assec00/Association of Economists/July 2000

Methodologies for Measuring the Accumulated Knowledge Base in R & D[1]

by

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Introduction

Research yields results in terms of the sum of knowledge available to all possible users. These may be other scientists or may be commercial entities which seek to apply such knowledge for economic gain. It is convenient to visualise such knowledge as a "pool" resource which has public good characteristics. It can be drawn down without affecting the supply of the good as it is commonly in the public domain, and it can only be privatised when private entities control the provision of research or fund research and apply patents to any results forthcoming. This paper is about the public pool of R&D knowledge. The benefits to other scientists is an interesting question but is not followed up here.

The problem addressed in this paper is how to model the draw-down of research knowledge into the real economy. It would be ideal if chunks of knowledge could be identified and cast into a cost-benefit model. In fact, the pool of knowledge is rather undifferentiated until it finds some practical use. The cost of obtaining particular knowledge is lost in the overall process of research organisation. Given this vagueness in research cost it is difficult to trace a direct line of cause and effect from the costs to the benefits. This paper therefore examines:
(a) whether <u>stocks</u> of research knowledge designated for particular sectors have some relationship to changes in sectoral productivity in national income terms. At this level of aggregation, particular pieces of research knowledge cannot be identified and broad-brush association between cause and effect must be sought. Designated research knowledge itself is not particularly precise as such a concept is somewhat in conflict with the idea that research knowledge is a public good without specific applications identified, and:
(b) whether <u>incremental additions</u> to the stock of R&D as represented by past R&D expenditure patterns have an effect on sectoral productivity. The effect of previous expenditure on changes in productivity can be modelled as a system of distributed lags. In effect, such a model can measure the uptake of research knowledge as it is generated without involving the stock of knowledge concept. While this hypothesis sounds the less plausible in modelling a public resource, it does provide more logical explanations of the research/productivity relationship.

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[1] Contributed paper for the Annual Conference of the New Zealand Association of Economists, Wellington, July, 2000.
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The Data

Expenditure data on R&D can be obtained from the surveys carried out by MoRST in recent years and from Government records (MoRST var). This is available at a national level and broken down into the main economic sectors (See Appendix). National accounting data provides time series of economic investment, labour force and net output on a sectoral basis (25 sectors in NZSNA) and hence provides estimates of average total factor productivity (TFP) for each sector. Using a production function approach, the adoption process can be incorporated in the analysis of productivity change (Industry Commission 1995). 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 (Coe and Helpman 1993). Cost of knowledge is represented by firm investment in R&D, and depreciation is represented by knowledge going out of date or being superseded (Griliches 1979, 1980). 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 certain science-based 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 (Johnson and Pazderka 1993). These flows can be treated econometrically to estimate an average rate of return or cost-benefit ratio.

It will be remembered that annual data for R&D expenditure by firms and government is the primary source of data. Previous results (Johnson 1999) were based on the construction of "stock" variables using pre-determined depreciation rates (5%). To more systematically understand which approach to take, stocks were estimated for 5%, 10%, 20%, 30%, 40% and 50% depreciation rates. Secondly, lagged values of previous expenditure on R&D using polynomial distributed lags (PDLs) were investigated for the same data using the Almon formula (Almon 1965).

The general production function is Cobb-Douglas as follows:

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

where *R* is the stock of knowledge capital; and
Z is other factors affecting measured productivity beside Labour and Capital.

In the production function approach, a log linear version of equation (1) is estimated directly:

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

In the two-step productivity approach, equation (2) would be rewritten as :

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

In either case, estimates of the parameter *g* can be converted from an elasticity to an overall rate of return *dY/dR* as given by:

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

For the depreciation model we are using the specification:

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

(TFP = total factor productivity, PV = private stock of R&D, PU = public stock of R&D, AUR = Australian stock of R&D, EDU = national expenditure on university education)

The distributed lag model is based on the following specification:

(6) $TFP_t = f(\ PVE_{\ t-1}\ , PVE_{\ t-2}\ , ...PVE_{\ t-15})$

(PVE/PUE = annual private/public expenditure on R&D)

Depreciation rates

Table 1 shows estimated elasticities (*g*) and resulting rates of return for the agricultural (AG) and market (MK) sectors at different depreciation rates for stocks of R&D. This specification included Australian R&D and educational expenditure as independent variables (as in (3) and (5) above) and has the best DW.

Table 1: TFP Results with varying Depreciation Rates

	MKPV		**MKPU**		**AGPV**		**AGPU**	
Rate	***g***	**$ror**	***g***	**$ror**	***g***	**$ror**	***g***	**$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 previously, 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 1 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. The rates of return on private R&D suggest large social returns to the previous investment.

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 (6). Private and public R&D equations are estimated separately for the market (MK) and agriculture (AG) sectors (Table 2).

Table 2: Estimated lag system for R&D investment

Lag	**MKPVE**		**MKPUE**		**AGPVE**		**AGPUE**	
	g	**$ror**	***g***	**$ror**	***g***	**$ror**	***g***	**$ror**
-1	-.001	-0.1	.130	1.2	.147	2.5	.459	0.9
-2	-.026	-0.6	.045	0.4	.114	2.0	.207	0.4
-3	-.040	-0.9	-.014	-0.1	.088	1.5	.029	0.1
-4	-.044	-1.0	-.051	-0.5	.070	1.2	-.085	-0.2
-5	-.040	-0.9	-.068	-0.6	.058	1.0	-.145	-0.3
-6	-.030	-0.7	-.070	-0.6	.052	0.9	-.160	-0.3
-7	-.016	-0.3	-.059	-0.5	.049	0.8	-.140	-0.3
-8	.001	0.1	-.040	-0.4	.049	0.8	-.094	-0.2
-9	.018	0.4	-.016	-0.1	.050	0.9	-.034	-0.1
-10	.035	0.8	.010	0.1	.052	0.9	.032	0.1
-11	.048	1.1	.034	0.3	.053	0.9	.094	0.2
-12	.056	1.2	.052	0.5	.051	0.9	.143	0.3
-13	.057	1.2	.061	0.5	.046	0.8	.167	0.3
-14	.049	1.1	.058	0.5	.037	0.6	.158	0.3
-15	.031	0.7	.039	0.4	.022	0.4	.105	0.2
Sums	.096	2.1	0.112	1.1	0.940	16.1	.736	1.4
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 public 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 3 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 3: All sectors PDL structure

Sector	**Private R&D**		**Public R&D**	
	sum of *g*	**$ror**	**sum of *g***	**$ror**
Agriculture	.940	16.2	.736	1.4
Fishing	.939	14.2	.506	0.3
Forestry	.821	15.1	-.632	-1.1
Processing	.408	3.1	.256	3.7
Manufacturing	.195	2.0	-.201	-3.0
Energy	.355	7.3	.197	1.7
Building	.837	62.5	. 258	10.2
Transport	.339	25.2	-.187	-9.0
Market economy	.096	2.1	.112	1.0

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 and Eveleens quote an internal rate of return for agriculture of 30 per cent. These results suggest higher internal rates of return than this in some sectors. 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 private 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.

The overall result shows that total national expenditure on R&D in the private sector returns to the nation $2 for every $ spent. Owing to the delays in reaching a positive result, this is equivalent to an internal return of 2.1%! This is much lower than the return suggested by the stock method. For the public sector, the average return is only $1 for every $ spent. Public expenditure on science is only just recovered in gdp terms. This is equivalent to a 0.1% internal rate of return, but is not negative as the stock results indicated. These overall results tend to confirm earlier suspicions that the respective rates of return to private and public expenditure were out of balance in TFP terms in the past, and that total returns on R&D investment are relatively disappointing.

Implications

We started with the hypothesis that research knowledge is a pool resource with public good properties. The process of utilisation of this resource was modelled along conventional lines by treating the accumulation of knowledge as a capital stock valued at cost and subject to some rate of obsolescence. We tested different rates of obsolescence (depreciation) of the stock thus created and found little differentiation in the results both for sign of the response and the rate of return on capital. Returns to private R&D were all positive and returns to public R&D were all negative. Alternatively, the additions to the stock of research knowledge were modelled in a distributed lag framework where delays in uptake could be identified. A definite pattern emerged of 4-5 year delays in private R&D and 12-13 years in public R&D. Both responses were positive in the longer run.

These results demonstrate that modelling a pool resource like scientific knowledge is fraught with difficulties and that the literature and methodologies on the subject have not yet reached a fully satisfactory level. It may be too difficult in the aggregate data available at the sector level but some progress might be made at the individual application level where the cost of the research and resulting benefits can be readily identified. Even this approach does not account for spillovers from the pool from one sector to another, nor the benefits of knowledge gained to other scientists. There are also international spillovers to be considered as the "pool" has always been a global one and the benefits available to all those who wish to find them

There are also questions about the quality of data available. The series on public expenditure on R&D is faithfully recorded back to the 1960s by NRAC and the government departments. It may be sub-divided quite accurately for the major economic sectors supported by R&D effort at the time. There is no equivalent R&D data for the private sector except for the MoRST series since 1989. The data used in this analysis relies heavily on an extrapolation based on shares of national income. This imparts a similarity to the sector data on private R&D that runs throughout this analysis. Even so, sectoral TFP statistics exhibit quite different behaviours in response to a variable based on this definition of their R&D efforts.

Members of the audience might like to suggest further hypotheses and specifications for future research!

References

Almon, S. (1965), The Distributed Lag Between Capital Appropriations and Expenditures, *Econometrica 33, 178-196.*

Coe, D. and Helpman, E. (1993), International R&D Spillovers, *IMF Working Paper no 84,* Washington.

Griliches, Z. (1979), Issues in Assessing the Contribution of Research and Development on Productivity Growth,, *Bell Journal of Economics 10, 92-116.*

Griliches, Z. (1980), R&D and the Productivity Slowdown, *American Economic Review 70, 343-348.*

Johnson, L. and Pazderka, B. (1993), Firm Value and Investment in R&D, *Managerial and Decision Economics 14, 15-24.*

Johnson, R.W.M. (1999), The Rate of Return to New Zealand Research and Development Investment, New Zealand Association of Economists Annual Conference, Rotorua.

Industry Commission (1995), *Research and Development,* Report No 44, Volume III: Appendix, AGPS, Canberra.

Ministry of Science, Research and Technology (1990-98), *NZ Research and Development Statistics: All Sectors,* Wellington.

Scobie G. and Eveleens W. (1986), *Agricultural Research: What's it Worth?,* Ministry of Agriculture, Hamilton.

Appendix: Sectoral Data Available

In combination with the productive sectors recognised in the MoRST surveys, the Yearbook records of R&D expenditure determine the number of sectors which can be analysed for the whole period of the analysis. As the productivity data is presented on a national accounting basis (NZSNA), the following schema shows the sectors analysed:

Research sector		NZSNA sector
Agriculture	....	Agriculture
Fishing	....	Fishing
Forestry	....	Forestry
Processing	....	Food, Wood, Paper,Textiles
Manufacturing	....	Mining, Basic Metal, Chemicals, Non -Metallics, Machinery
Energy	....	Electricity, Gas and Water
Building	....	Building and Construction
Transport	....	Transport and Storage
Services	....	Trade, Communications, Finance, Community Services
Total Market Economy	....	Production sector (Ownership of Occupied Dwellings and Government are excluded)