A REVIEW OF THE EVIDENCE ON SCIENCE, R&D AND PRODUCTIVITY

Steve Dowrick

Paper prepared for the Department of Education, Science and Training

11th August 2003

CONTENTS

1. Introduction

The accumulation of knowledge through scientific research and its application to productive activity lies at the heart of modern theories of economic growth due to authors such as Romer (1990) and Aghion and Howitt (1992). The case that it is the accumulation of knowledge, rather than the accumulation of physical capital, that is the engine of long-run economic growth relies on the particular properties of knowledge – that it is a public good, that its accumulation is potentially limitless, and that its accumulation does not suffer from diminishing returns.

The public good nature of knowledge is nicely summarised by Stephan (1996: 1200):

> " .. it is not depleted when shared, and once it is made public others cannot easily be excluded from its use. Moreover, the incremental cost of an additional user is virtually zero and, unlike the case with other public goods, not only is the stock of knowledge not diminished by extensive use, it is often enlarged."

It is precisely this public good nature of knowledge that suggests that the market, left to its own devices, will tend to under-provide investment in knowledge creation. If others can readily copy innovations, and it is costly to prevent them from doing so, then those who invest in knowledge creation do not receive the full reward for the value of their efforts.[1] Hence a long tradition of public support for science and technology, from prizes offered for practical ways of measuring longitude to current systems of direct funding of research in public research organisations and universities as well as tax breaks for corporate research and development.

The public good nature of knowledge also raises the question whether a small country like Australia can adopt the global free-rider position - sit back and let other countries invest in R&D, then just copy their innovations.

Published evidence on the economic benefits of research, based on econometric studies, dates predominantly from the late 1980s. The evidence is spread across several sub-fields of the economics literature, including industrial organisation journals and journals dealing with economic growth and development, as well as some of the management literature. Much of the early evidence comes from the USA where the availability of data on firm and industry productivity matched with data on public and private R&D spawned a large number of studies. This evidence has been supplemented by more recent research on EU and OECD databases which allows us to generalise from the US results. Whilst there is very little by the way of microeconomic evidence on the links between R&D and productivity for Australian firms and industries, many of the recent macroeconomic cross-country studies use standardised OECD data which does include Australia.

Indeed, studies of cross-country evidence are perhaps the most appropriate for evaluating the national benefits and costs of R&D. To the extent that the benefits are diffused across firms and industries, data on aggregate productivity are most likely to capture the overall magnitude of benefits. Accordingly, this review pays particular

---

[1] Grilliches identifies two types of inter-firm spillovers: the flow of disembodied knowledge and ideas, and the embodied benefits of quality improvements in intermediate goods where the improvements have not been fully appropriated in the price.

attention to recent studies that have been conducted on the relationship between R&D expenditures and productivity growth across the countries of the OECD.

This review ignores the extensive literature based on case studies. Whilst there is a lot to be learnt from examples of successful research and development, particularly in relation to the inter-linkages between researchers, institutions and firms, these studies do not allow us to estimate the rate of return on R&D activities. The problem is selection bias, which is particularly problematic in the evaluation of research activities that are inherently risky. If case studies are based on successful projects, they will inevitably show a high ratio of benefits to costs; but they ignore the (large) number of projects that may have produced little or no measurable benefits.

Aggregated studies that attempt to measure the total economic benefits in relation to the total costs of R&D, including the costs of more and less successful projects together, can help us to assess the overall social value. The costs of R&D are typically obtained through surveys of business accounts or through national accounts statistics. Measurement of the economic benefits is more difficult. A common approach is to estimate the contribution of either R&D expenditures or the stock of accumulated R&D capital to the level of output or productivity, controlling for the contribution of other inputs such as physical capital and labour. The results are usually presented in one of two ways: estimates of the marginal product of R&D, sometimes referred to as the rate of return; or estimates of the elasticity of output with respect to the stock of R&D capital. A technical note on the relationship between elasticities and marginal returns is included in the Appendix.

These measures of the effectiveness of R&D are, of course, restricted to those benefits which show up in increased output or productivity. There are, of course, other objectives of research – such as national security, environmental protection, health and social cohesion - which need to be taken into account in assessing the overall effectiveness of public policy. This review concentrates, however, on the measurable economic benefits, and particularly on studies that provide insight into the rate of return on investment in R&D.

We review first the microeconomic evidence related to business sector R&D, based on studies of the productivity of firms and industries, before turning to evidence on the returns to public sector R&D – i.e. government labs and universities - and then to macroeconomic studies which examine the relationship between R&D and productivity at the level of national economies.

2. Microeconomic Studies of the Returns to Business R&D

Lichtenberg and Siegel (1991) present one of the earliest large-scale econometric studies. They study productivity growth for over two thousand US firms over the period 1972 to 1985, running regressions of the form:

growth in total factor productivity = a + b (R&D expenditure / output) + random shocks

where the regression coefficient b is an estimate of the direct marginal product of R&D and the net rate of return on R&D investment is given by (b – the depreciation rate of productive knowledge). They do not attempt to capture productivity benefits that might spill over to other firms, so their estimates are for private returns which might understate the value of the full social returns.

Lichtenberg and Siegel find that the gross rate of return on company-funded R&D is around 35 per cent, which is not dissimilar to the average of 29 per cent that they report from their survey of previous US studies. They report a high premium on the benefits of research classified as 'basic' rather than 'applied'. (They also report evidence that federally funded R&D has little significant impact on productivity – an issue to which I return later.)

Bernstein and Nadiri (1991) use the cost function, rather than the production function, approach to determine returns to R&D capital for 6 manufacturing industries in the USA over the period 1957-86. Their approach is more sophisticated than that of Lichtenberg and Siegel in several respects: i) they allow for process improvements to reduce costs of production and for product innovation to raise the profit margin on sales; ii) they estimate the stock of R&D knowledge that has been accumulated over a long time period, rather than using just the current flow of R&D effort, so taking into account likely delays between the R&D activity and its translation into productive innovations; and iii) they estimate several different spillover effects between industries: copying ideas on process improvements can reduce costs, whilst the effects of product innovation in other industries can either increase or decrease demand and price depending on whether the products of the different industries are complements or substitutes.

Estimation of a system of cost and price functions, allows Bernstein and Nadiri (1991) to estimate both private and social rates of return to R&D, where the social rate of return takes account of the spillover benefits (or costs) to other industries. Their results are summarised in Table 1. Note that their estimates are net of depreciation, which they assume – based on estimates from Hulten and Wykoff (1981) - to be ten percent per year for R&D capital.

Two features of their results stand out: First, there is no sign of a substantial risk premium on R&D investment relative to investment in plant and equipment: the net private rates of return in each industry are approximately equal (with the sole exception of Electrical Products). Indeed, the results are suggestive that investment in R&D may, on average, be privately optimal at the level of the individual firm – with net marginal rates of return being equalised across investment in both R&D and physical capital, consistent with a required rate pre-tax net rate of return of around 20%

Second, the spillover effects of R&D – captured by the difference between social and private returns - are positive and substantial for all but one of the industries.

Bernstein and Nadiri also identify the spillover network. For example, both the Chemical Industry and the Electrical Products Industry benefit from the R&D carried out in the Scientific Instruments Industry, whilst benefits flow to the Transportation Equipment Industry from research in Non-electrical Machinery.

Table1

Private and Social Marginal Rates of Return on Investment in US Manufacturing Industries, 1985

(before tax, net of depreciation)

	Investment in Physical Capital	**Investment in R&D**	
	Private Returns	*Private Returns*	*Social Returns*[1]
Chemical Products	20%	22%	46%
Fabricated Metal	21%	21%	21%
Non-electrical Machinery	24%	25%	40%
Electrical Products	18%	27%	31%
Transport Equipment	26%	23%	35%
Scientific Instruments	28%	28%	86%

Source: Bernstein and Nadiri (1991) Table 6

1. 'Social' returns are defined as private returns plus spillovers to the other industries covered in the study.

These results are broadly consistent with the conclusions of Nadiri (1993). He summarises the results of a large number of studies, mostly on US data, into the effect of R&D on productivity. Although methods and estimates vary considerably, he concludes that (gross) rates of return at firm level tend to be around 20% to 30%, whilst at industry level estimated rates of return tend to be higher – up to 40%. He reviews a range of studies that examine the linkages between firms and industries. They consistently find significant evidence of spillover benefits, although estimates vary considerably as to the magnitude of such spillovers.

Nadiri and Kim (1996) estimate private rates of return on investment in both physical capital and R&D for the manufacturing sectors of the US, Japanese and Korean economies over the period 1980-90. They employ a translog variable cost function that includes such inputs as labor, materials, physical and R&D capital with the physical and R&D capital treated as quasi-fixed subject to adjustment costs. They estimate mark-ups, returns to scale, rates of return on physical and R&D capital, and technical change. Their estimated rates of net return on R&D are relatively low compared with other studies, but are found to be somewhat higher than rates of return on investment in physical capital. This could reflect differences in the risk premium applied to the financing of R&D or it could reflect the spillover benefits between firms and industries within the manufacturing sector.

A recent study by Griffith, Redding and Van Reenen (2000) models the inter-industry and international spillovers amongst 13 industries across 12 OECD countries over 23 years (1970-92). We will consider their evidence on international spillovers later. But for the moment we note that, controlling for such spillovers in their three-way panel data analysis with around two thousand observations, they find that the gross rate of return on own industry R&D is over 40 *per cent* (see their preferred specification, Table 6, column 5). This estimate is based on data aggregated at industry level, so it internalises own-country within-industry spillovers. This is a carefully controlled study, taking account of unobserved country and industry specific effects as well as adjustments to the measurement of TFP for problems of measurement with respect to skill levels and hours of work. Their study takes account of most of the problems cited by Atella and Quintieri (2001) in relation to microeconomic studies.

Overall, we are led to the conclusion that business sector investment in R&D may, on average, be privately optimal at the level of the individual firm – with net marginal rates of return being equalised across investment in both R&D and physical capital, consistent with a required rate pre-tax net rate of return of around 20%. There is a large body of micro-econometric evidence from studies across a variety of OECD countries that rates of return are substantially higher at the level of industries, with gross rates of return of up to 40% or more suggesting that there are significant knowledge spillovers between firms and between industries.

3. Publicly funded research and the science base

i) Direct estimates of the productivity benefits flowing from public R&D

Some studies of the productivity effects of publicly funded R&D have suggested that returns were lower than those estimated on business R&D - for instance Lichtenberg and Siegel (1991) and Nadiri (1993). More recently, both OECD (2001) and Bassanini and Scarpetta (2001)[2] have reported cross-country regressions that suggest a negative return on public sector R&D - implying that private sector R&D may be crowded out by public sector R&D.

Subsequent research suggests that the results of these studies may be misleading for two sets of reasons. First, they failed to distinguish between different types of publicly funded research. Second, they failed to account for the time delay between productivity outcomes and the performance of public R&D, which tends to be focused more on the research than on the development side. Indeed both Bassanini and Scarpetta and the authors of OECD (2001) recognise the problem arising from the fact that their regressions relates productivity to contemporaneous public R&D expenditure. In footnote 36, p. 94, of OECD (2001) they proffer the rather feeble excuse that “lagging the R&D variable would have induced an excessive loss of degrees of freedom”, despite the fact that other studies have managed to do so.

There are several ways in which lags may be introduced into time-series analysis: by

[2] The publications by OECD (2001) and Bassanini and Scarpetta (2001) appear to be identical.

imposing a particular lag on R&D expenditures and testing for the optimal lag length; or by constructing a capital stock variable, K^R, from the history of R&D expenditures using the perpetual inventory method. The latter method allows for all of past R&D expenditures to have some effect on current productivity, albeit with an imposed rate of depreciation.

Studies which incorporate lagged effects and distinguish types of public R&D do, in fact, find significant positive productivity effects. For example, Mamuneas and Nadiri (1996) distinguish publicly funded R&D in the USA according to whether it is carried out in the business sector or in the public sector. Examining the cost-reducing benefits of R&D stocks in fifteen industries over the period 1956-1988, they find that both forms of public financed R&D generate statistically significant benefits, albeit with the stronger reduction in marginal costs coming from R&D performed within the business sector.

Analysing the marginal returns to aggregate publicly funded US R&D stocks, Nadiri and Mamuneas (1994) estimate the 'social' rate of return: the sum across manufacturing industries of the reduction in costs of production attributable to an extra dollar of public expenditure. Their estimates are summarised in Table 2.

Table 2
'Social' Rates of Return across 12 Manufacturing Industries on Publicly Funded R&D Stocks in the USA, 1956-86.

	Assumed marginal cost per $ of public spending			
	$1.00	$1.17	$1.47	
Public expenditure on R&D	8.7%	7.5%	5.8%	
Private investment in physical capital				8.6%

Source: Nadiri and Mamuneas (1994) Table 8A.

The rate of return on public R&D is naturally sensitive to assumptions made about the social cost of financing public expenditure, i.e. the marginal deadweight losses of the taxation system. Nadiri and Mamuneas report three different estimates, ranging from a rate of return of nearly nine percent per year if deadweight losses are trivial to a rate of around six percent if deadweight losses are as high as fifty percent. The upper estimate is very close to their estimate of the after-tax private rate of return on investment in physical capital.

The authors point out that these are under-estimates of the true social rate of return because they have measured the cost savings only for a sub-set of the economy. The economy-wide returns to publicly funded R&D are likely to be higher.

Guellec and van Pottelsberghe de la Potterie (2001) directly address the economy-wide returns to public R&D in their cross-country study. We discuss their study in more detail in Section 4, but we note for the moment their estimate that the long-run elasticity of productivity with respect to public R&D capital averages 0.17 over their sample of sixteen OECD countries. Furthermore, the elasticity is higher for countries with a relatively large share of university-performed research compared to government lab research. They interpret this finding as evidence "that much government performed R&D is aimed at public missions that don't impact directly on productivity (health, environment), whereas universities are providing the basic knowledge that is used in later stages by industry to perform technological innovation" (p.116). The elasticity of public research is also higher where the business R&D intensity is relatively high, indicating that the spillover benefits of public research are complementary with corporate research activities.

ii) Does public R&D crowd-out private R&D?

A survey of the econometric literature on crowding out was carried out by David, Hall and Toole (2000). They report mixed findings and are reluctant to come to any clear conclusion other than the need for further and more careful research. They do, however, note some patterns in their survey of previous findings. Studies conducted at firm level were more likely to report net substitution or crowding-out than were studies carried out at a higher level of aggregation. Moreover, crowding out was a common finding in US studies whereas a large majority of studies conducted in other countries found complementarity between public and private R&D.

I report here on three studies which are not covered in the David *et al.* survey.

Cohen, Nelson and Walsh (2002) use survey data to evaluate the influence of public research, conducted in either universities or government labs, on industrial R&D in the USA. They report that public research is "critical to industrial R&D in a small number of industries and importantly affects industrial R&D across much of the manufacturing sector" and that university research "both suggests new R&D projects and contributes to the completion of existing projects in roughly equal measure". They also report that the benefits of public research in stimulating industrial R&D are relatively high for both start-up firms and for larger established firms.

Mamuneas and Nadiri (1996) use econometric analysis to quantify the effect of public R&D on the level of business R&D in the USA. They find that public-financed R&D that takes place *within* industry stimulates business activity, whilst the public R&D performed outside the business sector tends to partially crowd out business R&D. They note that the 'crowding out' might reflect supply constraints in the market for scientists and engineers, whereby an increase in the demand for scientists in one industry might result in poaching of employees from other industries, hence reducing their apparent R&D effort. Indeed, Goolsbee (1998) argues that increased government R&D spending in the USA tends to increase incomes of scientists and engineers.

Guellec and van Pottelsberghe de la Potterie (2003) examine the effect of government funding on business R&D across 17 OECD countries, 1981-96. Their findings are very similar to those of Mamuneas and Nadiri whose study was restricted to the USA. They report that government funding stimulates business R&D expenditure (BERD) if the government research is contracted to the business sector, but tends to partially crowd out BERD when performed in government laboratories. BERD is not affected by university research. They also find that tax incentives are effective in stimulating BERD, whilst recognising that some of this effect may work through an increase in R&D costs.

Guellec and Van Pottelsberghe quantify the average stimulatory effect of direct government funding of private R&D as a 0.70 marginal increase in business funded

R&D for each dollar of direct non-defence government funding. This effect is found to be higher for those OECD countries with medium levels of subsidisation than for countries, such as Australia, with lower levels of public funding. Defence research carried out in the public sector does out private R&D. They also report that the positive impact of government support on corporate research – through both direct funding and R&D tax incentives – is substantially enhanced when the levels of support are stable over time.

iii) The relationship between Science, innovation and the location of research

There is a body of work investigating the links between scientific research, sometimes defined as university-based research, and measures of innovation. Some of these studies investigate the extent to which the benefits of research are concentrated within the geographic region where the research is carried out.

For example, Acs, Audretsch and Feldman (1994), following Jaffe (1989), analyse survey data on the rate at which firms register both patents and significant product innovations across US states and fields of technology in 1982. Their regression results are summarised in Table 3. The authors conclude that own R&D activity is particularly important for large firms, which have sufficient scale to run their own labs, whilst smaller firms tend to benefit from the knowledge created in publicly funded research. The effectiveness of public research is enhanced by geographical proximity to private sector research labs.

Table 3
Determinants of Innovation Rates across the States of the USA

	i) Patents	ii) Innovation All Firms	iii) Innovation Large Firms	iv) Innovation Small Firms
log (industrial R&D expenditure)	**0.67** (8.9)	**0.43** (4.7)	**0.95** (7.1)	**0.55** (4.2)
log (university research)	**0.24** (3.6)	**0.43** (6.0)	**0.45** (4.6)	**0.66** (5.8)
log (university research x proximity to industrial labs)	0.02 (0.2)	**0.17** (1.9)	0.03 (0.7)	**0.11** (2.0)
log (population)	0.06 (1.3)	-0.07 (-1.3)	-0.55 (-6.6)	-0.31 (-3.9)
number of observations	145	125	145	145
R^2	0.96	0.90		

Source: Acs, Audretsch and Feldman (1993), Tables 3 and 5.

Notes: Numbers in columns i) and ii) are the reported OLS regression coefficients; the numbers in columns iii) and iv) are the coefficients from Tobit regressions; t-statistics are reported in brackets. Coefficients in bold are significant at the ten percent level. University research expenditures are measured by state and by technological field, other variables by state.

Similar results are found by Audretsch and Vivarelli (1996) in their study of the determinants of annual regional patenting activity across fifteen regions of Italy over the period 1978-86. They confirm that own R&D is particularly important for large firms, whilst small firms benefit both from their own R&D and also from the presence of university-based scientific research activity in their region.

These studies deal with the contemporaneous relationship between innovation, private sector R&D activity and publicly funded research. As such, it is not clear that the strong correlations that have been identified are necessarily evidence of causation. It is plausible to suppose, for instance, that universities might respond to patterns of industrial activity and innovation by concentrating their research activities in those areas where the private sector is locally active.

Adams (1990) identifies causal relationships by allowing for time delays between the publicly funded basic research and its eventual application to industrial production. His study relates the rate of productivity growth in 18 US manufacturing industries over the period 1953-83 to the rate of publication of scientific papers across nine scientific fields. Productivity growth is found to depend on the accumulated stock of field-specific scientific research, operating with a twenty-year lag, and on the employment by industry of scientists in the appropriate fields.

A subsequent paper by Adams (1993) examines the relationship between the volume of R&D activity and the scientific base for a panel of fourteen R&D-performing industries in the USA over the period 1961-86. He seeks to explain R&D activity as a function of the lagged stocks of scientific research in particular fields (proxied by the number of papers published worldwide) interacted with the proportion of employed scientists specialised in the field. He reports that the size of the scientific base does have a significant positive impact on the level of R&D activity. The implication is that basic scientific research provides fertile ground for applied commercial development.

This conclusion is supported by Mansfield (1991) who analyses surveys of US businesses. Firms report an average lag of seven years between the publication of academic research on which they have relied and the timing of their subsequent commercial innovation. Using estimates of the commercial value of the recorded innovations, Mansfield calculates the average rate of return on academic research to be of the order of magnitude of 28 *per cent*.

iv) Other benefits flowing from Public R&D

Of course, publicly funded R&D may result in benefits that are not captured in productivity measures. Salter and Martin (2001, p. 520) cite a number of surveys of firms which suggest that the private sector gains substantially from publicly funded research in a variety of ways:

1. Increasing the stock of useful knowledge;
2. Training skilled graduates;
3. Creating new scientific instrumentation and methodologies;
4. Forming networks and stimulating social interaction;
5. Increasing the capacity for scientific and technological problem-solving; and
6. Creating new firms.

Benefits that relate to training and network creation are unlikely to be picked up in studies of particular firms and industries because they are likely to be diffused throughout the economy. Such benefits should, however, be measurable in economy-wide studies.

4. Macroeconomic Studies of Returns to R&D

Studies that analyse national productivity and R&D are most likely to capture the full extent of inter-firm and inter-industry knowledge spillovers as well as the benefits associated with training and networks. This is indeed what we find, with macroeconomic studies consistently finding high rates of social returns, above 50 per cent.

A disadvantage of macroeconomic studies is that, compared with studies of firms, there is much less cross-sectional variation to analyse – with data usually restricted to the OECD group of countries. But that is offset in some studies by the use of time-series data for each country, which not only expands the degrees of freedom in the statistical testing but also allows for time lags in the implementation of R&D. Many of these studies investigate both the social returns to internal R&D and the spillover benefits of foreign R&D. In this section we focus on results relating to internal R&D.

One of the first macroeconomic studies was conducted by Coe and Helpman (1995) who calculated stocks of domestic R&D (aggregating public and private) using the perpetual inventory method with an assumed depreciation rate of either 5 percent or 15 percent. They estimate pooled cointegrating regressions on TFP data for 22 OECD countries over 20 years (1971-90).

Their results yield estimated elasticities of TFP with respect to domestic capital stocks which are higher for the G7 countries than for the smaller OECD economies. Table 4 summarises their findings. Of most relevance to Australia is their estimate that gross rates of return to domestic R&D average 85% for the smaller OECD countries.[3]

---

[3] Given a constant elasticity, the implied rate of return is unrealistically high at nearly 200% for a country like Australia that has a particularly low ratio of R&D to GDP (0.04). Coe and Helpman

Table 4
Coe and Helpman's (1995) Estimates of National Returns to Domestic R&D

	G7 Countries	15 other OECD Countries
Assumed 5% depreciation rate		
a. Elasticity of Business Sector TFP wrt Stock of Domestic R&D Capital	0.234	0.078
b. Ratio of R&D Capital to GDP	0.19	0.09
c. Marginal rate of social return (gross of depreciation) = a / b.	123%	85%
Assumed 15% depreciation rate		
d. Elasticity of Business Sector TFP wrt Stock of Domestic R&D Capital	0.247	0.109

Source: Coe and Helpman (1995), Table 3 (regression iii), Table A7 and Table B1 (regression iii).

Further studies have produced rather lower estimates of social returns. For instance, Frantzen (2000) uses data on R&D expenditures, rather than capital stocks to predict rates of growth of TFP across the OECD economies over the period 1961-91. This leads to an estimate of the gross rate of return on domestic R&D investment that is close to sixty percent. Similar estimates are reported by Lichtenberg and van Pottelsberghe de la Potterie (1996, p.14) who use panel data analysis. They estimate that social rates of return on domestic R&D average 51% in the large G7 economies and 63% in six smaller European countries.

Bassanini and Scarpetta (2001) also examine the effects of domestic R&D on rates of productivity growth amongst OECD countries, in this case over the period 1981-98. In their regression analysis, using pooled cross-section and time-series data, they find strongly positive effects. They do not present their results in terms of elasticities. Rather they quantify the predicted effects of an increase in this spending as follows:

> ".. a 0.1 percentage increase in R&D intensity would have a long-run effect of about 1.2 per cent higher output *per capita* under the 'conservative' view that changes in R&D do not permanently affect output growth. However, .. if the R&D coefficient is taken to represent growth effects, a 0.1 percentage point increase could boost output *per capita* growth by some 0.3-0.4 per cent. These estimated effects are large, perhaps unreasonably so, but nevertheless point to significant externalities in R&D activities." (page 32)

The estimates of social rates of return in these more recent macroeconomic studies are lower than the Coe and Helpman estimates. Nevertheless the range of estimates lies between 50 and 60 percent which – compared to microeconomic estimates – suggests that there are substantial positive spillovers that are not captured by the firms or industries that carry out the R&D investment.

---

should, perhaps, have tested the stability of their coefficient across more groups of countries with different R&D intensities, not just the G& group versus the rest.

All of the studies summarised above aggregate public and private R&D expenditures. There are, however, two recent studies by Guellec and van Pottelsberghe de la Potterie (2001) and Guellec and van Pottelsberghe de la Potterie (2003) which explicitly examine the macroeconomic effects of publicly funded R&D.

The first study analyses the relationship between national TFP levels and three distinct stocks of R&D capital based on: i) domestic business-performed R&D; ii) foreign business-performed R&D; and iii) public R&D performed in the higher education sector and government labs. Following Coe and Helpman (1995) they construct time series of each capital stock using the perpetual inventory method with a 15 percent annual rate of depreciation. They estimate a pooled time-series cross-section model across 16 OECD countries over 19 years (1980-98).

Their econometric estimation and testing methods are thorough. They test for lagged effects, finding a two-year time lag for the initial impact of business sector R&D capital on productivity and a three-year time lag for the initial impact of public R&D capital. (The use of capital stock measures allows R&D performed in a particular year to have a continuing effect on productivity beyond the time of the initial impact.) They control for the business cycle by including a capacity utilisation variable. By estimating a dynamic error-correction model they are able to take account of both short-run and long-run effects. They control for unobserved country-specific and year-specific effects. They control for the potential endogeneity using 3 Stage Least Squares estimators and they test for robustness with respect to the exclusion of each country in turn.

Their principal results are expressed as the long-term elasticities of TFP with respect to stocks of R&D capital. The elasticity of productivity with respect to business R&D capital averages 0.13 across countries and across time. It is tending to increase slightly over time, by about 0.005 per year - i.e. from 0.12 to 0.14 over their sample period. The elasticity tends to be slightly higher in countries with a high ratio of business R&D expenditure to business value added. The elasticity tends to be slightly smaller in countries with high defence-related public R&D spending and slightly higher in countries with high public R&D spending on civilian projects.

The long-run elasticity of productivity with respect to public R&D capital averages 0.17. It tends to decline slightly over time, from 0.18 to 0.16 over the sample period. It is higher for countries with a relatively large share of university-performed research compared to government lab research.[4] The elasticity of public research is also higher where the business R&D intensity is relatively high, indicating a significant flow-on effect from public research through business innovation.

Interestingly, the estimated elasticities of 0.13 for business sector capital and 0.17 for public sector R&D capital are close to the Coe and Helpman (1995) estimates for total R&D capital which average 0.15 across 22 countries. Although Guellec and van Pottelsberghe de la Potterie (2001) do not report their data on the ratio of R&D capital stocks to GDP, we can presume that the gross rates of return on both public and private R&D capital are of the same order of magnitude as the Coe and Helpman estimates of 85% for the smaller OECD economies.

---

[4] The authors interpret this finding as evidence "that much government performed R&D is aimed at public missions that don't impact directly on productivity (health, environment), whereas universities are providing the basic knowledge that is used in later stages by industry to perform technological innovation."

5. International technology transfer: technology gaps and absorptive capacity

There is widespread evidence that the rate of technology transfer between countries depends on the policies and activities of the recipient country. Two schools of thought are strongly represented in the empirical literature on international technology flows. The first considers international trade to be the principal mechanism for transfer. The second considers domestic investment in both education and research to be the enabling mechanism.

i) Trade as the conduit of international technology spillovers

A series of studies, following Coe and Helpman (1995), tries to quantify the role of trade as the conduit of R&D spillovers. Coe and Helpman examined variations in the annual growth of total factor productivity (TFP) for 21 OECD countries, plus Israel, over the period 1970-90. Their econometric analysis finds that the stock of knowledge in one country, measured by cumulated and discounted historical R&D expenditures, raises productivity in trading partners. Using a measure of the total foreign capital stock weighted by bilateral import shares, the average elasticity of domestic TFP with respect to foreign R&D capital is 0.09. It is higher for countries with high import ratios. Given Australia's relatively low import ratio over the period in question, they estimate that the elasticity of Australian TFP with respect to foreign R&D is only 0.055.

Broadly similar results are obtained by Lichtenberg and van Pottelsberghe de la Potterie (1998) who use a different trade-weighting system to aggregate foreign R&D capital. They report an average elasticity of domestic TFP with respect to foreign R&D capital of 0.11, with a lower elasticity of 0.054 for low-trading countries like Australia.

It is not clear exactly why the extent of technology transfer should depend on the magnitude of trade with a technologically advanced economy. One plausible explanation stems from the observation by Eaton and Kortum (2001) that the high R&D economies are also the major world exporters of capital goods. The trade variables used in the above studies may be acting as a proxy for the import of high tech capital goods for which the producers are unable to expropriate all of the rents.

R&D, human capital and absorptive capacity

The second school of thought on international technology transfer is based on the models of Nelson and Phelps (1966) and Abramovitz (1986). There are two forces in operation. The size of the technology gap relative to the world frontier represents the scale of opportunity to acquire productivity-enhancing technology either through licensing or through investment by technology rich multi-national corporations or simply through copying and reverse-engineering. The opportunity to acquire foreign productivity is not sufficient, however, to generate rapid economic growth. A country must also possess the capacity to identify, capture, implement and adapt the technology. This 'absorptive capacity' is often modelled as a function of the level of human capital of the technology-acquiring country. Without a highly skilled scientific workforce to identify the appropriate technologies, or without a technologically capable management and production workforce, a country will be unable to make use of the foreign technologies.

Howitt and Mayer-Foulkes (2002, p.6) argue that successful adoption of foreign technology "requires tacit knowledge which is less accessible the further removed is the adopter's everyday cultural and technological experience and skill level from that of the innovator." Productivity growth is the product of the technology gap and absorptive capacity which is a function of the rate of domestic innovation which is in turn dependent on the level of innovation-effective skills.

Benhabib and Spiegel (1994) carry out econometric estimation to explain variation in 20-year growth rates (1965-85) on a cross-section of 78 countries. In their preferred model, technological progress is the sum of two components: an exogenous component, as in the neo-classical model; and a semi-endogenous component, related to the rate of absorption of technology from the technological leading country, captured by an interactive term between the productivity gap and the level of human capital. They report that the interactive term is statistically significant.

Broadly similar results are reported by Dowrick and Rogers (2002). This study differs from that of Benhabib and Spiegel (1994) in that the analysis is carried out on a panel of growth data, enabling the authors to control for country-specific growth effects. They also use an instrumental variable estimator to control for reverse causation between growth and the explanatory variables. They confirm the finding that the level of human capital facilitates technological catch-up, especially amongst the middle-income and richer countries. The benefits of education in technological absorption is further confirmed both by Frantzen's (2000) cross-section study of OECD countries.

Further evidence on the determinants of absorptive capacity comes from a recent study of industry-level productivity growth covering 12 industries in 13 OECD countries since 1970 - see Griffith, Redding and Van Reenen (2000). Their most relevant finding is that not only do high levels of domestic R&D and educational attainment stimulate the growth of total factor productivity, but also the returns are significantly higher for industries which are operating below the technological frontier. They interpret these findings as evidence that investment in both R&D and education increase the capacity of industries to absorb technology from the overseas leaders.

The dual role of domestic R&D in promoting not only domestic innovation but also technology transfer from overseas is particularly interesting. Quoting from Griffith, Redding and Van Reenen (2000, p.2):

> *By actively engaging in R&D in particular intellectual or technological fields, one acquires .. tacit knowledge and can more easily understand and assimilate the discoveries of others. ... In other words, R&D is as crucial for technology transfer as for innovation and plays a role in developing 'absorptive capacity'.*

The importance of own R&D for the acquisition and implementation of foreign technology is confirmed by the macroeconomic study of Guellec and van Pottelsberghe de la Potterie (2001). They suggest that the most important criterion for effective absorption of particular technologies is active domestic research in the cognate field. Accordingly they weight foreign stocks of business R&D capital by bilateral technological proximity (as measured by the technological fields of patents) and report an average elasticity of TFP with respect to foreign R&D capital of over forty percent. This elasticity of technological absorption is higher in countries that are themselves research intensive, leading the authors to conclude:

> *If firms from a country want to take full advantage from international spillovers, they have to spend on R&D; the free rider approach clearly does not work.*

6. Conclusions

Microeconomic studies of the economic returns to R&D which were conducted in the 1980s and early 1990s on samples of firms and industries from different countries produced a wide range of estimates. More recently, the availability of standardised OECD data on different categories of R&D expenditure, the increasing sophistication of theoretical and econometric modeling, and the opportunity to compare microeconomic estimates with macroeconomic estimates have produced a more coherent and consistent overall picture.

Estimates of private returns to firms' own investment in R&D still produce varying figures, but there is an emerging consensus that gross returns in the range between 20% and 30% are both common and plausible. Taking account of risk-premia required to finance commercial R&D and taking account of depreciation rates on R&D capital, the net private return on R&D investment appears to be broadly comparable with the return on investment in physical capital.

Microeconomic studies confirm the existence of significant spillovers of knowledge from the firms that perform the R&D to other firms and industries. Taking account of measured spillovers typically raises the estimated gross rate of return on business investment into the range between 30% and 40%. But authors warn that these are likely to be underestimates of the true social rate of return because the microeconomic studies do not usually cover all of the sectors of the economy.

Macroeconomic studies, which by definition cover all sectors of the economy, do indeed find significantly higher returns to R&D in OECD countries, with estimates ranging from 50 % to over 100 %. Macroeconomic studies that distinguish between public and private sector R&D and allow for longer lags for the latter to affect productivity, find that public sector R&D contributes significantly to productivity, albeit less strongly than private sector R&D. .

Both microeconomic and macroeconomic studies find that an important source of productivity growth in all OECD countries comes from the international diffusion of technology.

Some of the most interesting and policy-relevant evidence concerns the interactions between various elements of the innovation system:

* Business R&D is complementary to public sector civilian R&D – raising investment in one sector stimulates the productivity of the other.

* The rate at which small firms innovate is dependent on their proximity to university researchers in the relevant fields.

* A country's ability to absorb foreign technology is enhanced by investment in education and by investment in own R&D.

These latter findings reinforce the view that although the rest of the world provides a huge source of ideas and technologies, a country like Australia cannot rely on a strategy of passive absorption to maintain strong productivity performance. In order to benefit from the global public good of world knowledge, countries need to have well trained scientists, a technologically capable workforce and active engagement in cutting edge research.

APPENDIX

Technical Notes on Elasticities, Marginal Returns and Spillovers

Estimation of econometric models typically produces measures of either the marginal product of R&D or the elasticity of output with respect to the stock of R&D capital. Some studies measure the elasticity of total factor productivity. Some studies estimate R&D spillovers. All of these concepts can be represented within the standard economic framework of production.

We represent the level of output as a function of the inputs of physical capital, K, human capital, H, and R&D capital, where we distinguish between own R&D, R^o, and external R&D stocks (accumulated by other firms and/or the public sector), R^e:

$$Y = Y(K, H, R^o, R^e) \qquad (1)$$

The private marginal product of R&D capital is $\partial Y/\partial R^0$, sometimes referred to as the gross rate of return to R&D. Estimates of the elasticity of output with respect to the stock of R&D capital can be converted into estimates of marginal returns by dividing the elasticity, η^R, by the ratio R^o/Y. This follows from the definition of the elasticity:

$$\eta^R \equiv \frac{\partial Y}{\partial R^0} \cdot \frac{R^0}{Y} \qquad \Rightarrow \qquad \frac{\partial Y}{\partial R^0} = \eta^R \div (R^0 / Y) \qquad (2)$$

Some studies analyse the influence of R&D on total factor productivity (TFP). The relationship to the production function approach is straightforward if the production function exhibits constant returns to scale with respect to K and H and if technological progress is factor neutral and determined by stocks of R&D capital. .

$$Y = A(R^e, R^o) F(K, H) \qquad (3)$$

Defining TFP as output deflated by a cost-weighted index of factor inputs, and assuming competitive pricing in output and factor markets:

$$TFP \equiv \frac{Y}{F(K,H)} = A(R^e, R^o) \qquad (4)$$

From equations (3) and (4) we find that the elasticities of TFP and of output with respect to R&D capital are identical:

$$\begin{aligned} \ln Y &= \ln A(R^e, R^o) + \ln F(K,H) \\ \therefore\ \eta^R &\equiv \frac{\partial \ln Y}{\partial \ln R^0} = \frac{\partial \ln A(R^e, R^o)}{\partial \ln R^0} \equiv \frac{\partial \ln(TFP)}{\partial \ln R^0} \end{aligned} \qquad (5)$$

Thus estimates of the marginal product of R&D can be derived from studies of TFP as well as from production function studies. Equivalent estimates can be derived from the dual cost function.

Assuming diminishing marginal returns to each factor, the condition for optimal allocation of resources to R&D in a pure market economy is that the marginal product of own R&D, at its optimal level R*, should equal its marginal cost, r:

$$\frac{\partial Y(K, H, R^*, R^e)}{\partial R^o} = r \equiv p^R(i^R + \delta) \qquad (6)$$

where the marginal cost, or 'rental cost' of capital is equal to the sum of the depreciation rate, δ, and the risk-adjusted interest rate required to finance R&D investment, i^R, times the price of R&D relative to the price of output, p^R.

Most of the studies surveyed here provide either direct or indirect estimates of the gross marginal product of R&D. In itself, evidence of a high gross rate of return does not necessarily imply that there is sub-optimal investment. Such a conclusion would require evidence that the net return on R&D, i.e. the marginal product less the rate of depreciation, exceeds the risk-adjusted interest rate. It also needs to take account of the adjustments to equation (6) that are required in the context of an economy where the provision of public goods (including subsidies to R&D) is funded by distortionary taxation.

An alternative approach to policy evaluation is to examine the evidence on R&D spillovers. Such evidence comes from econometric studies of firms or industries which include measures of external R&D capital, R^o, allowing direct estimation of the spillover $\partial Y / \partial R^o$. Alternatively, studies of productivity which use aggregated data provide measures of $\partial Y / \partial R$, the return to aggregate R&D, $R=R^e+R^o$. Evidence that returns are significantly higher at the aggregated level than at the disaggregated level suggests the existence of positive spillovers.

References

Abramovitz, Moses (1986), 'Catching up, Forging Ahead, and Falling Behind', *Journal of Economic History* 46: 385-406.

Acs, Zoltan J, David B Audretsch and Maryann P Feldman (1994), 'R&D Spillovers and Innovative Activity', *Managerial and Decision Economics* 15 (2, Mar): 131-138.

Adams, James D (1990), 'Fundamental Stocks of Knowledge and Productivity Growth', *Journal of Political Economy* 98 (4): 673-703.

Adams, James D. (1993), 'Science, R&D, and Invention Potential Recharge: U.S. Evidence', *American Economic Review* 83 (2, May): 458-462.

Aghion, Philippe and Peter Howitt (1992), 'A Model of Growth through Creative Destruction', *Econometrica* 60 (March): 323-351.

Atella, Vincenzo and Beniamino Quintieri (2001), 'Do R&D Expenditures Really Matter for TFP?' *Applied Economics* 33 (11, Sept): 1385-1389.

Audretsch, David B. and Marco Vivarelli (1996), 'Firms Size and R&D Spillovers: Evidence from Italy', *Small Business Economics* 8 (3, June): 249-258.

Bassanini, Andrea and Stefano Scarpetta (2001), 'The Driving Forces of Economic Growth: Panel Data Evidence for the OECD Countries', *OECD Economic Studies* (33): 9-56.

Benhabib, Jess and Mark Spiegel (1994), 'The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data', *Journal of Monetary Economics* 34 (2): 143-173.

Bernstein, Jeffrey I and M Ishaq Nadiri (1991), 'Product Demand, Cost of Production, Spillovers, and the Social Rate of Return to R&D', *NBER Working Paper* 3625 (Feb).

Coe, David T. and Elhanan Helpman (1995), 'International R&D Spillovers', *European Economic Review* 39 (5): 859-887.

Cohen, Wesley M, Richard R Nelson and John P Walsh (2002), 'Links and Impacts: The Influence of Public Research on Industrial R&D', *Management Science* 48 (1, Jan): 1-23.

David, Paul A., Bronwyn H Hall and Andrew A Toole (2000), 'Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence', *Research Policy* 29 (4-5, April): 497-529.

Dowrick, Steve and Mark Rogers (2002), 'Classical and Technological Convergence: Beyond the Solow-Swan Growth Model', *Oxford Economic Papers* 54: 369-385.

Eaton, Jonathan and Samuel Kortum (2001), 'Trade in Capital Goods', *European Economic Review* 45 (7, June): 1195-1235.

Frantzen, Dirk (2000), 'R&D, Human Capital and International Technology Spillovers: A Cross-Country Analysis', *Scandinavian Journal of Economics* 102 (1): 57-75.

Goolsbee, Austan (1998), 'Does Government R&D Policy Mainly Benefit Scientists and Engineers?' *American Economic Review* 88 (2, May): 298-302.

Griffith, Rachel, Stephen Redding and John Van Reenen (2000), 'Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries', *London School of Economics, Centre for Economic Performance Discussion Paper* 2457 (May): 1-74.

Guellec, Dominique and Bruno van Pottelsberghe de la Potterie (2003), 'The Impact of Public R&D Expenditure on Business R&D', *Economics of Innovation and New Technology* 13 (3): 225-243.

Guellec, Dominique and Bruno van Pottelsberghe de la Potterie (2001), 'R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries', *OECD Economic Studies* 33: 103-126.

Howitt, Peter and David Mayer-Foulkes (2002), 'R&D, Implementation and Stagnation: A Schumpeterian Theory of Convergence Clubs', *NBER Working Paper* No. 9104 (August): 1-39.

Hulten, C R and F C Wykoff (1981) 'The Measurement of Economic Depreciation', in C. R. Hulten (ed.), *Depreciation, Inflation and the Taxation of Income from Capital* Washington: Urban Institute.

Jaffe, Adam B. (1989), 'Real Effects of Academic Research', *American Economic Review* 79 (5, Dec.): 957-970.

Lichtenberg, Frank R and Donald Siegel (1991), 'The Impact of R&D Investment on Productivity - New Evidence Using Linked R&D-LRD Data', *Economic Inquiry* 29 (April): 203-228.

Lichtenberg, Frank R and Bruno van Pottelsberghe de la Potterie (1998), 'International R&D Spillovers: A Comment', *European Economic Review* 42 (8): 1483-1491.

Lichtenberg, Frank and Bruno van Pottelsberghe de la Potterie (1996), 'International R&D Spillovers: A Re-Examination', *National Bureau of Economic Research Working Paper* 5668, July: 1-16.

Mamuneas, Theofanis P and M Ishaq Nadiri (1996), 'Public R&D Policies and Cost Behavior of the Us Manufacturing Industries', *Journal of Public Economics* 63 (1, Dec.): 57-81.

Mansfield, Edwin (1991), 'Academic Research and Industrial Innovation', *Research Policy* 20 (1, Feb): 1-12.

Nadiri, M Ishaq and Seongjun Kim (1996), 'R&D, Production Structure and Rates of Return in the U.S., Japanese and German Manufacturing Sectors', *European Economic Review* 30 (4): 749-772.

Nadiri, M. Ishaq (1993), 'Innovations and Technological Spillovers', *NBER Working Paper* No. 4423.

Nadiri, M. Ishaq and Theofanis P. Mamuneas (1994), 'The Effects of Public Infrastructure and R&D Capital on the Cost Structure and Performance of U.S. Manufacturing Industries', *Review of Economics and Statistics* 76 (1, Feb): 22-37.

Nelson, Richard R. and Edmund S. Phelps (1966), 'Investment in Humans, Technological Diffusion, and Economic Growth', *The American Economic*

Review 56 (1/2, Mar): 69-75.

OECD (2001), *The Sources of Economic Growth in OECD Countries*, Paris: OECD Publication Services.

Romer, Paul M. (1990), 'Endogenous Technological Change', *Journal of Political Economy* 98 (5): S1971-1102.

Salter, Ammon J and Ben R Martin (2001), 'The Economic Benefits of Publicly Funded Basic Research: A Critical Review', *Research Policy* 30 (3, Mar): 509-532.

Stephan, Paula E (1996), 'The Economics of Science', *Journal of Economic Literature* 34 (3, Sept): 1199-1235.