OECD Workshop on Productivity Measurement and Analysis
Bern, Switzerland
16-18 October, 2006

Revised: May 2007

Empirical analysis of the effects of R&D on productivity: Implications for productivity measurement?

Dean Parham[*]
Productivity Commission, Australia

ABSTRACT

This paper provides an overview of a study by Productivity Commission staff that sought to quantify the effects of domestic and foreign R&D on Australia's productivity performance. The estimates obtained were sensitive and imprecise and standard models were shown to be mis-specified. The use of capitalised R&D expenditure to proxy knowledge stocks is one possible contributor to the estimation problems.

The paper goes on to discuss the (Canberra-II Group) proposals to capitalise R&D in countries' national accounts. Treating R&D expenditure as an investment, rather than as an expense, is conceptually sound. But there are flow-on implications for the measurement of productivity in the national accounts. Uncertainties about representing R&D outputs by R&D expenditure and stocks of knowledge by a PIM-based accumulation of R&D expenditure cast some doubt on whether capitalisation of R&D in the national accounts would add meaningfully to current productivity estimates. The issue warrants further contemplation and investigation.

[*] PO Box 80 Belconnen ACT 2616 Australia. Email: dparham@pc.gov.au. The author is grateful for assistance and comments from Sid Shanks. Helpful feedback and comments were also received from Ian Bobbin, Ralph Lattimore and Jonathan Pincus. Remaining errors and omissions are his. The views expressed are those of the author and should not be attributed to the Productivity Commission.

1. Introduction

There is little, if any, dispute that R&D is a major source of long-term productivity growth. But there is empirical uncertainty about the *magnitude* of the productivity gains from R&D.

This quantitative uncertainty was again highlighted in a study by two colleagues at the Productivity Commission (Shanks and Zheng 2006).[1] They set out to update and extend previous time-series analysis of the effects of R&D on Australia's productivity performance.[2] Previous studies had generated estimates of returns to Australian R&D that seemed implausibly high—a result that is not uncommon in this type of analysis, irrespective of country of investigation (Diewert 2005). With the possibility that limitations on degrees of freedom had been an issue in the previous studies, it was judged that new analysis based on a further 10 years or so of data, plus developments in quantitative tests and techniques, could provide a clearer fix on the effects of domestic and foreign R&D on Australian productivity performance. As it turned out, the modelling results were fragile — and more so than expected. Estimates of performance effects fell within wide confidence intervals and were sensitive to seemingly reasonable modifications to variable and model specifications. Diagnostic tests revealed standard estimating equations to be mis-specified.

This paper outlines the Shanks and Zheng analysis and discusses the reasons for the empirical difficulty in pinning down a magnitude on the effect that R&D has had on productivity. One reason is the use of a constructed variable—capitalised R&D expenditure—as a proxy measure of the stocks of knowledge. The paper highlights the conceptual and empirical difficulties in using the constructed R&D capital in quantitative analysis. The paper goes on to discuss proposals to capitalise R&D expenditure in countries' national accounts and the implications for measurement of productivity in the national accounts. Many of the measurement concerns about R&D capital that arise in empirical analysis would also apply to capitalisation of R&D in the national accounts, especially in relation to productivity measurement.

The paper proceeds as follows. The next section outlines the key concepts for discussion and overviews broad trends in R&D in Australia and the OECD. Section 3 outlines the methods and results of the Shanks and Zheng study and discusses possible reasons for the vague findings. Section 4 highlights estimation problems that likely stem from the capitalisation of R&D. Section 5 describes the proposals for changes to national accounts conventions, which includes capitalisation of R&D, and

---

[1] The work was undertaken as part of an ongoing stream of investigations into productivity trends, their causes and their consequences. Papers and reports produced in this stream of work can be accessed at http://www.pc.gov.au/commission/work/productivity/index.html

[2] A number of available cross-country studies, for example, Englebrecht (1997) had generated the somewhat troublesome result that foreign R&D had a negative effect on Australian performance.

section 6 assesses their implications for productivity measurement. Concluding remarks are made in section 7.

2. Key concepts and trends

R&D, knowledge, innovation and productivity

R&D is conventionally defined as:

> ….creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. (OECD 2003)

The R&D process can be characterised (albeit rather crudely) as a process of transforming R&D inputs into R&D outputs. R&D inputs are the existing stock of knowledge, the expertise and creativity of researchers, supporting labour, capital services (from assets such as buildings, structures and equipment), materials and purchased services. R&D outputs are increments to the stock of knowledge and new technologies (applications of existing knowledge). These outputs might also be termed 'discoveries' and 'inventions'. R&D can also serve the purpose of enhancing 'absorptive capacity'—that is, the ability to identify, assimilate and apply relevant knowledge.

Conceptually, R&D finishes where commercialisation starts.[3] Further investment in pre-production or commercialisation activities is normally required to take inventions to the stage where they can be introduced into commercially-viable production and use.

The introduction of new commercialised technologies may also involve other complementary investments, which might rightfully share in the responsibility for performance gains. Adoption of some technologies also involves other costs, such as staff training and complementary investments in capital (other equipment or modifications to buildings).

R&D activity is not the only form of knowledge accumulation. Various economic theories have also highlighted the roles of education, acquisition through technology license or capital equipment (with embodied knowledge), and learning by doing.

There are various theories about how knowledge affects productivity. One view is that knowledge is just like a physical asset that exhibits diminishing returns. Other views

---

[3] In practice, the distinction between R&D and commercialisation may not be precise. Furthermore, R&D does not necessarily lead in linear fashion to commercialisation. The commercialisation process can identify the need for further R&D work to make an application viable.

emphasise the public-good nature of knowledge (spillovers from non-rival and non-excludable discoveries), and the positive influence of the size of the current stock of knowledge on the productivity of knowledge investment (which offsets diminishing returns). There are also theories about 'disruptive' technologies, which impose adjustment costs and have a negative effect on productivity for a time, before leading ultimately to stronger productivity performance.

Magnitude and composition of R&D effort

Australia is a small player on the world R&D stage. Three quarters of OECD R&D effort is concentrated in three regions — the US (which alone accounts for about 44 per cent of OECD expenditure on R&D), Japan and Europe (especially Germany and France). Australia accounts for about 1.3 per cent of R&D expenditure in the OECD area.[4]

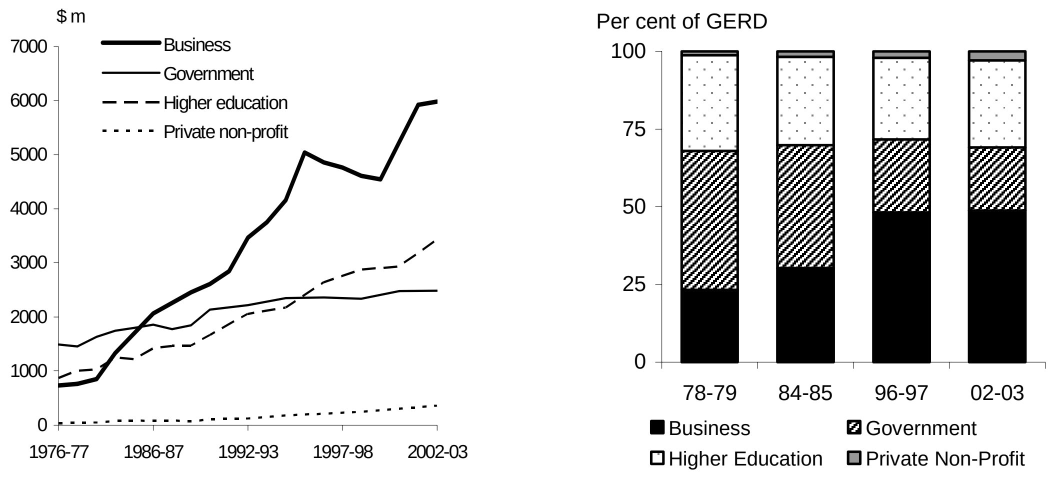
Most empirical analysis focuses on business sector R&D. Although public sector R&D is obviously also important to productivity, it is generally of a different ilk — having long-term effect on commercially-implementable knowledge and applications. Business R&D tends to be focussed more on near-term applications.[5]

Australian expenditure on R&D has expanded about fourfold in real terms since the mid-1970s. Most of the increase has been in business sector R&D and came between the mid-1980s and mid-1990s (Figure 1). There was also a shift in business sector R&D toward services in the 1990s (Figure 2), a development that is related to the increased use of information and communication technology (ICT) in Australia (Shanks and Zheng 2006).

[4] Australia ranked 11 in size of R&D spend in 2001 and was grouped with Sweden, the Netherlands, and Spain as countries spending between 1 and 2 per cent of the OECD total on R&D.

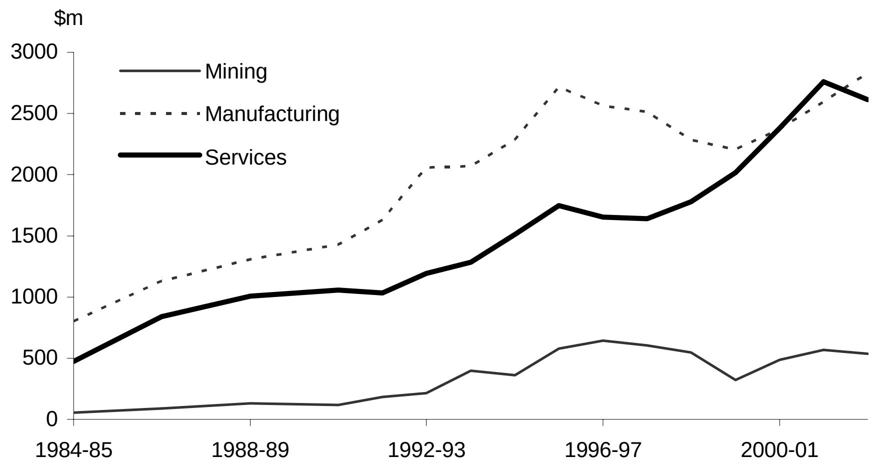
[5] There is also an issue with a characteristic of much public sector R&D that it becomes 'freely' available. The associated knowledge assets may have high spillover value, but have low value in terms of appropriable revenues.

Figure 1 **Real R&D expenditure and shares in total expenditure, by institutional sector, 1976-77 to 2002-03**



Source: Shanks and Zheng (2006)

Figure 2 **Real business R&D expenditure, by industry sector, 1984-85 to 2002-03**



Source: Shanks and Zheng (2006)

The broad features of the Australian trends were similar to world patterns, although there were differences in timing. Business R&D has become more important generally in the OECD area and there has also been an increase in services R&D, at least in the major R&D-performing countries. Growth in R&D activity in the OECD area was slower through the second half of the 1980s and the first half of the 1990s—the period of major R&D growth in Australia—but accelerated from the mid-1990s.

Local tax incentives are thought to have contributed substantially to the growth and timing of change in Australian R&D activity. Recorded R&D expenditure started to accelerate (through an announcement effect) in the lead up to the introduction of an R&D tax concession in the fiscal year 1985-86. At least some of the initial increase was due to reclassification of pre-existing expenditure as R&D, rather than to a genuine increase in activity. Growth in 'creative' use of the scheme led to introduction in 1996-97 of restrictions on the coverage and rate of tax concession. Business R&D expenditure declined in the second half of the 1990s (Figures 1 and 2).

R&D capital stocks

As outlined above, (genuine) R&D activity is an investment in knowledge accumulation and in the development of technologies. The corresponding assets—the stocks of knowledge and technologies—are intangible assets whose values are largely unobservable. There are some R&D output measures, specifically patents, but they have rather severe coverage and other limitations, especially for measurement of knowledge stocks on a national scale.[6]

This measurement difficulty looms as a fundamental problem in establishing a link empirically between R&D and productivity. As Fraumeni and Okubo (2002, p.1) aptly put it, 'Although the existence of a link between R&D, technical change, and economic growth is widely acknowledged, this link is difficult to quantify because the benefits from, or output of, R&D, a critical component of the link, are not easily measured.'

The main practical measurement option put forward (both in empirical analysis and national accounts proposals) has been to approximate the volume of knowledge assets by capitalised R&D expenditures, in which the series of expenditures is formed into a

[6] Patent protection tends to be used more for technological advances in products than in processes. Many contributions to the stock of knowledge simply cannot be patented. Some R&D-performing industries (such as software development) do not make significant use of patents, because the net benefits from costly and slow processes to secure intellectual property rights are outweighed by the gains to be had from speed of new products to market. Furthermore, simple patent count measures do not take account of the wide variation in the value of patents — which is very low in many cases. Markets for knowledge are also too thin to provide sufficient and reliable valuations on heterogeneous R&D outputs. Some knowledge can be marketed, for example, through license fees. But a lot of privately-generated knowledge is retained within individual firms in order to preserve technological and market advantage.

stock via the perpetual inventory method (PIM). The essence of the PIM is to form a yearly stock estimate by adding new R&D expenditure in the year to the existing stock and subtracting 'depreciation' or obsolescence of the existing stock. In equation form:

$$K_R^{t+1} = (1-\delta)K^t + R^t$$

where K_R^{t+1} is the R&D capital stock in year t+l, δ is a constant (or time-independent) rate of depreciation, K^t is the R&D capital stock in year t; and R^t is the R&D expenditure in year t.

Figure 3 gives a sense of the trends in domestic and foreign R&D capital stocks.[7] Foreign R&D stocks are weighted sums of R&D stocks in other countries of technology relevance to Australia. There are differences in the movements of domestic and foreign R&D stocks. Growth in the Australian R&D stock took off in the mid-1980s and slowed from the mid-1990s. Growth in the foreign stock was generally steadier, but showed a *decline* in growth rate from the mid-1980s to the early 1990s. The difference in timing suggests that there were some country-specific factors (such as tax incentives) driving Australian investment in R&D, rather than general changes in technological opportunities as represented by foreign R&D investment.

3. The Shanks and Zheng empirical analysis

Shanks and Zheng (2006)—hereafter referred to as 'SZ'—examined the relationship between R&D and productivity within a conventional quantitative framework. Its comprehensiveness, if not exhaustiveness, undoubtedly sets their study apart from others. As mentioned in the introduction, the fragility of results that became evident in the early stages of the project was something of a surprise, at least in terms of its extent, and led to a thorough-going search for alternative model and variable specifications that might yield more robust results. Of particular relevance in the context of this paper, the study hardly left a stone unturned in exploring the relationship between capitalised R&D and Australia's productivity.

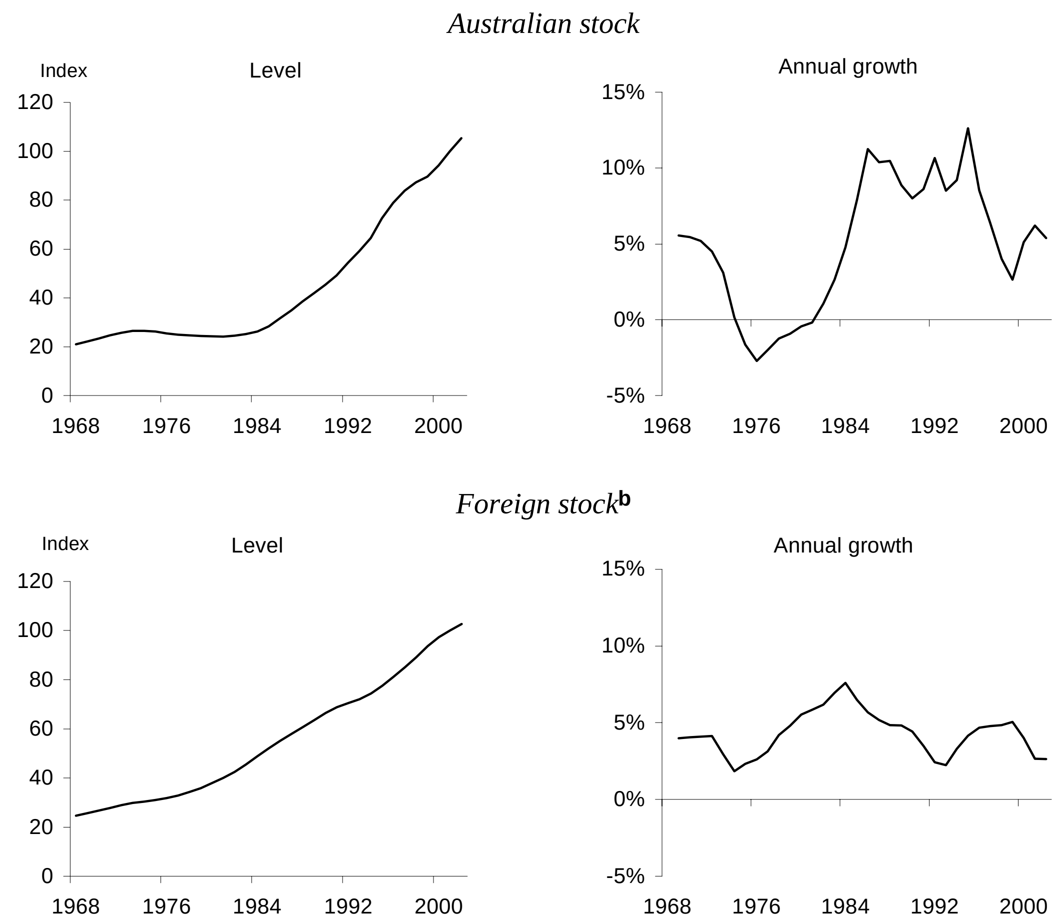
The starting point for the SZ analysis was a Cobb-Douglas production function of the form:

$$\ln Y = \ln A + \alpha_1 \ln K_o + \alpha_2 \ln K_R + \beta \ln L + \lambda t + \sum_{i=1}^{n_i} W_i \ln Z_i$$

[7] As discussed later in the paper, there is uncertainty about the appropriate depreciation rate to use in the PIM. Alternative assumptions obviously produce different results.

where Y is output, K_o is other (physical) capital, K_R is R&D capital, L is labour input, A is a constant, t is time and Z_i are control variables. The vast majority of R&D-productivity studies are set within this framework.

Figure 3 **Domestic and foreign business R&D capital stocks[a], level and growth, 1968-69 to 2002-03**



[a] Stocks of business sector R&D constructed via the PIM, with an assumed depreciation rate of 15 per cent. [b] Foreign stocks for individual countries weighted and summed using country shares in Australian imports of elaborately transformed manufactures as weights.

Source: Shanks and Zheng (2006).

Two transformations of this equation were estimated. Most reliance was placed on a 'two-step' method. Taking the physical capital and labour terms to the left-hand side, the dependent variable becomes MFP. Independent observations of MFP come from the national accounts.[8] The other transformation was to subtract the log of the labour input, L, from each side. The estimation equation in this case seeks to explain labour productivity.

Most of the analysis was conducted at the aggregate level—the market sector of the economy—for which MFP estimates are available from the ABS national accounts. Some analysis was also undertaken for certain industry groupings within the market sector—agriculture, mining, manufacturing, and (combined) wholesale and retail trade.

Alternative calculations of R&D capital stocks

SZ used the PIM to form R&D capital stocks as an approximation to stocks of knowledge. They were well aware that this is open to a number of criticisms (see SZ, pp. 65-73), but had little practical alternative. Nevertheless, they did attempt to explore the criticality of assumptions needed to implement the PIM by undertaking extensive sensitivity analysis. This included:

- alternative deflation of current R&D expenditures (use of a general producer price deflator or separate deflators for the labour, capital and materials cost components of R&D expenditures);
- alternative constant depreciation rates (between 5 and 30 per cent a year);
- use of variable depreciation rates (increasing from 7.5 to 15 per cent a year) to reflect the possibility of greater knowledge obsolescence over time as the economy became more open and subject to greater competitive pressure[9];
- formation of stocks from data on all performed R&D and from data on own-financed R&D; and
- formation of foreign R&D stocks based on a variety of weighting schemes to aggregate the R&D expenditures of different countries.

---

[8] The transformation conserves degrees of freedom because it becomes unnecessary to estimate the parameters α and β. The assumption underlying the transformation and use of national accounts estimates is that there are constant returns to scale and that competitive markets ensure that factors are paid according to their marginal products.
[9] Higher depreciation rates over time could also be consistent with a structural shift in R&D activity towards shorter-lived, ICT-based, services-oriented technologies.

The effects of different depreciation rate assumptions on the levels of capital stocks are shown in Figure 4 and on growth rates in capital stocks in Figure 5. The selection of a constant rate of depreciation in the range of 5 to 15 per cent does not affect the general trends. The rise in R&D capital is smoother, though, with a lower depreciation rate. There is a *decline* in R&D capital in the mid-1970s with the 10 and 15 per cent depreciation rates.

Estimation of standard levels models

SZ also explored many variations of general model specification. The standard model in levels was estimated both with limited control variables and with extended specifications of control variables. The limited specification was intended to capture long-term relationships and controls were only included to allow for spillovers from foreign R&D capital stocks, business cycle effects and time-dependent effects on productivity. The extended specifications also included variables to allow for such influences as human capital, infrastructure and changes in the policy and institutional environment.[10]

The standard static model with limited controls had highly serially correlated errors, implying a model mis-specification. Adding controls improved the behaviour of residuals, but the estimated coefficient on domestic R&D was imprecise. Whilst the point estimate of the return on R&D was evaluated at 60 per cent, a finding of a zero rate of return on R&D could not be rejected (Table 1).

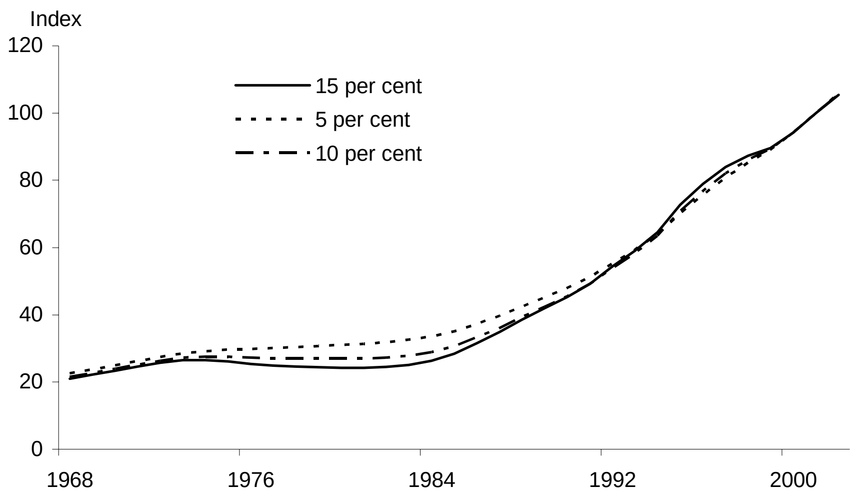
There was also exploration of dynamics and lags within the confines of limited degrees of freedom. This was designed to allow for the fact that there can be lags between R&D investment and discovery, between discovery and application and between application and commercialisation.[11] Extensive testing of dynamic specifications produced one better-behaved model but, again, the estimate of the domestic R&D coefficient was imprecise.

It was common to find a negative coefficient on either domestic R&D stocks or on foreign R&D stocks, depending on which control variables were included in extended model specifications.

---

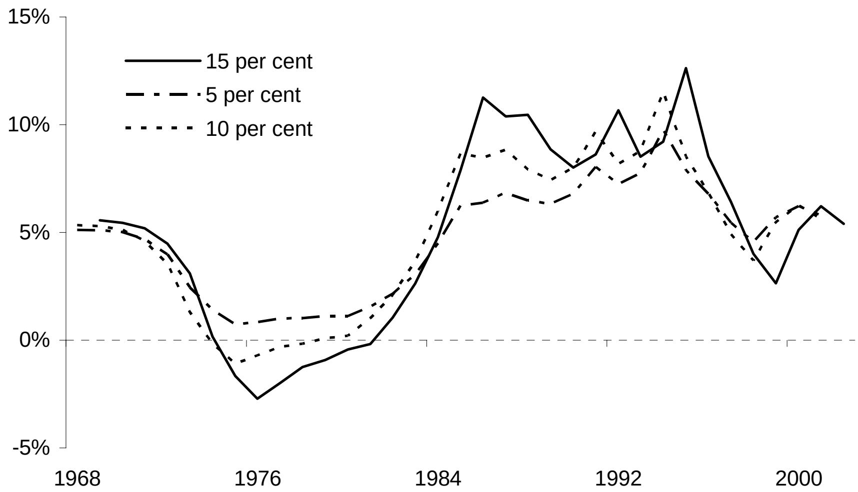
[10] A 'test-down' procedure was employed, in view of limitations on degrees of freedom, in order to identify stronger explanators and leave aside weaker ones.
[11] There can also be diffusion lags in an aggregate context. To a certain extent, the PIM captures the accumulation of a number of years of expenditure needed to generate discoveries and applications. But there is no weighting scheme attached to expenditures in different years.

Figure 4 **R&D capital stocks based on alternative depreciation rates**



Source: Shanks and Zheng (2006)

Figure 5 **Growth rates in R&D capital based on alternative depreciation rates**



Source: Shanks and Zheng (2006)

Table 1 **Estimates of the effect of R&D on Australia's productivity from standard levels models**[a]

Coefficient estimates with standard errors in brackets

	Domestic Business	*Foreign*	*Implied return (%)*	*Reject return of zero?*	*Comment*
1. Basic model (limited controls) -					
(a) Static	Mis-specified	Mis-specified			Highly serially correlated errors
(b) Dynamic	0.021 (0.034)	0.220*** (0.042)	60	No	One model statistically OK. Domestic coefficient imprecise.
2. Extended model (extended controls) -					
(a) Static	0.019 (0.044)	0.042*^ (0.023)	60	No	Adding controls did not 'uncover' a more precise coefficient estimate
3. Two equation MFP -					
(a) Basic static	0.020 **b** Post 85-86	0.281*** (0.023)	60	-	Slope shifts indicated a significant reduction in the domestic business elasticity post 1985-86

a *** Indicates statistically significant at greater than one per cent, ** five per cent, and * ten per cent. '^' indicates foreign measure based on USPTO patents granted rather than R&D-based knowledge stock. **b** Early to mid-1980s slope shifts were negative indicating a decreasing elasticity.

Source: Shanks and Zheng (2006)

Estimation problems were encountered irrespective of choice of specific depreciation rate. Sensitivity testing of alternative depreciation rates showed some variation in implied returns. But there was no strong tendency for models to favour higher or lower decay rates in terms of producing more precise estimates with better overall model fit.

Overall, it was possible to find models that explained MFP in reasonable fashion, but the contribution of domestic business R&D could not be pinned down. Human capital and reductions in industry protection were found to have quite robust effects. Effects of communications infrastructure, ICT capital, and moves to decentralised wage determination were generally well estimated, albeit with some sensitivity to specification.

Further exploration

SZ went even further in their quest to find a clear relationship. They specified other models in which R&D was related to productivity in *growth* form. These models were motivated by endogenous growth theories, but were simplified specifications. They overlooked mechanisms of knowledge accumulation other than R&D, and interactions between the mechanisms. One growth formulation related the change in growth of R&D stocks to the change in the rate of productivity growth. Another form related R&D intensity (R&D stocks or changes in R&D stocks in proportion to GDP) to changes in the rate of productivity growth.

A two-equation specification was also explored. Equations were separately specified for factors that affect business investment in R&D and for R&D and other factors that affect productivity. The two equations were estimated within a related system. This approach showed some promise, as well as a continuation of some estimation problems. There were indications that foreign R&D had a positive effect on the Australian economy both via domestic R&D and directly.

Why the fragility?

SZ put forward a number of possible explanations for the fragility of estimates, some of which appear specific to analysis of Australian R&D over the observation period used in their study. The observation period appeared important because the addition of another 10 years or so of data had increased fragility and reduced precision, rather than the other way around. This was attributed to: a number of shocks to both investment (including R&D) and to productivity that had disrupted and obscured a long-term relationship between R&D and productivity; and the inability to adequately control for these shocks in the regressions. In very broad terms, a series of policy and institutional changes that gathered momentum from the mid-1980s had helped to transform the Australian economy from being domestically-oriented and resistant to change to one that is more outward-oriented, flexible and innovative.

But there are perennial issues that undermine the stability and precision of results from this kind of analysis—irrespective of country of analysis (Diewert 2005). Limited degrees of freedom often contribute to a lack of precision in time series analysis. The tendency of variables to be collinear can lead to spurious results. Of particular note for this paper, there are also issues to do with the formation of R&D stocks.

4. A closer look at assumptions underlying the construction of R&D capital

Constructed variables sometimes present problems in econometric analysis because they are relatively ‘smooth’, exhibiting too little variation to be associated with the variation exhibited by other factors of interest. In this case, the variation in the constructed R&D stock variable is relatively smooth. Moreover, it is likely to be dampened in comparison to the variation in the true stock of knowledge. Several key assumptions in implementation of the PIM work to dampen variation in knowledge stocks, as represented by R&D capital.

The productivity of R&D activity

One key assumption underlying the PIM is that the rate at which R&D inputs produce R&D outputs—that is, the productivity of R&D activity—is fixed over projects and time. With this assumption, the volume of outputs of knowledge and technologies can be represented by the use of inputs for the purposes of accumulation into a stock.[12]

Fixed productivity of R&D across projects is implied by the method of deflation of current price expenditures on R&D inputs. In implementation of the PIM, uniform price deflation is applied to all current-price input expenditures at a point in time. This is tantamount to assuming that each dollar of expenditure at a point in time generates the same amount and quality of output.[13] In reality, R&D activity generates heterogeneous outputs with a wide range of qualities, and in different appropriability conditions.[14] A given usage of R&D input can therefore generate a wide range of asset values.

The assumption of intertemporal fixity in R&D productivity is implied by the accumulation of real R&D expenditure as an approximation to the accumulation of R&D outputs. There is plenty of evidence, however, that the productivity of R&D has not remained constant over time.

Technological opportunities and the organisation of R&D activity are two major influences on the productivity of R&D. Technological opportunities—crudely, the 'ease' of discovery and invention—flow and ebb as areas of research enter increasing returns in the early stages after a breakthrough and subsequently reach diminishing returns as a technology class becomes 'fished out'. How effectively and efficiently R&D is organised at the firm, industry, national and (increasingly) international levels also affects the amount of knowledge generated per unit of input used. For example, the focus on national innovation systems highlights the gains from development of

---

[12] The issue of successful/unsuccessful R&D is subsumed within the assumption of constant productivity of R&D. A constant productivity of R&D can capture a uniform rate of success in generating R&D outputs.

[13] It would not be necessary to assume that each dollar generates the same output if there was a constant pattern of outputs in terms of their type (eg basic discoveries and specific applications) and quality or significance. It could be then argued that a 'representative' relationship between R&D expenditure and outputs holds at each point of time and general price deflation can be applied. These are strong assumptions, however.

[14] Firms have a range of innovation strategies that can generate different outcomes with respect to the asset value of R&D activity. While some position themselves on the 'technology edge' and invest in R&D in order to generate knowledge assets, others undertake R&D in order to make relatively minor incremental adaptation of technologies, without expectation of long-lived payoff from their investment. In the extreme, some R&D could be for defensive reasons to ensure that there is less risk of a competitive penalty if the firm does not undertake some R&D in order to be aware of technological trends and where and how to access them. A lot of R&D is undertaken under conditions of 'winner takes all' rivalry. If one firm achieves the breakthrough, was all R&D undertaken by all competitors equally valuable?

research infrastructure and competencies, and from specialisation, collaboration and knowledge transfer and so on.[15]

The relationship between measured inputs and R&D outputs can also change as a result of input cost increases—unless they are fully stripped out by input cost deflators. The general evidence is that R&D costs have risen faster than general producer prices, although the degree seems to vary across countries and time (SZ, pp. 60-62). Use of a general GDP deflator would tend to overstate the increase in real R&D expenditure and, under the constant productivity assumption, the increase in R&D outputs. A particular case is where the salaries of researchers increased more rapidly than general costs; and more than general salaries in the instance where a general labour cost deflator is used.

Changes in policy settings have undoubtedly undermined the assumption of constant R&D productivity in a further way in Australia. As noted in section 2, the introduction of R&D tax concessions in the mid-1980s induced some 'phantom' increases in R&D expenditure, which would have meant that the volume of R&D output per measured dollar of input had declined, all other things equal. Much of the aggregate increase came through the entry of small firms which, if scale of activity is important, would not have promoted improved productivity of R&D. Moreover, the increasingly 'creative' use of the concession over time would have meant that the phantom increases were not confined to the period of introduction of the concession, when there was an incentive to reassign pre-existing expenditure as R&D activity. After the scheme was tightened in the second half of the 1990s, the phantom element would have declined and thereby raised the output/expenditure ratio in Australian R&D.

The depreciation of knowledge

The use of a constant rate of depreciation in implementations of the PIM is another practice that attracts concern. It is common to assume a single average depreciation rate or average asset life, selected with reference to the life of patents or similar information. Against this, it is contended that the rate of decay in the usefulness of knowledge varies across R&D outputs and, at times, in discontinuous ways. New discoveries can render some existing knowledge unexpectedly obsolete—or more valuable.

Changes in the composition of R&D activity can affect the average depreciation rates of knowledge. For example, it is widely considered that the asset values of outputs of

[15] Research collaborations in certain areas between industry competitors, coordinated multinational R&D activity through subsidiaries and contracting of R&D to new performing countries such as China and India play a much greater part these days in international business R&D.

ICT-based R&D are relatively short-lived. The shift toward ICT-based R&D in the 1990s would therefore have increased the average rate of depreciation.

Implications

The assumptions of constant productivity of R&D and of constant knowledge decay help to smooth the movements in R&D capital stocks, in comparison to likely movements in the true knowledge stocks. Variation in input use is likely to be less than the variation in outputs (and values) generated across projects and time. The assumption of constant knowledge depreciation is likely to have a strong dampening effect, as it removes the effect of random shocks to the value of existing knowledge.

The dampened variation in R&D capital stocks then becomes a problem for econometric analysis in establishing a link between variations in knowledge stocks and variations in economic performance. SZ did not attempt to test the assumption of constant productivity of R&D. They did test alternative depreciation rates and introduced a variable rate of depreciation, but found little improvement in results. It may well be that 'over-smoothing' still occurred within the range of depreciation alternatives tested.

5. Moves to capitalise R&D in the national accounts

There have been moves for some time to introduce capitalised R&D expenditures into countries' national accounts. Capitalisation of R&D was canvassed in lead-up discussions on the conventions to be introduced in SNA93, but was not included in the final agreement. The 'Canberra II Group' of national accounting experts has given the issue further consideration in discussions on a new round of proposals for changes to national accounts conventions.

The motivation for capitalising R&D in the national accounts comes, in a sense, from a different direction. In the analytical context, capitalisation of R&D is motivated by the desire to investigate the relationship between knowledge accumulation and growth. In the national accounts context, however, capitalisation stems from the question, 'Is R&D better treated as an expense or as an investment?' Approximation of knowledge stocks by R&D capital is a common component, but the relationship between R&D capital and growth is not an immediate focus of the national accounts proposals.

The case for treating R&D as investment is conceptually strong. Normally, R&D more closely resembles a commitment of resources in order to generate assets that can be drawn on in the future to generate a range of production gains. Treating it as such and capitalising R&D expenditures would provide a consistent accounting link between investment expenditure and the corresponding asset. Whilst it is argued below that the distinction between the 'expense' and 'investment' character of R&D is actually blurred, its portrayal as investment is theoretically sound.

It is proposed that the PIM method be used to construct R&D capital in the national accounts. Whilst there are likely to be some differences in the details of implementation, the fundamentals are likely to be along the lines outlined above in relation to the SZ study, namely:

- measurement of current price business R&D investment;[16]
- deflation of the series to provide volume measures;[17]
- accumulation of the investments into a stock; and
- application of a rate of depreciation to the stock.

There have been a number of experimental investigations of capitalisation of R&D and ways of incorporating R&D capital into the national accounts (Fraumeni and Okubo 2002, ABS 2004, Robbins 2006, Edworthy and Wallis 2006). These studies, in effect, take the accumulation of input expenditure, deflated by general price deflators, as a given. They tend to focus attention on the selection of an average rate of depreciation and the sensitivity of results to different depreciation rates.

Flow-on to other estimates

Capitalisation of R&D would have implications for a number of variables in the national accounts. With R&D treated as an investment, estimates of output and saving would be higher. With R&D capital treated as an asset, estimates of the aggregate capital stock and wealth would be higher.[18]

Various investigations suggest that capitalisation of R&D would make a sizeable difference to the *levels* of variables. For example, the ABS (2004) found that capitalising R&D would lift Australia's GDP by around 1.5 per cent. Fraumeni and Okubo (2002) estimated that US wealth would increase by 2 per cent. The effects of capitalisation are likely to vary across countries according to the relative importance of R&D.

---

[16] Estimates of R&D expenditure derived on the basis of the Frascati Manual (OECD 2003) include expenditure on assets such buildings, land and software. These estimates can be adjusted to form estimates of R&D investment by deducting expenditures on related assets and adding components to allow for consumption of capital and a 'normal' rate of return on capital used (ABS 2004).

[17] The price deflator chosen is usually based on input costs, rather than output prices. R&D expenditures on labour, capital and materials are deflated by respective cost deflators. Shanks and Zheng (2006) used a GDP implicit price deflator. They found not a lot of difference in accumulated stocks when they used separate factor cost deflators. With growth in contract research services, the possibility of better observing prices of research outputs is emerging. However, application is restricted by lack of time series of representative data.

[18] Fraumeni and Okubo (2002) have stated and illustrated that failure to treat R&D as investment understates a nation's savings, wealth and potential for growth, including productivity growth.

As constructed, capitalisation of R&D would have a smaller effect on the *growth* rates in variables. For example, the ABS (2004) found differences in annual rates of GDP growth of no more than 0.07 of a percentage point, and mostly near zero. The small effect on growth rates is due to the relative size of, and relatively smooth change in, R&D expenditure.

Despite the inherent difficulties in selecting values for key parameters of the PIM, there is a defensible argument that capitalising R&D as part of measurement of output and wealth is an improvement over the current practice of expensing R&D. Moreover, any uncertainty about accuracy in measurement is unlikely to intrude heavily on variables of most interest—especially, GDP growth.

6. Implications of capitalisation of R&D for national accounts estimates of productivity

However, the implications of capitalisation of R&D for the derivation of national-accounts estimates of productivity nevertheless warrants some attention. In this context, the probability that a change in conventions would have little effect on estimates does not necessarily provide comfort. The issue is whether capitalisation of R&D would deliver more accurate and meaningful estimates of productivity.

First, how would capitalisation of R&D affect productivity measures? On the measurement of labour productivity, capitalisation of R&D would affect the measurement of output, but not labour input. Applying the same arguments as discussed above in relation to output, capitalisation of R&D would raise the measured level of labour productivity, but would generally have only minor effect on measured growth in labour productivity.[19] On measurement of multifactor productivity, there is an input effect, as well as an output effect. The logical extension of capitalising R&D in the national accounts is that R&D capital would enter the measured capital stock and the measured flow of capital services. Thus the level of both numerator and denominator of MFP would be higher than otherwise. It is likely that the level of MFP would be higher, but not to the extent of the increase in the level of labour productivity.[20] The effect on MFP growth would depend on how rapidly R&D activity is growing and how prominent R&D capital is in relation to total capital.

Second, how accurately would the R&D-based effects on productivity be measured? There are two components to this question; the accuracy with which R&D outputs

[19] With productivity measured in index number form, the change in levels would not be discernible. The effect on productivity growth would be more noticeable if R&D intensity is relatively high and increasing.

[20] The effect on labour productivity is likely to be greater than the effect on MFP, at least in level terms, because of the inclusion of additional capital in the MFP calculation. The difference between higher labour productivity and MFP would be explained by higher measured capital intensity of production.

would be captured in the measurement of output; and the accuracy with which services from intangible knowledge assets are captured in the measurement of inputs.

Discussion above in the context of the SZ analysis highlighted strong concerns about the extent to which R&D outputs can be represented by R&D inputs (expenditure). The implicit assumption of constant productivity of R&D across projects and time does not sit comfortably with the comparatively idiosyncratic nature of the R&D process. Fundamentally, R&D activity is not like typical production activities in which each unit of input committed contributes equally (or at least in stable or predictable fashion) to the generation of output. There can be (variations in rates of) research failures; success can be subject to serendipity, threshold effects, and interactions with pre-existing knowledge; and the quality of successful outputs can vary widely.

On the accuracy of measurement of R&D-based knowledge assets, there is also the issue of how well depreciation of knowledge is captured in the PIM (in addition to the issue of representing knowledge outputs by R&D inputs). At least on the face of it, the use of smooth rates of depreciation does not sit comfortably with: the diversity in rates of depreciation in different types of knowledge; and discontinuous change in the value of knowledge as discoveries render some existing knowledge suddenly obsolete or latent knowledge suddenly more valuable. Furthermore, the way in which R&D capital would be incorporated in the aggregate productive capital stock could be challenged. Aggregation of R&D capital with other assets would require a rental price weight, which would be constructed from estimates of the rate of depreciation of, and rate of return on, R&D capital. From an empirical if not theoretical point of view, there are doubts (see SZ analysis) that capitalised R&D can be treated in the standard framework that rewards assets according to their marginal products and equates returns on assets in the current period.[21]

Third, despite the likely measurement deficiencies, would capitalisation of R&D nevertheless be better in relation to measurement of productivity than the current approach of expensing R&D? The answer is not clear-cut. Whilst R&D is conceptually investment-like, that characterisation likely has a general and longer-term validity. R&D is generally considered to be a high-risk investment. Businesses are prepared to write off a lot of expenditure across a number of unsuccessful projects, with the hope and intention of making a small number of highly-successful and financially-rewarding discoveries over the longer term. In effect, some of R&D expenditure is investment-like and some is expense-like. And the degree to which it is one or the other probably varies across time and countries.

[21] There is also the issue that measurement of knowledge stocks is limited to accumulation via R&D activity. Baldwin et al (2005) noted that capitalisation of R&D would omit knowledge accumulation through the importation of technologies, which is a major source of knowledge for Canada.

In sum, it is not clear that capitalisation of R&D in the national accounts would deliver more meaningful estimates of productivity. It may do so. But it may not. It is an issue that warrants further investigation.

7. Concluding remarks

Proposals to capitalise R&D in the national accounts can be supported by defensible arguments, at least in relation to estimates of output and wealth. Conceptually, R&D activity is more akin to investment than it is to an expense. It can be argued that capitalising R&D is more consistent with this conceptual ideal and would provide accounting consistency between investment expenditure and its corresponding asset formation. There is, however, uncertainty about the accuracy with which R&D expenditure represents delivery of R&D outputs. Nevertheless, from a practical point of view, treating R&D expenditure as an investment rather than as an expense is probably the 'lesser of two evils'. Moreover, treating R&D as an investment is not 'intrusive', at least with respect to estimates of growth in output.

However, the judgment that capitalisation of R&D may be the lesser of two evils does not make capitalisation of R&D 'right', especially in regard to the measurement of productivity. The arguments and evidence presented in this paper raise questions about the extent to which incorporation of an input-based measure of R&D output and a PIM-based measure of R&D capital in productivity estimates would be useful and meaningful. The issue warrants further investigation.

What should be done, from the point of view of productivity estimation? The short answer is to proceed with capitalisation of R&D in the national accounts with some caution. Further investigation of the investment/expense nature of R&D and the implications for conventional productivity measurement would be helpful. Assessments for different countries would also be useful, as a change in measurement practice may be more relevant to some countries than others. For the time being, three options could be considered: do nothing—make no change to productivity measurement methods; full implementation—introduce R&D into the output measure and R&D capital into the capital input measure; and partial implementation—introduce R&D into the output measure, but leave the capital measure unchanged.

Whatever is done, transparency about any changes in methods will be important. It will help policy debates if users are well informed about the limitations of the R&D measures and about the interpretation of the revealed effects on productivity.

With time and further analysis, it would be important to come up with improved R&D output and stock measures. This most probably requires a direct measure that is independent of R&D inputs. Conceptually, a measure based on the value of the intangible assets produced would give a more accurate measure of output (and depreciation over time). But, of course, the substantial practical difficulties explain why this is not currently done. However, as markets for knowledge develop, the information base is likely to improve.

More fundamentally, more work is needed to better understand and represent the process of knowledge accumulation. This goes beyond R&D and national accounts conventions. For example, accumulation of knowledge can involve complex interactions between R&D investment, existing knowledge and human capital. Better understanding of knowledge accumulation would not only help policymaking directly, but may also help to identify meaningful ways to improve national accounts conventions.

References

ABS (2004), 'Capitalising Research and Development in the National Accounts', Paper prepared by the National Accounts Research Section for the Canberra II Group meeting, Washington, 17-19 March.

Baldwin, J., Beckstead, D. and Gellatly, G. 2005, 'Canada's Expenditures on Knowledge Capital', Economic Analysis Research Paper Series, Statistics Canada, Ottawa.

Diewert, E. (2005), 'Productivity Perspectives in Australia: Conclusions and Future Directions', Paper from the rapporteur at the joint ABS/PC conference, *Productivity Perspectives 2004*, Productivity Commission, Canberra. (http://www.pc.gov.au/commission/work/productivity/conferences/pp2004/presentations/diewert/index.html)

Englebrecht, H-J. (1997), 'International R&D Spillovers Amongst OECD Economies', *Applied Economics Letters*, vol. 4, no. 5, pp. 315-9.

Edworthy, E. and Wallis, G. (2006), 'Research and Development as a Value Creating Asset', Paper presented to the Comparative Analysis of Enterprise (Micro) Data Conference, Chicago, September.

Fraumeni, B. and Okubo, S. (2002), 'R&D in the National Income and Product Accounts: A First Look at its Effect on GDP', Paper presented at the Conference on Measuring Capital in the New Economy, WP2002-01, Bureau of Economic Analysis, Washington, April.

OECD (2003), *Proposed Standard Practice for Surveys of Research and Development* (Frascati Manual), OECD, Paris.

Robbins, C. A. (2006), *Linking Frascati-based R&D Spending to the System of National Accounts*, Paper prepared for the Conference of the Group on Measurement of Non-financial Assets, Canberra, March 29th – April 1 2005.

Shanks, S. and Zheng, S. (2006), 'Econometric Modelling of R&D and Australia's Productivity', *Staff Working Paper*, Productivity Commission, Canberra, April. (http://www.pc.gov.au/research/swp/economicmodelling/index.html)