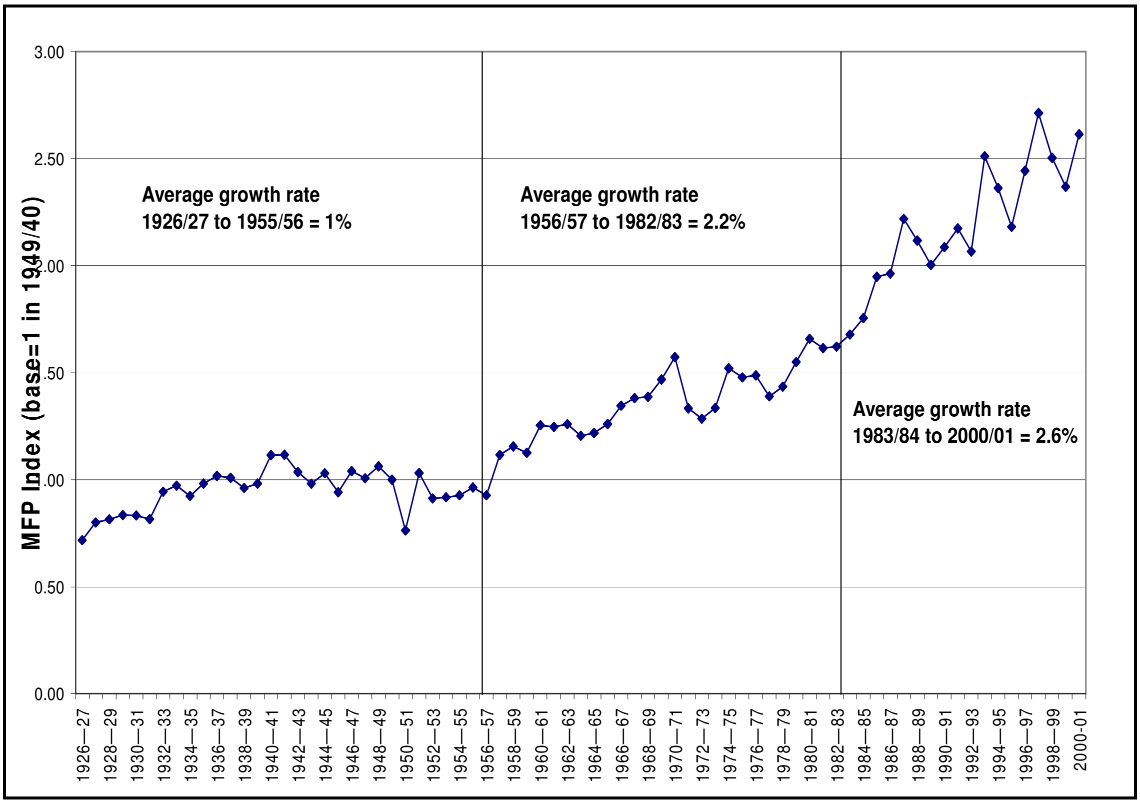
These subperiods were selected because 1957 and 1983 were low points in the midperiod productivity cycle. However growth rates are sensitive to chosen starting points. The growth rate in productivity from 1986 to 2001 has been 1.8%. The trend in productivity in New Zealand agriculture relative to that in Australia is graphed in Figure 2.

Table 2: Growth Accounting Decomposition[1] for each Industry: New Zealand: 1988-2004

Sector	Labour Productivity growth	Multifactor productivity growth	Weighted Capital-labour ratio growth
Agriculture, Forestry, Hunting and Fishing	3.0%	1.5%	1.5%
Mining and Quarrying	0.1%	-0.7%	0.7%
Construction	-0.6%	-0.9%	0.4%
Transport and communications	6.3%	5.5%	0.9%
Business and Property Services	0.1%	-0.1%	0.2%
Personal and community services	1.9%	1.6%	0.3%
Manufacturing	1.7%	0.8%	0.9%
Electricity, Gas and Water	5.0%	-0.2%	5.2%
Retail and wholesale trade	1.1%	1.0%	0.1%

[1]The growth accounting decomposition is given by: $\Delta\ln(Y/L)_t = \Delta\ln MFP_t + \alpha\Delta\ln(K/L)_t$. Here we have taken the average of each component in this decomposition over the period 1988 to 2004.

Figure 1 - Agricultural Multifactor Productivity in New Zealand: 1927- 2001



2.3 Productivity Growth in Australian Agriculture

Australia differs from most other countries in that there are two long term sources of data for analysis of productivity growth in agriculture. In addition to the traditional source of data at the sector level from the Australian Bureau of Statistics (ABS), there is an even longer series of data from ABARE based on farm surveys dating back to 1953. Estimates of growth rates for the agricultural and other sectors of the Australian economy for sub-periods from 1975 to 2004 based on ABS data are displayed in Table 3.

Parham (2004) provides recent estimates of productivity growth in Australia by measuring changes from productivity peak to productivity peak. Using data up to 1998/99, Parham estimated that productivity growth in the Australian economy during the 90s (93/94 to 98/99) was 1.8 percent, a percentage point higher than previously, and putting Australia in a favourable position relative to other OECD countries. Over this period of the 90s there was also a surge in agricultural productivity (4.3%). Parham found that productivity growth in agriculture in the 70s and 80s was subdued (Table 3), perhaps influenced by extensive drought conditions in eastern Australia during the early 1980's.

Agricultural productivity growth during the 90s was higher than all other sectors and higher than for previous decades. The growth rate in the wholesale trade sector was 3.2 percent, much improved on previous periods, and 3.7 percent in the communications services sector, down on previous periods. Up to 1993/94 productivity growth in the electricity, gas and water sector and in the communications sector generally exceeded that in agriculture and the growth rate in manufacturing was similar.

Table 3: Productivity Growth in Sectors of the Australian Economy, 1974/75 to 1998/99

	1974/75-1981/82	1981/82-1984/85	1984/85-1988/89	1988/89-1993/94	1993/94-1998/99
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)

Agriculture's performance relative to that of the rest of the market economy has improved markedly since the mid 80s. Prior to this time productivity growth in agriculture was less than 1.5 times that in the market economy but since then it has been at least 2.4 times and up to 3.7 times the rate in the market economy. Mullen and Crean (2006b) speculated that the surge in productivity in agriculture in the 90s might have been largely explained by the surge in productivity in the economy generally but this apparent gain in comparative advantage in the agricultural sector since the mid 80s would suggest otherwise.

It is interesting to note from Table 3 that productivity growth rates in other sectors of the economy seem as variable as that in agriculture and are often negative.

Agricultural productivity in Australia has also been analysed from farm survey data collected by ABARE. ABARE data are drawn from surveys of farms engaged in Australia's major crop and livestock enterprises, broadacre agriculture, using a gross value approach where there are up to four outputs and eight or more inputs. ABARE has been collecting farm survey data since 1952-53. In that time the target population for the surveys has been broadened from the Australian sheep industry, defined to include all farms carrying at least 200 sheep, to those engaged in broadacre agriculture in Australia, as covered by the Australian Agricultural and Grazing Industries Survey (Knopke et al. 2000). Farm survey data from the dairy industry have allowed irregular analyses of productivity in the diary industry. Until recently, (Alexander and Kokic 2005 being the exception) most of these studies were of a time series nature using annual measures of inputs and outputs on an average per farm basis. The dataset can be stratified in a number of ways including by region, state, size and enterprise specialisation (e.g. crop specialists, wool specialists).

Past studies of productivity growth in Australian agriculture based on ABARE farm survey data are reviewed in Mullen (2002) and Mullen and Crean (2006b). Estimates from the earliest studies of average rates of productivity growth in Australian agriculture ranged from 0.6 percent to 1.7 percent. Estimates of broadacre productivity growth from the more recent studies are in the 2.2 to 3.1 percent range.

The trend in productivity in broadacre agriculture in Australia is graphed in Figure 2. This series has been constructed by splicing a series of TFP estimates (Kokic, unpublished data provided to DPI, Victoria, 2006) for the period 1988 – 2004 to the series used by Mullen and Cox based on ABARE survey data for the period 1953 – 1994. The growth in TFP over the whole period was 2.5 percent.

There is some evidence that productivity has been growing at a faster rate in recent decades. Periods of atypical seasonal conditions and long investment cycles should make us wary about interpreting trends in productivity growth. However, Stoeckel and Miller (1982) argued that productivity growth in Australian agriculture increased after 1968/69, a 'watershed' year for agriculture after which while output continued to grow, inputs actually declined. Their study only extended as far as 1980 and inputs have grown since but it is true that since then the rate of growth in inputs has rarely exceeded one percent. Somewhat arbitrarily we have persisted with regarding 1968/69 as a 'watershed' year. Prior to this year TFP grew at the rate of 2.0 percent and since then it has grown at the long term rate of 2.5 percent.

Comparisons of TFP between nations and industries and through time need to be made cautiously. Several factors need to be considered in making these comparisons.

First, measures of TFP computed using index number approaches are non-parametric in nature which means that the statistical confidence intervals surrounding these estimates are unknown and hence the *statistical significance* of differences in TFP are unknown.

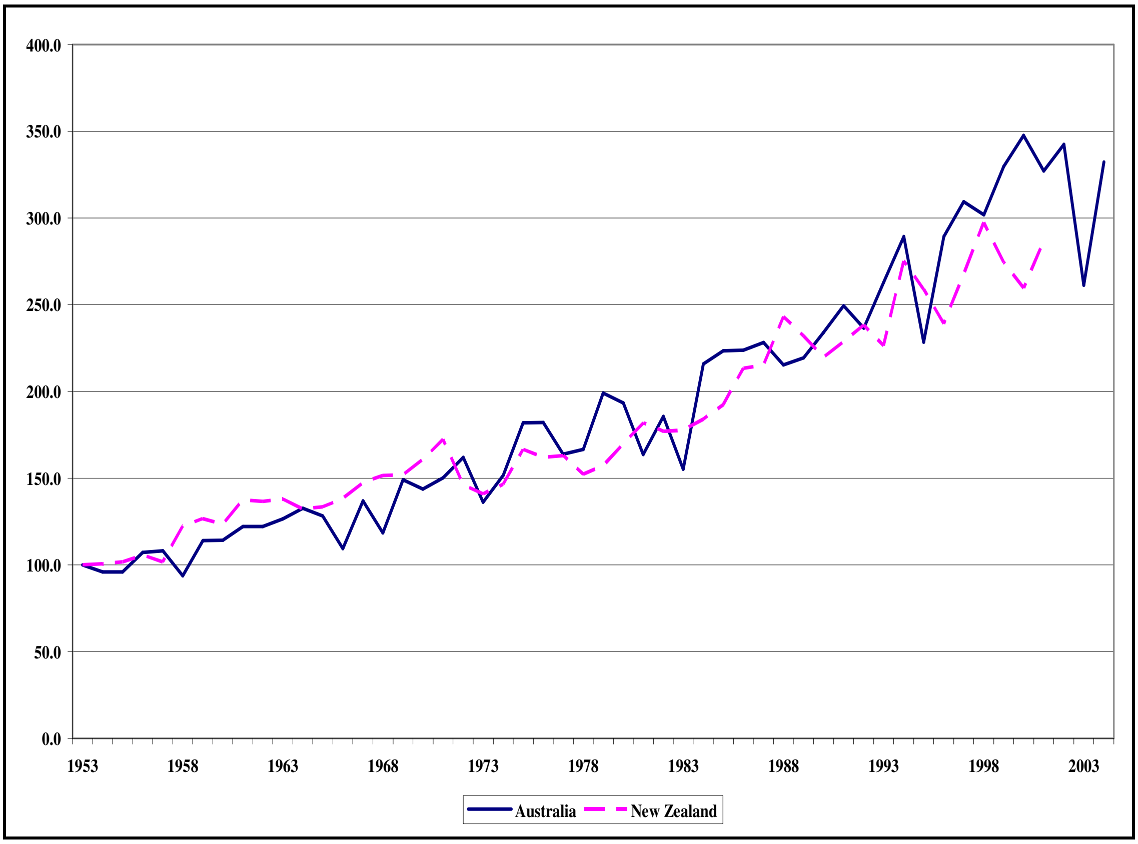
Second as Zheng (2005) pointed out, whether TFP in a sector is measured using a *gross value or value added approach* is significant. TFP estimates based on ABARE survey data use a gross value approach while estimates based on ABS or Statistics New Zealand sector data use a value added approach. There does not seem to have been a farm survey based dataset in New Zealand similar to the ABARE dataset in Australia.

Third, comparing TFP between countries such as Australia and New Zealand is best done in a *multilateral framework* as applied by Coelli and Rao (2003). We have not been able to do this here.

Fourth, TFP studies differ in the periods over which they estimate growth rates with implications for both intra and inter-country comparisons. Starting point issues may well compound this problem. The Productivity Commission computes growth rates between peaks in the productivity cycle. In much of the work referred to here, growth rates are estimated by regressing the log of TFP on a constant and a time trend over the observation period.

Since we have not used a multilateral framework over a common observation period, the practical implications are that while TFP studies in Australia and New Zealand can be surveyed for indications of differences in growth rates in TFP, little can be said about the statistical significance of differences in growth rates and nothing can be said about levels of productivity, distance from a production frontier, between the two countries.

Figure 2: Productivity Growth in Australian Broadacre Agriculture and New Zealand Agriculture



2.4 TFP Measures as Indicators of Technical Change

One of the objectives of productivity analysis is to estimate technical change from R&D as a residual derived by deducting the growth in inputs from the growth outputs. Because of the multi- input and output nature of production outputs and inputs have to be aggregated using price weights (index number) approaches or distance function (Malmquist) approaches. Index number approaches still predominate.

The Fisher Ideal Index is a popular measure of TFP but the assumptions for it to be an exact measure are onerous including:

- The underlying production function relating outputs to inputs has a quadratic functional form;
- Production is characterised by constant returns to scale;
- The industry is operating at a point of technical and allocative efficiency;
- Second order coefficients are equal; and
- Prices and quantities are accurately measured and reflect quality differences for inputs and outputs.

Our expectation might be that technical change is a smooth outward shift in a production frontier. However in practice TFP measures fluctuate markedly from year to year obviously reflecting more than technical change. The annual variation in TFP in agriculture in Australia and New Zealand is displayed in Figures 3 and 4 obtained by differencing the log of TFP.

The growth rate of productivity in broadacre agriculture in Australia fluctuates both frequently and widely. The range is between declines of two percent and increases of almost three percent and in 14 of 40 years the growth rate was negative. Productivity growth in New Zealand agriculture is also highly variable (Figure 4) although it varies in a narrower range than does TFP for broadacre agriculture in Australia. Presumably Australia's more variable climate explains this difference.

Some of the variation in Figures 3 and 4 is likely explained by seasonal conditions. Farmers commit inputs long before output outcomes are known and hence productivity will vary as seasonal conditions unfold. However as Chambers (2005, unpublished) in an analysis of US agriculture pointed out, the objective of productivity measurement is to analyse how production frontiers as a result of technical change are changing through time as a result of technical change and the variation observed in these figures is unlikely to represent this. True changes in the production frontier, as distinct from seasonally induced fluctuations have very different policy implications. Implicitly analysts understand this and discuss trends in growth over a number of years.

Standard measures of productivity have been developed under the assumption that production occurs in a non-stochastic world. Chambers argued that more is required than either ignoring the stochastic nature of production or making ad hoc non-stochastic adjustments. Rather, measures of productivity are required for a stochastic world based on state contingent production theory. The challenge is to develop such measures that can be estimated from observable market data.

Even if seasonal influences are removed it is unlikely that the path of TFP will follow a smooth trend line. The progress of technical change is unlikely to be smooth and constant. New wheat varieties, for example, are unlikely to become available at fixed intervals with fixed yield gains and technologies may break down, disease resistance in wheat for example, requiring more inputs to maintain output.

Figure 3: Annual TFP Growth Rates for Broadacre Agriculture in Australia

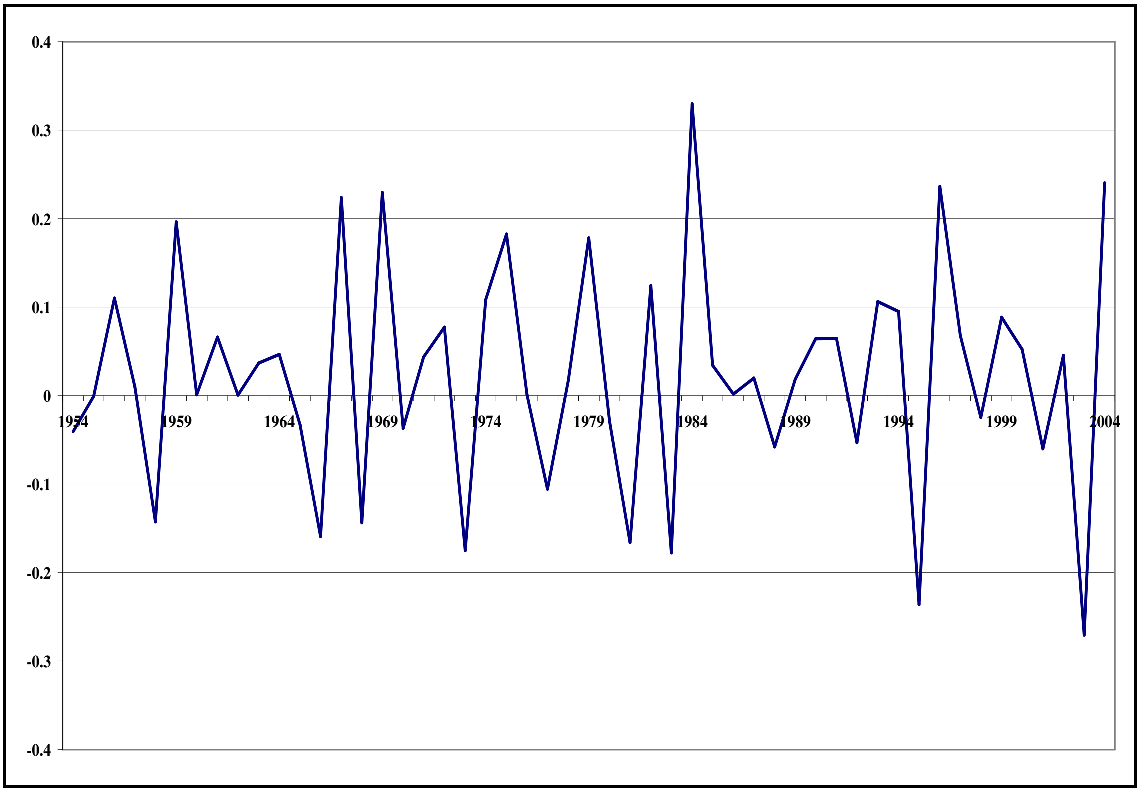
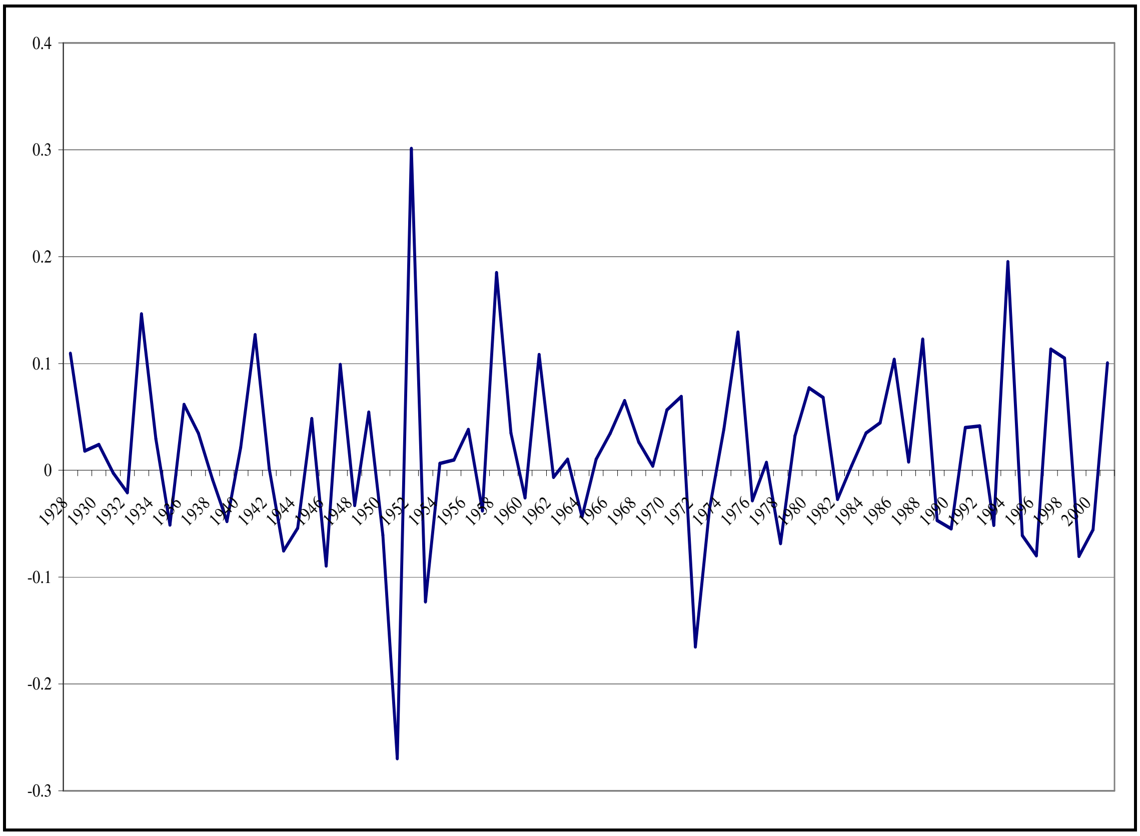


Figure 4: Annual Growth Rate of TFP for New Zealand Agriculture

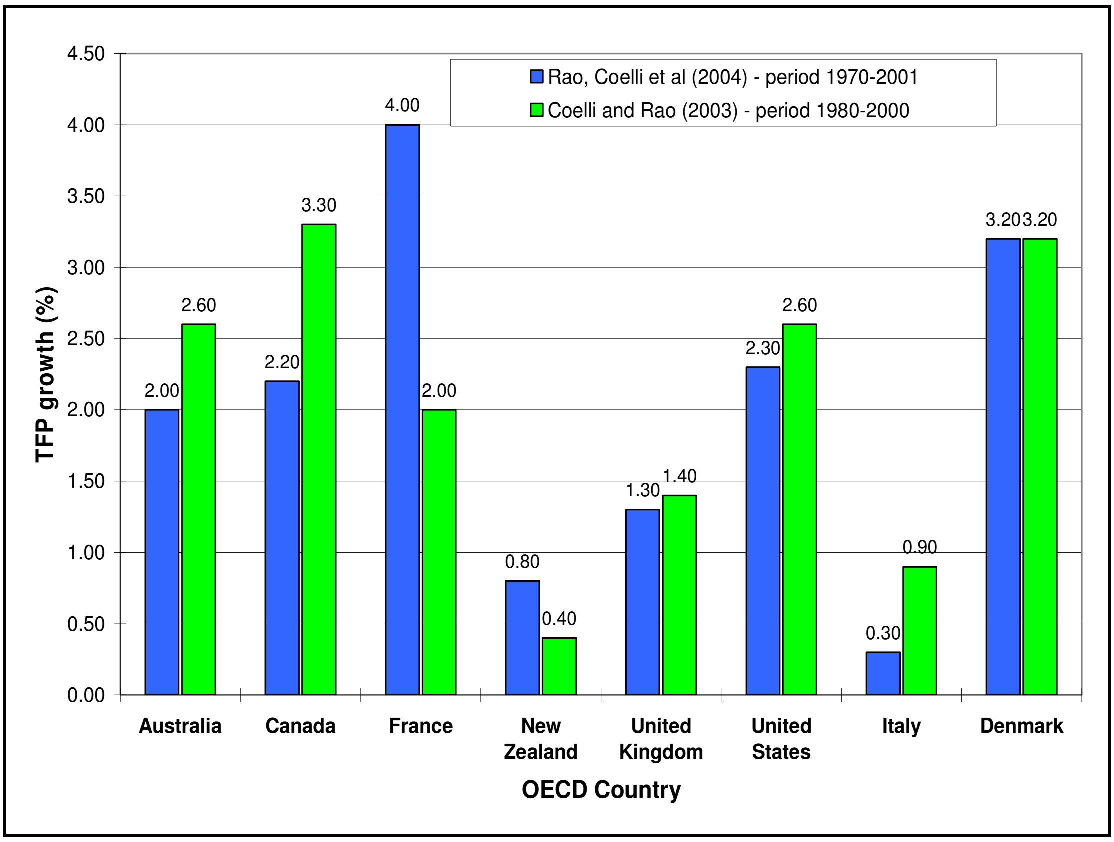


3. Productivity Growth and Competitiveness

Productivity growth is often assessed for its implications for 'competitiveness', a term generally only vaguely defined. All other factors being equal, increased productivity within a sector lowers real output prices and improves its international competitiveness. 'Productivity growth is central to the performance and international competitiveness of Australia's agriculture sector' (Productivity Commission 2005, pg 117). We compare productivity growth rates in agriculture with growth rates in other sectors in the domestic economy and with trends in the terms of trade. Productivity performance in Australia and New Zealand is also compared with that in the agriculture sectors of other countries.

There is a plethora of analyses of TFP at a sectoral level around the world but few have been conducted in a multilateral or transitive manner, a starting point especially if the question of convergence is of interest. From the studies reviewed in Mullen and Crean (2006a) we have selected the two most recent multi-country studies of Rao et al. (2004) and Coelli and Rao (2003) to give some idea of the relative TFP performance of agriculture in Australia and New Zealand (Figure 5). Their estimates covered more than 90 countries and account for 97 per cent of the world's agriculture

Figure 5: Productivity growth rates – selected OECD countries



Source: Rao et al (2004) and Coelli and Rao (2003)

Australia's performance compares favourably with other countries, particularly in recent times. For example, the results of Rao et al for the 1980-2000 period indicate

Australian agriculture achieved a TFP growth rate of 2.6 per cent, higher than their estimate of 2.0 percent for the 1970 – 2001 period and higher than estimates from earlier studies. This rate of growth is similar to that achieved by the United States. This reported acceleration in productivity growth is consistent with recent studies of productivity growth in Australian agriculture as described above. On the basis of the results for the 1980 to 2000 period, Australia has the third highest agricultural productivity growth rate in the OECD but, in this group, New Zealand vied with Italy for the lowest rate of growth.

Another common practice is to compare the rate of productivity growth with the terms of trade facing farmers. The trend in the terms of trade faced by Australian agriculture declined for about 40 years from 1953 (Figure 6) as is the conventional wisdom. However it is not true that the terms of trade decreased inexorably over the whole period and is still declining, as observed in much recent literature. Since the early 90s, there has been little trend in the terms of trade for agriculture as a whole. Using econometric techniques, we found that the terms of trade declined at the rate of 2.6 percent from 1953 to 1990, similar to the rates of productivity in broadacre agriculture reported later. Perhaps in the 50s the terms of trade were declining at a faster rate than productivity gains. Surprisingly, since 1991 there has been no statistically significant trend in the terms of trade.

As for Australia, there has been no trend in the terms of trade for either the New Zealand economy or its farm sector since the late 80s (Figure 7).

The terms of trade are only a partial indicator of the outcomes with respect to income that farmers might encounter as a result of the influence of new technologies and relative price changes. An obvious deficiency is the use of average numbers to represent the circumstances faced by farmers in diverse localities across New Zealand and Australia.

Competitiveness is a broader concept than productivity, even when related to the terms of trade. A gap exists in both conceptual and empirical terms, between competitiveness in delivered goods and its costs of production at the farm gate (Capalbo et al. 1990). The distinction is an important one in an agricultural context because of distortions in international markets associated with various forms of government intervention. In addition to trade policies, contributors to international competitiveness other than productivity growth include exchange rates, transportation costs and aspects of product quality. From economic theory, the range of substitution between inputs and outputs at any level of the economy – farm, industry, sector - is much richer than can be captured by an index of productivity and an index of prices. Nevertheless such indices provide broad indications of the pressures facing agriculture.

Figure 6: The Terms of Trade for Australian Agriculture

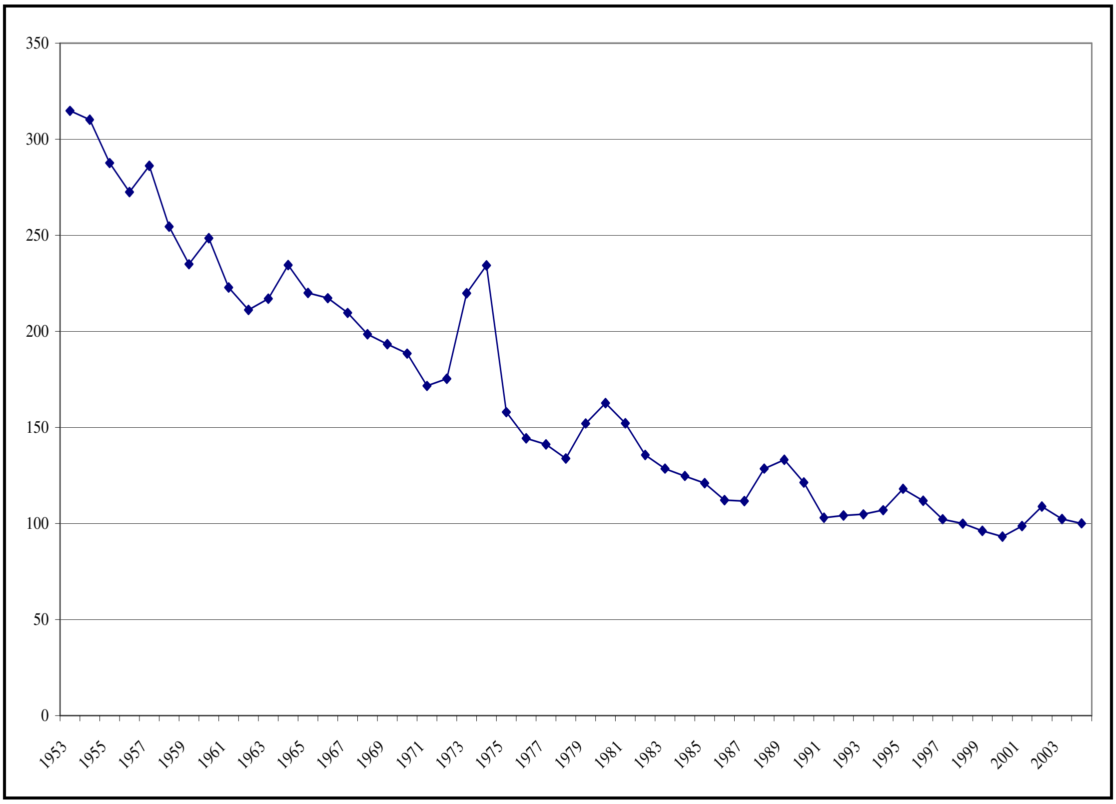
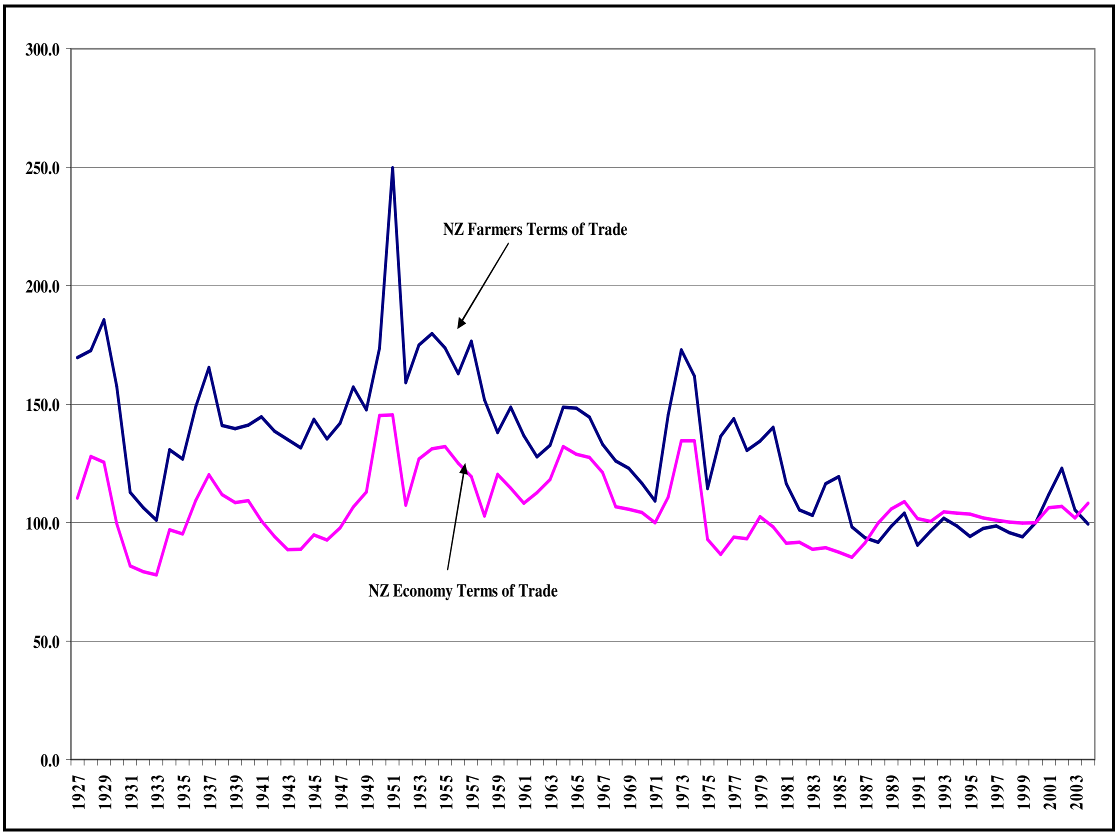


Figure 7: Terms of Trade for New Zealand Economy and Its Farm Sector



International competitiveness draws on the concept of comparative rather than absolute advantage (Krugman 1996 and Gopinath et al 1997). ‘While productivity growth of a sector or an economy is vital to a country's standard of living, absolute productivity comparisons across countries alone provide no insights into competitive advantage’ (Gopinath et al. 1997, pg 101). Gopinath suggests that what determines international competitiveness is the productivity of a country’s agricultural sector relative to other non-agriculture sectors compared with that of its major competitors. Shane et al (1998, pg 8) lends support to this view by stating that ‘the level of a country’s exports depends not on absolute but on comparative advantage’. This doesn’t diminish the importance of productivity, but does imply the need for some care in considering the consequences of differences in absolute productivity levels[1] for competitiveness and trade.

Hence, 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. As discussed earlier, agricultural productivity growth in Australia has been growing recently at a rate about three times faster than the rest of the market economy. This has not been the case in New Zealand where productivity in the agricultural sector has been growing at 0.9 times the rate in the business sector.

The Australian findings in respect to relative sector performance do not seem unique. Bernard and Jones (1996) in an analysis of 14 OECD countries over the period 1970-87 found that average productivity growth in agriculture grew at the rate of 2.60 percent per year as compared to 1.20 percent for industry (Table 4). Many countries reported higher agricultural sector TFP growth than did Australia for the 1970-1987 period. However, Australia performs well on the basis of its ratio of agricultural TFP growth to non-agricultural TFP compared to other countries. Australia’s ratio of 3.60 was significantly higher than the 2.17 average reported for the group and was only behind that of two other countries, the United States and the United Kingdom. This implies that Australia’s comparative advantage in agricultural production improved in general terms over the period. Other things being equal, this also suggests that Australia’s ability to compete with this group of countries on world markets has also improved in general terms.

It is not clear why the agricultural sectors of developed countries had higher rates of productivity growth than other sectors. Whether this is related to the nature of agricultural production and the common feature of economic development which traditionally has seen resources transfer out of agriculture, the large public investment in R&D that does not appear as an input (unlike research costs associated with more differentiated products), or specific attributes of agricultural technologies that result in large gains is not clear. Nor is it clear why the Australian agricultural sector’s performance has become even stronger in recent decades.

New Zealand agriculture has not performed as well. While New Zealand was not included in the Bernard and Jones study, we noted above that productivity growth in

[1] Krugman is particularly sceptical of the relevance of international productivity comparisons at a country level. He argues that national competitiveness is meaningless, that countries do not directly compete with each other like individual firms do and that prosperity is largely determined by domestic productivity growth.

agriculture was just below average productivity growth across all sectors in New Zealand.

Table 4: Productivity growth rates – agriculture versus other industries - 1970-1987 (selected OECD countries)

Country	**Agriculture** Average TFP growth	**Total industry** Average TFP growth	**Ratio of Ag TFP to Non-Ag TFP**
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**

4. Trends in Public Investment in Agricultural Research

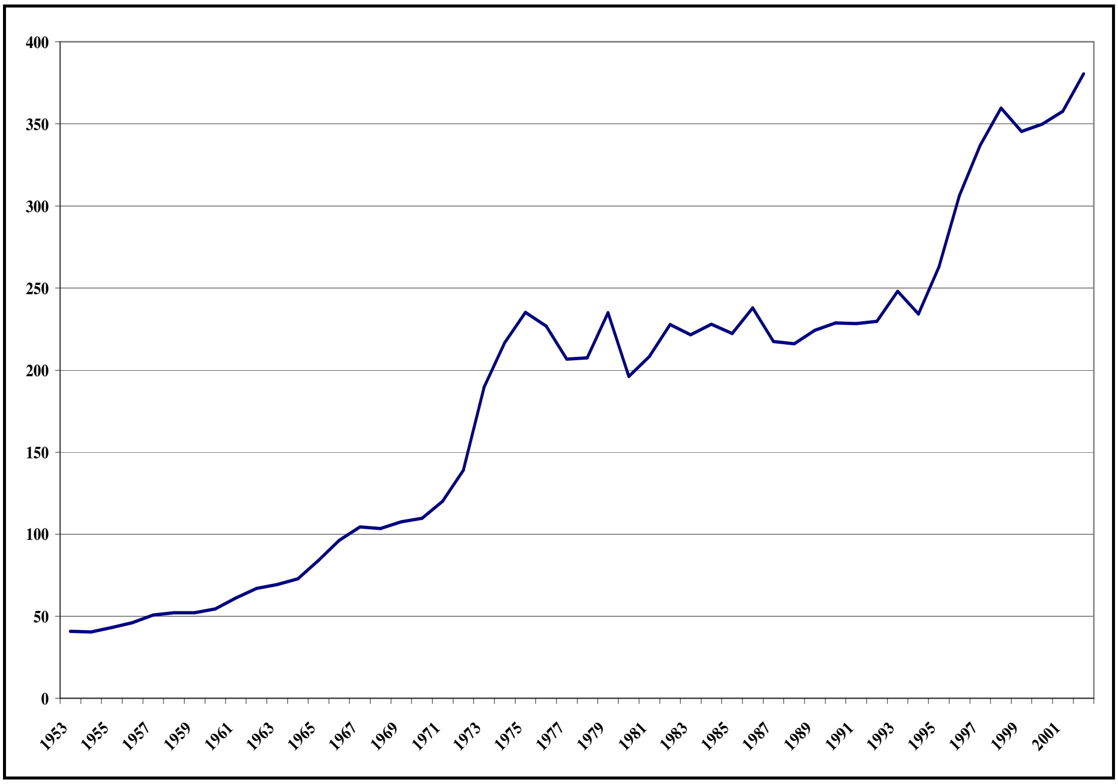
4.1 New Zealand

The institutional arrangements for the public funding of R&D in New Zealand have evolved over the last two decades. Up until the early 1980s, the majority of research funds were allocated to the former Department of Scientific and Industrial Research and the Ministry of Agriculture through the standard process of parliamentary appropriations. After a series of changes, the current system of funding emerged in which a significant part of the public sector funding for R&D is channelled through a series of state-owned research institutes. These institutes and universities submit competitive bids to the Foundation for Research, Science and Technology, which through a process of peer review allocates the public funding according to priorities established by the government based on the policy advice of the Ministry of Research, Science and Technology. Further details can be found in Jacobsen and Scobie (1999).

Public investment in agricultural R&D in New Zealand has risen from $217.8m (2004 $s) in 1975 to $322.2m in 2001/02. Over the same time private R&D in agriculture has risen from $17.4m to $58.5m, a significant increase from 7.4% to 15.3% in the share of R&D privately funded.

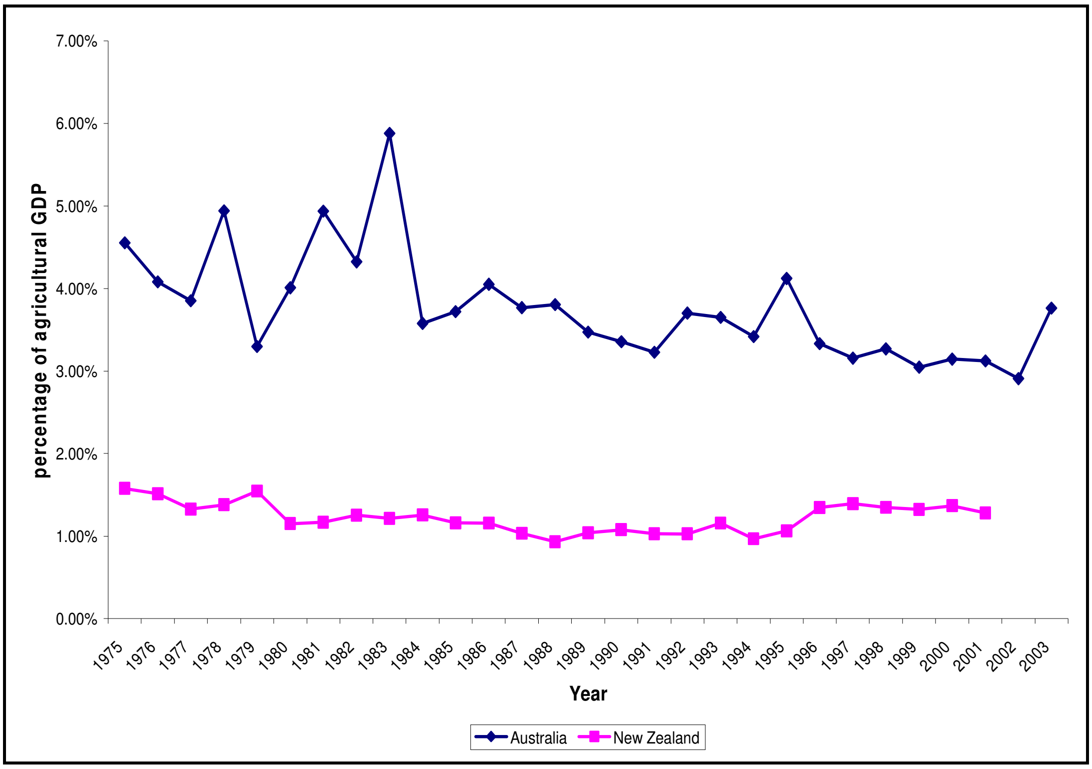
Public investment in agricultural R&D grew steadily until the late 60s, at which time there was a surge in investment until the mid 70s. From the mid 70s to the mid 90s there was little change in the annual level of public investment in real terms. Investment has grown strongly since the mid 90s (Figure 8).

Figure 8: Real Total Investment in Agricultural Research in New Zealand ($NZ 2004m)



New Zealand's level of public R&D spending as a percentage of agricultural GDP has remained relatively steady over this period, at a level of 1.6% in 1975 and 1.3% in 2001 (Figure 9).

Figure 9 - Australian and New Zealand public R&D intensities in agriculture



Australian data source: John Mullen (pers. comm.) and Australian Bureau of Statistics.

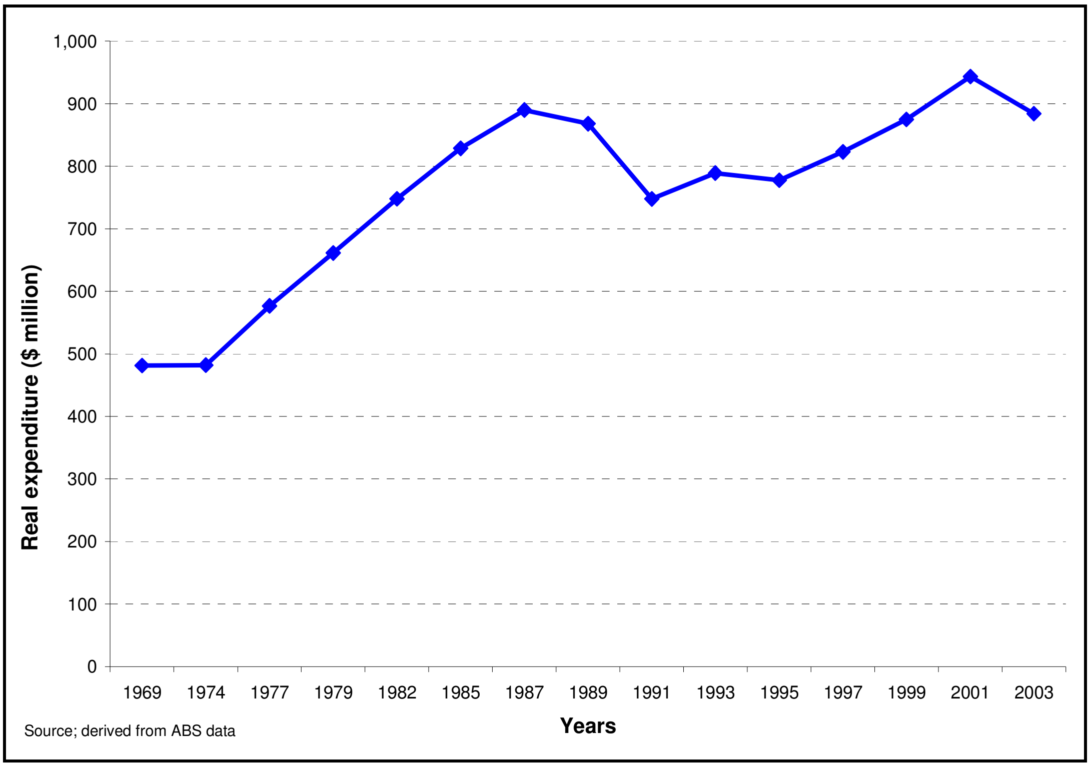
4.2 Australia

Data concerning expenditure on R&D in Australia are collected in a biannual survey conducted by the ABS which extends back in some form to 1968/69. In this paper all expenditure data have been expressed in 2004 dollars using a GDP deflator. The most recent ABS survey year was the financial year 2002/03. R&D expenditure data relate to financial years but we adopt the convention of referring to the 2002/03 year for example, as 2003.

Total real expenditure on agricultural R&D in 2003 was $1,028 m as estimated by the sum of expenditure on R&D in the plant and animal socioeconomic objective classes. As a percentage of total expenditure on R&D, expenditure on agricultural R&D in 2003 was eight percent. It has declined steadily from 20 percent in 1982. Expenditure on environmental research has never exceeded 10 percent of total expenditure and was 6.5 percent in 2003. ABS does not report the extent to which this environmental research is related to agriculture.

In Australia, the public sector has always been the dominant provider of research services to the agricultural sector. The business sector has generally been responsible for less than 10 percent of total agricultural R&D although its share in 2003 was 14 percent. This contrasts sharply with other developed countries where agricultural R&D is roughly shared between public and private sectors (Pardey and Beintema 2001). The focus of this paper is on publicly funded agricultural research.

Figure 10: Real Public Expenditure on Agricultural R&D in Australia (2004 dollars)



Public expenditure on agricultural research increased steadily from just under $500 m around 1970 to almost $900 m in 1987 (Figure 10). The level of spending in 2003 was little changed. In research intensity terms (expenditure/agricultural GDP), public funding for agricultural research has been drifting down from a high of almost six percent in 1987 to just over four percent in 2003 but this level of research intensity is double that in the late 60s. Much of the year to year variation in research intensity evident in Figure 9 arises from the variability of agricultural GDP in Australia rather than from the variability in funding, hence short term trends should be interpreted cautiously. Note a significant proportion of public expenditure on research is funded by the Research and Development Corporations (RDCs) as discussed below.

The trend in research investment portrayed in Figure 10 is difficult to read. Choosing either the late 60s or the early 90s would suggest that generally real investment in research has been growing but if the starting point is the mid 80s then there has been little growth in public research investment in agriculture.

A feature of the agricultural research sector in Australia has been the prominent role played by what are now known as the Research and Development Corporations (RDCs). In approximate terms, RDCs commission agricultural research on a competitive basis amongst public and private research providers using funds from levies on production and matching Commonwealth grants (up to 0.5 percent of the value of production). In 2003 total expenditure by the RDCs was $461 m (nominal) which is approaching half the total public expenditure on agricultural R&D, although it probably overstates RDC funding for agricultural 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 the LWA for example). In the 80s RDC funding only amounted to about 15 percent of total public expenditure on agricultural R&D.

4.3 Agricultural R&D in New Zealand, Australia and Elsewhere

The most recent international review of agricultural R&D is that by Pardey and Beintema (2001) based on 1995 data. At that time, investment in agricultural research worldwide was still growing but in developed countries the rate of growth had slowed from 2.2 percent in the 80s to 0.2 percent. In 'dollar' terms, expenditure on agricultural research in 1995 in developing countries exceeded that in developed countries with China, India and Brazil emerging as major investors. Public research intensity in developed countries was 2.64 percent and total agricultural research intensity was about 5.5 percent. Research intensity in less developed countries was often very low such that average public research intensity in the countries Pardey and Beintema reviewed was just over one percent.

New Zealand and Australia are similar in the importance of the public sector to agricultural research investment. In both countries the public sector provides more than 80 percent of funds, much higher than in other developed countries. However there are important differences. Unlike many developed countries, including Australia, public sector investment has been growing in New Zealand over the last decade whereas it has been stagnant elsewhere. However public research intensity in New Zealand at about 1.5 percent is low relative to other developed countries (2.6) percent and relative to Australia (4% in recent years).

5. Econometric Analyses of Returns to Research in New Zealand and Australia

Econometric analyses of returns to research are reviewed in Hall and Scobie (2006) and in Mullen and Crean (2006b). The theory and methodology for estimating the link between research and TFP are reviewed in these papers and in Alston, Norton and Pardey (1995). Empirical analyses of the link between research investment and productivity growth are 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 which yields a flow of benefits to producers and consumers over many years.

A key issue has been how best to construct the stock of knowledge variable. Typically it is constructed as a weighted sum of past expenditures on R&D where key parameters such as the length and shape of the R&D lag profile are imposed rather than estimated.

The approach of most empirical studies has been to regress an index of total factor productivity, TFP, against several explanatory variables including a stock of knowledge variable. Other explanatory variable include weather, the education level of farmers, the terms of trade, investment in extension and foreign investment in research to capture 'spillins'. Other factors influencing productivity growth that are often ignored or subsumed in a time trend are changes in communications, transport etc.

This estimation strategy presumes there is an underlying long term relationship such that investment in research gives rise to increased productivity, that both the dependent and independent variables are stationary in more technical terms. When this assumption is violated then the problem of spurious regression presents itself (Bannerjee et al. 1993).

5.1 Australian Studies

In an early study (not of an econometric nature), Scobie, Mullen and Alston (1991a) synthesised a production function linking expenditure on research with productivity growth in the Australian wool industry. Gauging public investment in wool production R&D to have been about $40m in 1985, they estimated that the average internal rate of return to Australia might be in the order of 9.5 percent and the internal rate of return to woolgrowers might be in the order of 25 percent. 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.

Until recent work by the Productivity Commission and by Black (2004 a &b), the only econometric studies of the returns to agricultural research in Australia had been reported in a series of papers co-authored by Mullen, notably Mullen and Cox (1995) but also Cox, Mullen and Hu (1997), Mullen, Morrison and Strappazzon (1996) and Mullen and Strappazzon (1996).

The focus of this research was on public investment in research and extension in broadacre agriculture and productivity growth in broadacre agriculture. Initially Mullen's dataset extended from 1953 to 1988 but was later extended to 1994. Mullen and Cox (1995) estimated that the returns to research in broadacre agriculture in Australia may be in the order of fifteen to forty percent. The low rate was associated with a 35 year research profile and the high rate with a 16 year research profile. These rates of return were larger than the rates of return hypothesised by Scobie, Mullen and Alston (1991b) but smaller than some of the estimates of the return to research in other countries noted above. Mullen and Cox (1995) concluded that: 'Given the uncertainty associated with any of these estimates, the differences are small and hence it is difficult to assert that Australia's agricultural research industry performs better or worse than the research industries of other countries……. We follow Fox (1985) in arguing that there is little evidence of a wide divergence between the return from public investments and the social returns from private investments. Hence there does not appear to be a strong basis for arguing either that there is under- or over- investment by government in agricultural research and extension in Australia. (p. 125)'.

The Productivity Commission (Shanks and Zheng 2006) undertook a comprehensive analysis of the relationship between investment in research, particularly by the business sector, and productivity growth in the Australian economy. Their opening warning was:

'However, despite the advances in data and methods, our research was unable to find a consistent robust measure of the impact of R&D on productivity. In addition to core data measurement issues, the most likely explanation is that the extra data period includes disruptions or 'shocks' to the relationship between R&D and productivity performance in Australia. This has frustrated attempts to clearly determine the magnitude of any long-term relationship between R&D and Australian productivity…… A major message from all the analysis is that, at least for the time being, empirical estimates of the effects of R&D on Australian productivity are unreliable. Any assessment therefore requires a high degree of judgment (p. xxv)'.

Part of the Productivity Commission brief was to assess the relationship between research investment and productivity growth at an industry level for agriculture, manufacturing, mining and wholesale and retail trade. Hence, Shanks and Zheng analysed the relationship between public (as opposed to business investment for other sectors) investment in agricultural research and productivity growth in agriculture (including forestry and fisheries) using ABS data. Their preferred model was a regression of the change in the log of TFP against public research intensity, use of public infrastructure (significant in all models), rainfall and farmers terms of trade. They estimated that productivity in the agricultural sector grew at the rate of 1.9 percent over their observation period from 1974-75 to 2002-2003. They used a permanent inventory method to construct a stock of knowledge variable from data on investment in research. The concern with the PIM approach is that research investment in the current period makes the greatest contribution to the stock of knowledge when the general expectation is that there is a lag of at least several years between investment in research and a change in the stock of knowledge in use.

It was surprising that the stock of foreign knowledge was not significant in the agriculture model but it was unclear whether the stock of foreign knowledge variable was that used for the whole economy or had been specifically constructed for agriculture.

Shanks and Zheng estimated that the rate of return to business investment at the level of the entire market economy was 50 percent. Their preferred estimate of the rate of return to public investment in agriculture was 24 percent, relatively precisely estimated in a range of from 1 to 46 percent, and within the range suggested by the earlier research of Mullen and Cox[2](1995). The estimated rate of return in the manufacturing sector was 50 percent and the returns to the mining and wholesale and retail sectors were 159 percent and 438 percent with very wide confidence intervals.

5.2 New Zealand Analyses

New Zealand analyses of the returns to research are reviewed in detail in Hall and Scobie (2006). The most significant of the earlier studies was that by Scobie and Eveleens (1987). They used data from 1926 to 1984 and found that research contributed significantly to the growth of productivity in the agricultural sector. They concluded that this contribution comes over an extended period of 23 years on

[2] 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 percent.

average, generating a real rate of return of 30 percent per year. However, they were unable to isolate the separate effects of research investment, extension efforts and the contribution from human capital.

Hall and Scobie (2006) using data from 1926, reported an even more exhaustive testing of alternative specifications of the relationship between research and productivity growth in New Zealand agriculture. They tested PIM, Kyock and Almon approaches to constructing a stock of knowledge variable. These approaches differ particularly in how current research is weighted in constructing the knowledge stock and in whether the lag profile is estimated or imposed. They attempted to distinguish the separate effects of private and public investment in research and were also particularly interested in the contribution of 'foreign' technology to New Zealand agriculture (proxied by US patents). The impact of other variables such as weather, education and extension on productivity were considered, as was the impact of policy reform in the 80s.

Hall and Scobie (2006) found that foreign investment in research was a significant variable in many specifications. However, the impact of domestic research was not stable across alternative specifications. In these circumstances it was hardly surprising that due to multicollinearity, the separate effects of public and private research in New Zealand could not be precisely estimated. Their estimates of the rate of return to domestic investment in research ranged from 0 to 354 percent, indicating little convergence across the methods. In both the Koyck and PIM models, they found a significant effect from domestic R&D in most specifications. Their "preferred" model, based on significant contributions to productivity of both foreign and domestic stocks of knowledge, yielded a rate of return of 17% p.a. to investment in domestic R&D. However, when they used Almon distributed lags they found a negative and significant coefficient on domestic R&D. The key message that can be drawn from these results is that the estimates of the contribution of domestic R&D are very sensitive to the method and specification adopted, and that even with lengthy time series data it is not easy to isolate the effect.

Hall and Scobie concluded that while foreign investment in research was likely to have a significant impact on productivity growth in a small open economy like New Zealand, it was also highly probable that a domestic research sector was required to identify relevant foreign knowledge and adapt it to the New Zealand environment, despite the difficulties they encountered in precisely estimating the contribution of domestic investment in research.

5.3 Importance of 'Spillovers' in Agricultural Research

A 'hot spot' of interest in the returns to research literature is the significance of 'spillovers'. Agricultural research creates knowledge some of which has only local implications but some of which 'spills over' to neighbouring districts, States and countries. These knowledge 'spillovers' have implications for estimating the relationship between productivity growth and investment in research and for research policy. Given the relatively small size of their agricultural sectors, knowledge 'spillovers' are likely to be significant for Australia and New Zealand and a proper area of concern for science policy

Few econometric studies have been able to isolate the importance of ‘spillovers’ of agricultural research across State and national borders. In Australian studies, Mullen and co-authors did not attempt to estimate returns from research at a State level nor did they attempt to analyse the contribution of foreign R&D. Shanks and Zheng were not successful in their attempts to estimate the influence of foreign R&D. Hall and Scobie did find that foreign knowledge was consistently an important determinant of TFP in New Zealand agriculture.

Nevertheless, while the empirical evidence is scarce, there would be little disagreement with the view that the information generated by agricultural research ‘spills over’ across state and national borders. Several studies in America including those by Huffman and Evenson (1993) and Alston (2002) found empirical evidence that ‘spillovers’ from public research between US States were an important source of productivity growth. For example, Alston estimated that an increase in public research in California of $1 in 1950 generated $26.69 of benefits within California and $23.02 of benefits elsewhere in the US or $43.71 in total. This compared with the return for all US States of $49.71 from a $1 increase in federal research expenditure suggesting further gains from can be had from reorganising the funding of research to equalise these marginal gains.

Some evidence of international ‘spillovers’ is provided by commodity specific studies. Of particular relevance here is a series of studies by Brennan and co-authors who have estimated significant benefits to Australia, both to consumers and to producers, from some of Australia’s investment in research at CGIAR (Consultative Group on International Agricultural Research) centres such as CIMMYT (Brennan and Fox 1998) and (Brennan and Quade 2004)), ICARDA (Brennan et al. 2003), ICRISAT (Brennan and Bantilan 2003) and IRRI (Brennan et al. 1997).

Alston (2002) concluded that up to one half of productivity gains in a state or nation may arise from research conducted elsewhere. As noted ‘spillovers’ of this magnitude detract from our confidence in econometric studies which do not adequately account for them. More importantly, potential ‘spillovers’ of this magnitude have important implications for research policy. On the one hand, states or nations undertaking research have little incentive to recognise benefits accruing outside their boundaries in allocating research resources and from a national or international perspective underinvestment in research may result. On the other hand, states or nations may overinvest in some types of research best done at a higher geopolitical level because the agroclimatic area to which the research applies is larger than a state or nation. In this case, states or nations may benefit by targeting potential ‘spillins’, noting the view of Hall and Scobie that a domestic research capability is still needed to adapt these knowledge ‘spillins’ to local conditions. Clearly, as discussed further below, there seem significant payoffs to managing and coordinating agricultural research in ways that recognise these ‘spillovers’.

6. Making Sense of if all

If research does cause productivity then the relationship is likely to be in the form of one between some long term underlying rate of TFP and a long term rate of research investment[3]. The short term variations observed in TFP are unlikely to be responses to short term fluctuations in R&D given the long lags involved in changing the stock of knowledge in use. Short term fluctuations in TFP are most likely responses to weather and prices over periods of several years but are likely also to reflect economy wide influences over medium term periods. Any assessment of the long term trend in TFP must be made from lengthy TFP series, although this long term trend may change.

The long term trend in productivity, which we argue is in the vicinity of 2.5 percent per year for broadacre agriculture in Australia, reflects the influence of slow moving factors like research induced technical change, the education levels of farmers, and the state of public infrastructure in the form of transport and communications. Another slow moving variable is farm size but while there is evidence that larger farms have a faster rate of productivity growth, Mullen and Cox (1996) found that using a TFP measure which accounted for scale effects gave no discernible difference in the estimated rate of productivity growth at the level of Australian broadacre agriculture.

Acknowledging its speculative nature, we make some assessment of how this underlying rate productivity growth may be decomposed. In our view, perhaps up to one half of one percent can be attributed to factors such as public infrastructure and education levels of farms. Scobie, Mullen and Alston (1991) suggested that in the absence of technical change, the underlying rate of productivity growth in the Australian wool industry might be one percent, twice the rate we are now suggesting. Since Scobie et al.'s research, rates of productivity growth of less than one percent have been observed for specialist livestock producers, particularly wool producers, and technical regression over long periods seems to us unlikely, hence the halving of the underlying rate.

The literature suggests that the largest component of TFP can be attributed to technical change. Technical change, accounting for two percent, arises from public and private research investments in research and extension where a significant component of both activities is related to the adaptation of foreign knowledge 'spillins'.

The contribution of foreign knowledge to productivity growth means that rates of return to research which only include Australian investment in research will be overestimated to some extent, while acknowledging that Australian R&D resources are required to adapt foreign knowledge to Australian conditions[4]. In the absence of fully specified econometric models to provide estimates of the contribution to TFP in Australia from both domestic and foreign research investments, an arbitrary attribution of TFP between these sources can be attempted.

As noted above, Alston has argued that, certainly between states but even between nations, foreign research may be as important as domestic research. The extent of

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[3] Perhaps Friedman's terminology of permanent income and consumption could be adapted to permanent levels of TFP and research investment. In fact models with lag TFP as an explanatory variable can be cast in this mould.

[4] They will be understated from a global perspective because the benefits other nations received from Australian R&D are not recognised.

spillovers depends on similarities in climate and land resources and in the nature of agriculture. Australia's climate and its dependence on broadacre agriculture, particularly a unique wool industry, suggests that foreign spillovers while still important to Australia, consider chemicals and machinery for example, may be less important than domestic knowledge. Hence in Australian broadacre agriculture, domestic R&D activities may be responsible for productivity growth in the order of 1.2 percent and foreign 'spillins' for 0.8 percent, a 60:40 split.

Two scenarios for investment analysis are to relate Australian R&D investment first, to productivity growth at the rate of 2.0 percent and second, to productivity growth at the rate of 1.2 percent. These scenarios 'bracket' the potential benefits from domestic research benefits. Under our assumptions domestic research generates productivity gains of at least 1.2 percent but no doubt some domestic research is used to capture the benefits from foreign 'spillovers'. At the extreme domestic research is required to capture any of these foreign benefits, hence the 2.0 percent scenario.

Figure 11 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. This decomposition is based on the assumption that in recent decades, domestic R&D has advanced productivity at the rate of 1.2 percent per year, foreign R&D contributed 0.8 percent, leaving other domestic sources contributing 0.5 percent. We have assumed that prior to 1969 productivity grew at 80 percent of its current rate and have made pro rata adjustments. Almost half the value of output in 2003 can be attributed to new technology generated by domestic research since 1953. At a real rate of interest of 4%, the compound value of the stream of benefits from domestic research from 1953 to 2003 is $A878b (all in 2004 $s).

As pointed out in Mullen (2002) the benefits of 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 percent of benefits or about $700 b in this case.

Mullen, Lee and Wrigley (1996) assembled a database on public investment in research and extension in Australia from 1953 to 1994. This database has since been extended to 2003 using ABS data. It was backcast to 1927 to allow the estimation of models with research lags of 26 years in order for IRRs to be estimated over a similar period to the New Zealand analysis. The compound value of public investment in research between 1953 and 2003 has been $64.5b and the estimated total back to 1927 has been $75.7b (all in 2004 $s). Mullen (2002) estimated that private R&D in Australia and public extension expenditure might add a further 40 percent to domestic R&D investment, giving a total of $90.3b since 1953 and $106b since 1926.

This data on benefits and costs allows an indicative assessment of returns from research in Australian agriculture under a number of scenarios (Table 5).

Under the most optimistic scenario where all productivity gains at the rate of 2.0 percent are attributed to domestic research since 1927, the internal rate of return (IRR) is 21% and the benefit/cost ratio is 17.5:1[5]. If we assume that productivity gains from domestic public and private research and extension result in productivity gains of 1.2 percent then the IRR is 17% and the benefit cost ratio is 8.3:1. In both these scenarios, benefits from this stream of research investments accruing after 2003 for potentially many more years are ignored.

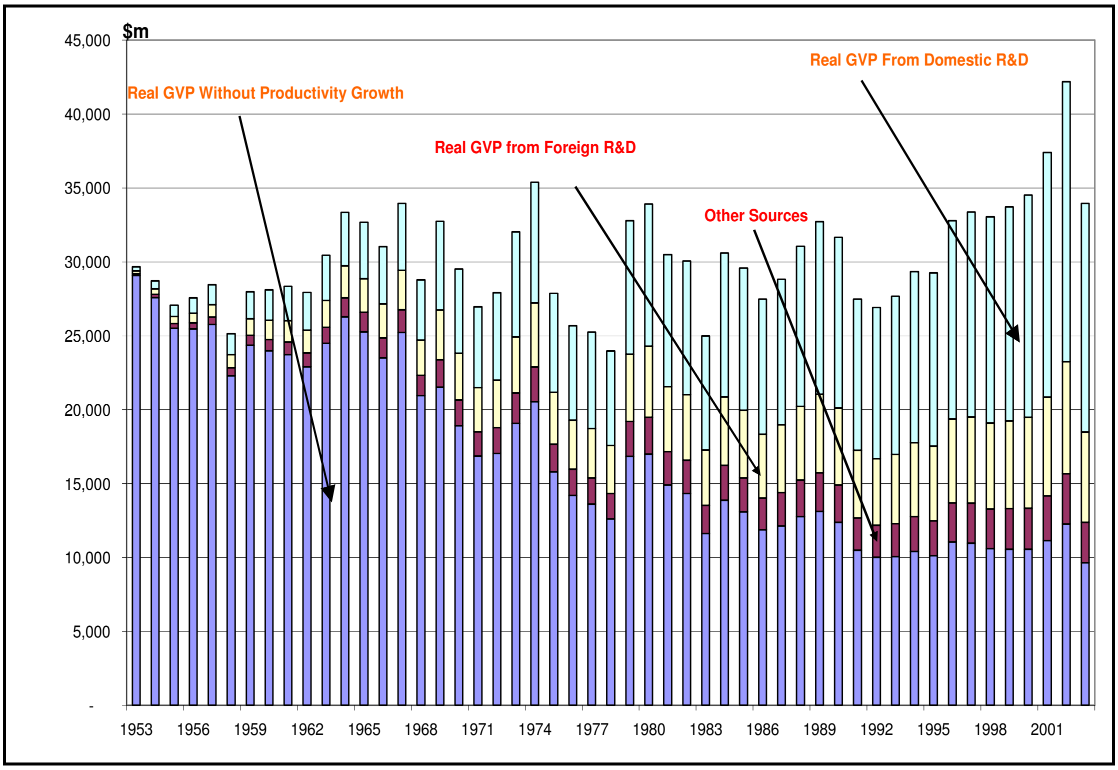
These IRRs based on gross benefits are most comparable to those normally reported in the literature. Table 5 reports IRRs and benefit cost ratios for scenarios in which the leakage of benefits to non-residents of Australia is recognised. They are a little lower. All estimated IRRs are within the range first suggested by Mullen and Cox, albeit at the lower end of this range.

Table 5: Rates of return to research in Australian agriculture

Scenario:	**B/C ratio**	**IRR**
Productivity growth @ 2.0%:		
(a) Public research only		
R&D from 1927	17.5	21%
R&D from 1953	20.5	
(b) Public + private research + extension		
R&D from 1927	12.5	19%
R&D from 1953	14.6	
(c) (b) + Gains to Australians only (80%)		
R&D from 1927	10.0	18%
R&D from 1953	11.7	
Productivity growth @ 1.2%:		
(a) Public research only		
R&D from 1927	11.6	18%
R&D from 1953	13.6	
(b) Public + private research + extension		
R&D from 1927	8.3	17%
R&D from 1953	9.7	
(c) (b) + Gains to Australians only (80%)		
R&D from 1927	6.6	16%
R&D from 1953	7.8	

[5] IRRs were estimated by using a cost stream from 1927 to 2003 and a benefit stream from 1953 to 2003. They are sensitive to this assumption.

Figure 11: Sources of Productivity Growth in Australian Agriculture



We have conducted a similar assessment of likely returns to agricultural research in New Zealand for the period 1953 to 2001. We have assumed that agricultural productivity grew at the rate of 1.4 percent from 1953 to 1985 and at the rate of 1.8 percent from 1986 to 2001. We have assumed that the underlying rate of productivity growth from investment in public infrastructure and education has been about 0.4 percent per year leaving 1.4% per year (since 1986) coming from private and public domestic research and extension and from foreign knowledge 'spillins'. We have assumed that half the research knowledge stock comes from foreign sources leaving the rate of productivity growth attributable to domestic R&D in the order of 0.7 percent for the 1986 – 2001 period and 0.5 percent between 1953 and 1985.

The consequences of these assumptions are presented in Figure 12 and Table 6. At a real rate of interest of 4%, the compound value of the stream of benefits from domestic research from 1953 to 2001 is $NZ95b (all in 2004 $s) out of total benefits from all sources of productivity of $NZ 228b.

Using Hall and Scobie's R&D dataset, the compound value of total public and private investment in research between 1927 and 2001 has been $NZ 25.6b ($NZ 23.5 from public sources). Since 1953 total investment has been $NZ 21.4b.

Figure 12: Sources of Productivity Growth in New Zealand Agriculture

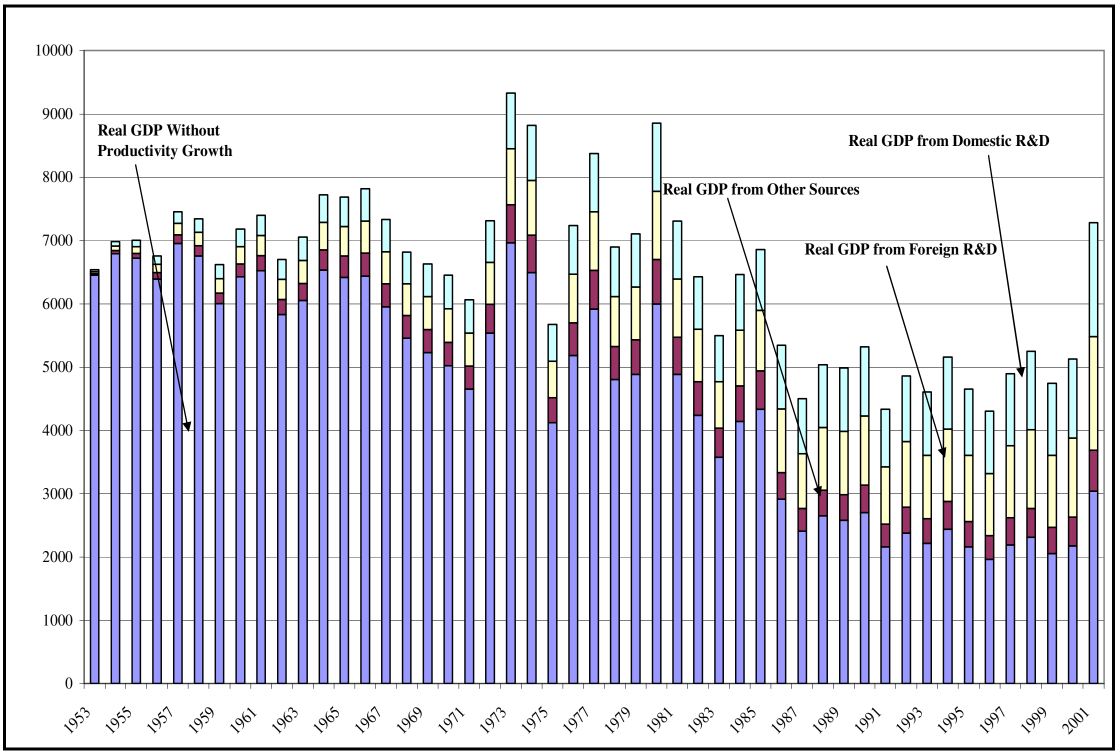


Table 6: Some Returns to Research Scenarios for New Zealand Agriculture

Scenario:	B/C ratio	IRR
Productivity growth @ 1.4%:		
(a) Public research only		
R&D from 1927	7.5	17.9%
R&D from 1953	9.0	
(b) Public + private research + extension		
R&D from 1927	6.8	17%
R&D from 1953	8.2	
(c) (b) + Gains to New Zealand only (80%)		
R&D from 1927	5.5	16.3%
R&D from 1953	6.6	
Productivity growth @ 0.7%:		
(a) Public research only		
R&D from 1927	4.0	14.5%
R&D from 1953	4.9	
(b) Public + private research + extension		
R&D from 1927	3.7	14.1%
R&D from 1953	4.4	
(c) (b) + Gains to New Zealand only (80%)		
R&D from 1927	3.2	13%
R&D from 1953	3.9	

In Table 6 are reported various investment scenarios concerning domestic public and total research and for scenarios in which all gains are attributed to domestic research compared with scenarios in which significant gains are attributed to other sources in the domestic economy and to foreign sources. Under the most optimistic scenario where all productivity gains at the rate of 1.4 percent are attributed to domestic public research since 1927, the internal rate of return (IRR) is 17.9% and the benefit/cost ratio is 7.5:1. If we assume that productivity gains from domestic public and private research and extension result in productivity gains of 0.7 percent then the IRR is 14% and the benefit cost ratio is 3.7:1. In both these scenarios, benefits from this stream of research investments accruing after 2001 for potentially many more years are ignored.

7. Conclusions

Productivity growth in Australian agriculture compares favourably with both other sectors of the Australian economy and agricultural sectors in other countries. New Zealand has performed less favourably with productivity growth around two thirds that of Australia. This suggests a gain in comparative advantage for Australian agriculture whilst New Zealand may be losing ground..

It would be foolhardy to make definitive judgements about the sources of Australia's apparent success, particularly the contribution of public investment in research. In Australia real investment in research can at best be described as unchanging since the late 80s. In New Zealand investment was flat for two decades from the mid 70s but has recently risen strongly. Nevertheless, the intensity of Australia's public investment in agricultural research (the ratio of investment to agricultural GDP) has been more than twice that in New Zealand and above average for OECD countries, and the obvious question that arises is whether New Zealand should be increasing its investment in research.

We find no definitive econometric evidence that the returns from investment in research in New Zealand is much higher than in Australia, as would be expected if New Zealand was underinvesting in research. In fact financial analysis we undertook based on our judgement about rates of productivity growth that could be attributed to domestic research in Australia and New Zealand suggests that returns to research may have been higher in Australia than New Zealand.

Of course decisions about public investments in agricultural research need to consider the opportunity cost of investments elsewhere in the community but information about these opportunity costs seems more scarce than information about the returns from public investments in agricultural research. In both Australia and New Zealand if agricultural research remained as efficient as in the past, then current rates of agricultural research remain a good investment but the hypothesis that there is severe underinvestment in either country is difficult to support empirically.

Perhaps the relative success of Australia can partly be explained by the different structure and size of agriculture in the two countries. Australia's larger agricultural sector may mean greater profitable research opportunities. In addition, extensive cropping has a larger share of total production in Australia than New Zealand. At least in developed countries the evidence suggest that productivity gains have been larger in annual cropping industries than in livestock and other industries with long production cycles. Similarly there is some evidence that the returns from research are larger from cropping research than livestock research. In Australia there has been a significant shift in research resources towards plant research. A priori there do not appear to be strong reasons why the flow of new cropping technologies should necessarily continue to exceed the flow of new livestock technologies as has been the case in recent decades, although longer breeding cycles impose a cost.

Other important drivers of agricultural productivity include the education levels of farmers, investment in public infrastructure in the form of transport and communications and the degree of regulation in factor and product markets. From our experience there seems little evidence that differences in these factors might explain differences in productivity between New Zealand and Australia.

Both Australia and New Zealand are small economies relying heavily on export markets. These markets do not seem to be attractive to firms investing in research into embodied technologies in the form of chemicals, machinery and biotechnology. 'Spillins' of foreign technology may contribute up to one half of technical change in these two countries. In Australia there are 'spillovers' between States and no doubt in New Zealand there are regional research institutes. Science policy and the management of research resources must actively seek to exploit such 'spillovers' by encouraging collaboration between research institutions and rationalising investment. The public good characteristics of research make it more difficult at this international level both to estimate the benefits from research and to design equitable and efficient funding mechanisms, as it is at a national level.

Additionally both countries have an incentive to further develop mechanisms whereby industry has an incentive to invest profitably in research by exploiting the non rival nature of R&D while at the same time limiting 'free rider' problems.

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