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Do R&D tax credits work? Evidence from a panel of countries 1979–1997

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Do R&D tax credits work? Evidence from a panel of countries 1979–1997

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Abstract

This paper examines the impact of fiscal incentives on the level of R&D investment. An econometric model of R&D investment is estimated using a new panel of data on tax changes and R&D spending in nine OECD countries over a 19-year period (1979–1997). We find evidence that tax incentives are effective in increasing R&D intensity. This is true even after allowing for permanent country-specific characteristics, world macro shocks and other policy influences. We estimate that a 10% fall in the cost of R&D stimulates just over a 1% rise in the level of R&D in the short-run, and just under a 10% rise in R&D in the long-run.

Author Keywords: Tax credits; R&D; Panel data; Tax competition

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1. Introduction

US and European policy makers have been concerned about the technological performance of their countries for large parts of the Twentieth Century. These concerns were sharpened by the Post War rise of the Japanese economy which enjoyed very high growth rates until the 1990s based on a strong technological base and high commitment to R&D. The phenomenal growth of the Asian tiger economies over the 1980s and mid-1990s, in particular South Korea, has also been based on a high-tech strategy. These competitive threats have coincided with an intellectual movement in economic theory which emphasises the conscious accumulation of R&D and human capital in explaining economic growth (e.g. Aghion and Howitt (1992)).

In an effort to increase their level of innovation many countries have turned to fiscal incentives for R&D, often involving substantial sums of taxpayers' money. The US GAO (1989) estimated that R&D tax credits cost approximately $7 billion in revenue during the 1981–1985 period. More recent estimates suggest that the US R&D tax credit will cost around $2.24 billion in lost revenue over fiscal years 1997 through 2002 (Gravelle, 1999). The E.U.'s (1995) survey on state aid suggests that its members spent over $1 billion per annum on R&D tax incentives during the early 1990s.

Economists, however, have generally been skeptical of the efficacy of tax incentives. One cause of this skepticism is the view that R&D is not very sensitive to changes in its (after tax) price.[1] More recently, however, several studies of the impact of the US Research and Experimentation Credit have found that there was a considerable response in US corporate R&D behaviour. In particular Hall; Hines and Baily and Lawrence, 1992 and Mamuneas and Nadiri (1996) find R&D price elasticities of at least unity. A reason for this revisionism is the argument that the US experience provided a 'natural experiment' which enabled researchers to obtain cleaner estimates of the responsiveness of R&D to changes in its user cost. Previous studies, so the argument goes, suffered from an absence of large and truly exogenous variation over time in the R&D tax price.

Although attractive, there are at least three difficulties with concentrating upon only one country to evaluate the effectiveness of fiscal provisions. Firstly, because the variation is essentially macroeconomic it is very difficult to disentangle the true effect of the credit from other contemporaneous macro-economic events, such as world demand conditions. Secondly, the variation between firms in the effectiveness of the credit is essentially due to their different tax positions (e.g. whether they have any taxable profits) and expectations about future R&D spending. These are likely to be highly endogenous, as is recognised in the more recent work. The approach taken in this paper is to draw on cross-country data where there have been several policy experiments with the fiscal treatment of R&D. We essentially use the introduction and modification of rules governing the taxation of R&D (which vary both within and between countries over time) to identify the effects of tax-price changes on R&D. Thirdly, generalising results obtained from using the data on one country to other countries can be misleading.[2]

The plan of the paper is as follows. Section 2 lays out our modelling strategy and describes the tax and economic data (with more details in the Appendix A and Appendix B). Section 3 outlines our econometric approach and Section 4 presents the results. Some concluding remarks are made in Section 5. To pre-empt somewhat, we find evidence that R&D responds to changes in its user cost with a long run elasticity of around unity.

2. Measuring the cost of R&D investment

Despite the wide and increasing prevalence of tax incentives for R&D there are very few academic studies outside the US which have documented their size and effectiveness.[3] The approach we take to measuring the impact of corporate income taxation on the price of investing in R&D was pioneered by Hall and Jorgenson (1967). [4] This methodology combines information about tax rates, depreciation allowances and integration of personal and corporate income taxes. The aim of this approach is to derive the pre-tax real rate of return on the marginal investment project that is required to earn a minimum rate of return after tax. This will be a function of the general tax system, economic variables and the treatment of R&D expenditure in particular. We allow this rate of return to vary across countries and over time.[5] The derivations presented here are close to those in Devereux and Griffith (1998) and the interested reader is referred to that publication for more detail.

2.1. Domestic cost of R&D investment

For expositional purposes we drop the country and asset subscripts from the tax and economic parameters for the first part of this section. In our empirical application all tax parameters are allowed to vary over time, across countries and assets. This is made clear in the final equations of this section.

Consider a profit maximising firm which makes an investment in R&D in period one that earns a return in period two. We assume that this firm is financed by retained earnings and that the ultimate shareholder is exempt from personal taxes. We further assume that the firm does not anticipate tax changes. The value of the firm at time *t* in the absence of tax is given by the net present value of the income stream, denoted V_t* (all variables with a * superscript denote 'in the absence of tax'),

$$(1+i)V_t^* = D_t^* + V_{t+1}^* \tag{2.1}$$

where *i* is the nominal interest rate and D_t* is the amount of dividend paid by the company to the ultimate shareholder (in the absence of tax). Dividends paid by the parent are given by,

$$D_t^* = f(G_{t-1}) - R_t \tag{2.2}$$

where $f(.)$ is the net income function, G_{t-1} is the end of period $t-1$ value of the R&D stock and R_t is the investment in R&D. The price of output and R&D are normalised to unity in period *t*. The equation of motion of the R&D stock is given by $G_t = (1-\delta)(1+\pi)G_{t-1} + R_t$ where δ is the economic depreciation rate and π is the one period inflation rate that is assumed common to output and R&D stock but is allowed to vary over time and across countries. We consider an investment in R&D which increases the stock by one unit in period *t* only by letting R&D investment rise by one unit in period *t* and decline by one unit, less depreciation, in period *t*+1 so that

$$dR_t = 1, \qquad dR_{t+1} = -(1-\delta)(1+\pi). \tag{2.3}$$

This perturbation of the capital stock yields a return of

$$df(G_t) = (p+\delta)(1+\pi_t) \tag{2.4}$$

where *p* is the pre-tax financial return (which is allowed to vary over time, countries and assets in the empirical application). The economic rent, Π*, earned by the firm from a perturbation in its R&D stock in the absence of tax is given by the change in (2.1). Using ((2.2), (2.3) and (2.4)) this can be written,

$$\begin{aligned} \Pi_t^* &= (1+i)\,dV_t^* = dD_t^* + dV_{t+1}^* \\ &= 1 + \frac{(p+\delta)(1+\pi) + (1-\delta)(1+\pi)}{(1+i)} \\ &= \frac{1+p}{1+r} - 1 = \frac{p-r}{1+r} \end{aligned} \tag{2.5}$$

where $r = \left[(1+i)/(1+\pi) - 1 \right]$ is the real interest rate.

Now consider how tax will affect the level of rent earned by the firm, holding *p* and *r* constant. There are three ways in which corporate income tax enters.

1. The firm pays tax on its revenues at rate τ.

2. The cost of the R&D investment to the firm is reduced by depreciation allowances. We summarise these by A^d. Depreciation can be given on a declining balance or straight line basis.[6] If depreciation allowances are given on a declining balance basis at rate φ (and begin in the first period) the value of the depreciation allowance will be τφ in period one, and in subsequent periods the value falls by $(1-\phi)$. We can denote the net present value of the stream of these depreciation allowances A^d,

$$A^d = \frac{\tau\phi(1+r)}{(\phi+r)} \tag{2.6}$$

where *r* is the firm’s discount rate. For straight-line depreciation the equivalent expression is

$$A^d = \tau\varphi. \tag{2.7}$$

3. The cost of the R&D investment to the firm is reduced by tax credits, which we summarised by A^c. We can calculate the net present value of the tax credit, A^c, which will depend on the rate and design of the tax credit. The main features that affect the value of a tax credit are: (i) whether the credit applies to total or incremental expenditure, (ii) how the base level of expenditure is defined in the incremental case, and (iii) whether the credit is capped at the firm level. For a volume based tax credit (where the credit is on total expenditure) the value of the credit to the firm will equal the rate (τ^c)

$$A^c=\tau^c. \tag{2.8}$$

In some cases the amount of the credit reduces the cost of the asset for deduction purpose (e.g. the Canadian ITC), in which case $A^c = (1-\tau)\tau^c$.

For an incremental credit, with a base that is defined as the k-period moving average[7] the value of the credit is given by,

$$A^c = \tau^c \left(B_t - \frac{1}{k}\sum_{i=1}^{k}(1+r)^{-i}B_{t+i} \right) \tag{2.9}$$

where τ^c is the statutory credit rate, B_{t+i} is an indicator which takes the value 1 if R&D expenditure is above its incremental R&D base in period t and zero otherwise. If the credit has a cap on the absolute amount a firm can receive, as in France, then A^c will either be as above (if the firm is below the cap) or zero (for firms above the cap).

These A^d, A^c summarise the net reduction in investment costs. The cost of an investment project which is unity before tax is $(1-(A^d+A^c))$ after tax. Reducing the investment by $(1-\delta)(1+\pi)$ in period t+1 (as expressed in (2.3)) generates a reduction of $(A^d+A^c)(1-\delta)(1+\pi)$ in these allowances.

A final aspect of the tax system that must be considered is any imputation credit available on dividends paid to the shareholder. Dividends are assumed to be paid net of any such credits so that the value of the firm in the presence of tax becomes,

$$(1+i)V_t = \gamma D_t + V_{t+1}$$

where γ measures the degree of 'tax discrimination' between retained earnings and distributions. An expression for the net present value of economic rent (the change in value of the firm) in the presence of tax, equivalent to (2.5), can be defined,

$$\begin{aligned}\Pi &= (1+i)\,\mathrm{d}V_t = \gamma \mathrm{d}D_t + \mathrm{d}V_{t+1} \\ &= \gamma\left[\frac{(p+\delta)(1-\tau)+(1-\delta)(1-(A^d+A^c))}{(1+r)} - \left(1-\left(A^d+A^c\right)\right)\right].\end{aligned}$$

We consider the impact of tax on the marginal project (i.e. where economic rent is zero). Setting Π=0 and solving for *p* we obtain the cost of capital, $\tilde{p}$

$$\tilde{p} = \frac{(1-(A^d+A^c))}{(1-\tau)}(r+\delta)-\delta.$$

We calculate the user cost (the cost of capital with depreciation added back) for a domestic investment in R&D for three assets (indexed by *j*) and for each country (*i*) and year (*t*). These are given by

$$\rho^d_{ijt} = \frac{\left(1-\left(A^d_{ijt}+A^c_{ijt}\right)\right)}{(1-\tau_{it})}\left[r_{it}+\delta_j\right]. \tag{2.10}$$

The depreciation allowances and tax credits vary across types of asset, countries and time, the statutory tax rate and real interest rate vary over country and time. The economic depreciation rate varies over asset. We consider investment in the manufacturing sector into three types of asset for use in R&D — current expenditure, buildings, and plant and machinery. An important assumption in the modelling strategy used here is that current expenditure on R&D is treated as an investment — that is its full value is not realised immediately. The economic depreciation rates used are 30% for current expenditure on R&D, 3.61% for buildings and 12.64% for plant and machinery. The domestic user cost of R&D for an individual country is then given by

$$\rho^d_{it} = \sum_{j=1}^{3} w_j \rho^d_{ijt} \tag{11}$$

where w_j are weights equal to 0.90 for current expenditure, 0.064 for plant and machinery and 0.036 for buildings (see Cameron (1994)). The inflation rate and nominal interest rate are taken from OECD Economic Outlook. [8] How the possible endogeneity of these variables to the investment decision is dealt with is discussed below.

2.2. The tax data

There is no published series of the tax-adjusted user cost of physical capital or R&D capital across countries and over time. We implement the formulae in the previous section by collecting details of the tax system in operation in each of the nine countries for every year from 1979 to 1997. Our main source of data were the annual Price Waterhouse 'Doing Business in…' guides which document the current tax system in great detail.[9]

Table A.1 shows the evolution of our measure of the user cost of R&D for a domestic investment (as described by Eq. (2.10)). The user cost would equal $(r_t + \delta_j)$ if a cash flow tax were applied to R&D (i.e. if R&D were fully expensed). Since most of R&D expenditure consists of current expenditure, which is fully expensed in all the countries considered, the number is near to this in countries which give no special allowance for R&D and is less than $(r_t + \delta_j)$ in countries which offer tax credits or accelerated depreciation allowances.

There are a variety of factors driving the differences between countries over time (including changes to the treatment of R&D, the general tax system and to the real interest rate) but the sharp differences between countries are dominated by the impact of the tax credits. To illustrate this we strip out variation due to changes in the real interest rate and focus on the tax component of the user cost. This 'tax component' of the user cost, denoted $\rho_{it}^{d\tau}$, is calculated as in (2.10) but uses a constant real interest rate of 10% and inflation rate of 3.5% over time and across countries and is shown in Table A.2.

The user cost varies substantially both over time and across countries. Four of the countries — Australia, Canada, Spain and the USA — all have had generous regimes at some point. Fig. 1 charts the tax component of the user cost for these four countries. The four less generous countries are shown in Fig. 2. Italy, Germany and the UK do not give any substantial generally available tax incentives for R&D. Japan is in an intermediate position. France has given a more generous tax credit, but has also had a cap on the total amount of the credit that can be claimed. Appendix A gives more detail about the tax treatment of R&D in each country.

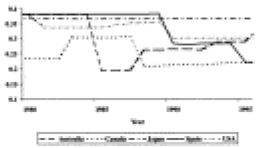 **Display Full Size version of this image** (6K)

Fig. 1. Economic constant user cost: five most generous countries.

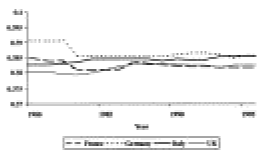 **Display Full Size version of this image** (5K)

Fig. 2. Economic constant user cost: four least generous countries.

The user costs shown in Table A.1 are calculated for a representative firm which is assumed to increase its level of R&D year on year and to have sufficient tax liability to be able to claim any tax credit in full. For the French tax credit, which is capped at between FF3 to FF40 million over the period, the firm is also assumed to be large enough to claim the full credit so the cap is binding. This means the marginal user cost is unaffected by the tax credit. [10]

The time series and cross sectional profile of our measure of the user cost closely matches those from a number of other studies that have used micro and country level data to calculate alternative measures of the user cost. For example, the time series correlation of our after tax price with Hall's (1993) 'average tax price of R&D' for the US is 0.93, and with Dagenais et al.'s (1997) 'effective price of R&D' for Canada is 0.62. Our 1989 and 1993 country rankings of the user cost of R&D have a cross sectional correlation of 0.79 and 0.88 with Warda's (1994) 1989 and 1993 rankings, and our 1990 country rankings have a correlation of 0.817 with the OECD's (1999d) measure of tax subsidies per $1 of R&D.

2.3. R&D and production data

Along with information on the tax system in each country it is necessary to draw on information relating to R&D and output. The OECD publishes a database (ANBERD) which contains information on business enterprise R&D (BERD) on a consistent basis across the main OECD countries since 1973. The data are reported at the country level on the basis of the location at which the R&D was undertaken. This is unlike firm level company accounts data which records R&D on the basis of the nationality of the parent firm. A number of recent studies have highlighted the increasing internationalization of R&D.[11] Using the ANBERD data has the advantage that the location of R&D can be matched more closely to the tax regime under which it falls. It also enables us to address the relocational issue since it measures the amount of R&D undertaken in each location. Company accounts data does not typically distinguish the geographical location of firm's R&D activities.

The OECD R&D data reports R&D which is *conducted* by the business sector separately from government- and university-conducted R&D. It includes the R&D performed in the state-owned industries (e.g. French aerospace) as well as R&D conducted by firms but funded by the government. Using a separate data source (MSTI, see Appendix B), we can disaggregate the BERD data by source of finance. The sub-component that we are interested in is own funded (r_{it}^{d}) and government funded (r_{it}^{g}). This provides another advantage over company accounts data since it allows us to strip out the government funded element of business-conducted R&D, which is generally not eligible for an R&D tax credit.[12] Government funded–industry-conducted R&D accounts for between 10 and 20% of total BERD in the USA, France, UK, Canada, Italy, Germany and Spain and less than 10% in Australia and Japan.

We focus on the manufacturing sector because of the difficulties of measuring R&D in the service sector (see Young (1996)). The manufacturing sector accounts for an average of around 80% of business-conducted R&D in the countries considered here. [13] The R&D data have been matched to information on value added from the OECD STAN dataset which is complementary to ANBERD. Our base sample contains 165 country–year observations.[14] Fig. 3 shows the ratio of business enterprise R&D (industry own-funded) to GDP in each country. It is clear that there has been a general move towards higher R&D intensities in almost every country, although the rate of change has been far faster in some countries (e.g. Japan) than others (e.g. Britain). One noticeable feature of Fig. 3 is that the smaller countries (Australia, Canada, Italy and Spain) have lower R&D intensity than the larger countries. From Table A.1 it can be seen that three of these countries offer generous allowances for R&D. Clearly there are many factors other than corporate income tax which will affect the level of R&D expenditure in each country. These include the pattern of intellectual property rights, industry–university linkages, geographical location and cultural differences (see Cohen and Levin (1989) for a discussion). We cannot hope to control for all of these, but so long as these factors only change slowly over time we can account for them statistically by allowing a country-specific intercept. What we identify in our empirical application is the impact of the *relative* user cost of R&D on the *relative* amount of R&D conducted in each country. ‘Relative’ in this context means R&D normalised against the country-specific historical average and relative to the year-specific world average. The relationship between relative R&D intensity and relative R&D user costs in our data is illustrated in Fig. 4.[15] It is clear that there is a negative correlation between high user costs and R&D intensity in the raw data.

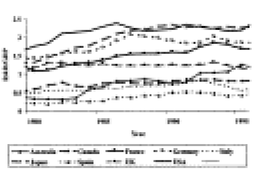
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Fig. 3. Own funded R&D share production.

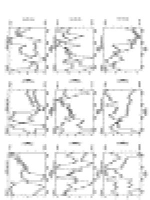
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Fig. 4. Relative R&D/Y and relative R&D user cost — all countries.

3. An econometric model of R&D

The basic model we estimate is a simple model of R&D investment of the form

$$r_{it}=\alpha+\beta y_{it}-\gamma \rho_{it}^{d}+u_{it} \tag{3.1}$$

where i indexes countries and t years, α is a constant, r_{it}=ln (industry-funded R&D); y_{it}=ln (output) and ρ_{it}^{d}=ln (user cost of R&D) as defined by Eq. (2.10). Eq. (3.1) could be considered to be the stochastic form of the demand equation for R&D capital derived from a CES production function where, in steady state, R&D capital (G) is proportional to the flow of R&D investment.[16] The coefficient on the tax price (γ) can be interpreted as the price elasticity of R&D with respect to its user cost.[17] Alternatively (3.1) could be viewed as a convenient empirical starting point for our investigation of the relationship between tax credits and R&D (this is the approach of most papers in the literature).

There are many other features of these countries, for example the supply of scientists, language and culture, that are both determinants of R&D and correlated with the user cost. So long as these are broadly stable over time, they can be captured by country fixed effects (f_i). There may also be common technology shocks that effect the ability of firms to perform R&D in the industrialised world (the increasingly widespread use of computer-based technologies, for example). We seek to control for these by including a full set of time dummies (t_t). Thus (3.1) can be re-written as the conventional within-groups (or least square dummy variable) estimator:

$$r_{it}=\beta y_{it}-\gamma \rho_{it}^{d}+f_i+t_t+v_{it}. \tag{3.2}$$

One worry is that the user cost of R&D may be endogenous leading to an upward bias in our estimates of the coefficients. It is a function both of the tax system and of a range of other economic variables, one of which is the real interest rate. This is generally procyclical, and thus positively correlated with R&D expenditure. In addition, the economic variation in the user cost of R&D is probably measured with more error than the tax variation, which could lead to attenuation bias. For these reasons we instrument the user cost with the tax component of the user cost of R&D capital ($\rho_{it}^{d\tau}$). We also instrument current output with lagged output because of concerns about simultaneity.

The model in (3.2) is static and we would like to allow for dynamics due for example to adjustment costs. One route is to specify a fully dynamic model and estimate the Euler equation. Unfortunately, Euler equation representations of R&D investment tend to be rather unrobust. Here we consider a simpler dynamic specification by introducing a lagged dependent variable:

$$r_{it}^{d}=\lambda r_{it-1}^{d}+\beta y_{it}-\gamma\rho_{it}^{d}+f_i+t_t+v_{it}. \tag{3.3}$$

We test this against more general dynamic forms.[18]

One may doubt the consistency of the estimated parameters in (3.3) due to the bias of the within-group estimator in the absence of strict exogeneity. Nickell (1981) has shown that for stationary variables this inconsistency is $O(1/T)$ and so recedes fairly rapidly as the number of time periods increases. In our case T is 19 (the estimating sample runs from 1979 to 1997). In an (overidentified) instrumental variables regression the impact of the Nickell bias can be tested with the Wald test on the over-identifying restrictions.[19] This test is asymptotic in NT (the total numbers of data points) so our sample should be sufficiently large for this to have some power.

Both real R&D expenditure and output are highly persistent series. This could lead to spurious correlation. However, it is likely that the two series are cointegrated. We therefore test for serial correlation in the residuals and for cointegration using a Dickey–Fuller test.

4. Results

4.1. Main results

The results from estimating (3.2) and (3.3) are presented in Table 1. The first column gives OLS estimates of the static R&D model. The coefficient on the R&D user cost is highly significant and implies an own price elasticity of about 0.35. Output is also significantly positive, as are the full set of country and time dummies.[20]

Table 1. Main results[a]

Dependent variable		(1) r_t OLS	(2) r_t IV	(3) r_t IV	(4) $r_t - y_t$ IV	(5) $r_t - y_t$ IV
Lagged ln (R&D)	r_{t-1}	–	–	0.868	–	–
				0.043		
Lagged ln (R&D/Y$_t$)	$r_{t-1} - y_{t-1}$	–	–	–	0.859	0.850
					0.047	0.045
ln (user cost)	ρ_t	−0.354	−0.499	−0.144	−0.124	−0.143
		0.101	0.115	0.054	0.060	0.058
ln (output)	y_t	1.184	1.364	0.143	–	–
		0.224	0.319	0.163		
Long run elasticity — user cost				−1.088	−0.878	−0.957
(P-value)				0.024	0.056	0.027
Wald test (P-value)		–	0.000	0.813	0.368	–
Durbin–Watson statistic		0.374	0.428	1.842	1.768	1.753
Country dums		Yes	Yes	Yes	Yes	Yes
Year dums		Yes	Yes	Yes	Yes	Yes
Observations		165	156	155	155	164

As discussed above, we are concerned about endogeneity of the user cost that arises due to variation in the economic component and of output arising from simultaneity. We discussed various potential endogeneity problems in the previous section. To address these in column (2) we implement an IV procedure. Instruments include current and lagged values of the tax-only component of the user cost (ρ_{it}^{τ} and ρ_{it-1}^{τ}), and the first and second lag of output. The estimate of the price elasticity increases in absolute value to almost 0.5. The presence of serial correlation or the existence of a 'Nickell bias' should be reflected in the rejection of a Wald test of instrument validity. The Wald Test does indeed reject the specification of column (2). We believe that this is driven by the dynamic mis-specification.

The third column incorporates the lagged dependent variable. As with other studies of R&D, this is highly significant and reduces the estimate of the impact elasticity of the user cost. Nevertheless, the estimate of the long-run effect of the user cost on R&D spending is close to unity and significant at conventional levels. The Wald test fails to reject the instruments in column (3) when we included lagged R&D, thus the model has passed a key diagnostic test. Since the long-run effect of the output term is also close to unity we impose constant returns and estimate an R&D intensity equation in column (4). Column (5) imposes a more restrictive instrument set to demonstrate that the model is robust. The short-run elasticity of the R&D user cost is just over 0.14 and the long-run elasticity is approaching unity.

Since real R&D expenditure and output are both potentially non-stationary $I(1)$ variables it is important to check that the error terms from our preferred dynamic regressions are stationary to rule out the possibility of spurious correlations. As a first test for stationary residuals the lack of any significant autocorrelation in the Durbin–Watson statistic for the residuals in columns (3), (4) and (5) is promising. Running a Dickey–Fuller test on the residuals from the regressions in columns (3), (4) and (5) confirms this, rejecting the H_0 that the errors are $I(1)$ for all nine countries in a country by country test and joint test.[21]

In Table 1 our estimation procedure, as noted above, uses country-specific intercepts to control for fixed effects relying on asymptotic consistency in the T dimension of the panel. An alternative estimation technique suggested in the panel data literature[22] is to first difference the model and use lags of R&D and production dated $t-2$ and before and lags of the tax component of the user cost of capital dated $t-1$ and before to instrument for the first differences of the explanatory variables. Although this procedure is asymptotically consistent its finite sample properties are sensitive to the predictive power of the instruments. When a time series is very persistent, as R&D is, lags will be poor predictors of future changes and the first difference estimator may suffer from large finite sample bias.[23]

Nevertheless, we did experiment with some first differenced specifications and found our point estimates to be in accordance with those reported in Table 1, but with far larger standard errors. Estimating a static version of our favoured intensity specification yielded an impact elasticity (standard error) of −0.364 (0.359). Estimating the preferred dynamic intensity specification (columns 4 and 5) yielded an impact elasticity (standard error) of −0.454 (0.389) and a long run elasticity (P-value) of −0.996 (0.338).

We also conduct a number of robustness tests. Before turning to those, however, we consider two issues — the potential endogeneity of government behaviour and the use of stock rather than flow data. Firstly, consider the problem that government behaviour may be endogenous. For example, if governments tended to introduce R&D tax credits when R&D was unexpectedly low this would cause us to *underestimate* the effectiveness of fiscal measures. It is difficult to deal with this adequately without a model of government behaviour, but a simple check is to drop the current tax component of the R&D user cost from the instrument set in column (4) and rely solely on the lagged tax component. As expected the elasticity does rise, but the change is very small and the estimates are less precise. The short run elasticity is −0.142 with a standard error of 0.077; and the long run elasticity is −0.982.

Replacing the flow of R&D by a measure of the 'R&D capital stock'[24] leads to a lower, but still significant, implied impact elasticity (−0.087 with a standard error of 0.024). The long-run elasticity is much larger, but this is because of the extremely high coefficient on the lagged dependent variable.[25] We prefer the flow estimates however because of the inherent difficulties with constructing an R&D capital stock with an unknown depreciation rate of knowledge.

How well does our model do at tracking observed R&D changes during large shocks to the tax-adjusted use cost? To address this question we look at the three largest proportional changes in the user cost of R&D and compare our prediction of the impact effect to the actual outcome and to a 'naive' forecast.[26] The three policy changes we look at are: (i) Australia introduced a super depreciation allowance in 1985 which reduced the after tax price of investing in R&D by 49%; (ii) Canada revised the nature of its R&D tax credit in 1983 leading to a 37% increase in the user cost; (iii) Spain introduced an R&D tax credit for the first time in 1990 leading to a 24% fall in the user cost.

The results are shown in Table 2. The first column shows the percentage change in the user cost. Compared to a 'naive' model (using only country dummies and time dummies to predict R&D intensity), knowledge of the tax-price elasticity provides important extra information. Our model over-predicts the change in R&D intensity in Australia, but with a lower forecast error than the naive model. For Canada the naive model predicts a small rise in R&D intensity whereas our model correctly picks up the large fall. We significantly underestimate the large rise in Spanish R&D following the introduction of the tax credit in 1990, but the naive model does markedly worse.

Table 2. Estimated vs. actual change in R&D intensity after three largest changes in R&D user cost[a]

	(1) Proportional change in user cost	(2) Proportional change in R&D intensity	(3)	(4)
		Model prediction	Naive prediction	Actual
Australia, 1985	−49.4	+12.0	+8.1	+10.8
Canada, 1983	+36.7	−9.6	+1.2	−12.1
Spain, 1990	−24.4	+5.2	+2.3	+19.8

Like much of the recent work on the impact of the user cost on investment and R&D the magnitude of our elasticities is larger than found in the early empirical literature[27] but compared to recent work using US micro data (e.g. Hall and Hines) our estimates of the price elasticity of R&D are somewhat lower. There are two potential reasons for these differences that we would like to highlight. Firstly, the differences may be due to the inherent problems of using aggregate data. We can only make crude controls for the differential tax positions of firms and the specific features of many of the credits (such as capping or special allowances for small firms). Secondly, it may be that the recent estimates on micro-economic data have been overestimating the impact of the tax credit either due to a failure to properly control for the endogeneity problems at the firm level (firms have some choice over their tax position) or due to the problem of companies relabelling what counts as R&D. Our R&D data comes from national surveys of R&D managers according to the OECD Frascati definition. These surveys are confidential and not available to the tax authorities, which should reduce incentives to relabel. Evidence on the incidence of relabeling is sparse, although government auditors in the US and Australia did not find widespread abuse (see Hall (1995)).

We can also compare our estimates to recent work on tax and fixed investment, although this is not straightforward due to specification differences (in particular, we have not calculated an R&D stock in our main results). We re-estimated our equations in a form comparable to Cummins et al. (1994) Table 9:

$$\frac{R_{it}}{G_{it-1}} = \omega \rho_{it} + f_i + t_t + u_{it} \qquad (4.1)$$

where the dependent variable is the ratio of the flow of R&D to its lagged stock (we use a 30% depreciation rate and data from as far back as 1973 to construct the R&D stock). In their comments on their Table 9, Cummins et al. (1994) report an estimate of the coefficient on the user cost of fixed capital (ρ_{it}) of −0.65 in 'tax reform' years. The coefficient (standard error) in our data is remarkably similar: −0.72 with a standard error of 0.18.[28] In fact, we believe our implied effects are larger than Cummins et al. (1994), since the overall mean of the coefficient on the user cost is much smaller if we include the years in their data when there were no major tax reforms We also attempt a comparison with Chirinko et al.'s (1999) analysis of fixed investment. Using the same specification as their Table 4 (all variables in first differences with current and two lags of user cost and output) we obtain a coefficient on the user cost of −0.389. This compares with −0.241 in their paper.

We have not considered changes in the prices of non-R&D factors of production, implicitly assuming that their influence was captured by GDP, the fixed effects and time dummies. The most worrying omission is the user cost of fixed capital. Therefore, we calculate a tax-adjusted user cost of fixed capital (κ_{it}) in an analogous way to the user cost of R&D.[29] The time series profile of these across countries reveals that there has been some degree of cross country harmonization of the tax treatment of physical capital, a finding which stands in contrast to the divergence in the tax treatment of R&D revealed in Table A.2 (see Chennells and Griffith (1997)). When we include the user cost of physical capital as an additional variable the coefficient is negative and significant at conventional levels. This suggests complementarity between R&D capital and physical capital. The coefficient on the R&D user cost is somewhat reduced compared to column (5) of Table 1 (long-run elasticity of −0.774 with *P*-value of 0.105).

The impact of government policy is parameterised in this paper in the form of fiscal incentives for business-funded–business-conducted R&D. Government-funded R&D could also have an impact on the level of R&D either through a crowding-in or a crowding-out effect. For example, many governments are reducing their direct support for business R&D at the same time as they are increasing fiscal incentives for R&D. If this direct support crowded out private R&D then it could be the withdrawal of government subsidies rather than R&D tax credits which are raising privately funded R&D.[30] We test this by directly including lagged government funded (business performed) R&D (normalised on output). We find that there is a positive and significant correlation between government R&D and private R&D.[31] After including government R&D the long-run elasticity is −0.745 with *P*-value of 0.051.

We also estimated models with more general dynamic models but found that this was the preferred dynamic representation of the data. For example, we included an extra lag of all four explanatory variables. The extra lagged variables were jointly and individually insignificant (*P*-value on joint *F*-test is 0.260).

4.2. Differences in the elasticity across countries, industries and time

The heterogeneity in the user cost coefficient across countries is of natural interest. Identifying a country-specific elasticity is very difficult as we only have a maximum of 19 time series observations per country. To tackle this problem we regress relative R&D intensity on the relative user cost, that is we measure R&D intensity and R&D user cost relative to their current world means. We run this regression for each country separately. Even though we have only a small number of observations, R&D is negatively related to its user cost in seven of the nine countries and significantly so in three of them.[32] Fig. 4 plots the two series for each country.

Another way of examining the sensitivity of our result to the exclusion of particular countries is to drop each country in turn and examine the change it makes to the estimated parameters. The price elasticity was significantly negative at (at least) the 10% level regardless of which country was dropped (in the specification shown in column 5 of

Table 1). The coefficients (standard errors) on ρ_t when each country was dropped in were: dropping Australia −0.174 (0.069); dropping Canada −0.115 (0.065); dropping France −0.149 (0.063); dropping Germany −0.139 (0.062); dropping Italy −0.142 (0.062); dropping Japan −0.143 (0.062); dropping Spain −0.155 (0.063); dropping UK −0.137 (0.061); dropping USA −0.150 (0.065).

We also experimented with alternative methods for constructing the R&D user cost to allow for heterogeneous effects of the tax system across firms in different countries. Our results are robust to plausible alterations in the construction of the user cost. For example, assuming that the representative French firm did not hit its R&D cap implies that the French regime was more generous in the 1980s than we have assumed. Re-estimating under this alternative assumption produces a quantitatively lower estimate of the price elasticity (but it is insignificantly different from the final column of Table 1). The short run elasticity is −0.118 (0.050) and the long-run is −0.831 (*P*-value=0.041).[33]

The R&D data can also be broken down by industry. We have not conducted our analysis at this level because the main tax variation is macroeconomic. Variation in the tax price would arise at the industry level due to different asset mixes (about which we do not have accurate information) and due to various industry-specific tax breaks. It is of interest however, to estimate our preferred model on data for each of the 20 manufacturing industries separately and examine how the elasticities vary. The estimated elasticities for the domestic user cost are contained in Table 3. As can be seen, 18 of the 20 tax price elasticities are negative and 12 of these are significant at conventional levels. Of the two industries that have perversely positive elasticities (Aerospace and Shipbuilding) neither are significant. Both of these industries are recipients of significant government subsidies, so it could be argued that R&D investment has not been determined by the usual market mechanisms.

Table 3. Industry level regressions[a]

Industry	ISIC code	Domestic tax elasticity (S.E.)
Aerospace	3845	0.710 (0.389)
Basic metal industries	3700	−0.788 (0.216)
Chemical products	3500	−0.509 (0.126)
Drugs and medicines	3522	−1.275 (0.306)
Fabricated metal products	3800	−0.679 (0.133)
Food, beverages and tobacco	3100	0.213 (0.160)
Iron and steel	3710	−0.799 (0.267)
Metal products	3810	−0.852 (0.213)
Motor vehicles	3843	−0.455 (0.168)
Non-electrical machinery	3820	−0.831 (0.216)
Non-ferrous metals	3720	−1.022 (0.249)
Non-metallic mineral products	3600	−0.335 (0.188)
Other manufacturing	3900	−1.815 (0.430)
Paper, paper products and printing	3400	−0.550 (0.320)
Instruments	3850	−1.479 (0.251)
Radio, TV and communication equipment	3832	−0.214 (0.255)
Rubber products	3550	−0.873 (0.235)
Shipbuilding and repairing	3841	0.066 (0.655)
Textiles, apparel and leather	3200	−0.946 (0.332)
Wood products and furniture	3300	−1.071 (0.489)
Economy wide		−0.516 (0.111)

We also conducted some experiments to see whether the coefficient on the domestic user cost varied significantly over time. There was a suggestion that the tax price elasticity had decreased, but this change was never significant at conventional levels.[34]

5. Conclusions

Tax incentives seem a natural policy tool for a market-oriented government wanting to increase R&D expenditures. Firms decide where and how to spend their R&D rather than having it determined through a bureaucratic central authority. Economists, however, have traditionally been skeptical over the efficacy of fiscal provisions, partially for the reason that the absolute tax price elasticity of R&D was believed to be low. In this paper we have examined the sensitivity of R&D to changes in its user cost in nine countries over the period 1979–1997. Variation in fiscal incentives across countries and over time serve as quasi-experiments helping to identify the elasticity of R&D with respect to changes in the user cost.

Our primary conclusion is that fiscal provisions matter. There is considerable variation in the user cost of R&D within and across countries induced by the very different tax systems that have operated over our sample period. The econometric analysis suggests that tax changes significantly effect the level of R&D even after controlling for demand, country-specific fixed effects and world macro-economic shocks. The impact elasticity is not large (just over −0.1), but over the long-run may be more substantial (about unity in absolute magnitude).

Should one conclude then that R&D tax credits are desirable? Although the analysis counters the objection that they are ineffective it does not imply that they are necessarily desirable. Several other elements would have to enter a cost–benefit analysis in addition to the elasticity of R&D. Firstly, there are the administrative costs of monitoring the credit system. Secondly, there are many potentially perverse incentives induced by the design of different credit systems which could cause distortions to economic activity. Thirdly, it is not obvious in a world of international spillovers that a country would not be better off free-riding on the R&D efforts of other countries rather than attempting to subsidize innovation itself.

As a final point, the existence of R&D tax rivalry has the implication that governments may be strategically choosing their R&D policies. Competition between governments for the location of R&D could be very costly. We have taken government behaviour as exogenous in the paper, but tax competition implies that government policy and particularly the existence of R&D tax credits should be endogenised. This is one of our avenues of future research.

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Appendix A. Tax treatment of R&D

The data on the main features and parameters of the tax systems is briefly summarised here and is detailed in Bloom et al. (1997) and Chennells and Griffith (1997). Table A.1 shows the user cost of R&D for every country and every year in our sample. This is ρ_{it} and is calculated as described by Eq. (2.10).

Table A.1. User cost of R&D, ρ_{it}

	Aus	Can	Fra	Ger	Ita	Jap	Spa	UK	USA
1979	0.299	0.203	0.305	0.326	0.288	0.308	0.276	0.259	0.303
1980	0.290	0.191	0.286	0.309	0.237	0.285	0.283	0.259	0.289
1981	0.324	0.189	0.311	0.322	0.293	0.309	0.291	0.313	0.289
1982	0.325	0.193	0.323	0.320	0.308	0.326	0.293	0.319	0.295
1983	0.324	0.264	0.323	0.330	0.312	0.329	0.319	0.341	0.291
1984	0.347	0.291	0.333	0.336	0.314	0.320	0.323	0.340	0.305
1985	0.176	0.280	0.339	0.332	0.326	0.316	0.340	0.335	0.293
1986	0.164	0.267	0.342	0.350	0.331	0.321	0.298	0.340	0.293
1987	0.169	0.269	0.350	0.339	0.333	0.323	0.348	0.332	0.284
1988	0.226	0.195	0.346	0.333	0.331	0.324	0.345	0.326	0.291
1989	0.237	0.191	0.337	0.321	0.342	0.307	0.350	0.322	0.298
1990	0.240	0.198	0.354	0.344	0.352	0.316	0.265	0.342	0.241
1991	0.240	0.194	0.342	0.329	0.341	0.312	0.251	0.305	0.233
1992	0.242	0.211	0.345	0.314	0.362	0.305	0.245	0.323	0.225
1993	0.250	0.210	0.327	0.306	0.343	0.303	0.240	0.319	0.228
1994	0.269	0.221	0.336	0.322	0.339	0.316	0.242	0.337	0.239
1995	0.269	0.221	0.336	0.322	0.339	0.316	0.199	0.337	0.239
1996	0.310	0.221	0.336	0.322	0.339	0.316	0.199	0.337	0.239
1997	0.310	0.221	0.336	0.322	0.339	0.316	0.199	0.337	0.239

Table A.2 shows the tax component of the user cost of R&D. This is calculated as described in Eq. (2.10) but holding the interest and inflation rate constant at 10% and 3.5%, respectively. This is the variable that is used as an instrument for ρ_{it}.

Table A.2. Tax component of the user cost of R&D, ρ_{it}^{τ}

	Aus	Can	Fra	Ger	Ita	Jap	Spa	UK	USA
1979	0.380	0.238	0.385	0.391	0.383	0.366	0.382	0.380	0.379
1980	0.380	0.233	0.385	0.391	0.383	0.366	0.382	0.380	0.379
1981	0.380	0.233	0.384	0.391	0.383	0.366	0.382	0.380	0.337
1982	0.380	0.233	0.384	0.391	0.383	0.366	0.382	0.379	0.337
1983	0.380	0.303	0.381	0.386	0.383	0.366	0.382	0.379	0.337
1984	0.380	0.303	0.381	0.386	0.384	0.366	0.382	0.380	0.337
1985	0.193	0.303	0.381	0.385	0.384	0.366	0.382	0.381	0.337
1986	0.193	0.303	0.381	0.385	0.384	0.366	0.382	0.382	0.345
1987	0.197	0.307	0.384	0.385	0.384	0.366	0.382	0.383	0.351
1988	0.263	0.206	0.383	0.385	0.384	0.366	0.382	0.383	0.351
1989	0.263	0.209	0.383	0.385	0.384	0.366	0.382	0.383	0.356
1990	0.263	0.212	0.382	0.386	0.385	0.366	0.283	0.383	0.303
1991	0.263	0.214	0.382	0.386	0.384	0.366	0.281	0.382	0.303
1992	0.263	0.211	0.382	0.386	0.384	0.366	0.283	0.382	0.303
1993	0.289	0.217	0.382	0.386	0.385	0.366	0.283	0.382	0.303
1994	0.289	0.219	0.382	0.385	0.386	0.366	0.283	0.382	0.303
1995	0.289	0.219	0.382	0.386	0.386	0.366	0.222	0.382	0.303
1996	0.333	0.219	0.382	0.386	0.386	0.366	0.222	0.382	0.303
1997	0.333	0.219	0.382	0.385	0.386	0.366	0.222	0.382	0.303

The follow sub-sections describe the key features of the tax system in each country that affect the user cost. See Chennells and Griffith (1997) for more details about the general tax system in each country.

A.1. Australia

A special depreciation allowance of 150% for R&D expenditure was introduced in 1985. Current expenditure can be written off in the first year, plant and machinery over 3 years and buildings over 40 years. The statutory tax rate on retained earnings in Australia was 50% up until 1988 when it was reduced to 39%. It was further reduced to 33% in 1993. This reduction in the statutory tax rate reduced the value of the allowance for R&D.

A.2. Canada

Expenditure on current costs and plant and machinery for R&D can be fully deducted in the first year throughout the period considered here and on buildings from 1979 until 1987.

From 1979 to 1982 there were two types of tax credit for R&D, one absolute and the other incremental. The absolute credit was 10% of total R&D expenditure. The incremental credit was 50% on expenditure above the average of the previous 3 years. In 1983 these two credits were replaced by the Investment Tax Credit (ITC). This is 20% of total R&D expenditure, but it fully reduces the cost of the asset for deduction purposes, which reduces the effective rate to around 11%.[35]

We have modelled the provincial credits available in Ontario as they are one of the most generous and Ontario is one of the larger industrial regions. In 1988 Ontario introduced a 25% super-allowance on all expenditure that qualifies for the national credit, minus the amount given for the national credit. This has the impact of nullifying the reduction in the 100% write off due to the reduction of the deductible costs by the value of the credit. In addition, Ontario gives a 35.7% credit on incremental expenditure. Incremental expenditure is defined as additional spending about the average of the past 3 years expenditure.

The calculation of the Canadian statutory tax rate on retained earnings for manufacturing firms is shown below

	1979	1980–1982	1983	1984	1985–1986	1987
Basic rate	46.00	46.00	46.00	46.00	46.00	45.00
less provincial abatement	10.00	10.00	10.00	10.00	10.00	10.00
	36.00	36.00	36.00	36.00	36.00	35.00
[Federal surtax in %]	[0]	[5]	[2.5]	[0]	[5]	[3]
Federal surtax @ x%	0.00	1.80	0.90	0.00	1.80	1.05
less manuf. deduction	6.00	6.00	6.00	6.00	6.00	7.00
Federal rate	30.00	31.80	30.90	30.00	31.80	29.05
plus local taxes	13.00	13.00	13.33	13.33	13.33	13.33
Statutory tax rate	43.00	44.80	44.23	43.33	45.13	42.38
	1988	1989	1990	1991	1992	1993
Basic rate	38.00	38.00	38.00	38.00	38.00	38.00
less provincial abatement	10.00	10.00	10.00	10.00	10.00	10.00
	28.00	28.00	28.00	28.00	28.00	28.00
Federal surtax @ 3%	0.84	0.84	0.84	0.84	0.84	0.84
less manuf. deduction	2.00	3.00	4.00	5.00	5.00	6.00
Federal rate	26.84	25.84	24.84	23.84	23.84	22.84
plus local taxes	12.60	12.60	12.60	12.60	13.90	12.50
Statutory tax rate	39.44	38.44	37.44	36.44	37.74	35.34
	1994	1995	1996	1997		
Basic rate	38.00	38.00	38.00	38.00		
less provincial abatement	10.00	10.00	10.00	10.00		
	28.00	28.00	28.00	28.00		
Federal surtax @ 3%	0.84	0.84	0.84	0.84		
less manuf. deduction	7.00	7.00	7.00	7.00		
Federal rate	21.84	21.84	21.84	21.84		
plus local taxes	12.50	12.50	12.50	12.50		
Statutory tax rate	34.34	34.34	34.34	34.34		

A.3. France

France had a variety of tax credit schemes over the 1980s. These all had upper caps on the total amount of credit which could be claimed by any one firm, with this cap being between FF3 and FF40 million over the period. Because of the high concentration of R&D in large firms we assume that our representative firm is large enough to claim this credit in full, so that the effective credit rate is zero. However, we also present estimates under the alternative assumption that our representative firm lies below this cap. These tax credit schemes are described here.

In 1983 a 25% tax credit was introduced on the real increase in qualifying R&D expenditure over the past year, with a FF3 million per year cap. The credit rate was increased to 50% in 1985 and the cap raised to FF5 million. In 1988 firms were given the choice between a 50% credit on the increase over the previous year's expenditure, with a maximum of F5 million (increased to F10 million in certain cases). Alternatively, for the years 1988, 1989, and 1990 they could get a 30% credit on the increase over their 1987 expenditure, with a maximum of F3 million. This latter option is more valuable to firms expecting to increase their R&D spending and is what we model. Although the headline rate of credit fell (from 50 to 30%) the value of the subsidy to R&D increased because the base used to calculate the increase in R&D expenditure was fixed at the 1987 level eliminating the impact of current R&D spending on the calculation of the future base. In 1991 the credit returned to 50% on the increase in real expenditure, but the base was extended to the most recent 2 years and the cap raised to FF40 million. This reduced the value of the subsidy since the base was changed back from a fixed base to a moving average. In addition to these tax credits, from 1983 to 1986 expenditure on buildings used for scientific research was given an accelerated depreciation allowance of 50% on a straight line basis.

The statutory tax rate on retained earnings in France was: 50% from 1979 to 1986, 45% from 1986 to 1987, 42% in 1988, 39% in 1989, 37% in 1990, 34% from 1991 to 1992 and 33.3% from 1993 to 1997.

A.4. Germany

No special tax depreciation provisions or credits are given on R&D expenditure. The statutory tax rate in Germany is 61.8% from 1979 to 1989, 56.6% in 1990, 58.2% from 1991 to 1992, 56.6% in 1993, 52.2% in 1994, 55.2% from 1995 to 1996 and 54.7% in 1997. These include a local municipal trade tax which varies from 9 to 20% (we assume 13.1% throughout based on OECD (1991)). This municipal tax is deductible as an expense from the central corporate tax base. For 1991 and 1992 it also includes a 'Solidarity' Surcharge of 3.75%. For 1995 and 1996 there was a surcharge of 7.5% on corporation tax, falling to 6.5% in 1997.

A.5. Italy

No special tax depreciation provisions or credits are given on R&D expenditure. The statutory tax rate in Italy is 36.3% from 1979 to 1981 (the National tax rate (IRPEG) is 25%, local tax rate (ILOR) 15% which is fully deductible, hence the statutory rate is $(1-0.15)\times0.25+0.15=0.363$). In 1982 a surcharge of 8% is applied to IRPEG and ILOR giving a statutory rate of 38.8%. In 1983 the IRPEG increase to 30% giving a statutory rate of 41.3%. From 1984 to 1990 the IRPEG is 36% giving a statutory rate of 46.4%. From 1991 to 1992 the ILOR becomes only 75% deductible so statutory rate increases to

47.8%. From 1993 to 1997 the ILOR is not deductible, so the statutory tax rate is 52.2%. In 1994 there is an additional 1% tax.

A.6. Japan

Japanese firms can claim a 20% credit on R&D spending exceeding the largest previous annual R&D expenditure. The credit is limited to 10% of tax due before the credit. Buildings and plant and machinery used for R&D activity are also eligible for accelerated depreciation allowances. Several additional special credits are also available, although we do not model them here.[36]

	1979 –1982	1983 –1985	1986	1987 –1989	1990	1991 –1994	1995 –1997
Basic rate	40.00	42.00	43.33	42.00	40.00	37.50	37.50
Enterprise tax	12.00	12.00	12.00	12.00	12.00	12.00	12.00
Inhabitants tax	6.92	7.27	7.50	7.27	6.92	6.49	6.49
	58.92	61.27	62.83	61.27	58.92	55.99	55.99
Less deductibility of Enterprise tax	−6.31	−6.56	−6.73	−6.56	−6.31	−6.00	−6.00
	52.61	54.71	56.10	54.71	52.61	49.99	49.99
Surcharge						0.94	
Statutory tax rate	52.61	54.71	56.10	54.71	52.61	50.93	49.99

Inhabitants tax is 17.3% of national tax; surcharge is 2.5%

A.7. Spain

Up to and including 1989, Spain applied the same rules for R&D as for any new assets. These included investment tax credits for all new fixed assets at 10% (1983, 1988–1989), 12% (1984), 15% (1985–1987).

From 1990 the following rules apply for investment tax credits in R&D: 15% on intangibles, 30% on new fixed assets. In 1995 depreciation rates were increased to 10% straight line for buildings and 100% for plant and machinery and current expenditure on R&D. A tax credit of 20% of the level and further 40% incremental over 2-year previous base was also given.

The statutory tax rate on retained earnings in Spain was 55% from 1979 to 1983 and 35% thereafter.

A.8. UK

Capital expenditure on equipment used for 'scientific research' in the UK qualifies for a 100% first year allowance under the Scientific Research Allowance (SRA). It is not entirely clear how scientific research has been defined and until recently companies have claimed that most capital expenditure for R&D purposes did not qualify for this allowance. We have therefore not modelled this as universally available. These is, however, some suggestion that this situation has changed in recent years.

The statutory tax rate on retained earnings in the UK is 52% from 1979 to 1982, 50% in 1983, 45% in 1984, 40% in 1985, 35% from 1986 to 1989, 34% in 1990, 33% from 1991 to 1996 and 31% in 1997.

A.9. USA

Since 1954 all R&D expenditure has been fully deductible. The Economic Recovery Tax Act of 1981 introduced a tax credit on incremental R&D expenditure which has remained in place, although there have been many subsequent changes to its design, and the credit has never been made a permanent feature of the tax system. The rules governing the operation of the US tax credit are complex and are only sketched out here. A detailed explanation can be found in Hines (1994) and Hall (1995). In particular, we do not consider the foreign allocation rules as we consider only purely domestic firms. The statutory rate of the credit was 25% between 1981 and 1985 and has been 20% since then. From 1981 until 1990 incremental expenditure was defined as spending above the average of the last 3 years expenditure. In 1990 the definition of the base changed to the 3-year average ratio of R&D over sales (with a maximum of 16%) times sales. In addition, the rules governing the deductibility of the credit have changed. Up until 1988 the credit was not deducted from taxable income. In 1989 it was 50% deductible, and from 1990 onwards 100% deductible.

The national tax rate on retained earnings in the USA was 46% from 1979 to 1986, 34% from 1987 to 1992 and 35% from 1993 to 1997. There are also State taxes which vary from State to State and across time. We have used an average value from 1991 of 6.6% and treated this as deductible. Thus the statutory tax rate used is 49.6% from 1979 to 1986, 38.4% from 1987 to 1992 and 39.3% from 1993 to 1997.

Appendix B. Economic variables

The economic variables are drawn from a variety of sources. The ANBERD dataset contains business enterprise R&D (BERD) at the industry level (OECD, 1999a). These correspond to the Frascati definition and are drawn from surveys by member states. Output is taken from the STAN dataset also produced by the OECD (1999c) which can be matched into the ANBERD data. The separation of R&D by source of finance is achieved by using the figures from Main Science and Technology Indicators (OECD, 1999b). Output and other non-R&D variables are deflated using the GDP deflators. R&D expenditure is deflated by a weighted average composed of 50% wages and 50% GDP deflator. See Bloom et al. (1999) for more details.

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[1] See, for example, Mansfield (1986). Other sources of skepticism, such as relabelling other expenses as 'R&D', are discussed in Griffith et al. (1995). See also Gravelle (1999) for a discussion of the current policy debate in the US.

[2] There are few econometric studies outside the US. Recent exceptions include Dagenais et al. (1997) and Bernstein and Bernstein for Canada; Asmussen and Berriot (1993) for France and Australian Bureau of Industry Economics (1993) for Australia. These studies also tend to find larger elasticities. For a survey see Hall and Van Reenen (1999).

[3] See [2] and Bloom et al. (1997) which describes the different R&D tax incentives in eight OECD countries over time (1979–1994).

[4] This approach has been extended in numerous ways in, inter alia, King; Auerbach; Keen; OECD and Devereux and Devereux and Griffith (1998).

[5] There is a growing body of evidence to suggest that capital markets are imperfectly integrated, see Bovenberg and Gordon (1996).

[6] In practice depreciation allowances can be much more complicated than described here. The method and rate can change over the life of the asset, they can begin in the second period or half way through the first period. These are taken account of in the empirical application. See Appendix A and Appendix B and Chennells and Griffith (1997) for details.

[7] The impact of incremental credits has been well documented in numerous articles, among them, Eisner and Hall and Hines (1994). The value of the credit here is calculated under the assumptions that the firm correctly anticipates future R&D growth and is not tax exhausted.

[8] The interest rate used is the long-term interest rate on government bonds and the inflation rate is the GDP deflator.

[9] We also used various other sources including KPMG guides and the International Bureau of Fiscal Documentation (IBFD) reports. We are grateful to Lucy Chennells and Sergio Ramos (the librarian at Price Waterhouse) who both contributed greatly to the collection of this data.

[10] We also calculated the tax credit for a smaller representative firm which is a marginal claimant in the French example. Under these specifications the French tax credit has a relatively generous marginal rate. The results for our specifications are not strongly affected.

[11] See, for example, Granstrand and Serapio and Patel and Vega (1999).

[12] An exception to this is Japan which gives a special tax credit on government funded R&D. We do not model this credit here.

[13] Even in Canada, the country with the smallest manufacturing sector share of GDP, which also has some of the most rigorous measurement of service sector R&D (Young, 1996), the manufacturing sector's share of total business-conducted R&D was still over 60% in 1995.

[14] We have 19 years of data (1979–1997) for the UK, Italy and Canada and 18 years for the other countries (1979–1996).

[15] We regress each variable separately on a full set of time and country dummies and then calculate the residuals.

[16] Since in steady state $\Delta G=0$, then $R=\delta^r G$ where δ is the R&D stock depreciation rate. If this is constant then $\alpha=-\ln\delta$ in (3.1). Otherwise we can include fixed effects and time dummies, as we do in (3.2) and our empirical application, to allow for differences in country-specific knowledge depreciation rates.

[17] Technically the coefficient γ is the elasticity of substitution between R&D and other factors. Note, however, that the total elasticity of R&D with respect to its user cost ($\eta_{G\rho}$) is $-(1-s)\sigma-s\eta$ where s is the share of R&D capital in total costs and η is the elasticity of product demand. Since the share of R&D in total costs is very small (about 2%) it is likely that γ will be approximately equal to $\eta_{G\rho}$.

[18] For notational simplicity we refer to the symbols ρ^d and $\rho^{d\tau}$ as ρ and ρ^τ in the empirical section.

[19] In Table 1 the Wald test statistic is

$$\frac{\hat{E}'Z[Z'Z]^{-1}Z'\hat{E}}{\hat{E}'\hat{E}/\mathrm{df}} \tag{3.4}$$

where Z is a dimension $NT\times m$ matrix of instruments, $\hat{E}$ is the NT vector of fitted residuals, m is the number of instruments, $\mathrm{df}=m-k$ is the degrees of freedom and k is the number of explanatory variables ($k<m$). Under the H_0 that our instruments are valid and the time dimension of our panel is sufficiently long to ignore the Nickell bias this is asymptotically distributed $\chi^2(m-k)$.

[20] Dropping the year dummies from column (3) leads to a higher estimate of the long run elasticity −1.142 with a P-value of 0.019. Part of this correlation is due to the global trend towards higher R&D intensities and more generous tax treatments of R&D. This is stripped out by the year effects.

[21] These were: −3.467, 4.337, −2.812, −4.967, −4.846, −3.383, −4.354, −4.259, −3.448 for Australia, Canada, France, Germany, Italy, Japan, Spain, the UK and the USA, respectively, where these all have 1%, 5% and 10% significance levels of −3.75, −3.00 and −2.63, respectively. The joint panel Dickey–Fuller test statistic was −12.10 with a 1%, 5% and 10% significance level of −3.069, −2.886 and −2.576.

[22] See, inter alia, Anderson and Hsiao (1982) and Arellano and Bond (1991).

[23] See Hall and Lach and Blundell and Bond (1998) for an extensive discussion of this problem. The autoregressive coefficient on R&D in our data (estimated either by OLS or within groups and including a full set of time dummies) is 0.99.

[24] This is calculated using the perpetual inventory method and assuming a depreciation rate of 30% and a pre-sample growth rate of 5%. We use data from 1973 so we have 8 years pre-sample.

[25] The coefficient on the lag is 0.97, implying a long run elasticity of 3.42.

[26] We use the model of column (5) in Table 1, so the estimates include the time dummy effects. The longer-run effects will depend on the evolution of the tax system and other factors, so we focus here on the impact effects.

[27] For recent surveys see Hall and Van Reenen (1999) on R&D or Hassett and Hubbard (1997) and Chirinko et al. (1999) for fixed investment.

[28] If we include a lagged dependent variable the estimated long-run effect is −1.124, quite similar to the estimated elasticity in Table 1.

[29] These are described and discussed in Chennells and Griffith (1997). As with R&D we use the tax component as the instrument for the user cost of physical capital.

[30] See David et al. (1999) for a survey.

[31] The coefficient (standard error) on government R&D was 0.060 (0.021). This is consistent with the findings of Guellec and von Pottelsberghe de la Potterie (1998) who use similar data on a shorter time period.

[32] The coefficient (standard errors) on the country-specific regressions were as follows: Australia −0.542 (0.317), Canada −0.040 (0.205), France −0.123 (0.227), Germany −1.361 (0.226), Italy −0.708 (0.485), Japan 0.347 (0.200), Spain −0.597 (0.216), UK −2.647 (0.503), USA 0.099 (0.496).

[33] See Bloom et al. (1999) for many more examples.

[34] For example, allowing an interactive effect of the user cost with a dummy variable equal to unity after 1987, gave a coefficient of 0.121 with a standard error of 0.076 in column (5) of Table 1.

[35] The statutory tax rate on retained earnings (including local taxes) was 44.2% in 1983, this makes the effective tax credit rate, $(1-0.442)\times 0.20=0.112$.

[36] These include a 6% credit for small and medium sized firms, a 7% credit for investment to promote basic technology and a 6% credit on R&D carried out in cooperation with government