Rates of Return on New Zealand R&D[1]

by

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This paper reports on a survey of past trends in national and sectoral R&D expenditure in New Zealand back to 1962 and models used to measure the rate of return to investment in R&D. Cobb Douglas models are compared with productivity models and are used to explore the interaction between R&D and labour and capital variables. Polynomial distributed lag models are investigated and the results compared with stock models. The average rates of return to R&D investment vary across sectors of the economy - some being surprisingly high - but some results remain ambiguous to interpret.

Introduction

The rate of return on research and development investment by firms (R&D) is notoriously hard to measure and trace through complex production systems. The main difficulty appears to be separating out the effects of other changes in the production system from those due to R&D. When aggregation occurs in the form of sectoral and national accounting systems, measurement is even more hit or miss. In this paper, national accounting data is used to measure the production effects, and industrial survey results to measure expenditure on R&D by firms on a sectoral basis.

Second, the nature of R&D investment does not lend itself to direct economic accounting. One view is that R&D is more like a pool resource than a point resource; the results of previous research are generally publicly available and often funded by the state. This is particularly so in the farm sector. In some other sectors, the control of information is more tightly held and private research results can be completely internalised. Nevertheless, the main characteristic of research knowledge is that it is more like a public good than a private good, and its use does not diminish its supply.

It is usual for science expenditure to be designated for a particular sector in science reporting [this may well be a convenience for statisticians than a profound analytical concept]. When R&D knowledge is drawn into the firm's production systems from the general pool some economists talk of spillovers in R&D (Industry Commission 1995). Conceptually, the firm may be using R&D results designated for a completely different sector. The different sources of R&D knowledge may contribute to increased productivity in a joint manner. In the complementary case, firms get more effect by using both types of R&D together than using them on their own. In the substitution case, the multiplicative effect is negative, and the types of research are effective substitutes for each other. This

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hypothesis can be tested on both public and private R&D which has been designated for a particular sector.

It is thus useful to distinguish between the different sources of R&D knowledge. "Private" R&D is that R&D carried out by private firms or sponsored by private firms - this includes industry research institutes mainly privately funded. "Public" R&D is that funded by the state and includes universities. Since cross-funding is quite common, these classifications are working models of R&D ownership rather than precisely defined categories. The main distinction between them is that private research tends to be internally used and owned, while public research fairly quickly enters the common pool.

The pool of research knowledge extends across international boundaries. We could postulate complementary and substitution relationships between internal and externally sourced R&D in a similar way to the above. Just as for inter industry R&D, there may be expenditure or stock data available for overseas R&D - a dominant country or countries need to be identified. For private overseas R&D, a substitute measure like patents registered can be used (Schimmelpfennig and Thirtle 1998).

Some of these conceptual relationships entered into discussions of science reform in New Zealand in the early 1990s (Johnson 1997). Prior to that time, Government departments carried out the bulk of R&D from funds provided by Government. Private sector R&D consisted of a few large firms with science interests and a set of industry research organisations jointly funded by Government and industry. The reforms removed the research provision from departments and transferred it to another set of research institutes organised on a commercial basis. The funds formerly used by the departments were placed in a common pool (the Public Good Science Fund) and distributed to all research institutes on a competitive bidding basis. The aim of the reform was to encourage greater private participation in the research process, and to diminish the central role of Government in funding and policy direction. At a second stage, direct university funding was placed in the public good science fund and the university scientists entered the bidding process alongside the research institutes, private organisations and private persons. Basic to the discussions was the hypothesis that state investment in R&D was "crowding out" private R&D.

Aims of the Paper

Conventional economic analysis of rates of return requires an investment profile of an innovation over the lifetime of its impacts. In the simplest case, a cost-benefit analysis of the profile of costs and returns provides an internal rate of return to the initial investment in R&D. Crop and animal innovations can sometimes be traced this way, but the general process of technological adoption is a lot more diffuse as we move away from simple cases. This problem is exacerbated by the lack of partial data on innovation and the dependence on national accounting systems which aggregate across firms and particular industrial processes. In this paper, rates of return to R&D investment have to be estimated by econometric methods and this approach obscures the simplicity of the internal rate of return calculation. [We can estimate a relationship between an investment and an output over a period of time which gives an average rate of return but not an internal rate of return].

National accounting data can provide time series of investment and output on a sectoral basis (25 sectors in NZSNA) and hence estimates of total factor productivity (TFP) for each sector. Using a production function approach, the innovation process can be incorporated in the analysis of productivity change. This can take a number of forms. In this paper, knowledge is first treated as a stock variable which grows and shrinks as information is added to it or lost from it. Cost of knowledge is represented by firm investment in R&D, and depreciation is represented by knowledge going out of date or being superseded. Thus the pool of knowledge is valued at cost and not by what it potentially could generate in increased returns. Secondly, the research process could be viewed as a continuous cost of producing goods (either through taxes paid or in-house investment) that eventually pays off through better performance. Where such costs can be identified, current levels of performance can be seen as a function of some weighted combination of all previous annual expenditures on R&D. These flows can be treated econometrically to estimate an average rate of return.

Expenditure on research knowledge seeking would ideally be provided by industry surveys attached to censi of industrial production. Annual investment in R&D would then match more exactly the data on factor productivity. This data has not been regularly collected in New Zealand though it was collected for a period around 1970. This gap leaves a major research task for the investigator. Sectoral information on R&D investment has to be built up separately from Government and University records and those surveys of private industry that have taken place[3]. The completion of this task for New Zealand by the author enabled fair to good quality statistics to be derived for public and private sector expenditure on R&D back to 1962.

In general terms, the objective function for the present research hypothesis was as follows:

$$O_{ij} = f(K_{ij}, L_{ij}, M_{ij}, R_{ij}, S_{ij}, T_{ij})$$

where O_{ij} = total output of i^{th} industry in the j^{th} year,
K_{ij} = flow of capital services in each industry in each year,
L_{ij} = flow of labour services in each industry in each year,
M_{ij} = intermediate inputs or materials used up by each industry in each year,
R_{ij} = flow of own (private) R&D ideas in each industry in each year,
S_{ij} = flow of interindustry (non-private) R&D ideas in each industry in each year,
and T_{ij} = flow of offshore R&D ideas in each industry and each year.

More detailed specification of the production function and the definition of variables is developed next.

Model Specification

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[3] Out of the 21 SNA production sectors used by the Statistics Department only nine sectors had identifiable and matching R&D data. These nine sectors and the total market sector are reported in this paper. The Government and Ownership of Dwellings sectors are omitted from the national accounting data set.

The objective function is to estimate the contribution of public and private R&D to economic growth on a sectoral basis. The procedure calculates multi-factor productivity in a growth accounting framework, and then econometrically estimates how much of the multi-factor productivity can be explained by R&D, while controlling for other possible influences on measured productivity (Englander *et al*,1988, Coe and Helpman 1993, Industry Commission 1995). The first step is to estimate the Cobb Douglas production function directly, in which net output is a function of labour and capital alone.

(1) $$Y = A K^a L^b,$$

where Y is net output, A is productivity, K is the stock of physical capital; L is labour and a and b are exponential coefficients.

If productivity can be explained by changes in the stock of R&D capital and other factors, then equation (1) can be rewritten as:

(2) $$Y = K^a L^b R^g Z^s,$$

where R is the stock of R&D capital; and Z represents other factors affecting measured productivity including foreign R&D and educational influences.

In the production function approach, a log linear version of equation (2) can be estimated as in (3):

(3) $$ln\, Y = a\, ln\, K + b\, ln\, L + g\, ln\, R + s\, ln\, Z,$$

with no further restrictions placed upon the parameters (i.e. on K and L). The estimate of g would provide a direct estimate of the percentage increase in output obtainable from a one per cent increase in R&D stocks, holding all other factors constant.

In the two-step productivity approach, equation (3) would be rewritten as :

(4) $$ln\, Y - a\, ln\, K - b\, ln\, L = g\, ln\, R + s\, ln\, Z$$

Under the additional assumptions that $a + b = 1$ and that a and b equal capital and labour income shares, the left-hand side of (4) equals multi-factor productivity (in level, not growth form), as conventionally measured in a growth accounting framework. Observations on multi-factor productivity can then be regressed on the variables shown on the RHS. In either case, estimates of the parameter g can be converted from an elasticity to an average rate of return dY/dR as given by:

(5) $$dY/dR = g\, (Y/R).$$

The capital variable K is derived from capital expenditure data by the perpetual inventory method:

(6) $$K_t = (1 - f)\, K_{t-1} + E_{t-1}$$

where K_t is the stock of conventional capital at the beginning of period t in constant prices; K_{t-1} is the stock of capital at the beginning of period t-1; E_{t-1} is capital expenditure during period t-1 in constant prices; and f is the depreciation or obsolescence rate of capital.

The perpetual inventory method is also applied to R&D expenditure (Coe and Helpman 1993). R&D knowledge is regarded as a stock of available technologies which can be added to and subtracted from. The reduction process can be treated as a form of depreciation (Griliches 1979). The initial stock of knowledge has to be established from the available data by a formula of the kind:

(7) $$S_o = E_o / (e + f) ,$$

where S_o is the stock of R&D capital at the beginning of the first year for which expenditure data is available; E_o is the annual expenditure on R&D (in constant prices) during the first year; e is the average annual logarithmic growth of R&D expenditures for the nearest relevant years; and f is the depreciation (obsolescence) rate of knowledge (Coe and Helpman 1993, Griliches 1980).

The assumption is that if the stock had been growing *before* the first year at a certain rate, then the estimate of the total starting stock will be that much higher than it would have been if expenditure were capitalised by the rate of depreciation alone (Industry Commission 1995). In the estimates used in this paper, e was estimated for the first ten years after 1962, and f was initially set at 5 per cent per year.

Alternatively, a model can be specified which tests for the cumulative effect on productivity of *annual* expenditures on R&D (see Johnson and Pazderka 1993). This involves fitting a distributed lag function to successive values of the independent variable, following the methodology of Almon (1965) which smooths the coefficient estimates. Under specified circumstances, the sum of the elasticities and the mean lag can be computed. Such procedures thus give an indication of how much time elapses before R&D becomes effective as well as the cumulative returns that accrue to the continuing investment.

In the case of (1), the model to be estimated is as follows:

(8) $$ln\ O_t = f(ln\ L_t , ln\ K_t)$$

In the case of (2) and (3), the model to be estimated is as follows:

(9) $$ln\ O_t = f(ln\ L_t , ln\ K_t , ln\ PVT\ R\&D_{t-1} , ln\ PUB\ R\&D_{t-1})$$

In the case of (4), the model to be estimated is as follows:

(10) $$ln\ TFP_t = f(ln\ PVT\ R\&D_{t-1} , ln\ PUB\ R\&D_{t-1} , ln\ EXT\ R\&D_{t-1} , ln\ EDUINV_t)$$

In the case of a distributed lag model:

(11) $\ln TFP_t = f(\ln PVE_{t-1}, \ln PVE_{t-2}, \ldots\ldots \ln PVE_{t-15})$

where PVE_{t-1} = annual expenditure on private R&D.

R&D stocks are set at the beginning of operating year t, annual expenditure on R&D is assumed to have ceased at the beginning of operating year t, external R&D applies the idea of foreign spillovers (Industry Commission 1995), and education expenditure represents other influences on sectoral productivity (Industry Commission 1995, Coe and Helpman 1993).

Results

(i) Table 1 shows estimates of the coefficients of the Cobb-Douglas production function on a sectoral basis without R&D for the period 1962-98:

Table 1: Cobb Douglas Parameters

Sector	**LFS**	"***a***"	"***b***"	**R^2**	**DW**
AG	.63	-2.55 (-6.1)	2.41 (8.7)	.84	.76
FS	.48	0.64 (1.6)	0.75 (5.1)	.91	.26
FO	.15	-0.46 (-2.3)	2.94 (10.0)	.81	.28
PC	.66	0.54 (4.7)	0.94 (29.1)	.96	.80
MN	.53	0.43 (3.8)	0.27 (10.1)	.79	.55
EN	.28	0.06 (1.1)	1.69 (66.0)	.99	.64
BD	.72	0.75 (7.5)	0.57 (7.0)	.81	.64
TR	.71	-0.71 (-2.4)	0.46 (6.4)	.67	.20
SV	.61	0.51 (5.2)	0.25 (6.1)	.99	.68
MK	.60	0.54 (5.2)	0.56 (18.9)	.98	.32

(parenthesis="t" test)

As equation (1) in the paper shows, the basic production function is Cobb Douglas; real GDP is the dependent variable and "labour" and "capital" are the independent variables. This provides a check on the summing properties of the *a* and *b* coefficients, and provides a baseline for later analysis. All DW statistics are very low hence serial correlation is present throughout. Average factor shares (LFS=labour share) are 60:40, but sectors differ. Only the total market economy (MK) provides some approximation to the average, with the service sector (SV) and manufacturing (MN) somewhere near.

The energy (EN), forestry (FO) and farming (AG) sectors are obviously capital responsive, as is processing (PR). Agriculture, forestry and transport (TR) are declining employment sectors, especially in later years. The influence of additional variables is discussed below.

(ii) Table 2 shows the effect of adding the R&D and "other" variables to the Cobb-Douglas specification 1962-98 (as in equations in (i) above):

Table 2: Cobb Douglas and R&D

	"*a*"	**"*b*"**	**PV**	**PU**	**AU**	**EDU**	**DW**
AG							
	-2.56 (-6.1)	2.42 (8.7)					.76
	0.66 (1.3)	1.63 (2.2)	2.24 (6.3)	-2.01 (-5.7)			1.23
	1.08 (2.5)	2.15 (1.6)	2.56 (3.9)	-2.57(-5.6)	-0.1(-0.2)	0.5(2.8)	1.87
FS							
	0.64 (1.6)	0.80 (5.2)					.26
	0.74 (1.8)	-1.10 (-2.2)	0.10 (0.2)	1.24 (5.2)			.74
	0.17 (0.4)	-1.06 (-2.4)	1.08 (.06)	0.61(0.9)	0.5(1.0)	-1.1(-2.9)	1.00
FH							
	-0.46 (-2.3)	2.94 (10.0)					.28
	-0.07 (-0.7)	-0.28 (-0.7)	0.57 (6.8)	0.06 (0.5)			.62
	-0.38 (-0.1)	0.38 (0.7)	-0.25 (-1.0)	0.37 (3.1)	0.94(4.0)	-0.51(-2.7)	.98
PC							
	0.54 (4.7)	0.95 (29.1)					.80
	-0.12 (-0.5)	-0.37 (-0.7)	-0.51 (-1.3)	1.29 (3.5)			1.25
	-0.04 (-0.2)	-0.34 (-0.4)	-0.15 (-0.3)	1.00 (2.4)	-0.1(-0.7)	-0.1(-0.2)	1.33
MN							
	0.43 (3.8)	0.27 (10.1)					.55
	0.51 (3.2)	0.42 (1.3)	0.12 (0.2)	-0.23 (-0.4)			.55
	0.75 (4.7)	-0.20 (-0.5)	1.38 (1.7)	-1.19 (-2.1)	0.44(2.6)	0.07(0.2)	.99
EN							
	0.06 (1.1)	1.69 (66.0)					.64
	0.17 (2.6)	0.63 (2.6)	0.45 (2.8)	0.02 (0.4)			.97
	0.20 (2.6)	0.73 (2.7)	0.45 (1.5)	0.01 (0.01)	0.04(0.4)	-0.10(-0.8)	.96
BD							
	0.75 (7.5)	0.57 (7.0)					.64
	0.94 (9.8)	0.21 (1.1)	0.06 (2.1)	0.05 (0.6).			.88
	0.99 (11.2)	0.55 (2.4)	0.58 (3.4)	-0.47 (-2.6)	-0.59(-1.7)	0.16(0.9)	1.23
TR							
	-0.71 (-2.4)	0.46 (6.4)					.20
	0.02 (0.1)	-1.54 (-3.8)	1.06 (2.3)	0.09 (0.2)			.37
	0.52 (3.0)	-0.32 (-1.7)	-0.07 (-0.4)	0.16 (1.2)	0.71(12.5)	-0.16(-1.4)	1.71
SV							
	0.51 (5.2)	0.25 (6.1)					.68
	0.81 (8.5)	0.38 (8.2)	-0.35 (-2.5)	0.16 (1.4)			1.32
	0.75 (6.1)	0.33 (3.3)	-0.37 (-2.5)	0.21 (1.5)	0.06(0.6)	-0.02(-0.2)	1.31
MK							
	0.54 (5.2)	0.56 (18.9)					.32
	1.06 (12.5)	0.58 (4.1)	0.70(4.5)	-0.78 (-7.1)			.89
	0.95 (9.3)	0.37 (1.7)	0.57 (3.5)	-0.59 (-3.6)	0.07(1.2)	0.03(0.5)	.96

While the introduction of more variables has stabilised the DW ratio, only EN and SV have labour and capital coefficients which resemble the factor shares. Marginal products are by implication either too high or too low. Euler's theorem is not observed. In the case of returns to R&D; for private R&D seven sectors give positive elasticities, but three are negative (FO, PC, & SV); for public R&D six sectors are positive and four are negative (AG, MN, BD, MK).

(iii) Cobb Douglas coefficients by sub-periods (Table 3):

(3rd specification in (ii) above):

Table 3: Cobb Douglas by subperiods

Period	1962-83		1984-98		1962-98	
Variable	*a*	*b*	*a*	*b*	*a*	*b*
AG	.79	3.28	.76	5.97	1.08	2.14
FS	.70	-.94	.09	-.35	.17	-1.06
FO	-.60	-3.46	.46	-7.2	-.04	.37
PC	.32	.67	.33	-1.33	-.04	-.34
MN	.59	-1.15	.38	.32	.75	-.20
EN	.13	-.78	.07	-.52	.20	.73
BD	1.11	.42	1.05	.85	.99	.55
TR	-.38	.22	.46	.57	.52	-.32
SV	-.09	2.67	.24	-.37	.76	.33
MK	1.81	-1.35	.69	-.75	.95	.37

In the sub periods the coefficients do not follow factor shares in any systematic way. Trends in labour and capital inputs in these periods are not entirely random but appear to be influenced by the build-up of investment or labour force changes unrelated to annual output.

(iv) R&D coefficients by sub periods (Table 4):
(3rd specification in (ii) above):

Table 4: R&D by subperiods

Period	1962-83		1984-98		1962-98	
Variable	**PV**	**PU**	**PV**	**PU**	**PV**	**PU**
AG	2.40	-2.47	1.10	-.41	2.56	-2.57
FS	-1.38	2.78	2.15	.45	1.18	.61
FO	1.36	1.42	1.96	-1.34	-.25	.37
PC	-1.19	1.77	1.37	.47	-.15	.99
MN	.62	-.34	-.27	1.41	1.38	-1.19
EN	1.51	-.16	-.02	.09	.46	.98
BD	.69	-.96	-.25	.52	.58	-.47
TR	-1.05	.27	-.19	-.45	.-.07	.16
SV	1.77	-3.50	-.99	1.89	-.37	.21
MK	.96	-.04	.04	1.07	.57	-.59

In some cases, the whole period appears to be the average of the sub periods but in others random factors appear to be pulling the results apart, e.g. MN, EN, SVand MK. In turn, these variable results lead to variable estimates of the rate of return on R&D capital (5% depreciated) discussed below.

(v) Rate of return on R&D stocks of capital (Table 5) (coefficients from (iv) above):

Table 5: Rates of return to R&D in Cobb Douglas
($return per depreciated $ invested)

Period	**1962-83**		**1984-98**		**1962-98**	
Variable	**PV**	**PU**	**PV**	**PU**	**PV**	**PU**
AG	58	-8	24	-1	60	-7
FS	-25	3	45	0.4	27	0.5
FO	65	4	57	-3	-6	1
PC	-17	44	11	7	-2	21
MN	12	-11	-3	21	21	-25
EN	48	-2	-1	1	14	13
BD	134	-41	-17	17	63	-34
TR	-122	16	-14	-14	-9	11
SV	33	-26	-10	8	-5	1
MK	39	-1	1	10	17	-7

These results need to be interpreted in context. If there is a coincidence of GDP change and R&D stock available, the log-log coefficient (elasticity) can be quite responsive. Hence, in some cases (PV in BD and AG) very high returns to previous investment in R&D show up. On the other hand, negative coefficients, reflecting inverse annual changes between GDP and R&D stocks available, are reasonably frequent across all sectors. Since these are over considerable periods of time in each sub period, it can only be concluded that output is not driven by any notions of *recent* scientific activity in these sectors. In the aggregate, there are higher returns to private R&D investment than public investment and these appear to be concentrated in the earlier period rather than in the latter period.

(vi) using TFP as the dependent variable (equation 10)(Table 6):

Table 6: Determinants of Total Factor Productivity 1962-98

Explanatory Variables	AG	FH	FO	PR	MN	EN	B/C	TR	SV	MK
Stocks of R&D										
Private	2.91	0.07	-0.62	0.69	0.74	0.34	0.29	0.12	-0.33	0.39
	(6.7)	(0.1)	(-2.6)	(2.2)	(1.9)	(1.3)	(1.9)	(0.8)	(-2.3)	(3.1)
Public	-2.51	0.33	0.37	-0.18	-1.03	0.04	-0.16	-0.19	0.17	-0.38
	(-6.7)	(0.4)	(2.3)	(-0.6)	(-2.9)	(0.4)	(-1.1)	(-2.3)	(1.3)	(-3.3)
External	-0.46	0.57	1.39	0.35	0.42	0.26	-0.37	0.79	0.13	0.13
	(-2.7)	(1.0)	(5.7)	(0.2)	(5.2)	(3.6)	(-1.7)	(15.1)	(3.2)	(3.7)
Additional Variables										
Education	0.60	-1.13	-0.51	-0.29	0.16	-0.16	0.22	-0.22	-0.04	0.02
	(3.7)	(-2.8)	(-2.1)	(-1.8)	(1.0)	(-1.1)	(1.2)	(-2.5)	(-0.9)	(0.4)
Summary Statistics										
R^2	*0.96*	*0.78*	*0.91*	*0.94*	*0.63*	*0.98*	*0.59*	*0.97*	*0.92*	*0.95*
DW	*1.80*	*0.67*	*0.66*	*1.19*	*0.95*	*1.18*	*0.94*	*1.45*	*1.32*	*0.84*

(figures in parenthesis are t-values)

This transition involves the assumption that the factor shares used in national accounting bear some relation to the true elasticities for labour and capital. The remaining variables are the same - only the dependent variable has changed. The change in specification has changed some estimates of the R&D elasticities but others remain little changed. In private R&D, the estimate for processing is quite changed; in public R&D it is processing again and transport. Non-significant coefficients tend to occur in the same sectors in both specifications. In summary, both specifications tend to give roughly similar estimates of the R&D elasticities.

(vii) Rates of Return to R&D in TFP specification (Table 7):

Table 7: Rates of return to R&D in TFP specification
($ return per $ of depreciated stock @ 5% at beginning of year)

Category	AG	FH	FO	PR	MN	EN	B/C	TR	SV	MK
Private R&D	68.7	1.6	-14.9	7.6	11.5	10.2	31.8	13.4	-4.6	11.9
Public R&D	-6.7	0.3	1.0	-3.7	-21.7	0.5	-11.8	-14.4	1.0	-4.8

These results confirm the indications given by the elasticities. The return on private investment in R&D is very positive in agriculture, fishing, manufacturing, energy, building and the total market sector. The return on public investment in R&D is very positive only in energy and is generally negative.

Some interpretation of such results is thus desirable. Stocks of R&D, as defined, appear to be positively associated with changes in production in the current year in six cases for private R&D and only one in public R&D. Sectoral production responses are consistent for private R&D suggesting short term responses to R&D investment. There do not appear to be relationships that express a short term response to public R&D. Where the response is negative, it has to be deduced that production consistently falls when R&D stocks rise. Here there is either no response to R&D stocks or confounding factors are entering the situation. Further discussion will be found below after alternative specification of the R&D variables has been examined.

(viii) Specifying the R&D process in econometric terms

It will be remembered that annual data for R&D expenditure by firms and government is the primary source of data. The above results are based on the construction of "stock" variables using pre-determined depreciation rates. To more systematically understand which approach to take, stocks were estimated for 5%, 10%, 20%, 30%, 40% and 50% depreciation rates for the MK and AG data sets and the regressions re-run. Secondly, polynomial distributed lags (PDLs) were estimated for the same data using the Almon formula. For the depreciation model we are using the specification:

(12) $TFP_t = f(PV_{t-1} , PU_{t-1} , AUR_{t-1} , EDU_{t-1})$

The Almon PDLs are based on the following specification:

(13) $TFP_t = f(PVE_{t-1} , PVE_{t-2} , ...PVE_{t-15})$ $(E = \text{annual expenditure})$

a. Depreciation rates:
Table 8 shows elasticities and resulting rates of return for the agricultural and market sectors at different depreciation rates for stocks of R&D. This specification includes Australian R&D and educational expenditure as independent variables and has the best DW.

Table 8: TFP Results with varying Depreciation Rates

	MKPV		**MKPU**		**AGPV**		**AGPU**	
Rate	***b***	**$ror**	***b***	**$ror**	***b***	**$ror**	***b***	**$ror**
5%	.34	10.2	-.35	-4.4	2.59	61	-2.32	- 6.2
10%	.30	13.2	-.29	-5.3	2.28	86	-1.98	-7.8
20%	.20	14.6	-.20	-6.2	1.61	100	-1.46	-9.6
30%	.15	15.6	-.17	-7.5	1.28	111	-1.24	-11.6
40%	.12	16.1	-.15	-8.5	1.08	120	-1.11	-13.5
50%	.11	18.2	-.14	-9.8	0.95	128	-1.03	-15.3
Annual	.07	22.4	-.07	-9.5	0.69	178	-0.65	-18.7

($ror = rate of return per $ of depreciated investment in R&D at indicated rate)

As was shown in Table 6, total factor productivity was positively related to private R&D stocks and negatively related to public R&D stocks in the market economy (MK) and agriculture (AG) sectors. But as Table 8 shows, manipulation of the depreciation rate is compensatory (at least for the two sectors shown). The elasticity decreases as the depreciation rate rises until annual data takes over completely (remember that 50% depreciation implies that most of the change in TFP is "explained by" the previous years' investment in R&D and only half the stock of a year earlier and so on).

The rate of return on the investment in R&D (as defined) is remarkably constant across different depreciation rates. Immediate past investment dominates all the results**.** The general pattern remains one of positive returns for private R&D and negative returns for public R&D in the perpetual inventory specification implied.

b. Polynomial distributed lags:

Polynomial distributed lags (PDLs) provide smoothed coefficients determined by fitting a polynomial function to past annual values of a predetermined number of years of the independent variable. In this case the number of past years was set at 16. The current value of the independent variable is dropped as the specification requires. Other possible influential variables are not included so all possible gains are attributed to successive values of the one independent variable as in (13). Private and public R&D equations are estimated separately for the market and agriculture sectors (Table 9).

Table 9: Estimated lag system for R&D investment

Lag	**MKPVE**		**MKPUE**		**AGPVE**		**AGPUE**	
	b	**$ror**	***b***	**$ror**	***b***	**$ror**	***b***	**$ror**
-1	-.001	-0.3	.130	17.6	.147	37.9	.459	13.2
-2	-.026	-8.3	.045	6.1	.114	29.4	.207	5.9
-3	-.040	-12.8	-.014	-1.9	.088	22.7	.029	0.8
-4	-.044	-14.1	-.051	-6.9	.070	18.1	-.085	-2.4
-5	-.040	-12.8	-.068	-9.2	.058	14.9	-.145	-4.2
-6	-.030	-9.6	-.070	-9.5	.052	13.4	-.160	-4.6
-7	-.016	-5.1	-.059	-8.0	.049	12.6	-.140	-4.0
-8	.001	0.3	-.040	-5.4	.049	12.6	-.094	-2.7
-9	.018	5.7	-.016	-2.2	.050	12.9	-.034	-0.9
-10	.035	11.2	.010	1.4	.052	13.4	.032	0.9
-11	.048	15.4	.034	4.6	.053	13.6	.094	2.7
-12	.056	17.9	.052	7.0	.051	13.1	.143	4.1
-13	.057	18.2	.061	8.2	.046	11.8	.167	4.8
-14	.049	15.7	.058	7.8	.037	9.5	.158	4.5
-15	.031	9.9	.039	5.3	.022	5.6	.105	3.0
Sums	.096	30.7	0.112	15.1	0.940	242.5	.736	21.2
Turning points	4, 13		6, 13		6, 12		6, 13	

As these regressions are multifactorial, each coefficient is an estimate of the elasticity with regard to that time lag. The sum of the coefficients gives the average elasticity with respect to R&D. In all cases, the sum is positive and looks as though it will stay positive though diminishing quickly as extra years are included. Contrary to previous results, therefore, the return to R&D expenditure is now positive if the longer term is taken into account. There is also a distinct short term benefit apparent in three cases. *Thus the pattern of build-up and use of a stock of knowledge may not follow any particular perpetual inventory rules*. These results show that in each case the return function is not monotonic, and hence two turning points appear. In this case, the mean lag estimation cannot be relied upon.

Negative returns can be interpreted as delays in the production process following new expenditure on R&D. On average, the delays appear to be of the order of 4-6 years before production responds, and the peak response is reached after 11-13 years. This compares with Scobie and Eveleen's (1986) estimate of 11 years for the agriculture sector for the period 1920-1980.

Table 10 shows the sum of the elasticity coefficients for annual expenditures on R&D in eight sectors and the total market economy examined in this project (the services sector has no separate identifiable R&D):

Table 10: All sectors PDL structure

Sector	**Private R&D**		**Public R&D**	
	sum	**$ror**	**sum**	**$ror**
Agriculture	.940	242	.736	21
Fishing	.939	214	.506	5
Forestry	.821	227	-.632	-17
Processing	.408	47	.256	56
Manufacturing	.195	30	-.201	-45
Energy	.355	109	.197	26
Building	.837	957	. 258	157
Transport	.339	378	-.187	-135
Market economy	.096	31	112	15

In most cases a positive long-term return is obtained. The exceptions are public R&D in the forestry, manufacturing and transport sectors. The magnitude of the rate of return estimate has to be interpreted as a social dividend to previous research undertaken by private and public agencies. It is not an internal rate of return which would have to take account of the lags in the response times. Scobie quotes an internal rate of return for agriculture of 30 per cent. These results suggest higher internal rates of return than this. The sectors with negative returns are characterised by long waits for positive results to be apparent.

These results also confirm that the turning points are fairly uniform across sectors at 4-6 years in the medium term and 12-13 years in the longer term. Since these results are so uniform it is likely that there is a common driving force behind the equations - this appears to be the link of R&D expenditure to GDP. On the other hand, the elasticities are also determined by changes in sectoral GDP which in some sectors is very different from the aggregate.

(ix) Spillovers in the Pool

In this section possible spillovers between private R&D *stocks* in a sector and other non-industry private R&D stocks, and between public R&D stocks and other non-industry public R&D stocks, are examined. Spillovers should be able to be identified if a multiplicative interaction variable is included in the estimated equation (See Table 11).

Spillovers in total R&D designated for agriculture and for private and public R&D for agriculture are examined. In the case of all agricultural R&D, there is a significant association between TFP and all other R&D available plus a positive interaction term with all other R&D. In the case of private R&D on its own, the association with other private R&D is not so strong though positive (significant at the 10% level) and the estimated interaction coefficient is negative but non-significant. For public R&D the association is negative but not significant and the interaction coefficient is negative and significant. While these are mixed results in sign, they do suggest that the agriculture sector is drawing down research results from the general pool of knowledge and that the effects are multiplicative. However both private and public R&D when analysed separately show negative interaction terms.

Table 11: Spillover Analysis for Agriculture

Variable	(1)	(2)	(3)	(4)	(5)	(6)
a.AmalgR&D	0.39	0.25	0.06	-0.02	-4.78	-4.97
	(10.4)	(0.4)	(0.5)	(-0.2)	(-6.3)	(-6.8)
b.External		0.62		0.61		
		(7.2)		(5.9)		
c.Education			0.72	0.06		
			(2.8)	(0.3)		
d.AmalgNonR&D					5.45	3.81
					(6.8)	(3.5)
e. ln a * ln d						0.13
						(2.1)
R^2	0.76	0.90	0.80	0.90	0.90	0.91
DW	0.31	0.76	0.43	0.76	0.90	1.05
f. Pvt R&D	1.24	1.91	2.28	2.91		
	(2.7)	(8.5)	(3.0)	(6.9)		
g. Pub R&D	-1.95	-1.91	-2.26	-0.09		
	(-7.0)	(-2.9)	(-7.2)	(0.1)		
h.. Non-Pvt-R&D	1.14		1.05			
	(1.7)		(1.8)			
i. ln f * ln h			-0.07			
			(-1.3)			
j. Non-Pub-R&D		0.41		-1.01		
		(0.5)		(-1.3)		
k. ln g * ln j				-0.13		
				(-2.3)		
R^2	0.94	0.94	0.96	0.95		
DW	1 .36	1.15	1.68	1.62		

Conclusions

Two major results have been achieved:

a. Euler's theorem is not observed in the models constructed. This raises doubt about the specification of the models particularly with regard to missing variables and the derivation of factor income.
b. The modelling of R&D knowledge is incomplete. The perpetual inventory method does not capture the workings of R&D on future production. The modelling of a distributed lag system shows that past R&D expenditure has short term and long term effects on production and that cumulative expenditure eventually has positive results in most of the sectors analysed.

It is also worth noting that TFP in agriculture is responsive to non-designated R&D available as a stock. There is some suggestion that there is a positive interaction between designated and non-designated R&D. These observations suggest further research into R&D as a general pool resource and less attention to designated R&D categories published by MoRST.

The policy implications of the study are that private R&D has more short term effect on increased production than public R&D. This probably reflects the over-investment in public R&D in the past relative to private R&D. On the other hand, the social return to R&D in most of the sectors studied is very positive and has generally repaid the initial investments many times.

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