The Role of R&D in Productivity Growth: The Case of Agriculture in New Zealand: 1927 to 2001

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Abstract

Productivity growth is a key determinant of rising living standards. The agricultural sector has been an important contributor to the overall growth of productivity in New Zealand. The average rate of multifactor productivity growth in agriculture from 1926-27 to 2000-01 was 1.8%. We find evidence that this rate has been increasing especially since the reforms of the 1980s. This paper estimates the contribution that R&D has made to agricultural productivity. It develops a theoretical framework based on the stock of knowledge available to producers. This model incorporates foreign stocks of knowledge and the spill-in effect for New Zealand. The estimation allows for extended lag effects of research spending on productivity.

We find that foreign knowledge is consistently an important factor in explaining the growth of productivity. It appears that the agricultural sector relies heavily on drawing on the foreign stock of knowledge generated off-shore. The contribution of domestic knowledge generated by New Zealand's investment in R&D is less clear cut. However, there is typically a significant positive relation between domestic knowledge and the growth of productivity. We find a wide range of estimates of the return to domestic R&D. The results are sensitive to the type of model used and the specification of the variables. Based on our preferred model we estimate that investment in domestic R&D has generated an annual rate of return of 17%.

The results underscore the importance of foreign knowledge in a small open economy. The very existence of foreign knowledge may be a necessary condition for achieving productivity growth in a small open economy. However in no way could it be argued that this was sufficient. Having a domestic capability that can receive and process the spill-ins from foreign knowledge is vital to capturing the benefits. The challenge is to be able to isolate those effects from aggregate data for the agricultural sector. In that task we claim only modest success.

JEL CLASSIFICATION	O30 Technological Change O40 Economic Growth and Aggregate Productivity
KEYWORDS	New Zealand; technological change; R&D; productivity; economics of knowledge; spillovers; rates of return; agriculture

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> "…. it is essential for scientists, however distasteful the task may be, to prove to the farm community the value of their discoveries in terms of pounds, shillings and pence."
>
> Lord Bledisloe
> Address to the Wellington Philosophical Society
> 26 October 1932

1 Introduction

Productivity growth is seen as a key element in both improving the relative income in New Zealand compared to other OECD countries and contributing to achieving higher living standards. Agriculture remains an important sector of the economy and productivity growth in agriculture has been an important contributor to improved performance in the overall productivity growth in New Zealand (Black, Guy and McLellan 2003).

Productivity improvements stem from many sources, but increases in the stock of knowledge are widely acknowledged as one strategy for enhancing productivity growth. Formal investment in R&D is one avenue through which to increase this stock of knowledge. In both the private and public sectors, decisions must be made about allocating resources toward investment in the generation of new knowledge.[1] Public investment in R&D represents a major share of total national R&D expenditure in New Zealand.

In order to determine the appropriate policy settings, a necessary condition is to understand the relationship between investment in R&D and the growth of productivity. The primary objective of this paper is to develop a conceptual model, derive a formal model that can be tested with historical data and thereby generate estimates of the impact of R&D on productivity growth in the agricultural sector. From this we can then estimate the rate of return to investment in R&D.

One of the critical issues in analysing the impact of investment in R&D is the need to recognise the long lags involved. Expenditure on a R&D project today might result in the

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[1] A secondary issue arises about the division of those costs between the public and private sectors. We do not address this issue in this paper.

generation of new knowledge and its adoption into production systems a decade or more from now. Hence investments made in R&D today arguably will not contribute to measured productivity growth until some time in the future. For this reason we have developed time series data for the key variables from 1926-27 to 2000-01.

As a consequence however, it is inevitable that there will have been important changes in the institutional environment. For many years agriculture was heavily taxed in New Zealand as a result of industrial protection policies and labour laws. The economic liberalisation of the 1980s had major implications for the agricultural sector. Furthermore, the arrangements for the conduct and funding of research have evolved through a number of forms, each having implications for the level and allocation of research expenditures.

A second critical feature given emphasis in this study concerns the contribution of knowledge generated offshore to productivity growth in New Zealand. Arguably a great deal of the innovation that takes place in a small open economy such as New Zealand comes not from domestic investment in knowledge, but rather from that which can be "borrowed" from offshore. To accurately assess the contribution of domestic investment in R&D to productivity growth, we need to isolate that part which is attributable to the borrowed knowledge, often referred to as the foreign spill-in.

The paper is organised as follows: Section 2 discusses the importance of the agricultural sector to the economy; Section 3 discusses the methodology and findings of the empirical literature; Section 4 reviews the theory behind and evidence on knowledge spillovers; Section 5 links the stock of knowledge to productivity and sets out our empirical specification; and section 6 discusses our results.

2 Agricultural R&D and the Contribution to Overall Productivity Growth

This section first considers the agricultural research intensity compared with Australia, and then reviews the growth performance of New Zealand's agricultural sector over time and compared with other industries.

2.1 Agricultural R&D

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 pair 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.[2]

Figure 1 shows the level of public spending on agricultural R&D in New Zealand compared to in Australia over the period 1975 to 2001, as a percentage of agricultural

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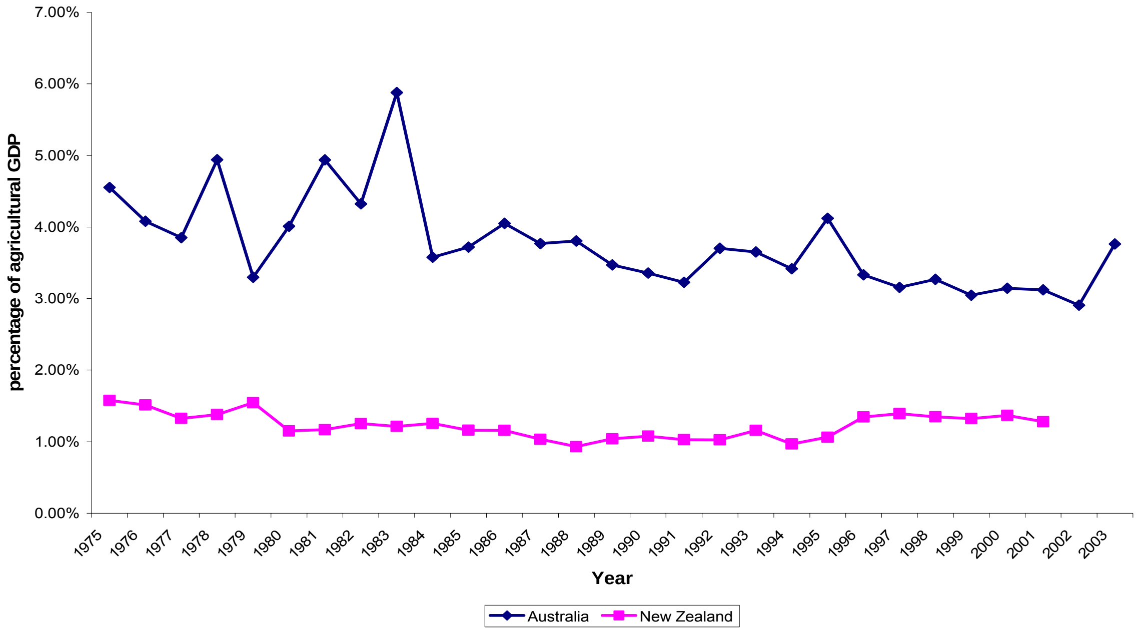
[2] For further details see Jacobsen and Scobie (1999)

GDP. Australia has invested a higher percentage than New Zealand throughout the sample period, with a high in 1983 of 5.9%. Since then the trend has been one of declining public R&D intensity in Australia, although from 2002 to 2003 there was an increase from 2.9% to 3.8%.

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



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

2.2 Productivity Growth

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. The primary sector's recent growth performance is outlined in Table 1 below.

Table 1: Recent Growth Performance: New Zealand: 1988 – 2004.

Sector	Annual average growth rates
Whole Economy	2.5%
Primary Sector	2.5%
Made up of:	
Agriculture	2.1%
Fishing	1.7%
Forestry and logging	5.0%

Data Source: Statistics New Zealand.

Primary sector average annual growth for the period 1988-2004 has been similar in New Zealand to that in Australia (see Table 2 below). The agricultural sector has also shown a similar growth experience over this period for both countries, with average annual GDP growth of 2.5% in New Zealand and 2.8% in Australia.

In Australia, the primary sector contributed 3.4% of total GDP (to the year ended June 2004 in 2002/03 prices), with the agricultural sector accounting for 93% of the total primary sector.

Table 2: Recent Growth Performance: Australia: 1988 – 2004.

Sector	Annual average growth rates
Whole Economy	3.4%
Primary Sector	2.9%
Made up of:	
Agriculture	2.8%
Forestry and Fishing	3.6%

Data Source: Australian Bureau of Statistics.

While the overall rate of growth of the primary sector in New Zealand has matched that of the economy as a whole, the productivity performance of the primary sector in New Zealand has been impressive (see Table 3). The primary sector had one of the highest average annual growth rates of labour productivity over the period 1988 to 2004 (with only the Transport and communications and the Electricity, gas and water sectors achieving higher growth).[3] This labour productivity performance was sourced equally from capital deepening and multifactor productivity growth, based on a growth accounting decomposition.

While the primary sector had one of the highest average annual labour productivity growth rates amongst industries in New Zealand (at 3.0%), this was still markedly less than primary sector labour productivity growth in Australia, which averaged 4.1% between 1988 and 2004.

We can also contrast the overall multifactor productivity growth for the primary sector of New Zealand and Australia. 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 3). In contrast, the comparable rate of growth in multifactor productivity in the Australian primary sector was 3.8% (Productivity Commission 2005). It is worth noting that this higher multifactor productivity growth in the primary sector was accompanied by a higher public R&D intensity in Australian agriculture (recall Figure 1).

Unfortunately, hours data is not available for the agricultural sector in New Zealand alone. Instead we have constructed a multifactor productivity series using employment numbers back to 1926-27 (see Figure 2). From 1988 to 2001 multifactor productivity in the agricultural sector grew by 1.3%, compared with multifactor productivity growth for the whole business sector of 1.4%. Over our entire sample period, average multifactor productivity growth in the agricultural sector has increased. Between 1927 and 1956, annual MFP growth averaged 1%, increasing to an average of 2.2% between 1957 and

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[3] Table 3 is an updated version of that presented in Black et al (2003).

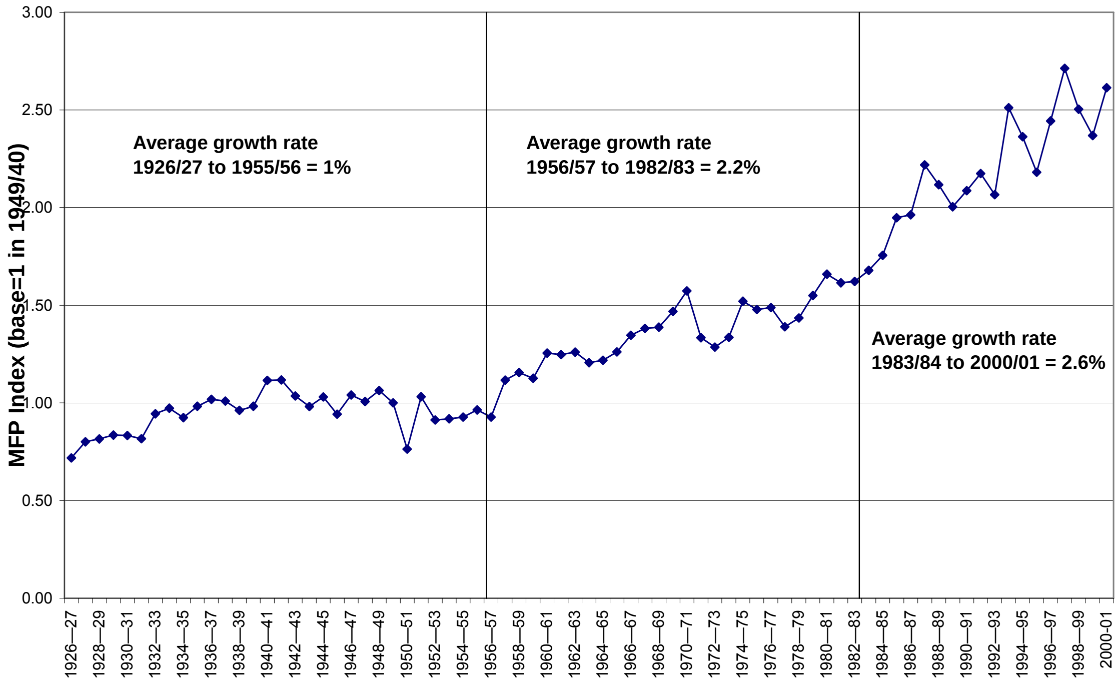
1983. From 1984 onwards MFP growth further increased to an annual average rate of 2.6%.

Table 3: Growth Accounting Decomposition 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%

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 2 - Agricultural Multifactor Productivity 1927-2001



3 Literature Review and Existing Estimates

3.1 Methodology

Since Solow's (1957) decomposition of economic growth, many empirical studies have tried to determine the importance of various factors which underlie the productivity residual. Investment in R&D has been one of these factors.[4]

The two main approaches that have been used in the empirical literature to assess the importance of R&D to productivity growth are econometric analysis and case studies. The main disadvantage of the case study approach is its lack of representativeness. Since they only tend to concentrate on selected successful projects, it is not possible to draw general conclusions from their findings (for an example of the case study approach see Griliches (1958)).

Most econometric studies use either the production function approach (for example, Guellec and van Pottelsberghe 2001) or the cost function approach (for example, (Rouvinen 2002)). The two approaches are related – it is possible to derive a cost function from a production function, and vice versa – but they use different statistical methods and have different data requirements. Here we use the production function approach due to data availability.

Within the production function framework there are two alternative approaches: estimating the production function directly (i.e. regressing output or value added on conventional inputs plus R&D), or regressing multifactor productivity (MFP) on R&D.

Most of these econometric studies[5] have adopted the general version of the Cobb-Douglas production function, which in addition to the traditional inputs also includes knowledge capital:

$$Y_t = AL_t^{\alpha} C_t^{\phi} K_t^{\beta} X_t^{\delta} \qquad (1)$$

where Y is value added, A is a constant, L is labour, C is physical capital, K is the domestic R&D stock and X is the external stock of R&D available (spillover pool).

Usually, equation (1) is taken in logarithms to enable the estimation of the parameters of interest: β and δ, or the elasticity of output with respect to domestic and foreign R&D respectively. This leads to the following linear regression model:

$$y_t = a + \alpha l_t + \phi c_t + \beta k_t + \delta x_t + u_t \qquad (2)$$

where lower case letters denote logarithms of variables and u_t is a random error term.

Alternatively, if constant returns to scale are assumed, then equation (2) can be rewritten in terms of multifactor productivity (MFP) as:

$$mfp_t = a + \beta k_t + \delta x_t + u_t \qquad (3)$$

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[4] See for example Guellec and van Pottelsberghe (2004) and Frantzen (2000).

[5] For a comprehensive discussion of the econometric measurement of the effects of research see Alston et al (1995).

Thus the elasticity of MFP with respect to the stock of domestic R&D, β, estimated by equation (3), is equal to the elasticity of output with respect to the stock of domestic R&D.

Some studies choose instead to directly estimate the rate of return rather than the elasticity. By taking first differences and disregarding the depreciation of R&D, i.e., $\Delta k = \Delta K / K = RD / K$ (where RD represents R&D expenditure), and applying the same transformations to the foreign R&D spillover stock, then we have:

$$\Delta mfp_t = \rho_1 (RD/Y)_t + \rho_2 (XD/Y)_t + u_t - u_{t-1} \tag{4}$$

where $\rho_1 = \partial Y / \partial K$ is the marginal product of the domestic R&D stock, or the rate of return to domestic R&D.[6]

Since $\beta = \frac{\partial Y}{\partial K}\frac{K}{Y}$, it can be seen that there is a direct relationship between β and ρ_1; either one can be derived from an estimate of the other. That is,

$$\hat{\beta} = \hat{\rho}_1 \frac{K}{Y} \tag{5}$$

3.2 Empirical Evidence

The expansive body of empirical literature estimating statistically the part of productivity growth that can be attributed to R&D activities has been surveyed by Wieser (2005).[7] He concludes that on average there is a large and significant impact of R&D on firm performance, although the estimated returns vary considerably: the average estimated rate of return was in the order of 29% for the papers surveyed (for those which were significant),[8] with a lower bound of 7% (Link 1981) and an upper bound of 69% (Sassenou 1988). Wieser also conducted a meta-analysis and found that the estimated returns do not differ significantly between countries, although estimated *elasticities* appear to differ significantly between countries.[9]

Many of the early empirical studies were conducted for the agricultural sector. Table 4 reproduces Table 1 in Griliches (1992), showing rates of return in the agricultural sector estimated from both case studies and regression studies. The table shows that evidence from the international literature implies a substantial return to R&D in the agricultural sector.

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[6] Note that β = $\frac{\partial Y}{\partial K}\frac{K}{Y}$, so that $\beta \Delta k$ becomes $\frac{\partial Y}{\partial K}\frac{K}{Y}\frac{RD}{K} = \rho_1 \frac{RD}{Y}$

[7] Note that he only surveys those studies which use microeconomic data at the firm level.

[8] Twenty nine of the fifty papers surveyed found significant estimates of the rate of return.

[9] The reason for this divergence between rates of return and elasticities is due to the different estimation techniques used - the rates of returns (marginal products) in the sampled studies are measured by estimating the change in TFP that result from a one dollar unit increase in R&D, while the elasticities are measured by estimating the percentage increase in TFP that occurs in response to a one percentage increase in R&D.

Table 4: Selected Estimates of Returns to R&D in the Agricultural Sector

	Commodity	Rates of Return to Public R&D
Griliches (1958)	Hybrid Corn	35-40
	Hybrid Sorghum	20
Peterson (1967)	Poultry	21-25
Schmitz-Seckler (1970)	Tomato Harvester	37-46
Griliches (1964)	Aggregate	35-40
Evenson (1968)	Aggregate	41-50
Knutson-Tweeten (1979)	Aggregate	28-47
Huffman-Evenson (1993)	Crops	45-62
	Livestock	11-83
	Aggregate	43-67

A more recent study by Mullen and Cox (1995) estimated that the return from public investment in Australian agricultural R&D between 1953 and 1994 may have been in the order of 15-40%. Cox et al (1997) found support for these earlier findings using non-parametric techniques.

A comprehensive meta-analysis of rates of return to agricultural R&D is found in Alston, Chan-Kang, Marra, Pardey and Wyatt (2000). Their results show that the returns from 1,886 estimates found in 292 studies averaged 100% per year for research, 85% for extension, 48% for studies that estimated the returns to research and extension jointly, and 81% for all the studies combined. The median rates were 48.0% for research, 62.9% for extension, 37.0% for joint research and extension and 44.3% across all studies.

Unfortunately the literature is not replete with estimates of the impact of R&D in New Zealand. As a consequence, much of the policy on public investment in R&D has been made without any explicit estimates of the return that might be expected from that investment.

Two early studies focussing on the agricultural sector in New Zealand are Dick, Toynbee and Vignaux (1967) and Scobie and Eveleens (1987). Dick et al evaluated the returns to four particular projects and attempted to generate an estimate of the long term aggregate payoff. However their study was based on data for only one decade, arguably not long enough to pick up the full impact of research. Scobie and Eveleens 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 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.

Johnson (2000b) used data from 1962 to 1998 to estimate the effect of private and public investment in R&D on total factor productivity in nine sectors of the New Zealand economy. In the case of agriculture he found that private R&D had a significant effect and a rate of return of 68.7%. In contrast, public spending on R&D reduced TFP in agriculture, with the consequence that the rate of return was -6.7% to public spending. In an attempt to allow for foreign spillovers, Johnson found that higher levels of R&D in the Australian business sector reduced the level of TFP in New Zealand agriculture.

In a more recent study Johnson et al. (2005) use panel data over the same nine industries in New Zealand from 1962-2002 and report on average a significant impact on productivity from private R&D, but no effect from public R&D. They also find evidence that private R&D in the Building, Forestry and Other services industries positively affects productivity in the rest of the economy, i.e. it generates positive spillovers.

In short, there is a wide range in the estimates of returns to R&D. This arises in part due to the choice of model. Regrettably, it has been increasingly apparent that the estimates of return found using econometric studies are indeed sensitive to the assumptions and type of model. This conclusion is reinforced by the results of the present study.

4 Spillovers

Griliches (1979) has identified two types of spillover effects. The first type refers to the effect of research performed in one industry or country improving technology in a second industry or country, and may occur without any economic transaction. The second type of spillover refers to inputs purchased by one industry or country from another industry or country, which embody quality improvements that are not fully appropriated by the selling industry. This is a problem of measuring capital equipment, materials and their prices correctly rather than a case of pure knowledge spillovers. While in principle these two notions are quite distinct, in practice it is very hard to distinguish between them empirically. We do not attempt to adjust our capital and intermediate inputs data for quality in this paper.

Spillovers occur at both the national and international level. National spillovers are composed of two distinct elements: the extent to which firms in the same industry as the firm undertaking the R&D benefit from the R&D (intra-industry spillovers), and from firms in other industries (inter-industry spillovers). Evidence from the empirical literature suggests that spillovers between firms in the same industry are small (Productivity Commission 1995). Direct estimates of their magnitude by Bernstein (1988), Bernstein and Nadiri (1989) and Suzuki (1993) yield estimates in the range of 2 to 15%. Estimates of inter-industry spillovers indicate that they appear to be more significant than intra-industry spillovers, with most estimates lying in the range of zero to 150% (Productivity Commission 1995).

The evidence on international spillovers is more mixed. Mancusi (2004) states that results from different empirical studies seem to suggest that knowledge spillovers are mainly intra-national rather than international in scope.[10] However, the paper finds that international spillovers are always effective in increasing innovation (proxied by patents). Estimates by Coe and Helpman (1995) also suggest that foreign R&D has beneficial effects on domestic productivity, and that these are stronger the more open an economy is to foreign trade. Their estimates indicate that foreign R&D has a larger impact in all of the smaller countries in their sample except Australia, Finland, Spain and New Zealand.[11]

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[10] See, for example, Jaffe el al (1993), Branstetter (1996), Maurseth and Verspagan (2002).

[11] Their sample consists of the G7 countries as well as 15 smaller countries.

After finding that the correlation between R&D and productivity is weaker in small countries than in the G7 countries, Englander and Gurney (1994) argue that this is consistent with the view that large countries benefit from their own R&D, while small countries benefit largely from R&D done elsewhere.[12]

On the other hand, Engelbrecht (1997) finds that foreign R&D spillovers have a mainly negative impact on TFP in countries with relatively small domestic R&D capital stocks as a proportion of GDP, including New Zealand and Australia.

What are the international channels through which knowledge spills over between countries? Coe and Helpman (1995) argue that the benefits from foreign R&D can be both direct and indirect. The direct benefits consist of learning about new technologies and materials, production processes, or organisational methods. The indirect benefits arise from imports of goods and services that have been developed by trade partners. However, Wieser (2001) states that insufficient data exists to adequately differentiate between disembodied and embodied R&D.

To deal with this, researchers typically assume that all knowledge transferred between countries is embodied R&D or that the usage of knowledge between countries mirrors the usage of commodities between countries (Wieser 2001). For example, Coe and Helpman (1995) define the foreign R&D stock which enters a countries production function as the import-share-weighted average of the domestic R&D stocks of trade partners. This is implicitly assuming that the main channel through which R&D spills over from country to country is through international trade. However, Keller (1998) provides evidence that casts doubt on the effectiveness of trade as a mechanism for knowledge transfer, finding higher coefficients on foreign R&D when using random weights instead of those used by Coe and Helpman. Eaton and Kortum (1999) also show that, except for small countries very near the source of information, trade is not the major conduit for the spread of new technology. By deriving a formal model of technology diffusion, they identify knowledge flows through cross country patenting rather than through the export and import of goods embodying them. Guellec and van Pottelsberghe (2001) argue that by computing technological proximity using patents granted by the United States Patent and Trademark Office and using these weights to form a foreign R&D stock, they are being consistent with the argument by Eaton and Kortum (1999), i.e. they are assuming that technology circulates directly, with no need for exchange of goods as a vector. Patent citations have also become a widely used tool for the purpose of tracing knowledge flows (Mancusi 2004).

Alston (2002) has reviewed the evidence on spillovers within the literature devoted to the agricultural sector. While there are few studies within the agricultural literature which actually take spillovers into account, those that do provide evidence which suggests that interstate and international spillovers from public agricultural R&D account for a significant share of agricultural productivity growth.[13]

Johnson et al (2005) attempt to measure spillovers by including an Australian R&D stock variable in their estimating equations, to proxy the foreign spillover pool. Their results indicate that the Australian R&D stock does not seem to have a direct impact on productivity in New Zealand.[14] However, they concede that this might indicate that the

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[12] They do not, however, directly estimate the impact of foreign R&D on domestic productivity.

[13] See for example Huffman and Evenson (1993), and Bouchet et al (1989).

[14] Johnson (2000b) also used the Australian R&D stock to proxy the foreign spill-in pool, and found a negative relationship between this variable and TFP in the agricultural sector, although a positive relationship in 6 out of the 9 industries sampled, and a positive relationship in the market sector.

Australian R&D stock is a bad proxy for international R&D, as 35% of the world's R&D is produced in the US, with Japan the next highest producer (14%) and the rest of the OECD producing 25%.[15] Thus a large portion of international spillovers comes from the US, with a very small proportion produced in Australia (1.4% of the total R&D produced in the OECD). Here we include US patents as a proxy for international R&D spillovers. Using patents ensures that we avoid accounting for outputs of no international consequence. Also, Crawford, Fabling, Grimes and Bonner (2004) find evidence that increased R&D expenditures increases the number of patents. A simple correlation coefficient of 0.91 between US patent numbers and US R&D expenditures from 1953 to 1998 suggests that US patents are a potentially reasonable proxy for R&D and hence the stock of foreign knowledge.

The positive externality generated by international technology flows, will crucially depend on the ability of the destination country to understand and exploit external knowledge. Such ability is a function of past domestic R&D experience, a concept introduced by Cohen and Levinthal (1990) and referred to as "absorptive capacity". Mancusi (2004) uses self-citations to measure the effect of absorptive capacity, arguing that self citation indicates that a firm who has done some research in the past has then generated a new idea building on the previous research in the same or in a related technology field. She finds that absorptive capacity increases the responsiveness of a country's innovation to both national and international spillovers. However, its effect differs depending on the position of the country with respect to the world technological frontier: the larger the gap of a country from the technological leaders, the lower is its ability to absorb and exploit external knowledge, but the larger appears its potential to increase this ability.

Griffith et al (2001) also study the relevance of absorptive capacity by analysing the ability of countries to catch up with the more technologically advanced countries. They found that domestic R&D is statistically significant in this catch-up process. Thus R&D stimulates growth directly through innovation and also indirectly through technology transfer. They also identified a role for human capital in stimulating innovation and absorptive capacity. Eaton and Kortum (1999) also show that a country's level of education plays a significant role in its ability to absorb foreign ideas.

The "absorptive capacity" argument not only means that the country is more able to take advantage of foreign research, it also means that the marginal return to domestic R&D will be higher the more foreign R&D the country has access to. That is, if the stock of available foreign knowledge is increased, increasing domestic research expenditure will be more profitable.[16]

5 Estimation

5.1 Basic model/included variables

The underlying concept to be developed in this section is that output depends on the following:

a) The level of inputs under the control of the farmer (fertiliser, labour, machinery, buildings, etc).

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[15] Data is for 2003, source: OECD, Main Science and Technology Indicators

[16] See Evenson, Scobie and Pray (1985) for a discussion.

b) The influence of uncontrollable variables (weather, pest and disease outbreaks, financial deregulation, terms of trade).

c) The use that is made of current and past investments in knowledge about how to select, combine and manage the inputs. That knowledge can reflect both domestic and foreign investments in R&D.

Formally, this can be represented by an agricultural production function:

$$Y_t = Y(\underline{I}_t, \underline{Z}_t, RD^d_t, RD^d_{t-1}, ..., RD^d_{t-n}, RD^f_t, RD^f_{t-1}, ..., RD^f_{t-k}) \qquad (6)$$

where:

Y_t = the volume of agricultural output in year t;

$\underline{I}_t$ = a vector (I_{1t}, 1_{2t}, …., I_{nt}) of n controllable inputs in year t;

$\underline{Z}_t$ = a vector (Z_{1t}, Z_2t, …., Z_{mt}) of uncontrollable variables in year t; and

RD_t = R&D in year t, either domestic expenditure (d) or foreign expenditure (f).

The uncontrollable variable we use in our specification is weather, measured as the tenths of days of soil moisture deficit weighted by the four major agricultural activities (dairy, sheep, beef, and crops). The National Institute of Water and Atmospheric Research (2001) found that the agricultural component of GDP is negatively correlated with the strength of the southerly airflow over the country, and that milk fat production is negatively correlated with annual days of soil moisture deficit, regional summer temperature, and regional spring and summer rainfall. Buckle et al (2002) also show that climate is an important contributor to the overall business cycle, and that it appears to have been the dominant source of domestic shocks over the period 1984-2002. However, as Makki et al (1999) point out, weather may not be an important variable in the long-run time series analysis of productivity. It is reasonable to assume that annual weather variation is a random phenomenon, and there may be no long-run relationship with agricultural productivity, although short run variation in output and productivity may reflect seasonal conditions.

The controllable inputs which appear in the vector $\underline{I}_t$ include intermediate inputs, capital stock, labour, extension workers, and human capital stock. The capital stock includes livestock, plant, machinery and equipment, land improvements, and the value of all unimproved land. The labour variable is measured as the number of full-time equivalent workers plus working owners. The human capital stock has been calculated as the sum of current and past numbers of students enrolled in agricultural related courses (using a lag length of 15 years). A human capital index was then constructed (equal to 1 in 1949/50) from this human capital stock with a lag of 2 years to capture the lag between enrolment and graduation. Extension workers represent the number of Advisory Services Division staff in the Ministry of Agriculture and Forestry up until privatisation in 1984/85, after which time estimates of this have been drawn from various sources.[17] Extension is seen as impacting directly on agricultural productivity as well as speeding the adoption of new technology. Extension agents disseminate information on crops, livestock, and management practices to farmers and demonstrate new techniques as well as consulting directly with farmers on specific production and management problems.

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[17] For more detail about the data refer to Appendix 2.

Technological advances enter the production function in two forms. In the first place improvements are embodied in the inputs themselves, through enhanced design, improved and extended features, new materials, and indeed new inputs. A 1930 tractor or variety of wheat is clearly not the same as a 2001 tractor or wheat variety.

These enhancements arise, in part, from the R&D efforts of firms who supply the machinery, seeds, chemicals, financial, consultancy and marketing services to producers. They are continuously seeking innovations which enhance the quality of their products or services. They expect to recover the costs of this innovative activity through the sale of the item or service.

This raises an inherent problem of measurement. Ideally the vector I_t refers to the quantity of inputs used, where these are of standard quality. When measuring inputs over a long period their nature is bound to change, and some of the technological advances will be embodied in these data.

The second type of technological advance arises from improved knowledge. This results in more efficient use of the same quantity of inputs through better management decisions. Information about grazing management, the timing of fertiliser or pesticide applications, and tail painting for more accurate heat detection are all examples of technological advances which involve essentially information, rather than physical inputs. In summary, technological change is reflected in part by inputs of enhanced "quality" (captured in the vector, $\underline{I}_t$) and partly through the improved stock of knowledge, which is added to through investments in formal R&D (RD_t), and through more informal channels such as on-the-job learning. This study does not isolate the effect on productivity of these informal contributions.

The notion that there is a relationship between investment in research and increments to the stock of knowledge has been used by several authors including Griliches (1979) and Minasian (1969). As Pardey (1986) observes, "it follows naturally from the perception that general science progresses by a sequence of marginal improvements rather than through a series of discrete essentially sporadic breakthroughs".

At any point in time, producers have available to them a stock of knowledge on which they can draw generated either from domestic sources (RD) or foreign sources (RD^f). Both serve as sources of new knowledge but are not perfect substitutes. Organised farm tours to other countries are testimony to the implied demand by producers for access to foreign stocks of knowledge.

While the stock of knowledge may be added to through new investment in R&D, the amount of stock which is actually utilised at any point in time does not necessarily increase one-to-one with the extra R&D expenditure. It is not uncommon to hear scientists bemoaning the lack of use by producers of their findings. Leaving aside the question of whether the findings were relevant in the first place, there are a number of forces which govern the rate at which these increments to the stock of knowledge will be incorporated into production systems.

It is reasonable to suppose that dominant among these forces will be the profitability of the innovation. An advance which does not raise real income (through increasing output, reducing costs, saving time, eliminating unpleasant tasks or lowering variability) will almost certainly fail to be adopted in any widespread or sustained manner.

The cost to the producer of acquiring the innovation will be an important determinant of its profitability, and hence of the rate of utilisation which can be expected. In the case of a new input, or improvements to an existing input, part of the total cost will be the direct monetary price charged for the input. But, in addition, the producers must invest time and effort in learning about the product and its potential applicability to their circumstances. In the case of improved knowledge the entire acquisition costs are made up of these “learning costs”. Factors which lower these costs can be expected to increase the amount of new knowledge actually utilised. Extension services, farming journals, trade publications, the daily paper, radio and television all disseminate information and enhance the acquisition of new knowledge.

In addition changes in the structure of an industry will alter the cost of acquiring new information. A farmer with 100 hectares of barley has more incentive to invest time and effort in searching for information about new varieties, than one growing, say, 2 hectares. This would suggest that the trend to larger production units in say dairying, would *cet. paribus* lead to a higher rate of investment in and absorption of R&D.

Finally, the education and experience of farmers, their “human capital”, affects the cost of acquiring new information. Schultz (1974) has referred to this as the “value of the ability to deal with disequilibria”. The argument is simply that the operating environment is constantly changing - seasonal conditions, prices, costs and technology are never static. Entrepreneurship requires that these changes be continuously monitored, assessed and appropriate actions taken. Those with greater levels of human capital are presumed to be able to perform these tasks more readily.

Introduction of a new technology changes the operating environment; the greater the level of human capital, the more rapidly the new information (R&D) will be assessed and incorporated.

Evenson (1984) likens the structure of scientific and technological activities in agriculture to that of other economic activities. There is much specialisation in research, just as there is among firms producing different consumer goods. The industrial sector involves different stages of production; some firms produce coal, which is used by others for producing steel bars, which are bought by others to produce parts which are sold then to manufacturers of appliances.

In agricultural research there are counterparts which undertake “pre-technology research” (plant genetics, reproductive physiology, entomology) using as inputs the knowledge generated by the general sciences (e.g. chemistry, biology). The outputs of this stage are then used in the development of technology which is in turn screened and adapted for final use.

The preceding discussion leads to the development of a capital theoretic view of the generation and diffusion of knowledge. In other words, the existing stock of knowledge is seen as part of the capital stock of the agricultural sector in the same way that physical capital represents an input into farm production. Like other forms of capital, knowledge must be created through investment, and it is subject to obsolescence.

Thus we have a production function relating output to the stock of knowledge as in Griliches (1979):

$$Y = F(\underline{I}_t, \underline{Z}_t, K_t) \tag{7}$$

Where K_t represents the current stock of knowledge. We can then continue following Griliches and assume that there exists a relationship between K and W(B) RD, an index of current and past levels of R&D expenditures, where W(B) is a lag function describing the relative contribution of past and current R&D levels to K, and B is the lag operator. Thus:

$$K = G\left[W(B)RD, v\right] \tag{8}$$

where v is another set of unmeasured influences on the accumulated level of knowledge and

$$W(B)RD_t = (w_0 + w_1 B + w_2 B^2 + ...)RD_t = w_0 RD_t + w_1 RD_{t-1} + w_2 RD_{t-2} + ... \tag{9}$$

Thus output becomes a function of current and past R&D expenditures as set out in equation (6). The fundamental objective of this study is to statistically measure the relation between agricultural output (Y_t) and the current and past values of research expenditures, or W(B)RD, while holding constant other factors which influence output.

Griliches defines W(B)RD as a measure of R&D “capital”. One of the major issues in the measurement of such “capital”, he argues, is the fact that the R&D process takes time and that current R&D may not have an effect on measured productivity until several years have elapsed. This forces one to make assumptions about the relevant lag structure W(B). We discuss alternative lag structures in the next section.

5.2 Empirical specification

We attempted to estimate the production function set out in the previous section, but found that intermediate inputs and capital stock were highly correlated with R&D expenditures (correlation coefficients of 0.97 and 0.95 respectively). Thus we constructed a multifactor productivity index as our dependent variable, calculated using a fisher index of GDP (gross output less intermediate inputs) divided by the weighted sum of capital and labour. Thus our final specification was:

$$mfp_t = \beta_0 + \beta_1 weather_t + \beta_2 extension_t + \beta_3 hk_t + \beta_4 W(B)RD_t + \beta_5 W(B)RD_t^f + u_t \qquad (10)$$

where all variables are in logarithms, weather is our soil moisture deficit variable, extension is the number of extension workers, hk is our human capital index, W(B)RD is current and past domestic R&D expenditures, and $W(B)RD^f$ is current and past foreign R&D expenditures (here proxied by current and past patent numbers). These main variables are plotted in Figure 3 below.

We also ran this basic model including a dummy variable, equal to zero before 1984 and one from 1984 onwards. This provides a crude test of whether there is a structural break in our data. That is, has the changed institutional settings and economic environment induced by the reforms impacted on MFP in the agricultural sector?

There are many factors which will be omitted from the typical production function set out above, including the learning by doing mentioned in section 5.1, and improved managerial and organisational practices. These omitted factors not only affect productivity growth but also affect the incentives to invest in R&D. Comin (2004) states that some evidence in favour of the potential importance of this omitted variable bias comes from the fact that, after Jones and Williams (1998) included fixed effects in their regression, the effect of R&D on TFP growth almost disappeared. However, due to data limitations it is impossible to correct for this problem.

Another problem which has been discussed in the literature is that of double counting. This occurs because the expenditures on labour and physical capital used in R&D are counted both in the R&D expenditures as well as in the measures of labour and capital, and so should be removed from the measures of labour and capital used in production. Schankerman (1981) demonstrates that the failure to remove this double counting has a downward bias on the estimated R&D coefficients. Within the agricultural sector, this would be a problem only to the extent that research is carried out by farm owners and farm workers themselves. We believe this would have a minimal effect in New Zealand.

Another problem which arises in any economic time series analysis is that of non-stationary variables. Regressions involving non-stationary variables may result in spurious results. Szeto (2001) notes that there are three solutions to the problem of spurious regression. The first approach is to take first differences of the data before estimating. The second approach is to add the lagged value of the dependent variable. Finally one may consider the cointegration approach.[18] We employ both of the latter two approaches in this paper (discussed below).

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[18] Non-stationary variables may be used in a levels regression if they prove to be cointegrated.

To employ the cointegration approach, one must first establish whether the variables in the regression are I(1). We tested all of our series for unit roots using the Augmented Dickey-Fuller unit root test. All series appear to be non-stationary, I(1) processes, except for the human capital index, the public R&D stock, the number of soil moisture deficit days, and MFP, the first two found to be stationary with drift and the latter two to be stationary with drift and trend (see Appendix 1 for unit root tests). However, the unit root test of MFP is very sensitive to the lag length chosen – for all lags greater than zero the Augmented Dickey-Fuller test could not reject the null of a unit root in the series. Also, the Phillips-Perron unit root test accepts the null of a unit root for the MFP series. Therefore we can be fairly sure that we are regressing an I(1) variable on (mostly) non-stationary explanatory variables and hence there could be a cointegrating relationship (which is determined by testing the residuals for stationarity).

As discussed in the previous section, the fact that increments to the stock of knowledge may not be utilised the moment they become available means that the relationship between R&D *expenditures* and output will not be contemporaneous. Thus it is important to capture this in the estimation procedure.

Alston, Craig and Pardey (1998) highlight the importance of lag lengths in estimating the returns to research. Many studies have used relatively short lag lengths. These may well capture the link between investment in research and increments to the stock of knowledge. However, production depends on the flow of services of the entire stock of knowledge rather than recent additions to it. They find that using a model that allows for the impact of research on productivity to last much longer than conventional approaches, the real marginal rate of return to research in the USA was found to be much lower than studies with inappropriate lag lengths.

However, one cannot simply include many lagged values of the R&D expenditures as this runs into problems of multi-collinearity. In order to overcome this problem, it is necessary to impose some structure on the nature of the lags. We have adopted three different approaches to this problem. In the first case we form estimates of the stock of knowledge (or R&D capital) using the Perpetual Inventory Method (PIM). In the second case we use a Koyck transformation and in the final case we impose a polynomial lag structure.[19] Each approach is discussed in turn in the following sections.

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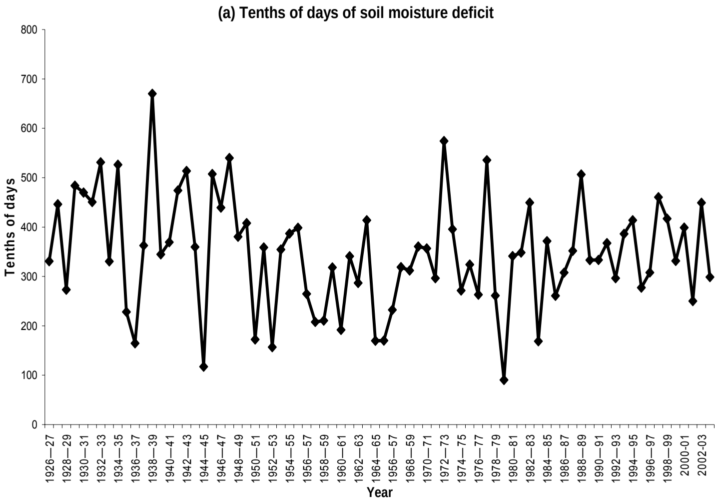
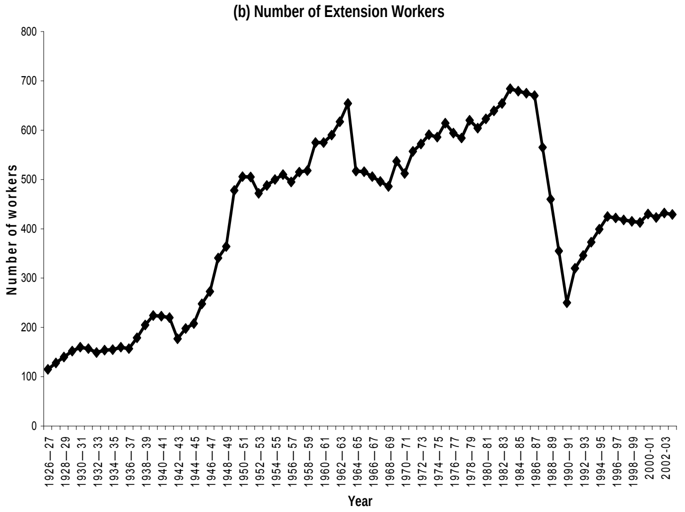
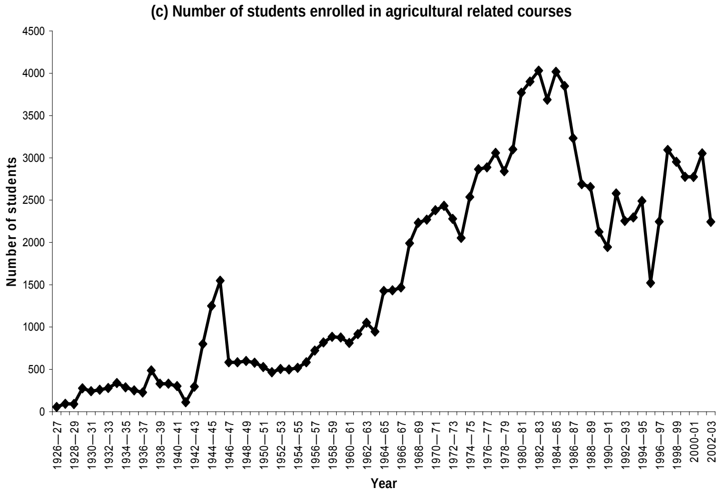
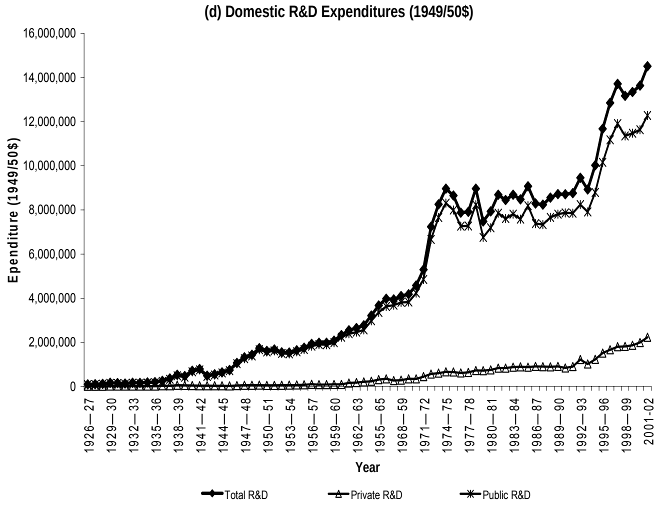
[19] The Perpetual Inventory Method is a model whereby past flows are accumulated into a stock using weights. All three of our approaches can therefore be classified as using the PIM. The difference between what we label the "PIM" models and our Almon models are the weights used in the accumulation: the "PIM" models use geometric weighting. The difference between our "PIM" models and our Koyck Transformation models is the estimation procedure: our "PIM" models assume a depreciation rate and enter the accumulated stock directly into the production function, whereas the Koyck models estimate the weights from the regression model once the transformation has been applied. Thus for simplicity we have labelled the geometrically weighted PIM, with the depreciation rate assumed, as our "PIM" models.

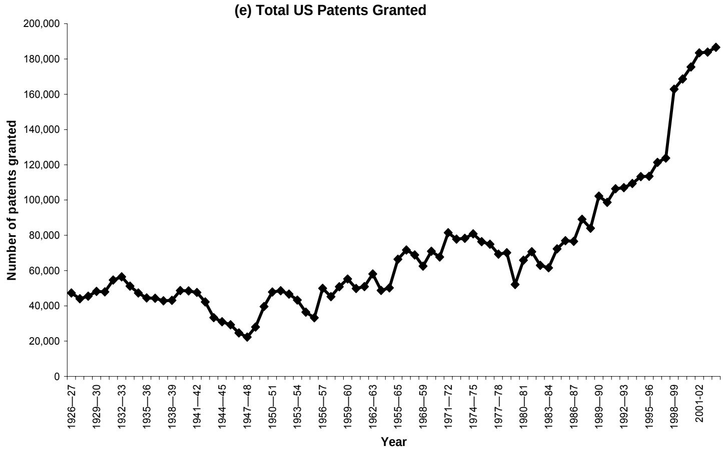
Figure 3: Main Variables

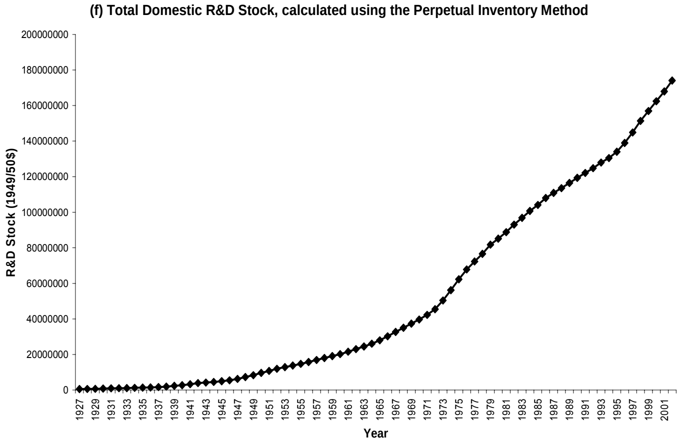

(a) Tenths of days of soil moisture deficit


(b) Number of Extension Workers


(c) Number of students enrolled in agricultural related courses


(d) Domestic R&D Expenditures (1949/50$)


(e) Total US Patents Granted


(f) Total Domestic R&D Stock, calculated using the Perpetual Inventory Method

5.2.1 Creating knowledge stocks using the Perpetual Inventory Method

The Perpetual Inventory Method (PIM) is used to create a stock of capital (in this case knowledge) from a flow of investments based on the following equation:

$$\mathrm{K_t = R_t + (1\text{-}\delta)K_{t\text{-}1}} \tag{11}$$

where K_t is the R&D stock in year t, $\mathrm{R_t}$ is R&D expenditure in year t and δ is the depreciation rate. The initial stock (K_0) is calculated as:

$$K_0 = \frac{R_0}{g + \delta} \tag{12}$$

where R_0 is the value of the R&D expenditure series in the first year available, and g is the average geometric growth rate for the R&D expenditure series between 1927 and 1947.[20]

This results in the following relationship between the stock of knowledge and current and past R&D expenditures, i.e. the specification of W(B)RD:

$$K_t = RD_t + (1-\delta)RD_{t-1} + (1-\delta)^2 RD_{t-2} + ... \tag{13}$$

A limitation of this formulation is the need to specify a depreciation rate. Coe and Helpman (1995) and Johnson et al (2005) assume an annual depreciation rate of 5%.[21] As the estimation of the Koyck model gives an implicit estimate of the rate (see Section 6.1) then we have adopted a rate of 30% for consistency across these models.[22]

The estimating equation now becomes:

$$mfp_t = \beta_0 + \beta_1 weather_t + \beta_2 extension_t + \beta_3 hk_t + \beta_4 K_t^d + \beta_5 K_t^f + u_t \tag{14}$$

We used the Phillips-Loretan method to estimate the long-run relationship between these constructed R&D stocks (stocks of foreign R&D were calculated in the same way using patents data[23]) and MFP. This method is outlined in Razzak and Margaritis (2002), and requires the non-stationary variables to be cointegrated. We tested for cointegration using the methodology developed in Johansen (1991, 1995) and found evidence of one cointegrating equation.

The advantage of using the Phillips-Loretan method is that it adjusts for endogeneity of the explanatory variables by augmenting the regression with leads and lags of the differenced explanatory variables. Griliches (1979) argued that future output and its profitability depend on past R&D, while R&D, in turn, depends on both past output and the expectation about its future. If that is so, any unobserved shock to productivity that raises output could indirectly raise investment in R&D. Under those circumstances, OLS-based estimates of the coefficient on R&D will be biased. Most R&D studies do not adjust for endogeneity and we do not attempt to adjust for this in our other specifications. However,

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[20] 20 years was chosen to compute *g* following Caselli (2003).

[21] Johnson (2000) investigated the effect on estimated rates of return to the R&D stock when the depreciation rate was varied, and found that the rate of return was remarkably constant across different depreciation rates.

[22] We explored the effect of other lower rates, but the signs and significance of the coefficients on R&D were less satisfactory. Results using alternative depreciation rates are presented in Appendix 3.

.[23] For the starting value of the foreign "stock of knowledge" we have simply used the number of patents granted in 1926/27 instead of using equation (11).

a Granger causality test between the domestic R&D stock and MFP indicates that causality flows from R&D to MFP: the null hypothesis that the R&D stock does not Granger cause MFP was rejected at the 10% level while the null hypothesis that MFP does not Granger cause the R&D stock could not be rejected.

On the other hand, foreign R&D can be expected to be exogenous. As New Zealand is taken to be a small open economy, it takes the foreign stock of knowledge as given. Conditions in New Zealand are assumed not to materially alter the world stock of knowledge

5.2.2 Using a Koyck transformation

The specification of the lag structure in equation (13) requires the assumption that the depreciation rate is known. As Griliches (1979) notes: "The only thing one might be willing to say is that one would expect…social rates of depreciation to be lower than the private ones". To overcome the need to specify an assumed rate of depreciation, we also run our model using the Koyck transformation. This transformation allows the estimation of the decay parameter directly from the regression and also overcomes the spurious regression problem by including the lagged dependent variable as an explanatory variable. The lag structure using this transformation is:

$$K_t = RD_t + \lambda RD_{t-1} + \lambda^2 RD_{t-2} + \ldots \qquad (15)$$

And the estimating equation becomes:

$$\begin{aligned} mfp_t &= \beta_0 + \beta_1 weather_t + \beta_2 extension_t + \beta_3 hk_t + \beta_4 RD_t + \beta_5 RD_t^f \\ &+ \lambda mfp_{t-1} - \beta_1 \lambda weather_{t-1} - \beta_2 \lambda extension_{t-1} - \beta_3 \lambda hk_{t-1} + u_t \end{aligned} \qquad (16)$$

The contemporaneous contribution to MFP given by domestic R&D is β_4, whereas the contribution from all past and current domestic R&D is given by[24] :

$$\frac{\beta_4}{1-\lambda} \qquad (17)$$

and a similar construction applies in the case of foreign R&D under the assumption that the decay parameter is the same as for domestic R&D (i.e. λ).[25]

5.2.3 An Almon Polynomial Lag Structure

Both of the above specifications for the lag structure (PIM and the Koyck transformation) assume that the effect of an R&D investment in year t declines at a constant rate as the lag length increases. Griliches (1998) concludes that the usual declining balance or geometric depreciation does not fit very well the likely gestation, blossoming, and eventual obsolescence of knowledge.

Griliches (1979) was the first to argue that the lagged effects of R&D on output could reasonably be expected to follow a bell-shaped distribution. The Almon polynomial lag

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[24] This is because $\sum w_k = w_0\left(1+\lambda+\lambda^2+\lambda^3+\ldots\right) = w_0\left(\frac{1}{1-\lambda}\right)$ since the expression on the right side is an infinite geometric series whose sum is 1/(1-λ) provided 0< λ<1.

[25] We checked the coefficient restrictions on the lags of the weather, extension and human capital variables using the Wald test.

structure allows us to capture this in empirical estimation. The specification of the lag structure becomes (with constrained endpoints)[26]:

$$K_t = a_2 \sum_{i=0}^{k} \left(i^2 - k - 1 - ki \right) RD_{t-i} \qquad (18)$$

This results in a second-order polynomial distribution of the contributions of R&D to MFP, which we used for both domestic and foreign R&D expenditures. We tested whether the series exhibited a cointegrating relationship by testing the residuals of each model specification for stationarity, and found evidence of cointegration.

In order to adequately capture what are inevitably lengthy lags in the generation and diffusion of knowledge, a lengthy time series is needed. This project uses annual data from 1926-27 to 2000-01. The definitions and sources of the data are set out in Appendix 2.

Yee et al (2002) argue that, unlike research, agricultural extension input can be expected to have an almost immediate impact on agricultural productivity. Therefore we include the current number of extension workers in our model specification.

6 Results

In this section we present the results of estimating the relationship between R&D and productivity for the agricultural sector. We take each of the three formulations in turn. In addition we present the results of using a simplified model following Scobie and Eveleens (1987).

6.1 Using stocks of knowledge

The results from running the Philips-Loretan model using R&D stocks generated by the PIM are summarised in Table 5.[27] We ran a number of variants of the basic model including and excluding human capital, and with and without the dummy variable to represent structural shifts. In no case was the variable representing human capital significant. In both cases where the structural shifter for post 1984 was included the coefficient was highly significant. When human capital is removed from the model, the coefficient on the domestic R&D stock becomes significant at the 1% level.

The facts that 1) both human capital and domestic R&D are insignificant (or barely so) when both are included in the regression; and 2) each becomes individually significant when the other is omitted, point to the presence of multicollinearity. In fact, the simple bivariate correlation between these two variables is 0.99. Further evidence that multicollinearity is a problem is given by running the same regression in different (arbitrary) time periods. If two explanatory variables are correlated, a different sample will likely produce opposite results. We ran the regression with both variables included (and the dummy excluded) for the period 1927 to 1964 and the same regression from 1964 to 2001, and found that, while the coefficient on human capital was positive in both samples (although insignificant in the earlier period and significant in the latter period), the coefficient on the domestic R&D stock went from being negative and significant in the first

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[26] See Appendix 2 for more details.

[27] The Lead and lag order of the independent variables is 2.

period to being positive and significant in the period 1964-2001.[28] Such correlations mean that the corresponding regression coefficients cannot be interpreted because it is impossible to fix or control one variable while changing the other in the presence of this high correlation.

One solution to the problem is to remove those variables which are highly correlated with others (in this case we removed the human capital index) and therefore redundant. However, the drawback of this approach is that no information is obtained on the deleted variable while the importance of those in the equation may be overstated. Hence the significant coefficient on the domestic R&D stock in models 3 and 4 may be picking up some of the contribution of the omitted variable for human capital as well as the R&D effect itself.

If we ignore this and conclude that the elasticity of MFP with respect to domestic R&D is 0.148 (model 3 which is the preferred specification), then this implies a rate of return of 16.7% to the domestic R&D stock (in the long-run), assuming an R&D intensity (defined as the R&D stock divided by GDP) equal to the average over our sample period.[29] This return is lower than that estimated when we include human capital in the equation (model 1), indicating that the estimated coefficient on domestic R&D in Model 3 (our preferred specification) is not picking up the effect of human capital (the omitted variable) as well as the effect of domestic R&D.

The coefficient on cumulated patents (our proxy for the foreign stock of knowledge) is highly significant and positive in all four models. This indicates that foreign spill-ins to the agricultural sector are an important source of new knowledge and they are associated with the productivity performance of this sector. The estimated elasticity of MFP with respect to the foreign spill-in stock ranges from 0.25 to 0.35. That is, for a 10% increase in the number of patents granted in the US, MFP in the agricultural sector of New Zealand would increase from between 2.5% to 3.5%.

The coefficients on both weather and extension variables are never significant; except for extension in Model 4. In the case of extension this result is somewhat surprising, as with more extension workers we would expect new knowledge to be disseminated to users faster and therefore for more extension workers to have a positive impact on MFP.

Table 5: Estimates of the model using R&D stocks

Independent variables:	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Weather	-0.129	0.136	-0.102	-0.118
Extension	-0.190	-0.352	-0.156	-0.466***
Domestic knowledge stock	0.232*	-0.097	0.148***	0.260***
Foreign knowledge stock	0.309**	0.334***	0.352***	0.248**
Human capital	-0.102	0.148		
Dummy84	0.270***		0.243***	
Adjusted r2	0.930	0.932	0.934	0.931

Note: The asterisks indicate the degree of significance of the estimated coefficient; *** = 1%; ** = 5%; * = 10% and an absence of asterisk indicates the coefficient was only significant at more than 10%.

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[28] The coefficient on the foreign stock of knowledge also exhibited this trait (negative and significant in one period and positive and significant in the other). The bivariate correlation between human capital and cumulated patents is 0.95, while the correlation between the domestic R&D stock and cumulated patents is 0.96. Thus there are several variables adding to the multicollinearity problem.

[29] See equation (5) as to how we calculate our rates of return using our estimated elasticities.

6.2 Estimates based on the Koyck transformation

The insignificance of the weather variable in both the PIM and Koyck models could be due to the fact that weather only has a short-run impact on productivity in the agricultural sector, whereas we are estimating long-run relationships. Another possibility for the insignificant results is the use of MFP as the dependent variable – if weather has an equal effect on both outputs and inputs, this effect will be netted out when MFP is used.

Table 6 summarises the results from running the regression model using a Koyck transformation. Again we have run the model including and excluding the human capital and the dummy variable for structural change. As with the PIM models above, the dummy variable is always significant, suggesting that there could be a structural break in the data following the reforms. Again, the coefficient on the domestic R&D variable becomes significant when we exclude the human capital index from the regression.[30] The coefficient on the human capital index is never significant. The foreign spill-in variable is again significant for all six models, with an elasticity ranging from 0.10 to 0.14.

We also ran the Koyck transformation specification using education enrolment numbers instead of our human capital index (which is itself constructed from education enrolment numbers). This way we could also have all current and past enrolment levels included in a similar way to the research variables, if we assume that the decay parameter is the same.

We found that by including human capital in this alternative way, domestic R&D remains significant, although the contemporaneous effect of education on MFP is not significant. This is to be expected since the variable is enrolment numbers so will affect MFP with a lag. Thus it is more informative to look at the sum of the current and past enrolment rates by using equation (14), just as it is more informative to look at this sum for the domestic and foreign research variables.

Looking at these long-run estimates, we can see that foreign research is always significantly different from zero, while domestic research is significant in all but one of the models (it is not significant when human capital is included, but is significant when the dummy is added to the equation, even when human capital is still included). That is, once all of the past effects of research on productivity are taken into account, there is a significantly positive association with productivity. However, education is not significant even when we take into account the past effects on MFP. The elasticity of MFP with respect to domestic R&D, once all lags are accounted for, ranges from 0 to 0.21. The long-run elasticity with respect to foreign research ranges from 0.23 to 0.39. The corresponding implied rate of return to domestic R&D lies in the range 0 to 25%, once all of the effects of the R&D expenditure on subsequent output are taken into account.[31] Note that these Koyck models imply a depreciation rate of between 32% and 44%. Once again the weather variable is never significant and extension is always negative, and significant in 2 of the 6 specifications.

The insignificance of the weather variable in both the PIM and Koyck models could be due to the fact that weather only has a short-run impact on productivity in the agricultural

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[30] Note that the foreign patents variable is no longer as highly correlated with domestic R&D and human capital (0.688 and 0.689 respectively), indicating that the problem of collinearity only remains between the human capital and domestic R&D variables and thus only to the coefficient estimates of these two variables.

[31] This rate of return was calculated by constructing the implied R&D stock using a depreciation rate of $1-\lambda$, and a starting value calculated using the Perpetual Inventory approach (i.e. using equation 12, where $\delta = 1-\lambda$). The elasticity was then multiplied by the average GDP to R&D stock over our sample period to get the rate of return.

sector, whereas we are estimating long-run relationships. Another possibility for the insignificant results is the use of MFP as the dependent variable – if weather has an equal effect on both outputs and inputs, this effect will be netted out when MFP is used.

Table 6: Results from the estimations based on the Koyck Transformation

Independent variables:	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
Lagged productivity	0.677***	0.681***	0.565***	0.586***	0.667***	0.565***
Weather	0.017	0.017	0.017	0.018	0.017	0.019
Extension	-0.150	-0.220***	-0.128	-0.096	-0.220***	-0.094
Domestic R&D: one period effect	0.030	0.065**	0.090**	0.057**	0.057**	0.047*
Domestic R&D: total effect [a]	0.093	0.204***	0.207**	0.138***	0.171***	0.108**
Foreign R&D: one period effect	0.126**	0.092***	0.098**	0.124***	0.100***	0.135***
Foreign R&D: total effect [a]	0.390***	0.288***	0.225***	0.300***	0.300***	0.310***
Human capital	0.092		-0.069			
Dummy84			0.112**	0.088**		0.091**
Education:one period effect					0.015	0.019
Education: total effect [a]					0.045	0.044
Adjusted R^2	0.946	0.946	0.950	0.950	0.946	0.950
Wald (chi-squared) test of Coefficient Restrictions (null hypothesis: restrictions are true)[b]	1.39	2.25	3.48	0.30	1.94	0.13

Note: The coefficients for domestic R&D are computed using equation (15) and its counterpart for the foreign R&D.

Note: The asterisks indicate the degree of significance of the estimated coefficient; *** = 1%; ** = 5%; * = 10% and an absence of asterisk indicates the coefficient was only significant at more than 10%.

a: Significance levels for these long-run coefficients have been calculated using the delta method.

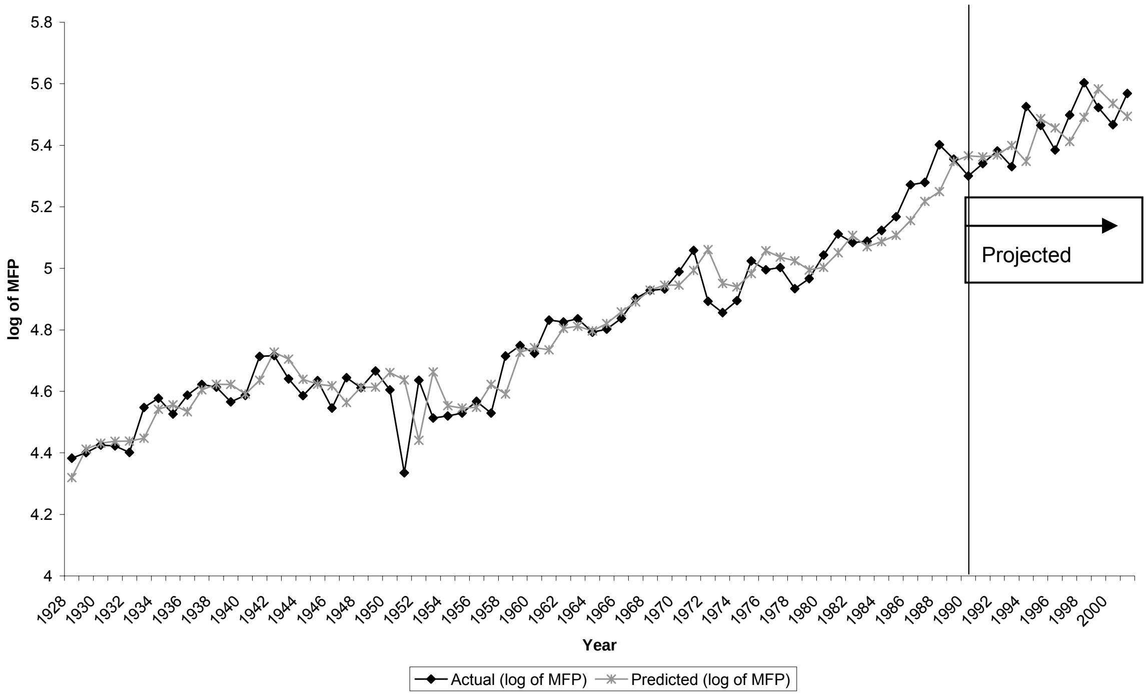
b: This tests whether the coefficient restrictions on the lagged variables in equation (16) (e.g. the coefficient on the lagged weather variable is equal to the coefficient on the weather variable multiplied by the coefficient on the lagged MFP variable) are true. The Wald statistic measures how close the unrestricted estimates come to satisfying the restrictions under the null hypothesis.

The coefficient on the extension variable is consistently negative. Based on concerns that there may be a serious discontinuity in the data (see Figure 2(b)) we re-estimated model 1 using data for a reduced sample period (1926-27 to 1983-84) which eliminated the period of the apparent break in the data series. However the results were similar to those found with the full sample period.

To some extent, the dummy variable could also be picking up this drop in extension numbers after 1984, as well as the drop in enrolment numbers which occurred around this time (as well as the effect of the reforms on agricultural productivity). In short, these changes were in themselves reflections of the many structural reforms that were taking place in the New Zealand economy, and it is not possible to isolate their separate effects within our models.

Figure 4 plots the dependent variable (the log of MFP) against its predicted values using Model 2 in Table 6. The model was run up to 1990 and then out of sample forecasts were computed. The model is found to perform well in this out of sample forecasting, predicting the variable nature of MFP after 1990, recognising that the model contains the lagged value of productivity as an explanatory variable.

Figure 4: Agricultural Productivity: Actual Versus Values based on estimation up to 1990 with projected values beyond 1990



6.3 Estimates using an Almon lag structure

Table 7 summarises the results from running equation 10 using second order polynomials for both domestic and foreign research. The lag lengths were chosen by first searching over all lags from 1 to 60 years (except when the dummy was included which meant it was only possible to search up to 55 lags). This involved running up to 3,600 regressions for each model to allow for every possible combination of domestic and foreign lag lengths. The search over lag lengths was conducted without fixing the sample period. The effects of fixing the sample period compared to allowing the sample period to vary according to the lag length is discussed below. The combination of lag lengths which gave the minimum value of the Akaike Information Criterion (AIC) was chosen as the preferred model.

When human capital is excluded, the sum of domestic R&D lags is negative and not significant, but becomes significant when the dummy is included. The sum of the lags of US patent numbers is always positive and significant, affecting New Zealand agricultural productivity even after 59 lags (when the dummy is not included). However, when human capital is included, the number of lags on this foreign research variable which effect MFP shortens to 13, while domestic R&D still affects MFP after 59 lags, compared with only 17 lags when human capital is not included. This indicates that the results are subject to considerable variation depending on the particular specification of the model.

The results are also sensitive to the choice of lag length. For example, if we instead of the AIC we were to chose the optimal lag lengths using the adjusted R-squared of each model, for Model 2 (i.e. excluding human capital and the dummy variable) we obtain a positive and significant number for the lagged contributions of domestic R&D (0.25), with a lag length of 24, as well as a positive and significant number for the sum of the lagged contributions for foreign patent numbers (0.21), although only with a lag length of 1. For model 1 (when we include human capital), human capital is negative and significant (with a coefficient equal to -0.55), and domestic R&D is positive and significant, with contributions over a period of 37 years (and the sum of the lagged contributions equal to 0.97). The sum of the contributions from our foreign spill-in variable becomes negative and significant (-0.83), with a lag length of 15.

We also ran this model by using a first order polynomial for the lags of the education variable (see models 5 and 6 in Table 7).[32] The sum of the contributions from both domestic and foreign research become insignificant when we include human capital in this way, while the sum of the lagged contributions from education is significant in both models.

Table 7: Results from the Regressions using Almon second order distributed lags

	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
Weather	0.279***	0.269***	0.156**	0.170***	0.014	0.011
Extension	-0.103	0.003	0.084	0.054	0.0.008	0.024
Domestic R&D	-1.942**	-1.578	-0.879*	-0.913**	-2.320	-2.266
No. of lags : domestic	59	17	12	11	46	46
Foreign R&D	4.317**	2.177***	1.727***	1.723***	4.371	4.034
No. of lags: foreign	13	59	54	54	32	32
Human capital	4.010**		0.235			
Education					1.882**	2.017**
No. of lags: education					31	31
Dummy84			0.141	0.170***		-0.040
Adjusted r2	0.857	0.806	0.893	0.897	0.948	0.965

Note: The coefficients for domestic R&D, foreign R&D, and education are computed as the sum of the coefficients on the individual lags.

Note: The asterisks indicate the degree of significance of the estimated coefficient; *** = 1%; ** = 5%; * = 10% and an absence of asterisk indicates the coefficient was only significant at more than 10%.

When estimating models with different lag lengths the sample period varies according to the length of the lag as observations are lost from the start of the series to accommodate the lagged effect. It is therefore possible that differences which might appear to arise from different lag lengths in fact arise from different sample periods.

Table 8 compares the results of regressions using the Almon second order distributed lags when we fix the sample period and when we allow the sample period to vary. We have minimised the search over different lag lengths by restricting both the domestic and foreign research variables to have the same lag length. Again, the number of lag lengths which gave the minimum value of the Akaike Information Criterion (AIC) was chosen as the preferred model.

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[32] Only searching over 46 lags due to memory constraints in eviews.

Table 8 shows that fixing the sample period can have a large effect on the number of lags chosen as the preferred model. In turn, the lag length appears to change the results significantly. For example, in Model 1, when we use a fixed sample period for the regression, a lag length of 18 years is chosen as that which minimises the AIC, resulting in a significantly positive coefficient on foreign R&D and human capital. Alternatively, when we allow the sample period to vary with the lag length, the AIC suggests a lag length of 59 years, with a negative and not significant coefficient on both foreign R&D and human capital. This highlights the sensitivity of results to the lag specification.

Table 8: Comparing the Almon Distributed Lag Models with Fixed and Unconstrained Sample periods.

	Model 1		*Model 4*		*Model 5*	
	Fixed Sample	Unconstrained Sample	Fixed Sample	Unconstrained Sample	Fixed Sample	Unconstrained Sample
Weather	0.261***	0.209**	0.024	0.019	0.294***	0.294**
Extension	-0.067	0.115	0.103	0.009	-0.012	0.045
Domestic R&D	-3.071	0.539	1.149*	0.154	5.655	1.785*
No. of lags : domestic	18	59	34	45	24	59
Foreign R&D	3.060**	-1.003	-1.651	0.618	-1.610	-0.195
No. of lags: foreign	18	59	34	45	24	59
Human capital	2.712**	-0.100				
Education					-4.048*	-3.100
No. of lags: education					24	59
Dummy84			-0.008	0.071		
Adjusted r2	0.794	0.762	0.918	0.932	0.800	0.788

6.4 The separate effects of public and private R&D funding

In this section we report the results of an attempt to isolate the separate contributions of public and private domestic research using both the PIM and Koyck models. The data for this are set out in Appendix 2.

An OECD report (OECD 2005) found that domestic private R&D and foreign R&D stocks impacted positively on productivity in all of the 16 OECD countries used in their panel estimation. However, domestic public R&D had a positive impact on productivity in only 12 of the 16 OECD countries. Johnson (2000b) looked at the contribution from private and public R&D in 9 industries in New Zealand. He found that private R&D was positively related to changes in TFP in 7 out of the 9 cases, while public R&D was positively related to changes in TFP in 4 out of the 9 cases. In the agricultural sector he found that public R&D was negatively related to changes in TFP. However, in another study by Johnson (2000a), he finds that the return to public R&D in the agricultural sector is positive depending on how the lags on R&D expenditure are dealt with in the estimation. The positive relationship was found when he used Almon distributed lags, while the negative relationship was estimated using the perpetual inventory method to construct a public R&D stock variable.

Tables 9 and 10 summarise our results when we include domestic R&D separately as private and public spending. Once again the dummy variable is significant in both the Koyck and PIM models. The weather variable is again not significant in any of the models and the extension variable continues to be mostly negative and sometimes significant.

In all of the models tested under both approaches, the coefficient for domestic public research is only significant in two specifications (model 5 under the PIM approach and model 7 under the Koyck Transformation are discussed below). The coefficient on domestic private R&D is significant in all 4 specifications of the perpetual inventory stock models, but is never significant in the Koyck models (except for model 8, discussed below). The elasticities with respect to the stock of private domestic R&D (see Table 8) therefore ranges from 0.14 to 0.63, with the implied rate of return ranging from 176% to 771% (assuming a Private R&D to GDP ratio equal to the average over our sample period).

The multicollinearity problem also arises between the public and private R&D expenditure variables, with a correlation coefficient of 0.96.[33] Therefore we may not be picking up the significance of domestic private and public R&D spending due to their high correlation with each other and with other variables in the model (both private and public R&D spending are also highly correlated with human capital). When we remove both human capital and private R&D expenditure from the regression models, domestic public R&D becomes significant in both the Koyck model and the PIM model (see model 5 in Table 9 and model 7 in Table 10). When we remove both human capital and public R&D expenditure from the Koyck regression model, we see a significant coefficient on the private R&D expenditure (see model 8 in Table 10). The corresponding rate of return to domestic public R&D in the Koyck model is 26%, and to domestic private R&D the corresponding rate of return is 32%.

Table 9: Estimating the separate effects of public and private domestic R&D: based on the perpetual inventory stock models

Independent variables:	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*
Weather	0.093	-0.107	0.081	-0.070	-0.120
Extension	-0.241**	-0.404***	0.058	0.053	-0.473***
Public Stock of Knowledge	0.062	0.125*	-0.010	-0.081	0.257***
Private Stock of Knowledge	0.576***	0.144*	0.631***	0.207***	
Foreign Stock of Knowledge	-0.382*	0.098	-0.433*	0.089	0.273***
Human Capital	-0.487***		-0.577***		
Dummy84			0.304***	0.343***	
Adjusted R^2	0.943	0.926	0.940	0.930	0.930

Note: The asterisks indicate the degree of significance of the estimated coefficient; *** = 1%; ** = 5%; * = 10% and an absence of asterisks indicates the coefficient was only significant at more than 10%.

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[33] An OECD report (2005) has also found that non-business R&D and business sector R&D are related: an increase of 1 standard deviation in the share of non-business R&D in GDP was found to raise business sector R&D by over 7%. Thus they concluded that private R&D will already embody many of the effects that come from public sector R&D.

Table 10: Estimating the separate effects of public and private R&D based on the Koyck transformation

Independent variables:	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*	*Model 7*	*Model 8*
Lagged productivity	0.677***	0.679***	0.549***	0.588***	0.676***	0.566***	0.695***	0.715***
Weather	0.017	0.017	0.017	0.019	0.017	0.018	0.017	0.015
Extension	-0.134	-0.146	-0.112	-0.083	-0.150	-0.093	-0.221***	-0.084
Domestic public R&D: one period effect	0.020	0.026	0.080*	0.044	0.026	0.044	0.061**	
Domestic public R&D: total effect	0.062	0.081	0.177**	0.107	0.080	0.101	0.200***	
Domestic private R&D: one period effects	0.026	0.033	0.038	0.011	0.031	0.002		0.046***
Domestic private R&D: total effect	0.080	0.103	0.084	0.027	0.096	0.005		0.161***
Foreign R&D: one period effect	0.109**	0.096***	0.077	0.125***	0.098***	0.136***	0.090***	0.088***
Foreign R&D: total effect	0.337**	0.299***	0.171	0.303***	0.302***	0.313***	0.295***	0.309***
Human capital	0.037		-0.127					
Dummy84			0.120**	0.084**		0.091**		
Education: one period effect					0.004	0.019		
Education: total effect					0.012	0.044		
Adjusted R^2	0.946	0.947	0.950	0.950	0.946	0.949	0.946	0.947
Wald (chi-squared) test of Coefficient Restrictions (null hypothesis: restrictions are true)	1.06	0.99	3.52	0.20	0.97	0.14	2.47	0.25

Note: The asterisks indicate the degree of significance of the estimated coefficient; *** = 1%; ** = 5%; * = 10% and an absence of asterisks indicates the coefficient was only significant at more than 10%.

6.5 A simplified Almon estimation

In this section we present results based on an updated version of the model estimated in Scobie and Eveleens (1987). This model is a simplified version of our Almon models presented above, in that the Almon distributed lag variable is a combination of human capital, extension and domestic R&D, and hence these variables are not entered into the regression equation separately. Foreign R&D is also not included in the model. The variable “Deviations from trend net farm income” is included as an explanatory variable, the argument being that in years of high income, farmers may be expected to increase their purchases of inputs.[34] We have not included this variable in our main specification due to concerns about endogeneity. The model is set out in equation 19 below:

$$mfp_t = \beta_0 + \beta_1 REH_t + \beta_2 weather_t + \beta_3 yd_t + u_t \qquad (19)$$

where REH is the variable combining research and extension defined as $\log[R_t+(E_t*HK_t)]$, and transformed by a second degree Almon polynomial lag structure with constrained

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[34] The trend line has been calculated using a Hodrick-Prescott filter.

endpoints, with a total lag length of 22 years, and yd is deviations of net farm income from a fitted trend line. The equation was estimated using the Cochrane-Orcutt correction for autocorrelation, and the results are presented in Table 11 below.

Using an internal rate of return calculation such as that used in Scobie and Eveleens (1987), the fitted second order polynomial implies a rate of return to domestic R&D of 70%.[35] The weather variable is again not significant, while the deviations from trend net farm income appear to have a negative effect on productivity, although the effect is very small. That is, in years of high income, productivity is depressed due to increases in farm spending on inputs.

Table 11: Results from the simplified Almon estimation

Independent variables:	Model 1
REH	0.338***
weather	0.025
Deviations from trend net farm income (yd)	-8.71e-07**
Adjusted R2	0.76

Note: The coefficient for REH is computed as the sum of the coefficients on the individual lags.

6.6 Testing the absorptive capacity hypothesis

We tested the absorptive capacity argument by interacting the foreign patents variable with both domestic R&D and human capital. A significantly positive coefficient on either of these interactions would indicate that, for a given amount of foreign R&D, increasing the amount of domestic R&D or human capital enables more effective absorption of this foreign research. Thus domestic R&D or human capital respectively would have both a direct and an indirect effect on MFP. We found neither interaction to be significant in the Koyck models and both interactions to be significantly negative in the Phillips-Loretan models. We do not believe that this constitutes definitive evidence that absorptive capacity is not important. One only has to ask how much foreign knowledge a country could absorb were it to have no domestic scientific capacity, to underscore that absorptive capacity is critical in a small open economy such as New Zealand. Rather it reflects the difficulty of defining suitable proxies and then isolating the effects econometrically from aggregate time series data.

The second interaction that we tested was between human capital and domestic R&D, the argument being that research will be more easily adopted and utilised if the sector has a larger stock of human capital, and thus research will have a larger impact on productivity. This interaction was not significant in the Koyck models and was negative and significant in the Phillips-Loretan models. We also tested the interaction between extension and domestic R&D, as more extension workers arguably allow more effective and quicker dissemination of research to those who will use it; this interaction was found to be significant in the Koyck model when the dummy variable was included in the regression equation, but insignificant when it was not included. In the Phillips-Loretan model this

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[35] In order to calculate an internal rate of return, two different research strategies were used: one holding research expenditure constant at the 2001 level, and the other following the same pattern with the exception that in the first year (2001) research expenditure was assumed to increase by 1%. Using the equation, MFP was then calculated under both strategies, and then GDP was calculated holding inputs constant at their 2001 level, the difference between the GDP levels under the two strategies being the benefit from the increased R&D.

interaction was never significant. These results may be an indication that extension staff facilitate the faster absorption of R&D and thus indirectly have a positive effect on MFP, whereas human capital does not appear to have a role in this absorption process.

We also tested whether the elasticity of domestic R&D has changed over time by including an interaction between the dummy variable and domestic R&D. We found this interaction to be insignificant in both the Koyck and PIM models, perhaps indicating that the effect of domestic R&D on agricultural productivity has not changed over time.

7 Summary and Conclusions

Productivity growth is important as a long run source of real income growth and higher living standards, as well as contributing to enhancing the competitiveness of New Zealand in world markets. This paper has analysed the long term growth of agricultural productivity in New Zealand. The central question addressed in the paper is the contribution of investment in R&D to that productivity growth.

The primary sector (made up of Agriculture, Forestry, Fishing and Hunting) has been an important contributor to the overall improved productivity growth in the New Zealand economy over the last decade. Furthermore, over the last 80 years the rate of growth of productivity in agriculture has continued to increase.

Investment in R&D is a potentially important factor in expanding the stock of knowledge. This stock of knowledge can be viewed as a capital input into agricultural production, and like any other capital input provides a flow of services to the production processes.

Domestic expenditure in both the public and private sector on agricultural research, adds to what we call a domestic stock of knowledge. However in a small open economy the stock of foreign knowledge that “spills in” also adds to the total stock of knowledge that is available to the sector. Given that New Zealand is a very small player and accounts for but a tiny fraction of global R&D efforts, it is to be expected that access to this foreign stock of knowledge would play an important role. Particular attention was given to this aspect in this study.

It is evident that all the benefits from research done today are not captured and reflected in higher productivity immediately. The outputs of the research investment add to the stock of knowledge and it is that stock which potentially contributes to improving productivity. In other words, research done 10, 20 or even 30 years that added to the stock of knowledge could still be relevant and contributing to today’s output. This raises major challenges in modelling the impact of R&D as we need to allow for long lags. Partly for this reason, this study has been based on annual data from 1926-27 to 2000-01. This provides, at least in theory, the opportunity to allow for extended lagged effects.

At the same time the use of stocks of knowledge raises the question of depreciation. Continuing the analogy with other forms of capital, some knowledge can be expected to “depreciate” – ie lose its ability to contribute to high productivity. We have analysed a range of depreciation rates, settling on 30% based on the performance of the models.

As there is no one accepted method of modelling the lagged effects of R&D this study presents the findings of three different approaches. The first estimates stocks of knowledge (both domestic and foreign) based on the perpetual inventory method which involves assuming a rate of depreciation of knowledge. The second allows for a decay parameter to be estimated rather than imposed, and provides an estimate of the long run effect of R&D (the Koyck transformation). The third approach is based on the argument that initially the contribution of research would be small, but as the knowledge generated diffuses and is incorporated in the production process the impact would grow. However in the long run findings of research done many years ago suffer from obsolescence – they were relevant for the particular technological and economic circumstances of say the 1950s, but much less so in 2005 (the Almon lag).

Table 12 gives a summary of the findings for the rate of return to investment in domestic R&D under the various methods. For each method we tried a range of specifications. These are the basis for the range of estimated rates of return shown in the table.

Table 12 - Summary of the annual average rates of return to Domestic R&D: Various methods

Method		Y/K	Estimated Rate of Return (%pa)
Stocks of Knowledge		Average over entire sample period	0 to 29%
		Average from 1950 to 2001	0 to 8.4%
		2001	0 to 5.5%
Koyck Transformation		Average over entire sample period	0 to 25%
		Average from 1950 to 2001	0 to 7%
		2001	0 to 5%
Almon Lag			Negative
Simplified Almon Lag	Internal Rate of Return		70%
Stocks of Knowledge	Domestic Public	Average over entire sample period	0 to 32%
		Average from 1950 to 2001	0 to 9%
		2001	0 to 6.3%
	Domestic Private	Average over entire sample period	176% to 771%
		Average from 1950 to 2001	76% to 334%
		2001	22% to 97%
Koyck Transformation	Domestic Public	Average over entire sample period	0 to 26%
		Average from 1950 to 2001	0 to 7%
		2001	0 to 5%
	Domestic Private	Average over entire sample period	0 to 354%
		Average from 1950 to 2001	0 to 153%
		2001	0 to 45%

It will be immediately apparent that there is little or no indication of convergence across the methods. In both the Koyck and PIM models, we were able to find a significant effect from domestic R&D in most specifications. Our "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 we used Almon distributed lags we found a negative and significant coefficient on domestic R&D. When we attempted to estimate the separate effects of private and public R&D we found that in almost all cases there was no identifiable contribution from the public investment, while the private R&D lead to a wide range of possible rates of return. 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.

In a variant of the Almon lag approach which essentially mirrors that used by Scobie and Eveleens (1987), we derive a return of 70% to total domestic R&D. This compares with a value of 30% from the earlier study. There has been a marked slowdown in the growth of R&D investment and at the same time the rate of growth in productivity has increased. It is possible this higher estimate reflects the lagged contribution of past investments. However, given the wide variations in our estimates and the fact that many cases showed no significant contribution of domestic R&D, we would caution against selecting any one figure as a reliable estimate of the return to domestic R&D.

In contrast we found that, virtually regardless of the method or specification of the model, the spill-in effect from foreign knowledge was an important factor explaining the growth of agricultural productivity (see Table 13).

Table 13 - Summary of the response of agricultural productivity to foreign knowledge: various methods

Method	Percentage change in productivity following a 10% rise in foreign knowledge
Stocks of Knowledge	2.5 to 3.5
Koyck Transformation	2.3 to 3.9
Almon Lag	0 to 43.0
Stocks of Knowledge (when separate private and public domestic variables included)	-4.3 to 2.7
Koyck Transformation (when separate private and public domestic variables included)	0 to 3.4

It should be noted that we are not able to distinguish between the different types of research included in the agricultural R&D expenditure data. For example, recently there has been some increased emphasis in public spending towards research projects whose objectives include ameliorating the environmental consequences of agriculture. As measured productivity does not directly reflect the investment in R&D related to environmental enhancement, this implies that our results might understate the true contribution of R&D to productivity growth.

It should also be stressed that because of the need to have a lengthy series of data we were limited in the variables we could use as a proxy for the foreign stock of knowledge and have relied on US patent data.

The results underscore the importance of foreign knowledge in a small open economy. In formulating policies for fostering innovation, these findings suggest that particular attention be paid to enhancing linkages with the international scientific community. This could take many forms including scholarships for training and research overseas by

New Zealand researchers, involvement of New Zealand in international scientific networks, sponsorship of international symposia in New Zealand, etc.

While not as consistently robust, our findings typically support the argument that the stocks of domestic knowledge are positively associated with productivity growth. The very existence of foreign knowledge may be a necessary condition for achieving productivity growth in a small open economy. However in no way could it be argued that it is sufficient. Having a domestic capability that can receive and process the spill-ins from foreign knowledge is vital to capturing the benefits. The challenge is to be able to isolate those effects from aggregate data for the agricultural sector. In that particular aspect we claim only modest success.

Appendix One: Unit root tests

The unit root tests used in this study are the Augmented Dickey-Fuller and Phillips-Perron tests. The optimal lag length has been chosen using Schwarz criterion.

All variables were tested first to ascertain whether a trend should be included in the unit root test. If we did not reject the unit root null hypothesis, we took the first difference of the series and reran the test excluding a time trend.

All variables were found to be I(1), except for the human capital index, the soil moisture deficit variable, and the MFP index which were all found to be stationary with drift and trend.

Appendix Table 1: Unit Root tests - levels

Vairable:	Lag Order	t-statistic
MFP Index	0	-3.32*
Total R&D expenditures	0	-2.45
Public R&D expenditures	0	-2.52
Private R&D expenditures	0	-0.80
Wet	4	-3.57**
US Patents	0	1.25
Cumulated US Patents	1	1.42
Human Capital Index	1	-3.03**
Total R&D Stock (using 30% depreciation)	4	-1.13
Public R&D Stock (using 30% depreciation)	4	-3.60**
Private R&D Stock (using 30% depreciation)	1	-0.94
Extension (number of workers)	1	0.80

*= sig. at 10% level, **=sig. at 5% level, ***=sig. at 1% level

Appendix Table 2: Unit Root tests – first differences

Vairable:	Lag Order	t-statistic
Total R&D expenditures	0	-7.82***
Public R&D expenditures	0	-7.96***
Private R&D expenditures	0	-8.63***
US Patents	0	-8.37***
Cumulated US Patents	0	-3.94***
Total R&D Stock (using 30% depreciation)	0	-3.73**
Private R&D Stock (using 30% depreciation)	0	-4.48***
Extension (number of workers)	0	-6.49***

*= sig. at 10% level, **=sig. at 5% level, ***=sig. at 1% level

Appendix Two: Almon Distributed Lag

This appendix sets out the algebra behind the Almon distributed lag polynomials, both using a first order polynomial (which we use for education lags) and using a second order polynomial (which we use for both domestic and foreign R&D lags).

If we start with equation (9) such that

$$W(B)RD_t = \sum_i w_i RD_{t-i}$$

Then if we assume a second order polynomial, we can replace w_i with

$$w_i = a_0 + a_1 i + a_2 i^2$$

Or if we assume a first order polynomial, then

$$w_i = a_0 + a_1 i$$

So we now have

$$W(B)RD_t = a_0 \sum_{i=0}^{\infty} RD_{t-i} + a_1 \sum_{i=0}^{\infty} iRD_{t-i} + a_2 \sum_{i=0}^{\infty} i^2 RD_{t-i}$$

or

$$W(B)RD_t = a_0 \sum_{i=0}^{\infty} RD_{t-i} + a_1 \sum_{i=0}^{\infty} iRD_{t-i}$$

respectively. That is, we have reduced the number of parameters to be estimated down to 3, in the case of the second order polynomial, or 2 parameters in the case of the first order polynomial.

While we did not constrain the endpoints for the first order polynomial (the lags of the education variable), we did constrain both endpoints of the second order polynomials (domestic and foreign research) such that

$w_{-1} = 0$ and $w_{k+1} = 0$

So we now have

$$W(B)RD_t = a_2 \sum_{i=0}^{k} \left(i^2 - k - 1 - ki\right) RD_{t-i}$$

which further reduced the number of parameters to be estimated to 1 (for each variable).

Appendix Three: Results using Different Depreciation Rates

This appendix discusses the results of the PIM model when we use different depreciation rates. Appendix Table 14 sets out the results using a 5% depreciation rate, while Appendix Table 15 shows the results from using 15% depreciation.

Using a depreciation rate of 5% for both domestic and foreign R&D, the domestic knowledge stock is significant in all 4 specifications, with a rate of return ranging from 9.5% to 15.3%. The foreign stock, however, is significant in only 2 of the 4 specifications. The dummy variable is never significant, nor is the human capital index.

When we instead use a depreciation rate of 15%, both the domestic and foreign stock of knowledge are significant in all 4 specifications. The rate of return to domestic R&D ranges from 14.3% to 24.1%. The human capital index and dummy variables are again not significant.

Table 14: Using 5% depreciation rate.

Independent variables:	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Weather	-0.050	-0.076	-0.064	-0.058
Extension	-0.429***	-0.387***	-0.407***	-0.358***
Domestic knowledge stock	0.341***	0.234**	0.231***	0.212***
Foreign knowledge stock	0.228	0.318*	0.234	0.342*
Human capital	-0.142	-0.021		
Dummy84	0.028		0.002	
Adjusted r2	0.928	0.936	0.932	0.938

Table 15: Using 15% depreciation rate.

Independent variables:	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Weather	-0.089	-0.099	-0.098	-0.084
Extension	-0.295*	-0.378***	-0.236	-0.413***
Domestic knowledge stock	0.336***	0.199*	0.172***	0.235***
Foreign knowledge stock	0.309***	0.334***	0.349***	0.283***
Human capital	0.198	0.019		
Dummy84	0.177		0.146	
Adjusted r2	0.929	0.934	0.932	0.936

Appendix Four: Description of the Data

This appendix describes the dataset we have constructed and lists the sources.

Gross Output (1949/50$)

Gross Farming Income divided by the Farm Output Price Index.

Gross Farming Income

1926/27 to 1966/67: Hussey and Philpott (1969). Table 1 Gross Income, Expenditure and Net Income "Gross Farm Income".

1967/68 to 1970/71: Nickel and Gibson (1983).

1971/72 to 1976/77: INFOS series SNAA.SAA4Z (Gross Output – total) less INFOS series SNAA.S1J4Z (Gross Output – Other Horticultural Products), SNAA.S1K4Z (Gross Output – Agricultural Services), and SNAA.S1L4Z (Gross Output – Other Products N.E.C).

1977/78 to 1985/86: INFOS series SNBA.SKHAA4 (Gross Output - total) less INFOS series SNBA.SLJ4 (Gross Output – other horticultural products), SNBA.SLK4 (Gross Output – Agricultural Services), and SNBA.SLL4 (Gross Output – other products N.E.C).

1986/87 to 2000/01: INFOS series SNCA.S1NP10AAT4 (Gross Output – total) less INFOS series SNCA.S7NP10JT4 (Gross Output – other horticultural products), SNCA.S7NP10KT4 (Gross Output – agricultural services), and SNCA.S7NP10LT4 (Gross Output – other products N.E.C).

Farm Output Price Index

1926/27 to 1965/66: Hussey and Philpott (1969). Table 3 Prices Received and Prices Paid "Price index of farm outputs".

1966/67 to 1977/78: Calculated from Ellison (1977) Table 1 Output per unit of Aggregate Input "Index of Gross Output (base 1949/50=100).

1978/79 to 1994/95: Calculated from INFOS series SNBA.SNZ (Volume of Production Index 1978=1000)

1995/96 to 2002/03: INFOS series PPIQ.SUX01 (Producer Price Index – Outputs)

Appendix Table 3: Output data.

Year	Gross Farming Income (nominal, $m)	Farm Output Price Index	Gross Output (1949/50$m)
1926—27	105.2	51.8	203.0888
1927—28	120.8	53.7	224.9534
1928—29	137.2	58.8	233.3333
1929—30	122.2	49.9	244.8898
1930—31	87	35.1	247.8632
1931—32	75.8	30.6	247.7124
1932—33	76	26.8	283.5821
1933—34	99.2	33.9	292.6254
1934—35	93.2	32.9	283.2827
1935—36	118	39.5	298.7342
1936—37	149.2	48.6	306.9959
1937—38	142.2	46.3	307.1274
1938—39	140.2	47.5	295.1579
1939—40	150	48.8	307.377
1940—41	169.9	50	339.8
1941—42	167.6	51.1	327.9843
1942—43	169.6	53.7	315.8287
1943—44	173.4	55.3	313.5624
1944—45	205.2	60.4	339.7351
1945—46	192.2	60.8	316.1184
1946—47	222.6	67.9	327.8351
1947—48	271.4	80.6	336.7246
1948—49	293.4	84.2	348.4561
1949—50	366.2	100	366.2
1950—51	582.6	155.4	374.9035
1951—52	436.5	116.4	375
1952—53	522.2	133	392.6316
1953—54	544.6	138.7	392.646
1954—55	562.1	140.1	401.2134
1955—56	554.4	135.1	410.3627
1956—57	614	147.5	416.2712
1957—58	592.7	132.9	445.9744
1958—59	564.2	121.7	463.599
1959—60	623.5	132.8	469.503
1960—61	613.9	125.2	490.3355
1961—62	595	119.2	499.1611
1962—63	654	124.5	525.3012
1963—64	763.6	140.5	543.4875
1964—65	792.1	141.9	558.21
1965—66	850.5	144	590.625
1966—67	824.5	137.1398	601.2113
1967—68	817.9	129.2162	632.97
1968—69	885.6	135.2921	654.5836
1969—70	893.8	132.961	672.2274

Year	Gross Farming Income (nominal, $m)	Farm Output Price Index	Gross Output (1949/50$m)
1970—71	934.9	131.4013	711.4848
1971—72	1358	184.4642	736.1861
1972—73	1759	232.1194	757.7997
1973—74	1908	246.0528	775.4434
1974—75	1469	193.8507	757.7997
1975—76	1972	255.4687	771.9147
1976—77	2561	315.716	811.1721
1977—78	2516	323.3559	778.09
1978—79	2929	368.3313	795.208
1979—80	4055	470.3501	862.1237
1980—81	4175	478.6533	872.2389
1981—82	4563	517.5958	881.576
1982—83	4625	508.0378	910.3653
1983—84	5455	585.2051	932.1518
1984—85	6623	669.6986	988.9524
1985—86	6109	611.4702	999.0676
1986—87	6068	609.2644	995.9552
1987—88	6611	625.6588	1056.646
1988—89	7202	701.212	1027.079
1989—90	8078	783.5345	1030.969
1990—91	7408	695.4529	1065.205
1991—92	8043	747.4223	1076.098
1992—93	8618	806.1019	1069.096
1993—94	9304	785.643	1184.253
1994—95	8944	754.2529	1185.809
1995—96	8705	783.2005	1111.465
1996—97	9187	797.7744	1151.579
1997—98	9753	785.5962	1241.478
1998—99	9586	778.8083	1230.855
1999-00	10368	843.892	1228.593
2000-01	13246	1000.812	1323.526
2001-02	15416	1149	1342.217
2002-03		1006	
2003-04		965	

Intermediate Consumption (1949/50$)

Intermediate Consumption (excluding Livestock Purchases and depreciation) deflated by the Farm Input Price Index.

Nominal Intermediate Consumption

1926/27 to 1966/67: Hussey and Philpott (1969). Table 1 Gross Income, Expenditure and Net Income, "Total Non-Factor Expenses" less "Depreciation" (Buildings and Structures and Plant and Machinery).

1967/68 to 1970/71: Ellison (1977) Table A5 Real Working Expenses "Total Non-Factor Expenses" less depreciation (average percentage of total intermediate consumption from previous 4 years multiplied by Total Non-Factor Expenses from Ellison).

1971/72 to 1973/74: INFOS series SNAA.SAA4G less the average percentage of livestock purchases to total Intermediate Consumption from 1974/75 to 2000/01, multiplied by total Intermediate consumption in each year.

1974/75 to 1977/78: INFOS series SNAA.SAA4G less INFOS series SNAA.S14G.

1978/79 to 1985/86: INFOS series SNBA.SKGAA4 less INFOS series SNBA.SMA4.

1986/87 to 2000/01: INFOS series SNCA.S1NP20AAT4 less INFOS series SNCA.S7NP20AT4.

Farm Input Price Index

1926-1966/67: Hussey and Philpott (1969) Table 3 Prices Received and Prices Paid "Price Index of Farm Inputs".

1967/68 to 1974/75: Hussey and Philpott price index updated using Ellison (1977) Table A5 Real Working Expenses "Price Index".

1975/76 to 1981/82: Updated using INFOS series FPIA.S39 (Farm Costs price index).

1982/83 to 2003/04: Updated using INFOS series FPIQ.SI9Y (Farm Expenses, excluding livestock, price index).

Value Added (1949/50$)

Calculated as Real Gross Output minus Real Intermediate Consumption.

Appendix Table 4: Intermediate Consumption and GDP data.

Year	Nominal Intermediate Consumption ($m)	Farm Input Price Index (1949/50=100)	Real Intermediate Consumption (1949/50$m)	Real GDP (1949/50$m)
1926—27	29	53	56	147
1927—28	30	54	56	169
1928—29	32	55	58	176
1929—30	33	55	59	185
1930—31	32	54	58	190
1931—32	29	50	57	190
1932—33	28	46	61	222
1933—34	28	45	63	230
1934—35	28	45	63	220
1935—36	29	46	64	235
1936—37	32	51	64	243
1937—38	37	57	65	242
1938—39	38	59	64	231
1939—40	44	60	73	234
1940—41	53	60	87	252
1941—42	55	64	87	241
1942—43	63	69	92	224
1943—44	72	73	100	214
1944—45	81	73	111	229
1945—46	74	78	96	221
1946—47	69	83	83	245
1947—48	90	89	101	236
1948—49	97	99	98	250
1949—50	129	100	129	238
1950—51	205	108	189	186
1951—52	149	127	117	258
1952—53	209	132	158	235
1953—54	198	134	148	245
1954—55	202	140	144	257
1955—56	195	144	136	275
1956—57	211	145	145	271
1957—58	176	152	116	330

Year	Nominal Intermediate Consumption ($m)	Farm Input Price Index (1949/50=100)	Real Intermediate Consumption (1949/50$m)	Real GDP (1949/50$m)
1958—59	177	153	116	348
1959—60	197	155	127	342
1960—61	168	159	106	385
1961—62	179	162	111	388
1962—63	210	163	128	397
1963—64	257	164	157	387
1964—65	274	166	165	394
1965—66	310	173	179	411
1966—67	285	179	160	442
1967—68	298	178	168	465
1968—69	351	191	184	471
1969—70	339	198	171	501
1970—71	360	209	173	539
1971—72	619	220	281	455
1972—73	742	233	319	439
1973—74	837	264	317	459
1974—75	679	294	231	527
1975—76	792	325	244	528
1976—77	1002	381	263	548
1977—78	1079	430	251	527
1978—79	1247	476	262	533
1979—80	1599	582	275	587
1980—81	1830	713	257	616
1981—82	2170	853	254	627
1982—83	2427	855	284	626
1983—84	2710	872	311	621
1984—85	3267	973	336	653
1985—86	3147	1080	291	708
1986—87	3179	1130	281	715
1987—88	3171	1183	268	789
1988—89	3603	1237	291	736
1989—90	4003	1308	306	725
1990—91	4005	1334	300	765
1991—92	4187	1345	311	765
1992—93	4913	1374	358	712
1993—94	5082	1383	368	817

Year	Nominal Intermediate Consumption ($m)	Farm Input Price Index (1949/50=100)	Real Intermediate Consumption (1949/50$m)	Real GDP (1949/50$m)
1994—95	4996	1390	359	826
1995—96	4969	1394	357	755
1996—97	4887	1405	348	804
1997—98	5086	1424	357	884
1998—99	5369	1438	373	858
1999-00	5696	1465	389	840
2000-01	6434	1553	414	909
2001-02		1622		
2002-03		1657		
2003-04		1684		

Capital Stock (1949/50$)

Sum of Livestock, Plant, machinery and Equipment, Improvements, and the value of all unimproved Agricultural land (valued by Hussey and Philpott (1969) as 1949/50$329.9m).

Livestock

1926/27 to 1966/67: Hussey and Philpott (1969) Table 15 Value of Livestock (in constant prices).

1967/68 to 1970/71: Ellison (1977) Table A1 Real Value of Livestock

1971/72 to 1983/84: NZOYB Chapter: Farming section: Livestock. Value of livestock in 1949/50$ estimated as No. of Sheep @ $5 + Cattle @ $30 + Pigs @ $6.

1984/85 to 2003/04: INFOS series AGRA.SACMZZZ (Total Cattle), AGRA.SADDZZZ (Total Pigs), AGRA.SAEJZZZ (Total Sheep), AGRA.SAFMZZZ (Total Goats), and AGRA.SAGXZZZ (Total Deer). Value of livestock in 1949/50$ estimated as Sheep @ $5 + Cattle @ $30 + Pigs @ $6 + Deer @ $20 + Goats @ $3.

Plant/Machinery/Transport

1926/27 to 1966/67: Hussey and Philpott (1969) Table 16 Real Value of Depreciated Plant and Machinery.

1967/68 to 1970/71: Ellison (1977) Table A2 Real Value of Depreciated Plant and Machinery

1971/72 to 1983/84: "Agricultural Statistics" Capital Expenditure on Tractors and Farm Machinery. NZOYB – Import Price Index (non-electrical machinery). Capital Expenditure deflated by Import Price Index to give Gross Fixed Capital Formation.

Capital Stock calculated from 1970/71 figure using the perpetual inventory method with 9% depreciation.

1971/72 to 1983/84: "Agricultural Statistics" Number of Farm Trucks. Real depreciated value of Farm Trucks calculated by multiplying the number of Farm Trucks by $570 (their real depreciated unit value in 1949/50 prices). These figures added to Plant / Machinery Capital Stock as calculated above.

1984/85 to 1998/99: Statistics New Zealand Gross Fixed Capital Formation and Productive Capital Stock series, by Industry and Asset Type. INFOS series OTPA.SIA1LY1 and OTPA.SIA1MD1 (import price indices for (non-electrical) machinery and for transport equipment). GFKF deflated by the import price index (and CPI where import price index unavailable) to give GFKF in 1949/50$, then Capital Stock calculated using the perpetual inventory model with 9% and 19% depreciation for Plant / Machine and for Transport Equipment respectively. Separate series for Plant / Machine Capital Stock and for Transport Equipment Capital Stock were calculated – the initial values for each were estimated from the 1983/84 Plant / Machine / Transport Capital Stock value by examining the relative size of each from the Statistics New Zealand Productive Capital Stock series.

1999/00 to 2003/04: As above, except GFKF for Agriculture estimated from GFKF – All Industries (INFOS series SNCA.S3NP51AN1140 and SNCA.S3NP51AN1150), using the percentage of all-Industries GFKF for each asset type attributable to Agriculture in the final 5 years of the Statistics New Zealand GFKF series.

Improvements

1926/27 to 1960/61: Hussey and Philpott (1969) Table 17 Deflated value of improvements in 1949/50 prices.

1961/62 to 1970/71: Ellison (1977) Table A3 Real value of improvements.

1971/72 to 1998/99: Statistics New Zealand GFKF by Industry and Asset Type series. Sum of the real values of GFKF in Residential Buildings, Non-residential Buildings, Other Construction, and Land Improvements. Improvements Capital Stock calculated using the perpetual inventory method with a 1.7% depreciation rate (from Philpott (1992), based on an average 60 year life for Improvements). Price Indices for these 4 asset types from Hussey and Philpott (1969) and Ellison (1977): Improvements price index, and from INFOS series FPIA.S41 (Farm Buildings), FPIA.S44 (Land Development), CEPQ.S2BF (Farm Buildings), CEPQ.S2GA (Residential buildings), CEPQ.S2GC (Other construction), CEPQ.S2GD (Land Improvements). The price indices for each constructed from combinations of the above series and the series FPIQ.SI9Y (general Farm Expenses) where an appropriate index is not available.

1999/00 to 2003/04: As above, except GFKF for Agriculture estimated from GFKF – All Industries (INFOS series SNCA.S3NP51AN1110, SNCA.S3NP51AN1120, SNCA.S3NP51AN1130, and SNCA.S3NP51AN1180), using the % of all-Industries GFKF for each asset type attributable to Agriculture in the final 5 years of the StatsNZ GFKF series.

Appendix Table 5: Capital Stock data.

Year	Livestock (1949/50$,000)	PLANT, MACHINERY, AND TRANSPORT (1949/50$,000)	REAL VALUE OF IMPROVEMENTS (1949/50$,000)	TOTAL CAPITAL STOCK (includes Unimproved Land value), 1949/50$,000
1926—27	230,934	46,300	417,339	1,024,473
1927—28	229,096	49,236	430,641	1,038,873
1928—29	237,404	50,941	443,283	1,061,528
1929—30	251,970	53,203	455,588	1,090,661
1930—31	270,238	58,045	466,292	1,124,475
1931—32	273,080	60,961	474,780	1,138,721
1932—33	267,554	59,964	483,212	1,140,630
1933—34	266,936	59,538	487,111	1,143,485
1934—35	275,086	59,938	490,901	1,155,825
1935—36	277,610	60,879	493,475	1,161,864
1936—37	281,886	63,799	495,577	1,171,162
1937—38	291,860	69,499	496,595	1,187,854
1938—39	300,418	74,433	496,853	1,201,604
1939—40	299,380	78,346	496,880	1,204,506
1940—41	294,404	78,901	497,244	1,200,449
1941—42	299,516	80,371	498,143	1,207,930
1942—43	303,400	80,775	501,109	1,215,184
1943—44	300,640	77,937	504,463	1,212,940
1944—45	302,620	79,506	510,819	1,222,845
1945—46	311,164	84,795	511,161	1,237,020
1946—47	309,942	85,107	514,237	1,239,186
1947—48	305,698	87,059	518,912	1,241,569
1948—49	307,192	90,824	524,275	1,252,191
1949—50	309,176	95,030	535,629	1,269,735
1950—51	321,078	102,819	556,448	1,310,245
1951—52	329,116	111,614	590,782	1,361,412
1952—53	334,756	121,647	637,188	1,423,491
1953—54	348,108	128,941	689,416	1,496,365
1954—55	366,294	136,977	745,703	1,578,874
1955—56	376,278	144,198	800,676	1,651,052
1956—57	385,478	147,664	856,037	1,719,079
1957—58	392,244	150,172	886,123	1,758,439
1958—59	410,464	153,617	921,228	1,815,209
1959—60	417,732	152,453	954,821	1,854,906
1960—61	419,388	154,985	991,709	1,895,982

Year	Livestock (1949/50$,000)	PLANT, MACHINERY, AND TRANSPORT (1949/50$,000)	REAL VALUE OF IMPROVEMENTS (1949/50$,000)	TOTAL CAPITAL STOCK (includes Unimproved Land value), 1949/50$,000
1961—62	439,618	157,082	1,032,044	1,958,644
1962—63	446,992	157,795	1,078,930	2,013,617
1963—64	456,278	158,045	1,144,787	2,089,010
1964—65	461,976	160,406	1,175,353	2,127,635
1965—66	477,076	161,860	1,200,885	2,169,721
1966—67	507,250	170,035	1,199,980	2,207,165
1967—68	536,172	172,897	1,275,759	2,314,728
1968—69	553,470	174,494	1,312,051	2,369,915
1969—70	561,151	175,324	1,366,364	2,432,739
1970—71	568,167	174,890	1,404,901	2,477,858
1971—72	562,830	175,463	1,405,745	2,473,938
1972—73	566,261	178,452	1,413,609	2,488,222
1973—74	553,000	185,748	1,426,122	2,494,770
1974—75	561,526	187,668	1,430,740	2,509,834
1975—76	557,904	189,429	1,434,195	2,511,428
1976—77	555,060	196,124	1,438,956	2,520,040
1977—78	560,564	196,973	1,442,545	2,529,982
1978—79	566,183	197,770	1,449,713	2,543,566
1979—80	560,948	202,446	1,460,739	2,554,033
1980—81	590,401	208,783	1,477,153	2,606,237
1981—82	593,006	216,739	1,496,049	2,635,694
1982—83	591,309	220,847	1,508,797	2,650,853
1983—84	582,679	227,420	1,520,257	2,660,256
1984—85	590,460	225,624	1,528,784	2,674,768
1985—86	587,308	209,099	1,526,947	2,653,253
1986—87	598,342	196,787	1,513,996	2,639,024
1987—88	576,911	184,934	1,499,752	2,591,497
1988—89	583,242	178,743	1,486,655	2,578,540
1989—90	559,433	181,449	1,477,370	2,548,152
1990—91	555,363	181,734	1,465,553	2,532,550
1991—92	546,220	183,937	1,454,568	2,514,625
1992—93	533,942	190,683	1,444,085	2,498,610
1993—94	525,734	200,205	1,437,262	2,493,101
1994—95	541,951	206,885	1,429,409	2,508,144
1995—96	549,179	208,781	1,426,750	2,514,611
1996—97	534,559	210,734	1,421,200	2,496,392
1997—98	535,677	210,109	1,414,695	2,490,380

Year	Livestock (1949/50$,000)	PLANT, MACHINERY, AND TRANSPORT (1949/50$,000)	REAL VALUE OF IMPROVEMENTS (1949/50$,000)	TOTAL CAPITAL STOCK (includes Unimproved Land value), 1949/50$,000
1998—99	523,751	206,864	1,409,794	2,470,308
1999-00	533,502	209,046	1,406,994	2,479,442
2000-01	528,314	214,246	1,404,207	2,476,668
2001-02	524,909	223,861	1,404,542	2,483,213
2002-03	522,886	231,962	1,406,211	2,490,960
2003-04	533,405	242,913	1,409,446	2,515,664

Labour Force

The "Full-time equivalent labour force" is the series we have used in the estimation.

Total Labour Force

1926/27 to 1966/67: Hussey and Philpott (1969) Table 9 Estimates of Farm Labour Force - "All Farm Labour".

1967/68 to 1974/75: Ellison (1977): Table A6 Index of Aggregate Inputs – "Labour".

1975/76 to 1979/80: NZOYB: Section Farming, Table Farm Employment Survey, unpaid family subtracted from total workers on farms.

1980/81 to 1995/96: INFOS series AGRA.SAMAZZZ, AGRA.SAMBZZZ, AGRA.SAMCZZZ, AGRA.SAMDZZZ. The sum of Full-time, Part-time, Casual, and Working Owners.

1996/97 to 2003/04: INFOS series HLFA.SJB3UA (Total persons employed – Agriculture, Forestry, Fishing), and series SNCA.S2ND10AAT4, SNCA.S2ND10ABT4, and SNCA.S2ND10ACT4 (Compensation of Employees in Agriculture, Forestry and Fishing respectively). The percentage of COE in the combined Agriculture, Forestry, Fishing group attributable to Agriculture was multiplied by the Total persons employed.

Working Owners

1926/27 to 1966/67: Hussey and Philpott (1969) Table 9 Estimates of Farm Labour Force - "All Farm Labour" minus "Paid Farm Workers".

1967/68 to 1979/80: Estimated as a percentage of Total Labour Force. The trend over the adjacent periods is of a steady increase in the percentage of Working Owners in the Total Labour Force. Therefore Working Owners as a percentage of the Total Labour Force was interpolated on a straight line between the 1966/67 figure of 61% and the 1980/81 figure of 71%, and the percentage in each year was multiplied by the Total Labour Force figure for that year.

1980/81 to 1995/96: INFOS series AGRA.SAMDZZZ – Working Owners.

1996/97 to 2003/04: Estimated as 60.9% of the Total Labour Force (in 1995/96 Working Owners made up 60.9% of the Total Labour Force).

Total Employees

1926/27 to 1966/67: Hussey and Philpott (1969) Table 9 Estimates of Farm Labour Force - “Paid Farm Workers”.

1967/68 to 1979/80: Total Labour Force minus Working Owners.

1980/81 to 1995/96: Sum of Full-time, Part-time, and Casual employees (INFOS series).

1996/97 to 2003/04: Total Labour Force minus Working Owners.

Full-time Employees

1926/27 to 1954/55: Hussey and Philpott (1969) Table 9 Estimates of Farm Labour Force - “Permanent Males” minus Working Owners (“Permanent Males” series ends in 1954/55).

1955/56 to 1979/80: Estimated as a percentage of Total Employees. Full-time Employees as a percentage of Total Employees was interpolated on a straight line between the 1954/55 and 1980/81 figures of 77% and 58% respectively, and the percentage in each year was multiplied by the Total Employees figure for that year.

1980/81 to 1995/96: INFOS series AGRA.SAMAZZZ – Full-time Employees.

1996/97 to 2003/04: Estimated as 58.1% of Total Employees (in 1995/96 Full-Time Employees made up 58.1% of Total Employees).

Part-time / Casual Employees

1926/27 to 2003/04: Total Employees minus Full-time Employees.

“Full-time Equivalent” number of Employees

1926/27 to 2003/04: Part-time / Casual Employees divided by two, plus Full-time Employees.

“Full-time Equivalent” Labour Force

1926/27 to 2003/04: Full-time Equivalent Employees plus Working Owners.

Appendix Table 6: Labour Force data.

Year	Number of Working Owners	Total Number of Employees	Number of Full-time Employees	Number of Part-time / Casual Employees	FTE Total Labour Force (Working Owners + FTE employees)
1926—27	62,800	79,200	37,800	41,400	121,300
1927—28	63,600	84,400	41,300	43,100	126,450
1928—29	64,600	83,400	46,600	36,800	129,600
1929—30	65,600	85,400	52,000	33,400	134,300
1930—31	66,400	88,600	52,600	36,000	137,000
1931—32	67,300	91,700	55,700	36,000	141,000
1932—33	68,300	92,700	56,700	36,000	143,000
1933—34	69,300	92,700	56,700	36,000	144,000
1934—35	71,300	91,700	54,700	37,000	144,500
1935—36	70,300	92,700	54,700	38,000	144,000
1936—37	69,300	91,700	53,700	38,000	142,000
1937—38	68,300	90,700	52,700	38,000	140,000
1938—39	65,300	91,700	53,700	38,000	138,000
1939—40	66,400	87,600	50,600	37,000	135,500
1940—41	66,000	74,000	36,000	38,000	121,000
1941—42	65,600	59,400	21,400	38,000	106,000
1942—43	64,500	60,500	22,500	38,000	106,000
1943—44	64,400	62,600	24,600	38,000	108,000
1944—45	63,300	66,700	28,700	38,000	111,000
1945—46	64,500	72,500	43,500	29,000	122,500
1946—47	65,700	69,300	47,200	22,100	123,950
1947—48	66,900	67,300	42,500	24,800	121,800
1948—49	68,000	65,700	41,200	24,500	121,450
1949—50	69,200	64,300	41,100	23,200	121,900
1950—51	70,400	62,600	41,000	21,600	122,200
1951—52	71,600	60,700	40,900	19,800	122,400
1952—53	71,600	60,000	42,000	18,000	122,600
1953—54	71,600	59,100	43,900	15,200	123,100
1954—55	71,600	58,800	45,100	13,700	123,550
1955—56	71,600	58,600	44,527	14,073	123,163
1956—57	71,600	57,700	43,430	14,270	122,165
1957—58	71,600	56,500	42,123	14,377	120,911
1958—59	71,600	55,600	41,054	14,546	119,927
1959—60	71,600	54,000	39,486	14,514	118,343
1960—61	71,600	52,500	38,014	14,486	116,857
1961—62	71,600	51,300	36,778	14,522	115,639
1962—63	71,600	50,100	35,559	14,541	114,430
1963—64	71,600	48,800	34,288	14,512	113,144
1964—65	71,600	47,700	33,174	14,526	112,037
1965—66	71,600	47,200	32,488	14,712	111,444

Year	Number of Working Owners	Total Number of Employees	Number of Full-time Employees	Number of Part-time / Casual Employees	FTE Total Labour Force (Working Owners + FTE employees)
1966—67	71,600	46,500	31,674	14,826	110,687
1967—68	72,787	45,813	30,878	14,935	111,132
1968—69	73,266	44,634	29,764	14,870	110,465
1969—70	73,673	43,427	28,649	14,779	109,711
1970—71	74,066	42,234	27,559	14,675	108,963
1971—72	74,577	41,123	26,540	14,583	108,409
1972—73	75,078	40,022	25,543	14,479	107,861
1973—74	76,692	39,508	24,933	14,575	108,912
1974—75	78,323	38,977	24,319	14,658	109,971
1975—76	82,922	39,847	24,577	15,271	115,134
1976—77	88,089	40,857	24,907	15,950	120,971
1977—78	93,393	41,791	25,178	16,614	126,877
1978—79	90,982	39,258	23,371	15,887	122,296
1979—80	94,968	39,493	23,228	16,265	126,328
1980—81	91,321	36,584	21,238	15,346	120,232
1981—82	96,051	39,897	23,374	16,523	127,687
1982—83	93,398	42,815	23,709	19,106	126,660
1983—84	86,981	41,967	22,787	19,180	119,358
1984—85	88,748	40,601	21,886	18,715	119,992
1985—86	86,653	38,974	20,650	18,324	116,465
1986—87	87,311	39,631	19,608	20,023	116,931
1987—88	85,045	36,952	20,866	16,086	113,954
1988—89	83,921	34,544	19,533	15,011	110,960
1989—90	87,203	36,888	21,404	15,484	116,349
1990—91	86,389	40,180	23,310	16,870	118,134
1991—92	84,515	36,982	20,459	16,523	113,236
1992—93	69,092	51,474	31,519	19,955	110,589
1993—94	64,247	44,714	30,745	13,969	101,977
1994—95	73,991	46,174	30,568	15,606	112,362
1995—96	73,547	47,284	27,490	19,794	110,934
1996—97	69,409	44,563	25,891	18,672	104,636
1997—98	68,627	44,061	25,599	18,462	103,457
1998—99	73,167	46,976	27,293	19,683	110,301
1999-00	76,231	48,943	28,436	20,507	114,921
2000-01	73,713	47,326	27,497	19,830	111,125
2001-02	78,046	50,108	29,113	20,995	117,656
2002-03	77,001	49,437	28,723	20,714	116,081
2003-04	74,056	47,546	27,624	19,922	111,641

R&D – expenditure

Total Agricultural R+D expenditure (1949/50$)

1926/27 to 1971/72: From Scobie and Eveleens (1987). Sum of Government expenditure, Funds to research associations, and Expenditure in Universities and other. Calculated from data in McBride (1966), and various NRAC, DSIR, and MAF reports.

1972/73 to 2001/02: From Robin Johnson dataset (most of which is in Johnson (2000)). Total R+D, Agriculture.

Nominal R+D deflated to 1949/50$ using INFOS series CPIA.SE9AJ

Private Agricultural R+D expenditure (1949/50$)

1926/27 to 1971/72 except 1926/27, 1927/28, and 1940/41 to 1944/45: From Scobie and Eveleens (1987). Private R+D is estimated to be approximately equal to the grants paid by DSIR to research associations – that is, that there is a 50:50 split between the contribution to research associations from producers and the government.

1926/27 to 1927/28: Estimated as 11.6% of Total R+D (the 1928/29 proportion).

1940/41 to 1944/45: Interpolated on a straight line basis between 1939/40 and 1945/46 values.

From 1926/27 to 1971/72 the data should be taken as a proxy for private R&D spending as they do not include expenditure by private firms. The research associations funded research beyond the farm gate in the processing sector which has the effect of enhancing the demand for the raw farm products.

1972/73 to 2001/02: From Robin Johnson dataset (most of which is in Johnson (2000)). Private R+D, Agriculture.

Nominal R+D deflated to 1949/50$ using INFOS series CPIA.SE9AJ

Public Agricultural R+D expenditure (1949/50$)

Total R+D minus Private R+D

Nominal R+D deflated to 1949/50$ using INFOS series CPIA.SE9AJ

US Patents

Data obtained from the United States Patent and Trademark Office. Total of Utility Patents (inventions) granted, Design Patents granted, and Plant Patents granted.

www.uspto.gov/web/offices/ac/ido/oeip/taf/h_counts.htm

Appendix Table 7: R&D data.

Year	Real Private R&D, 1949/50$,000	Real Public R&D, 1949/50$,000	Real Total Domestic R&D, 1949/50$,000	Total USPTO Patents Granted
1926—27	11	85	97	44,105
1927—28	12	90	102	45,514
1928—29	14	110	124	48,174
1929—30	19	147	166	47,938
1930—31	16	138	154	54,698
1931—32	22	113	135	56,448
1932—33	21	152	173	51,218
1933—34	18	144	162	47,372
1934—35	21	161	182	44,529
1935—36	22	174	196	44,388
1936—37	30	228	258	42,875
1937—38	35	326	361	43,130
1938—39	55	482	536	48,711
1939—40	49	423	472	48,467
1940—41	44	668	713	47,656
1941—42	40	750	790	42,242
1942—43	36	455	490	33,330
1943—44	32	522	554	31,007
1944—45	29	614	643	29,235
1945—46	25	720	745	24,640
1946—47	42	1,030	1,072	22,293
1947—48	56	1,265	1,321	27,973
1948—49	58	1,384	1,442	39,675
1949—50	67	1,664	1,731	47,847
1950—51	49	1,562	1,611	48,548
1951—52	53	1,621	1,674	46,676
1952—53	56	1,495	1,551	43,259
1953—54	62	1,478	1,541	36,446
1954—55	68	1,574	1,643	33,248
1955—56	79	1,678	1,757	49,894
1956—57	101	1,832	1,933	45,236
1957—58	85	1,898	1,984	50,835
1958—59	91	1,893	1,984	55,278
1959—60	95	1,982	2,078	49,828
1960—61	98	2,232	2,330	50,964
1961—62	160	2,393	2,552	58,082
1962—63	181	2,462	2,643	48,773
1963—64	210	2,564	2,774	50,189
1964—65	233	2,977	3,210	66,401
1965—66	313	3,357	3,670	71,707
1966—67	351	3,628	3,979	68,902

Year	Real Private R&D, 1949/50$,000	Real Public R&D, 1949/50$,000	Real Total Domestic R&D, 1949/50$,000	Total USPTO Patents Granted
1967—68	265	3,683	3,948	62,527
1968—69	284	3,813	4,098	70,997
1969—70	351	3,825	4,176	67,695
1970—71	347	4,232	4,579	81,544
1971—72	448	4,849	5,296	77,910
1972—73	568	6,664	7,232	78,308
1973—74	604	7,653	8,257	80,843
1974—75	662	8,303	8,965	76,432
1975—76	658	7,992	8,649	74,966
1976—77	613	7,268	7,881	69,371
1977—78	636	7,275	7,910	70,150
1978—79	724	8,238	8,962	52,104
1979—80	720	6,758	7,477	65,885
1980—81	751	7,187	7,939	70,699
1981—82	835	7,851	8,686	63,005
1982—83	832	7,612	8,444	61,620
1983—84	882	7,806	8,688	72,350
1984—85	895	7,584	8,478	76,969
1985—86	878	8,193	9,071	76,602
1986—87	913	7,380	8,293	89,140
1987—88	900	7,339	8,239	84,028
1988—89	894	7,660	8,554	102,216
1989—90	908	7,811	8,719	98,707
1990—91	840	7,864	8,705	106,435
1991—92	903	7,854	8,757	107,034
1992—93	1,222	8,240	9,461	109,414
1993—94	1,018	7,910	8,928	113,270
1994—95	1,230	8,790	10,021	113,518
1995—96	1,520	10,155	11,676	121,417
1996—97	1,665	11,184	12,849	123,791
1997—98	1,802	11,909	13,711	162,849
1998—99	1,819	11,350	13,169	168,638
1999-00	1,865	11,475	13,340	175,456
2000-01	1,997	11,636	13,633	183,492
2001-02	2,229	12,280	14,509	183,917
2002-03				186596

Agricultural Extension and Education

Education (number of students enrolled in Agriculture related courses)

1926/27 to 1983/84: From Scobie and Eveleens (1987). Data from NZOYB, students enrolled in Massey and Lincoln Agricultural Colleges (to 1940/41), students enrolled in degrees, diplomas, and certificates in Agricultural, Horticultural, Technology, Food Science, and Vet Science programmes (from 1941/42).

1984/85 to 1987/88: NZOYB, students enrolled in degrees, diplomas, and certificates in Agricultural, Horticultural, Technology, Food Science, and Vet Science programmes.

1988/89 to 1989/90: "Education Statistics of New Zealand", degrees, diplomas, and undergraduate university certificates in various Agricultural and Horticultural fields of study.

1990/91: NZOYB, estimated as the percentage change in Total university enrolments (all fields and levels) from the previous year, with this percentage applied to the 1989/90 Agriculture figure.

1991/92 – 1997/98: "Education Statistics of New Zealand", sum of National diploma or degree and Postgraduate university categories, for students enrolled in the Agriculture, Forestry, and Fishing field of study. This figure was reduced by 5.4% to remove Forestry / Fishing students (5.4% was the average proportion from 1981/82 to 1986/87).

1998/99 – 2000/01: Ministry of Education website (or "Education Statistics of New Zealand"), degrees, diplomas, and postgraduate university for various Agricultural and Horticultural fields of study.

2001/02: NZOYB, diplomas, degrees, and postgraduate university for Agriculture and Environmental Studies category.

2002/03: Ministry of Education website (or "Education Statistics of New Zealand"), university enrolments for Agriculture and Environmental Studies.

Human Capital Index (HKI)

Human Capital is estimated as the sum of the Education variable for the current year and previous 15 years (As in Scobie and Eveleens 1987), ie

$HKI_t = EDU_t + EDU_{t-1} + \ldots + EDU_{t-15}$

For the first 14 years of the data series it was assumed that the number of students enrolled pre- 1926/27 was the same as the 1926/27 figure.

The Human Capital Index is constructed with a lag of 2 years, and based in 1949/50. As the education variable is constructed of the number of persons enrolled in the various institutions, there will be a lag before these people graduate and are introduced to the work force. Up until this introduction point they do not add anything to the stock of human capital. It has been assumed that on average this lag would be 2 years. That is, $HKI_t = HK_{t-2} / HK_{1947/48}$

Extension (number of workers)

1926/27 to 1983/84: From Scobie and Eveleens (1987). Represents the number of Advisory Services Division staff in MAF, figures from ASD Head Office.

1984/85 onwards: Following privatisation of the ASD, figures for the number of extension workers / consultants operating are difficult to find. Estimates were found in several sources, and the missing year data was interpolated between adjacent data points on a straight line basis.

1986/87: Journeaux, Stephens, and Johnson (1997), Section "Historical Developments" – estimate of 670 ASD staff.

1990/91: Scrimgeour, Gibson, and O'Neill (1991), Section 2.1 "The number of extension workers in NZ", conservative estimate that the extension worker: farm holding ratio is about 1:330. With approximately 81,000 farm holdings (INFOS AGRA.SAAAZZZ) this implies about 250 extension workers.

1991/92: Bloome (1993), Section "Commercialisation", estimate that since 1985 the number of professional staff had fallen by over 50%, implying a figure of around 320.

1995/96: Journeaux, Stephens, and Johnson (1997), Section "The total extension sector" – estimate the number of full-time extension workers/ consultants at 425.

1998/99: from NZ Institute of Primary Industry Management (NZIPIM, professional association for agricultural / horticultural, and forestry/ fishing, consultants, accountants, and bankers). Membership numbers in each year were reduced by 40%, a rough estimate intended to remove bankers / finance, and forestry / fishing, while including some extension workers who are not members of NZIPIM. NZIPIM estimates that around 45% of members are consultants while 40% are bankers/finance.

Other Regression Variables

Weather

Calculated as tenths of days of Soil Moisture Deficit.

1926/27 to 1983/84: From Scobie and Eveleens (1987). Based on data from Met Office of regional SMD. A NZ average calculated by weighting regions by stock units (1 cow = 8 SU, 1 sheep = 1 SU, 1 beef = 6 SU, 1 acre crop = 10 SU) using regional livestock and crop data.

1984/85 to 2003/04. Soil Moisture Deficit data by region from MAF. Calculated using regional livestock data and the same stock units as previously (with cropland excluded).

Deviations from Trend Net Farm Income

Net Farm Income:

1926/27 – 1966/67: Hussey and Philpott (1969), Table 1 "Net Farm Income"

1967/68 – 1971/72: Ellison (1977), Table: Non-factor Expenses, "Net Farm Income"

1972/72 – 1983/84: From Scobie and Eveleens (1987), data from NZOYB, calculated as Personal income from farming (Section: Production accounts, Agriculture, "Operating

Surplus") plus Income of farm companies (Chapter: Incomes and income tax, Table: Incomes of companies, Total of Agriculture and livestock production) minus Rates and land taxes (Chapter: Local government finance: receipts, sum of catchment boards, county councils, land drainage boards and road boards).

1984/85 – 1995/96: INFOS series SNBA.SKBAA4 (Net operating surplus) minus SNBA.SKDAA4 (Indirect taxes)

1996/97 – 2000/01: The % changes in Net operating surplus (Gross operating surplus, SNCA.S2NB02AAT4, minus Consumption of fixed capital, SNCA.S3NK10AAT4) were applied to the final term (1995/96) in the SNBA.SKBAA4 (Net operating surplus) series. The definition of Consumption of Fixed Capital was altered as part of changes to the National Accounts, meaning that the post-1996/97 Net operating surplus data is of a different magnitude to the pre-1996/97 data. The new and old Net operating surplus series are highly correlated, however, so applying % changes to the final term of the old series allows us to create data consistent with the old definition to a high degree of accuracy. From this constructed Net Operating surplus series was subtracted Indirect taxes to give Net farm income (INFOS SNCA.S2ND24AAT4).

Nominal Net farm income data was deflated to 1949/50$ using INFOS series CPIA.SE9AJ

"YD" (deviation from HP trend line):

Over the 75 year period for which data is available, Net farm income seems to exhibit a long-term trend not particularly close to a straight line – therefore we used a Hodrick-Prescott trend line. Since planning horizons of farmers are unlikely to be more than a few years, a straight line trend may not capture very well the phenomenon of extra input purchases in good years. YD was calculated as the deviation from the HP trend line .

Appendix Table 8: Other Regression Variables.

Year	Education (no. of students)	Human Capital Index	Extension workers	Tenths of Days of Soil Moisture Deficit	Deviations from Net Farm Income
1926—27	56	0.11	115	331	4,530
1927—28	94	0.11	128	446	19,203
1928—29	90	0.11	140	273	34,082
1929—30	276	0.12	152	484	10,563
1930—31	242	0.12	160	470	-37,254
1931—32	259	0.15	157	451	-36,565
1932—33	279	0.17	149	531	-36,248
1933—34	338	0.20	154	330	8,811
1934—35	287	0.22	155	526	-7,192
1935—36	251	0.26	160	228	22,199
1936—37	228	0.29	157	165	46,239
1937—38	488	0.31	179	363	8,660
1938—39	330	0.33	205	670	-2,475
1939—40	330	0.39	224	345	-6,589
1940—41	302	0.42	223	369	5,341
1941—42	112	0.46	220	474	-4,265
1942—43	296	0.49	177	514	-22,249
1943—44	800	0.49	198	360	-39,862
1944—45	1,249	0.52	208	118	-21,818
1945—46	1,549	0.61	248	507	-46,797
1946—47	583	0.76	273	439	-17,484
1947—48	584	0.92	341	540	-6,509
1948—49	598	0.96	364	380	-7,404
1949—50	579	1.00	478	408	19,928
1950—51	528	1.04	506	172	121,421
1951—52	466	1.07	505	359	6,336
1952—53	505	1.10	472	157	4,861
1953—54	499	1.13	488	355	15,981
1954—55	519	1.16	500	387	9,792
1955—56	584	1.16	510	398	-1,280
1956—57	722	1.19	495	265	13,129
1957—58	817	1.22	515	208	14,602
1958—59	885	1.27	518	211	-20,393
1959—60	877	1.36	575	318	-433
1960—61	812	1.43	575	192	4,493
1961—62	917	1.44	590	341	-23,914
1962—63	1,051	1.39	617	287	-12,188
1963—64	946	1.31	654	414	13,199
1964—65	1,427	1.37	517	170	5,339
1965—66	1,434	1.41	516	170	3,849
1966—67	1,469	1.52	506	232	-11,376

1967—68	1,990	1.62	496	319	-26,901
1968—69	2,233	1.74	486	312	-35,427
1969—70	2,269	1.93	537	361	-35,062
1970—71	2,381	2.15	512	357	-48,999
1971—72	2,433	2.37	557	296	-35,641
1972—73	2,280	2.60	572	574	79,791
1973—74	2,053	2.83	591	396	60,184
1974—75	2,537	3.03	586	272	-36,358
1975—76	2,867	3.18	614	324	-7,298
1976—77	2,888	3.39	594	263	34,738
1977—78	3,059	3.63	584	535	-7,456
1978—79	2,842	3.89	620	261	31,425
1979—80	3,100	4.16	604	91	73,235
1980—81	3,771	4.39	623	341	4,063
1981—82	3,901	4.65	639	348	4,044
1982—83	4,030	4.95	654	449	-8,636
1983—84	3,688	5.26	684	169	15,886
1984—85	4,017	5.58	679	371	23,422
1985—86	3,849	5.79	675	261	-11,034
1986—87	3,232	6.01	670	308	-33,900
1987—88	2,690	6.21	565	352	-8,251
1988—89	2,656	6.31	460	507	-2,109
1989—90	2,126	6.35	355	333	2,090
1990—91	1,946	6.39	250	333	-31,356
1991—92	2,581	6.40	320	367	-7,430
1992—93	2,255	6.33	346	296	-20,138
1993—94	2,295	6.29	373	386	-349
1994—95	2,491	6.21	399	414	-14,831
1995—96	1,523	6.12	425	277	-19,747
1996—97	2,247	6.07	422	308	-16,793
1997—98	3,094	5.88	418	460	-30,293
1998—99	2,953	5.69	415	417	-39,413
1999-00	2,776	5.59	413	332	-20,120
2000-01	2,775	5.45	430	399	48,220
2001-02	3,053	5.34	423	250	
2002-03	2,243	5.18	432	449	
2003-04			429	299	

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