FEATURE

Emma Edworthy
Office for National Statistics

Gavin Wallis
HM Treasury

Treating research and development as a capital asset

SUMMARY

Treating research and development as an asset requires a number of important steps. The first step is to determine the components of research and development expenditure to be included as investment and then to translate those expenditure components into a National Accounts compatible format. The second step is the construction of appropriate deflators for research and development assets. The final step requires the estimation of appropriate depreciation rates for research and development capital. This article presents work undertaken by the Office for National Statistics on these three steps for the UK business sector and also some estimates of the productivity impact of research and development on business sector firms.

In the current environment of rapid technological change, research and development (R&D) has proved to be an important element of economic growth. R&D is considered one of a number of measures of innovation performance and various studies have shown that investment in R&D is an important source of productivity growth (for example Griliches, 1981). R&D investment reduces production costs, as inputs are more effectively transformed into outputs, and it alters output characteristics, thereby providing new products to the marketplace (Bernstein and Mamuneas, 2004). As a result, the promotion of investment in R&D has become a priority within the EU.

In Barcelona, in 2002, EU heads of government set a target for EU R&D to reach 3 per cent of gross domestic product (GDP) by 2010, with two-thirds of this coming from businesses. As a result, many EU countries set domestic targets, including the UK. The UK government set a target to increase R&D expenditure to 2.5 per cent of GDP by 2014. Total UK R&D currently stands at 1.78 per cent of GDP (Office for National Statistics (ONS), 2006).

The official guidelines for collecting R&D data come from the OECD Frascati Manual. This manual deals exclusively with the measurement of human and financial resources devoted to R&D, namely R&D 'input' data. It provides a platform for internationally comparable data on R&D. The manual describes R&D as 'comprising 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'.

The manual acknowledges three types of R&D activities: basic research, applied research and experimental development. Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. Experimental development is systematic work, drawing on the existing knowledge gains from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

Although it is widely accepted that expenditure on R&D by firms is a means to improving their productivity via new processes and product innovations, it is not recorded by National Accounts in a way that reflects this. R&D is currently treated as an intermediate input for businesses and current consumption for government and non-profit institutions.

At the Statistical Policy Committee (SPC) in November 2006, European Member States came to a conclusion on how to handle the introduction of R&D activity as capital formation in the update of the System of National Accounts (SNA). This conclusion will be presented to the UN Statistics Commission meeting at the end of February, when the SNA revisions will be agreed upon (the SPC expects the European view to be accepted).

The SPC concluded that 'compulsory' satellite accounts should be developed in the short to medium term in order to address the 'substantial' conceptual and measurement difficulties involved with treating R&D as an asset. It is recommended that the final decision on including R&D expenditure in core National Accounts should be taken once sufficient evidence is gained through experience in satellite accounts, showing that it can be measured with appropriate confidence.

In preparation for revisions to the SNA relating to R&D, Eurostat have funded an ONS project to assess the practical and methodological issues involved in capitalising R&D in National Accounts. This article presents work that has been completed as part of the project.[1]

Developing methodology

Linking Frascati-based expenditure to the SNA

In order to capitalise R&D in the National Accounts, Frascati expenditure data needs to be translated into an SNA-compatible format. The value of R&D needed to be capitalised within the SNA framework is gross output minus intermediate inputs. The first step involves converting Frascati sectors into SNA sectors. **Table 1** is a link table adapted from Robbins (2006).

De Haan and van Horsten (2005) suggest three product groups to help translate gross expenditure on R&D (GERD) to the SNA.

- **Market R&D** – the value should be determined by estimated basic prices. Production costs should be used if reliable market prices are not available.
- **Non-market R&D** – by convention is valued by the sum of production costs. They suggest that, by convention, all non-market output of goods and services is consumed by the government sector. They highlight that the sum of outlays as reflected by GERD is not consistent with the sum of production costs in accordance with National Account principles. They suggest replacing the figures on capital expenditure included in GERD with an estimation of consumption of fixed capital (COFC). COFC represents the reduction in the value of the fixed asset used in production during the accounting period resulting from physical deterioration, normal obsolescence or normal accidental damage. Robbins (2006) identifies R&D as a non-market good based on its producer, either government, universities or non-profit institutions.
- **Own-account** – the SNA rule is to value own-account production using market prices. When a suitable market price cannot be used, the 'second best' option should be used, that is, the sum of the production costs.

In order to arrive at gross output figures, intermediate consumption, capital services and net value added need to be summed. Net value added is the sum of compensation of employees, other taxes on production and imports *less* subsidies *plus* net operating surplus. A bridge table adapted from Peleg (2006) between the Frascati Manual and SNA data on R&D would include the following.

I. Output

A. Frascati Manual GERD

(1) **Plus** acquisition of R&D to be used as input in R&D production

(2) **Plus** depreciation of capital goods owned by R&D producers and used in R&D production

(3) **Plus** net operating surplus contained in R&D output measured at basic prices

(4) **Plus** other taxes less other subsidies on production

(5) **Minus** capital expenditures

B. R&D output by SNA93 definitions

Equal to GERD + (1) + (2) + (3) + (4) – (5)

II. Data for preparation of supply and use tables

Exports and imports of R&D

(1) R&D exports

(2) R&D imports

Not all the data implied by the above are available for R&D in the UK (operating surplus, exports and imports of R&D output). **Table 2** gives an indication of the UK data available and the adjustments needed to be made to come up with a satisfactory gross output figure.

Table 1
Link table – Frascati sectors to SNA sectors

Frascati Manual	SNA
Business enterprise sector	Non-financial corporations Financial corporations
Government sector	General government sector
Private non-profit sector	Non-profit institutions serving households (NPISH)
Higher education sector	General government NPISH
Abroad	Rest of the world

Table 2
UK data availability

Non-financial corporations	Financial corporations	General government	NPISH
Business Enterprise Research and Development (BERD) survey	BERD	GOVERD (HERD for public universities)	Non-profit expenditure on R&D (HERD for private universities)
Minus capital expenditure for financial corporations	**Minus** capital expenditure for non-financial corporations	**Minus** capital expenditure including those for land and structures	**Minus** capital expenditure by NPISH serving business
Plus expenditure for NPISH serving business	**Plus** expenditure for NPISH serving business	**Minus** current expenditure for non-plant machinery and equipment, as well as purchased and own-account software (estimated with ratio of equipment and software to gross output)	**Plus** capital services
Plus R&D purchased as an intermediate input to production of R&D in the corporate sector (includes cost of any purchased R&D)	**Plus** R&D purchased as an intermediate input to production of R&D in the corporate sector (includes cost of any purchased R&D)	**Plus** capital services	n/a
Minus historical cost depreciation	**Minus** historical cost depreciation	**Minus** payments for trade in R&D services	n/a
Plus capital services on structures, equipment and software owned by R&D performers and used to perform R&D in the UK	**Plus** capital services on structures, equipment and software owned by R&D performers and used to perform R&D in the UK	n/a	n/a

Key issues

Freely available research and development

The decision on whether or not to include freely available R&D as part of R&D gross fixed capital formation (GFCF) has proved to be controversial. The argument is focused largely on higher education and government sectors. At present the discussion is looking at excluding basic research for these two sectors, given that it would seem likely that there is no strategy in place to capture future economic benefits. Business enterprises, on the other hand, are assumed to have a profit motive and presumably think that their basic research will lead to future income, even if the results are published. Therefore, they can be expected to have a strategy in place to exploit the knowledge gained from their basic research (Aspden, 2006).

Since this article covers only business R&D, it is assumed that freely disseminated R&D is included. The case is also argued that unsuccessful R&D is a cost of producing R&D and is therefore indirectly incorporated into the market value of R&D assets given they are valued at cost. Therefore, unsuccessful R&D would not have an asset life independent of successful R&D in the National Accounts. This would see R&D being treated in the same way as mineral exploration, where it is viewed that the returns from the successes are sufficient overall to pay for failures.

Potential for double counting

There is a potential difficulty with an overlap with computer software. The Frascati Manual identifies the following types of capital expenditure:

- land and buildings
- instruments and equipment
- computer software

The UK BERD survey asks for data under land and buildings and plant and machinery and does not separate out software. Mandler and Peleg (2003) highlight two types of potential R&D software overlap:

- R&D may be performed with the aim of developing a software original
- the development of software may be part of an R&D project

Mantler and Peleg (2003) also distinguish between two types of products:

- an asset – the software – that can be used repeatedly in production
- R&D that is a product in itself, whether regarded as an asset or as intermediate consumption

Contrary to this view, de Haan and Van Horsten (2005) assume that R&D fully devoted to the development of a new software original will generally constitute an inseparable part of the production process, with a single identifiable output. Their view and current SNA93 says that all R&D with the specific goal of developing a software original should be identified as software and not as R&D. When it is not possible to separate R&D software development within an R&D project, then that software should not be recorded as a separate asset.

De Haan and Van Horsten (2005) agree with Mandler and Peleg (2003) accounting recommendations when software is developed as a supplementary tool. If it can be identified as such, then the software should be identified as a separate asset and the consumption of fixed capital of this software should be part of the production costs of R&D output.

The main issue for ONS is not so much double counting within the software industry, but the amount of R&D software being double counted within other industries. In BERD, software development outside the software industry is recorded under the product sold by the company. This software development (if classified as R&D by the company) will be included in their capital expenditure figures on the BERD form. This capital expenditure should already be counted as part of software expenditure in the National Accounts.

Developing solutions

Estimating current price gross fixed capital formation

In order to estimate 'at cost' GFCF, some adjustment to Frascati-based expenditure data needs to be made. **Figure 1** provides a diagrammatic representation of how to get from Frascati-based total expenditure on R&D to a position where R&D is capitalised in the National Accounts. Figure 1 identifies that capitalising R&D will impact on total National Accounts GFCF and also on capital consumption, with both these having an impact on measured GDP.

Three different methods are identified to derive the estimate of capital service flows from other asset classes. This capital service flow is essentially an estimate of the input of the other capital (mostly tangible capital), used in the R&D process, to the R&D capital stock. In the first model, this input is proxied by COFC plus an assumed return on those assets. In the second and third models, the capital service flow from the assets used in the R&D process is measured directly. One method uses rental rates, the other capital services growth rates. More detail on the methodology for estimating R&D GFCF using the three different approaches is provided in the technical note at the end of this article.

The expenditure data used to calculate GFCF is broken down into two clear areas, intramural (current and capital) and extramural. Intramural expenditures are all expenditures for R&D performed within a statistical unit or sector of the economy during a specified period, whatever the source of funds. Extramural expenditures are the amount a unit, organisation or sector reports having paid, or committed themselves to pay, another unit, organisation or sector for the performance of R&D during a specified period. This includes acquisition of R&D performed by other units and grants given to others for performing R&D. Intramural expenditure can be split further between:

- current expenditure:

  wages and salaries – includes all overtime payments, bonuses, redundancies, commissions and holiday pay and should be gross

  other – purchases of goods and services from outside the unit, including overseas purchases, and scientific services should be included, provided no R&D is involved. Contractors employed on R&D projects are included here
- capital expenditure:

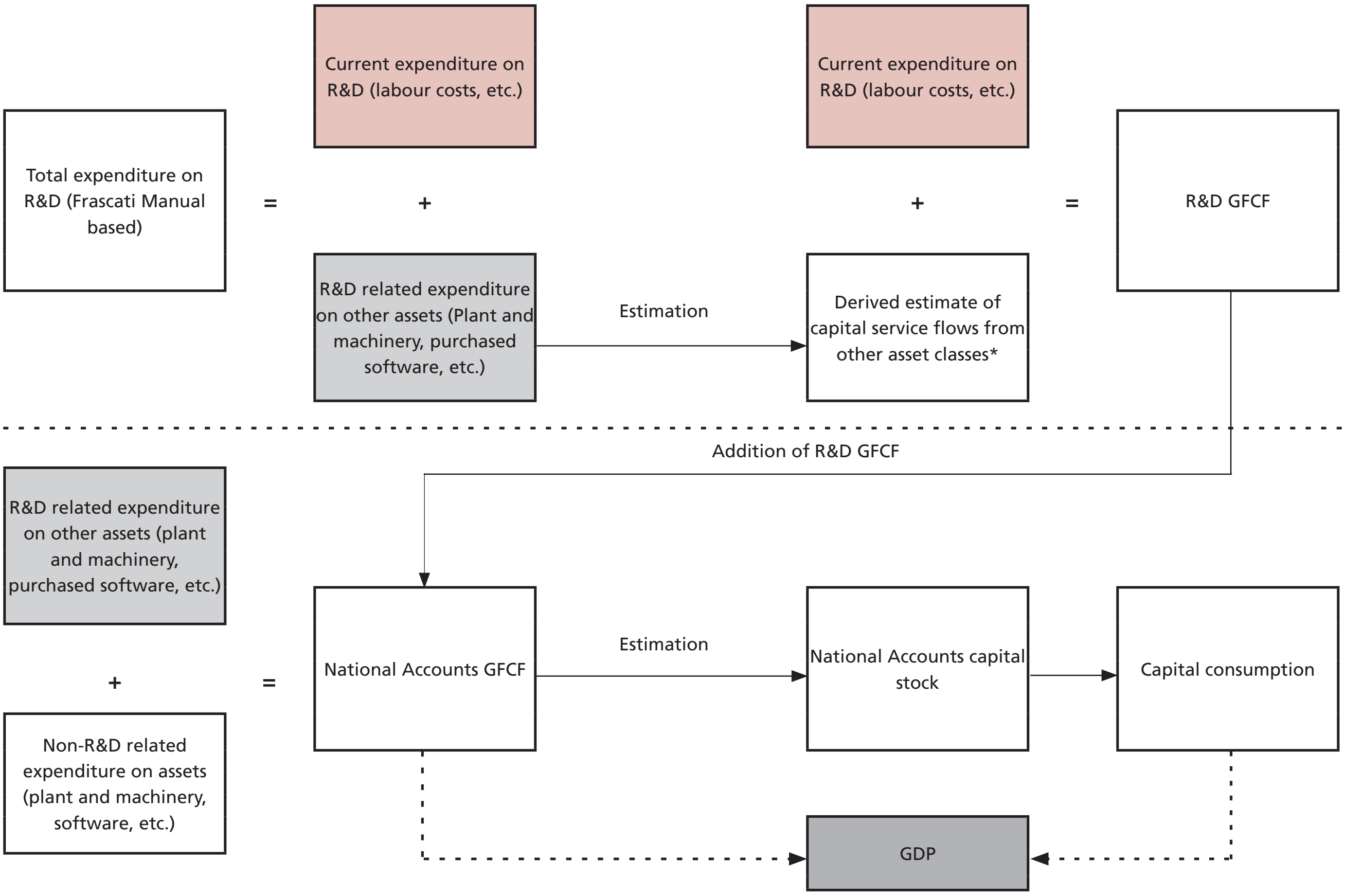
  land and buildings

  plant and machinery

Capital expenditure should include annual gross expenditure on fixed assets used in R&D projects. Land and buildings comprises the acquisition of land and buildings, costs of major improvements and modifications or repairs.

For the purpose of calculating R&D GFCF, both extramural and intramural expenditure are included. Extramural expenditure will obviously include R&D purchased both within and outside the UK.

Figure 1
Capitalising research and development expenditure



* Can either be derived as consumption of fixed capital COFC (capital consumption) plus a normal return on capital used, or direct capital services estimates

Constant price gross fixed capital formation: estimation of industry-specific deflators

To look at the contribution of R&D expenditure to economic growth and productivity, constant price R&D GFCF is the object of interest. This requires a suitable deflator in order to convert current price R&D GFCF into constant price GFCF.

The major problem associated with constructing a deflator for R&D is that it is a very heterogeneous product. By definition, every project is different. Given that the majority of R&D is carried out on own-account, this makes it hard, if not impossible, to calculate a market (output) price. As a result, the next best solution would appear to be the use of input prices.

The use of input-based indices to estimate output volumes may well seem inappropriate, but there are many other areas within National Accounts where they are used when a better alternative is not available. Industry-specific deflators for business R&D have been estimated using input prices for the following types of input:

- wages and salaries
- other current expenditure
- land and buildings
- plant and machinery

R&D cost components and appropriate weights are used to calculate a simple weighted index and a divisia index. Cameron (1996) argues that a divisia index is theoretically and empirically better at capturing changes in the cost of R&D than fixed weighted indices such as the Laspeyres or Paasche indices.

Table 3 shows data sources available for the UK for estimating input-based deflators for UK R&D. The availability of data sources determines the exact methodology that can be used when estimating input-based price indices.

The UK Business Enterprise Research and Development (BERD) survey form asks for firms to break down their average employment on R&D (number of full-time equivalents) into three areas:

- **scientists and engineers** – professional scientists or engineers engaged in the conception or creation of new knowledge, products, methods and systems

Table 3
Deflator data sources

R&D component	Proxied by	Source
Wages and salaries	Index of earnings of science and technology professionals	Annual Survey of Hours and Earnings (ASHE)
	Index of average earnings of technicians	ASHE
	Index of average earnings of administrative occupations	
Other current expenditure (materials, etc.)	PPI (input) materials and fuels purchased by manufacturing excluding food, beverages, tobacco and petroleum	Producer price indices
Capital	Separate index for plant and machinery, and land and buildings	National Accounts capital stock deflators

- **technicians** – qualified personnel who participate in R&D projects by performing scientific and technical tasks, normally under the supervision of professional scientists and engineers
- **other** – supporting staff include skilled and unskilled craftsmen, secretarial and clerical staff participating in R&D projects or directly associated with such projects

Wage information for these three occupational areas, in the form of gross weekly wages, is available from the Annual Survey of Hours and Earnings (ASHE). Data from ASHE are classified by standard occupational classification (SOC) and are available for 1997 to 2004 for the following occupations:

- science and technology professionals
- technicians
- administrative occupations

A simple weighting technique was used to create a deflator for wages and salaries and also a divisia index for comparison. Initially, a price index was calculated for each of the three employment areas, scientists, technicians and other workers and then the weights were applied to these indices:

$$W_s = \frac{E_s}{E_T} \; ; \; W_t = \frac{E_t}{E_T} \; ; \; W_o = \frac{E_o}{E_T}$$

where:

W_s: weight for scientists and engineers
W_t: weight for technicians
W_o: weight for 'other' workers
E_T: total Frascati-based expenditure on salaries and wages
E_s: Frascati-based expenditure on scientists and engineers
E_t: Frascati-based expenditure on technicians
E_o: Frascati-based expenditure on 'other' workers

The deflator for salaries and wages was then calculated as:

$$P_{WS} = P_s W_s + P_t W_t + P_o W_o$$

where P_s, P_t, and P_o are the price indices for scientists and engineers, technicians and other workers.

For other current expenditure, the producer price index (PPI) for materials and fuels purchased by manufacturers excluding food, beverages, tobacco and petroleum products was used. For the capital input to R&D, existing deflators from the National Accounts were used.

An aggregate R&D deflator for each of the 33 industries represented in BERD was estimated using the simple weighting technique and also as a divisia index for comparison.

Estimating depreciation rates for research and development capital

In calculating an R&D capital stock, evidence supports the use of the perpetual inventory method (PIM). The gross stock of R&D is then the measure of the cumulative value of past investment still in existence. The net capital stock would be equal to the gross stock less the accumulated depreciation on assets in the gross stock. Depreciation rates can be based on asset lives or they can be estimated using econometric methods.

Whereas some research treats R&D as a permanent part of the capital stock once added, the consensus thinking is that, once R&D capital has entered the capital stock, it is gradually removed by depreciation (consumption of fixed capital).

The empirical evidence on depreciation rates for R&D assets is limited. The research that has been carried out has either estimated depreciation rates using econometric models (for example, Bernstein and Mamuneas, 2004) or using a patent renewal method (for example, Pakes and Schankerman, 1979). The little evidence that has emerged from both types of analysis has on the whole produced a common message that industrial knowledge depreciates faster than physical capital. Mansfield (1979), Pakes and Schankerman (1979) suggest there is little knowledge capital left after ten years. Bernstein and Mamuneas (2004) estimate that R&D capital depreciates at two to seven times the rate of physical capital.

Bernstein and Mamuneas (2004) consider R&D depreciation within the context of intertemporal cost minimisation, where depreciation rates are estimated simultaneously with other parameters characterising the overall structure of production. They characterise R&D depreciation as a geometric or declining balance form. A geometric pattern is a specific type of accelerated pattern. An accelerated pattern assumes higher £ depreciation in the early years of an asset's service life than in the later years. This compares with a straight-line depreciation pattern that sees equal £ depreciation over the life of the asset. The justification for this comes from a series of papers by Griliches (1979, 1990 and 1995). Griliches gives two main justifications for this:

- there is approximately a contemporaneous link between R&D and the services emanating from this investment through innovation and invention
- typically, innovation and invention are short-lived, and replaced at a rapid rate

These imply that efficiency declines relatively fast in the early part of the service life of R&D investment, and therefore R&D depreciation approximates declining balance.

Nadiri and Prucha (1996) estimate a geometric depreciation rate of 12 per cent for the US manufacturing sector. They estimated a model of factor demand that allowed for estimating jointly the depreciation rates of both physical and R&D capital for the US total manufacturing sector. Their 12 per cent estimate of depreciation is very close to the ad hoc assumption usually used as a starting point in most empirical analysis, 15 per cent. They used only gross investment data to generate estimates of the depreciation rates as well as consistent series for the stocks of R&D capital. The 12 per cent estimate is not too dissimilar to studies that use R&D capital stocks as an input in the production function, Griliches (1980) and Bernstein and Nadiri (1988, 1991).

On average, the estimates for depreciation rates of R&D stock in empirical literature range from 10 to 25 per cent, though these tend to be for certain sectors of the economy. This corresponds to an average service life of about five to ten years.

Here, a depreciation rate for the business sector is estimated using econometric methods. The method will be to look at the impact past R&D has on output (gross value added at market prices) to assess the rate of depreciation. That is, if R&D undertaken five years ago has, on average, zero impact on value added today, then the life length mean of R&D can be deduced as being five years. The following equation was estimated:

$$\Delta GVA_t = \sum_{S=1\ldots T} \alpha_s C_{t-s} + N_t + K_t$$

where ΔGVA_t is the change in gross value added from time t to time $t-1$, C_t is investment in R&D, K_t is other capital inputs and N_t is labour input. Clearly there are various econometric issues surrounding the estimation of the equation above but these will not be discussed here.

Estimating research and development capital stock

With constant price R&D GFCF and an estimated depreciation rate, it is easy to estimate the R&D capital stock. The PIM is used to calculate the R&D capital stock with an assumption of geometric depreciation, and the methodology of Guellec and Van Pottelsberghe (2004) is used for calculating the net R&D capital stock in the initial year. Details are provided in the technical note at the end of this article.

UK data sources

Business Enterprise Research and Development (BERD)

The BERD survey is an annual survey designed to measure R&D expenditure and employment in the UK. Since 1995, it has used a stratified random sample, stratified by product group and employment sizebands, where sizeband 1 (400+) is sampled 1:1, sizeband 2 (100–399) is sampled roughly 1:5 and sizeband 3 (0–99) being sampled roughly 1:20. These sampling fractions were reduced in 1998 as 400 more forms were made available for sampling.

In the first stage of the sampling procedure, the largest 400 firms are chosen and in the 2003 survey this corresponded to those enterprises doing more than £2.6 million of R&D. These companies have either been identified from previous returns or from one of the other data sources. These 400 firms are then sent a long form (a long form is simply a survey form that has a larger number of questions than a short form).

There are a number of sources that contribute towards the sampling frame for the BERD. The Annual Business Inquiry survey asks a filter question about whether or not a firm engages in R&D. The Department of Trade and Industry and Scottish Executive provide ONS with R&D information on companies. Finally, the press is used to identify firms that are conducting R&D and these are added to the sampling frame.

For those firms not receiving a long form, they are broken down into the remaining two employment sizebands mentioned above. Enterprises are then selected randomly from each sizeband using the sampling fractions applicable to that band. Those identified are then sent a short form.

For non-selected firms, data is imputed on the basis that these enterprises have the same R&D to employment ratio as selected reporting units in their class.

Annual Respondents Database (ARD)

The other main source used is the ARD. This is a data set that combines information from ONS business surveys over time and contains a variety of useful variables, such as turnover and employment. Robjohns (2006) provides further detail on this data set, how it can be linked to other surveys such as the BERD, and recent developments.

National Accounts data

For the tangible capital used in the R&D process, data on life-length means and deflators is available from the National Accounts. Given a life-length mean for each type of tangible capital asset, the depreciation rate can be calculated as follows:

$$\delta = d/\bar{T}$$

where *d* is called the 'declining balance rate' and $\bar{T}$ is the life-length mean. d will differ across asset types, and the declining balance rates for different asset types can be found in Wallis (2005). When *d=2*, as it does for intangibles such as R&D, there is what is referred to as the 'double declining balance' method.

Capital services data

The estimates of capital services growth and rentals are based on Wallis (2005). Some aggregation was required to get from the 57 industries at which capital services estimates are published to the required 33 R&D product groups. Updates to the capital services estimates in Wallis (2005) will be published in a forthcoming issue of *Economic & Labour Market Review*.

UK estimates

Business investment in R&D and the R&D capital stock

Table 4 shows estimates for GFCF using three different methodologies and compares them with the current R&D expenditure-based measure as published in ONS (2006), *Research and Development in UK Businesses* (MA14). Table 4 shows that all three methods give GFCF above the MA14 estimate of total R&D expenditure. This means that the flow from the other capital assets being used as part of the R&D process, plant and machinery, and land and building, is greater than the expenditure on these assets. This reflects the fact that investment in the stock of these assets is greater than the depreciation of the stock, that is, there is an increasing stock of other assets that are being used in the R&D process.

The main thing to note from Table 4 is that the results from the three methods are quite similar. This means that despite methods 2 and 3 being preferable on theoretical grounds, as they directly measure capital services flows, using method 1 would give robust estimates. It is expected that some countries would not have the required capital services data to implement methods 2 or 3.

Research and development deflator

Figure 2 shows the estimated deflator for business sector R&D against the UK GDP deflator. A GDP deflator is commonly used in empirical studies as a proxy for an R&D deflator. It is clear from Figure 2 that the two differ quite a bit, suggesting that the GDP deflator is not a good proxy. Industry-specific deflators were also produced and these showed significant differences between industries.

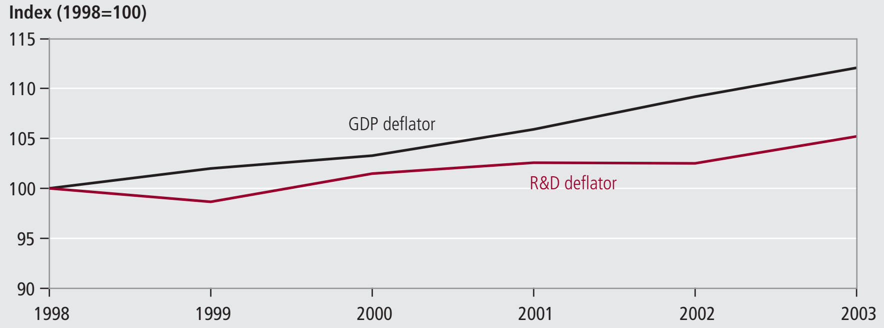
Table 4
Business investment in R&D

£ billion

Year	MA14: total R&D expenditure	Method 1	Method 2	Method 3
1997	9.5	10.3	10.4	10.2
1998	10.1	10.9	11.1	10.8
1999	11.3	12.5	12.7	12.3
2000	11.5	12.4	12.5	12.1
2001	12.3	13.5	13.4	13.1
2002	13.1	15.0	15.1	14.5
2003	13.7	15.1	15.1	14.6

Source: MA14 (ONS, 2006), methods 1, 2 and 3 are authors' own calculations

Figure 2
GDP deflator and estimated R&D deflator



Research and development depreciation rate

Preliminary results are based on a panel of industry data for the period 1998 to 2003. From this industry-level panel, a business sector depreciation rate was estimated. In future it is planned to use a firm-level panel to estimate industry-specific depreciation rates. **Table 5** shows the results of the chosen regression specification.

As the fourth lag of R&D investment is insignificant, the results suggest a life length mean for UK R&D of four years. If a declining balance rate of two is assumed and the formula for depreciation discussed already ($\delta = d/\bar{T}$) is used, this implies a depreciation rate for UK R&D of 50 per cent, a rate much higher than those rates presented in the empirical studies discussed above. Although these results are preliminary, they do suggest that the approach could provide sensible estimates of depreciation for R&D capital following further development and investigation. It should also be noted that this is a business sector depreciation rate and there could be substantial industry variations.

Research and development capital stock

Table 6 shows estimates of business sector R&D capital stock when a depreciation rate of 15 per cent is used (the most commonly assumed depreciation rate in empirical studies). **Table 7** shows estimates of UK business sector R&D capital stock using a 50 per cent depreciation rate, as estimated above. Clearly, the impact of using different depreciation rates is very large.

Contribution of research and development to productivity growth

After capitalising R&D, it is important to look at the impact this would have on productivity, as this can be used to help justify its treatment as an asset. The return of R&D investment was estimated using a firm-level panel created by merging BERD and ARD data for the period 1998 to 2003. The final data set used in the productivity analysis contained 16,095 firms.

The starting point was a model common to a lot of empirical studies of the R&D contributions to productivity growth, an extended Cobb-Douglas production function including time trends and firm specific effects:

$$Y = AN^{\alpha 1} K_T^{\alpha 2} K_R^{\alpha 3} E$$

where Y is a measure of value added, K_T is capital input (excluding R&D capital), N is labour, K_R is R&D capital, A is a parameter representing spillovers (proxied by the sum of R&D within the industry) and E is an error term. Taking logs and adding both a firm index i and a time subscript t, the equation becomes:

$$Y_{it} = a + \alpha_1 n_{it} + \alpha_2 k_{T,it} + \alpha_3 k_{R,it} + e_{it}$$

A simple regression (equation 1 in **Table 8**) gives an estimated elasticity of 0.095 per cent on R&D capital. This implies that a 10 per cent increase in R&D capital is associated with an increase in productivity of 0.95 per cent.

The simple regression analysis was extended to allow for different dummies, including interaction dummies, to account for a distinction between services and manufacturing industries and to account for foreign ownership (US, Japan and Europe). Equations 2 to 6 in Table 8 show the resulting estimated regressions.

Equation 2 shows that there is an average difference between services and manufacturing productivity, with services more productive. Equation 3 shows the results of including an interaction dummy for services and the R&D capital stock. The result suggests that an increase in R&D capital stock leads to a bigger increase in productivity for services than for manufacturing although the difference is not statistically significant at conventional levels.

Table 5
Regression results for depreciation estimation

Dependent variable: change in gross value added

Lag of R&D expenditure	Coefficient	Standard error	t-value
Lag 1	–9.16	5.01	–1.83
Lag 2	25.67	7.15	3.59
Lag 3	–24.59	6.91	–3.56
Lag 4	5.42	6.86	0.79
Lag 5	2.95	5.76	0.51

Table 6
Business R&D capital stock, 15 per cent depreciation

£ billion

Year	Method 1	Method 2	Method 3
1996	50.7	71.1	63.1
1997	53.4	70.8	63.9
1998	56.3	71.2	65.1
1999	60.4	73.2	67.7
2000	63.6	74.6	69.6
2001	67.6	76.8	72.2
2002	72.4	80.3	75.9
2003	76.5	83.4	79.0

Source: Authors' own calculations

Table 7
Business R&D capital stock, 50 per cent depreciation

£ billion

Year	Method 1	Method 2	Method 3
1996	19.6	19.7	19.8
1997	20.1	20.2	20.1
1998	20.9	21.2	20.8
1999	23.0	23.2	22.8
2000	23.9	24.1	23.4
2001	25.4	25.4	24.9
2002	27.6	27.7	26.9
2003	28.9	28.9	28.0

Source: Authors' own calculations

Table 8
Regression results for productivity impacts of R&D

Equation		N	K_T	K_R	Services	UK	US	Japan	EU
1	Spillovers	0.64*** (26)	0.33*** (21)	0.095*** (8.76)	n/a	n/a	n/a	n/a	n/a
2	Services dummy	0.69*** (29)	0.29*** (18)	0.061*** (6.35)	0.12*** (2.75)	n/a	n/a	n/a	n/a
3	Interactive services dummy	0.69*** (29)	0.29*** (18.4)	0.061*** (6.15)	0.008 (1.85)	n/a	n/a	n/a	n/a
4	Country dummies	0.67*** (28)	0.32*** (20.7)	0.066*** (7.12)	n/a	n/a	n/a	n/a	n/a
5	Country dummies	0.67*** (28)	0.32*** (20.7)	0.066*** (7.12)	n/a	0.20*** (4.94)	0.32*** (5.87)	0.12 (1.27)	0.08 (1.42)
6	Interactive country dummies	0.67*** (28)	0.32*** (20.7)	0.05*** (4.2)	n/a	0.25*** (4.75)	0.39*** (5.70)	0.019 (1.72)	0.011 (1.52)

Note:
t-value in parentheses, *** significant at 1 per cent level, ** significant at the 5 per cent level.

Taking account of firm ownership suggests that UK firms add more to productivity. The base in this regression is all firms not UK-, US-, Japan- or EU-owned. Finally it appears that UK-owned firms and US firms have an additional effect from an increase in the R&D capital stock on productivity over and above other countries.

Conclusions and future work

This article has addressed several issues involved in the capitalisation of R&D for the UK National Accounts. Three separate methods were presented for calculating R&D GFCF. The results presented in Table 4 show that estimates are robust to the three methods.

The estimate for a business sector R&D-specific deflator showed that the use of a GDP deflator in R&D capitalisation calculations is not an accurate proxy. Preliminary results imply a depreciation rate for UK business R&D of 50 per cent. This is a somewhat higher rate of return to UK R&D than that estimated in empirical studies to date. However, these results are only preliminary and more empirical econometric analysis is needed in this area.

The most notable thing that comes out of work that has been completed so far is that, not only is calculating depreciation rates the most difficult element, but also that the estimated R&D capital stock is more sensitive to the depreciation rate than it is to changes in the way R&D GFCF and R&D deflators are calculated. Estimating a whole economy life length mean using industry-specific data implied a depreciation rate of 50 per cent. However, the econometric issues surrounding this early stage estimation are acknowledged.

Firm-level data gave an estimated elasticity of 0.095 per cent on R&D capital. This implies that a 10 per cent increase in R&D capital stock is associated with an increase in productivity of 0.95 per cent.

Note

1. This article presents the current stage of an ongoing project jointly funded by ONS and Eurostat. As such, its content is work in progress and we would welcome comments and suggestions. All the analysis presented here was carried out before the latest ONS BERD data revisions. The statistical data presented here is Crown Copyright and is reproduced with the permission of the Controller of HMSO and the Queen's Printer for Scotland. Opinions expressed here are those of the authors and do not necessarily represent the views of HM Government. A longer, more technical, version of this article will be available in a forthcoming issue of *Statistika – Journal for Economy and Statistics.*

CONTACT

elmr@ons.gsi.gov.uk

REFERENCES

Aspden C (2005) 'Update to the 1993 SNA'.

Bernstein J I and Mamuneas T P (2004) 'R&D depreciation, stocks, user costs and productivity growth for US knowledge intensive industries'.

Cameron G (1996) 'On the measurement of real R&D – Divisia price indices for UK Business Enterprise R&D' at www.nuff.ox.ac.uk/users/cameron/papers/defl.pdf

De Hann M and Van Rooijen-Horsten M. (2005) 'Measuring output and capital formation in open economies', Statistics Netherlands.

Fraumeni B (1997) 'The measurement of depreciation in the US National Income and Produce Accounts', *Survey of Current Business*, July 1997.

Griliches Z (1979) 'Issues in Assessing the contribution of R&D to productivity growth', *The Bell Journal of Economics* 10, pp92–116.

Griliches Z (1981) *R&D patents and productivity*, NBER, The University of Chicago Press.

Griliches Z and Mairesse J (1981) 'Productivity and R&D at the firm level', in: Z Griliches (ed.) *R&D, patents and productivity*, The University of Chicago Press.

Griliches Z (1992) 'The search for R&D spillovers', NBER Working Paper No. W3768.

Guellec D and Van Pottelsberghe B (2004) 'From R&D to Productivity Growth: Do the Institutional settings and the source of funds of R&D matter?', *Oxford Bulletin of Economics & Statistics* 66(3), pp353–78.

Hall R E and Jorgenson D W (1967) 'Tax Policy and Investment Behaviour', *American Economic Review* 57(3), pp391–414.

Mandler P and Peleg S (2003) 'R&D software', Paper presented at second meeting of the Canberra II Group, OECD (Paris).

Mansfield E (1987) 'Price indices for R&D inputs, 1969–1983', *Management Science* 33(1), pp124–9.

Nadiri M I and Prucha I R (1993) 'Estimation of the depreciation of physical and R&D capital in the US total manufacturing sector', NBER Working Paper No. W4591.

Office for National Statistics (2006) *Research & Development in UK Businesses* (MA14) at www.statistics.gov.uk/downloads/theme_commerce/MA14_2004.pdf

Organisation for Economic Co-operation and Development (2001) 'Measurement of capital stocks, consumption of fixed capital and capital services'.

Organisation for Economic Co-operation and Development (2002) 'Frascati Manual: Proposed standard practice for surveys on Research and experimental development'.

Pakes A and Schankerman M (1979) 'The rate of obsolescence of knowledge, research gestation lags, and the private rate of return to research resources', NBER Working Paper No. W346.

Peleg S (2006) 'Harmonization between R&D Statistics and the National Accounts', Paper presented at the NESTI/Canberra II meeting in Berlin, Germany, May 31 to June 1.

Robbins C A (2006) 'Linking Frascati-based R&D Spending to the System of National Accounts', Bureau of Economic Analysis Working Paper, WP2006-03 and at http://bea.gov/bea/papers/Robbins_06_SNA_Fras.pdf

Robjohns J (2006) 'ARD2: the new Annual Respondent Database', *Economic Trends* 630, pp43–51 and at www.statistics.gov.uk/cci/article.asp?ID=1556

Rogers M (2006) 'Estimating the impact of R&D on productivity using the BERD-ARD data' at www.dti.gov.uk/files/file21908.pdf

Wallis G (2005) 'Estimates of the volume of capital services', *Economic Trends* 624, pp42–51 and at www.statistics.gov.uk/cci/article.asp?ID=1297

TECHNICAL NOTE

Methods for estimating R&D gross fixed capital formation

Method 1: Consumption of fixed capital (COFC) plus an assumed return

In method 1, the estimate of R&D GFCF is calculated as the following:

$$GFCF_t^{CP} = \left(C_t + \sum_a I_{at}^{CP}\right) - \sum_a I_{at}^{CP} + \sum_a COFC_{at} + \sum_a R_{at}$$

where C_t is current expenditure on R&D, I_{at}^{CP} is current price investment in the asset type *a* being used in the R&D process (using UK data only two asset types can be identified – land and buildings, and plant and machinery), $COFC_{at}$ is the consumption of asset type *a* being used in the R&D production process and R_{at} is the assumed return on asset type a being used in the production process.

COFC in time *t* for an asset of type *a* is given by the following:

$$COFC_{at} = K_{at} \cdot \delta_a$$

where K_{at} is the net stock of asset type *a* at time *t* and δ_a is the rate of depreciation of asset *a*. To calculate a net stock for each asset type, the perpetual inventory method (PIM) was used. A geometric PIM was used to calculate net stock as follows:

$$K_{at} = \sum_{\tau=0}^{\infty} (1-\delta_{a,t-\tau})^{\tau} \cdot I_{a,t-\tau}$$

where *I* is constant price investment in asset *a*. In constructing this PIM the following assumption was made about the net capital stock in the initial year, assuming a steady state:

$$K_{a0} = I_{a0} / \delta_a$$

Finally for this model, an estimate of R_{at} is needed. The Australian Bureau of Statistics assumption that the rate of return on capital used in the R&D process is 5 per cent was used:

$$R_{at} = 0.05 \cdot K_{at}$$

Method 2: Capital services estimated using rentals

In method 2, the estimate of R&D GFCF is calculated as the following:

$$GFCF_t^{CP} = \left(C_t + \sum_a I_{at}^{CP}\right) - \sum_a I_{at}^{CP} + \sum_a CS_{at}$$

where variables are as defined above and CS_{at} is the capital service flow at time t from the asset type *a* being used as part of the R&D process. Capital services refer to the flow of productive services from the stock of capital. Capital services estimates recognise that the same stock of capital may be used more or less efficiently.

For method 2 CS_{at} is calculated as the real level of capital services:

$$CS_{at} = K_{at} \cdot r_{at}$$

where r_{at} is the rental for asset *a* at time *t*. The rental is calculated using the Hall-Jorgenson (Hall and Jorgenson, 1967) formula for the cost of capital in discrete time *t*:

$$r_{at} = T_{at} \left[\delta_a \cdot P_{at} + R_t P_{a,t-1} - (P_{at} - P_{a,t-1})\right]$$

where P_{at} is the price of an asset of type *a* at time *t*, δ_a is the rate of depreciation, and R_t is the rate of return. T_{at} is the tax adjustment factor which is given by the following:

$$T_{at} = \left[\frac{1 - u_t D_{at}}{1 - u_t}\right]$$

where u_t is the corporation tax rate and D_{at} is the present value of depreciation allowances as a proportion of the price of asset type *a*.

Method 3: Capital services estimated using capital services growth rates

In method 3, the estimate of R&D GFCF is calculated as the following:

$$GFCF_t^{CP} = \left(C_t + \sum_a I_{at}^{CP}\right) - \sum_a I_{at}^{CP} + \sum_a CS_{at}$$

This is as in method 2. Here, however, CS_{at} is calculated using a different method. In the initial year, the capital services input to R&D is estimated using the real level of capital services as in method 2:

$$CS_{a0} = K_{a0} \cdot r_{a0}$$

Subsequent years are calculated as follows:

$$CS_{at+1} = CS_{at} \cdot g_{at} \text{ for } t = 1,2,...$$

where g_{at} is the growth rate of capital services for asset *a* at time *t*.

Estimating research and development capital stock

A geometric PIM was used to calculate the R&D net capital stock as follows:

$$RD_t = \sum_{\tau=0}^{\infty} (1 - \delta_{t-\tau})^{\tau} \cdot GFCF_{t-\tau}$$

where RD_t is the R&D capital stock at time *t*, $GFCF_t$ is constant price R&D GFCF at time *t* and δ is the depreciation rate of R&D (constant over time). The methodology of Guellec and Van Pottelsberghe (2004) is used to calculate R&D net capital stock in the initial year, RD_0. Guellec and Van Pottelsberghe (2004) assume a constant annual rate of growth of past investment:

$$RD_0 = \frac{GFCF_0}{1 - \lambda(1 - \delta)}$$

with $$\lambda = \frac{1}{1 + \eta}$$

where η is the mean annual rate of growth of $GFCF_t$.