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The Effects of Public Subsidies on R&D Employment: Evidence from OECD Countries

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Abstract

Existing empirical evidence suggests that public subsidies and fiscal incentives have a positive effect on the amount of private R&D expenditure. However, most studies have failed to address the possibility at least some of this increase may simply reflect the fact that R&D workers are being paid higher wages. Such an omission may imply that past research has over-estimated the effectiveness of R&D tax concessions. In the absence of widely-available R&D deflators, we consider the impact of a range of public subsidies on the number of full-time equivalent workers employed in R&D (i.e., researchers) in the business sector. Our findings strongly support the effectiveness of both direct subsidies and fiscal incentives.

JEL-Classification: O38, H25

Keywords: innovation policy, R&D tax credits, R&D investment

1. Introduction

In this paper, we examine whether subsidies and tax incentives increase R&D employment, using cross-country data on a panel of OECD countries between 1980 and 2005. A considerable body of empirical evidence suggests that public subsidies and R&D tax incentives have had a positive effect on the amount of private R&D expenditure (see Hall and van Reenen, 2000; Guellec and van Pottelsberghe, 2003; and Bloom et al., 2002). However, if the supply of R&D inputs – particularly highly skilled researchers – is inelastic, government support and fiscal incentives may serve to inflate their cost, rather than drive increases in real R&D effort. Studies that do not account for wage inflation potentially over-estimate the effectiveness of R&D tax concessions, possibly by as much as 50 per cent (Goolsbee, 1998). Recent evidence suggests that at least some of the observed increase in R&D expenditure is a result of higher wages (see Aerts, 2008; Lokshin and Mohnen, 2008; and Wolff and Reinthaler, 2008). These findings cast some doubt over the efficacy of public support for R&D[1] and remind us that our focus should be on the effects of policy interventions on *real R&D effort*, not R&D expenditure per se.

Firm-level studies of public support for R&D face multiple challenges. In order to evaluate the efficacy of tax incentives, for example, studies must account for the fact that R&D investment and its after-tax cost are usually jointly determined (Hall, 1995), which is typically done via instrumental variables which reduce the accuracy of estimates (e.g. Hall, 1992). To evaluate the effectiveness of government grants it is necessary to overcome selection issues, which are typically addressed via the application of a Heckman-type selection model (for example Aerts, 2008). Such studies generally suggest that firm R&D expenditure reacts positively to

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[1] Any conclusions in this regard are complicated by the fact that an increase in R&D wages could reflect the employment of higher quality R&D workers. In this light, an observed increase in R&D wages may be associated with an increase in real R&D effort. Like all other existing studies, we do not observe the skills of individual R&D workers, so we cannot address this possibility.

government support. Unfortunately however, it is not possible to disentangle the wage effect from the employment effect of R&D subsidies using firm-level data, since economy wide wage inflation may occur in the absence of any difference in the wages paid by subsidized and non-subsidised firms.

Studies using cross-country data, as we do in our paper, avoid many of these complex methodological problems. One of the main contributions of our approach is that we consider a comprehensive suite of different public R&D subsidies – including tax incentives, subsidies and direct government grants – which enables us to control for the substitutability of different R&D subsidies. For example, governments may choose to introduce more generous tax incentives while at the same time reducing direct government grants. Some recent studies (e.g. Wolff and Reinthaler, 2008) do not include tax incentives in their analysis of R&D subsidies and are therefore unable to account for the substitutability of different R&D support programs. Since we include all public subsidies for R&D, we can be certain that our analysis captures the net aggregate effect of all policy interventions.

To model country-specific fiscal incentive schemes, we compile separate indicators of the tax component of the user cost of both R&D labour and equipment. In this way, we hope to isolate the effect of subsidies on real R&D effort. Our results should also provide important information for the design of public support for R&D. Notwithstanding this, it is important to note that like all other studies we cannot account for changes in the quality of R&D employment. We should also concede the possibility that firms may relabel some existing activities to maximize their benefit from tax schemes (as noted, for example, by Hall, 1995), though this may be less likely in the case of the number of researchers employed than the dollar value of expenses.

This paper is organized as follows. The next section provides some background, while Section 3 outlines our approach and develops the methodology employed in this study. Section 4 introduces the model and data. Estimations and results are presented in Section 5 and Section 6 concludes.

2. Background

Most governments employ a range of different policy instruments – including government grants, subsidies, and fiscal incentives – to stimulate private R&D investment.[2] In this section, we provide a critical review of the major difficulties associated with identification of the effect of R&D policies on real R&D effort and how we address them in this paper.

An important branch of research on the effects of R&D subsidies has been undertaken at the firm level in countries such as the United States, Finland, Canada and the Netherlands. These studies have typically found that R&D tax incentives have a statistically significant, positive effect on business R&D expenditure (see Eisner et al., 1984; Hall, 1992; Hall and van Reenen, 2000; and Czarnitzki et al., 2004). Until fairly recently, this literature had failed to address the wage-inflation effect. Lokshin and Mohnen (2008), however, find evidence of a wage-inflation effect in their microeconometric study of fiscal incentives in the Netherlands, while Aerts (2008) finds a similar effect occurring as a result of R&D subsidies in Flanders.

One problem with firm-level studies is that they capture localized firm-specific effects which are not necessarily reflective of the aggregate, economy-wide, effects. To illustrate this possibility, consider a neoclassical market where firms recruit from a single (homogeneous) pool of R&D workers. In this case, a subsidy paid selectively to a sub-sample of firms will (a) raise the wage of *all* R&D workers (b) increase the share of workers employed by subsidised firms (c) decrease the share of workers employed in the non-subsidised firms. The effect of the subsidy on total R&D employment then depends on the elasticity of labour supply which,

[2] In principle, government support for R&D aims to address the potential market failure arising because of the public good nature of technology. Therefore the ideal metric for evaluating the welfare effect of government support for R&D would compare the value of spillovers generated by the additional R&D induced by the subsidy with the dead weight loss associated through raising tax revenue elsewhere. In this paper, we abstract from this more general question and focus on the effect of subsidies and fiscal incentives on real R&D effort, which we consider a necessary but not sufficient condition for policy desireability.

in turn, is likely to vary between the short and the long run. Although this stylised neoclassical market is unlikely to accurately reflect the realities of the R&D labour market, the illustration highlights the fact that an increase in employment at the firm level does not necessarily reflect an increase at the market level.

Studies using cross-country data avoid many of the difficulties faced by firm-level analysis. A number of previous cross-country studies have focused on the impact of various policy mechanisms on R&D expenditure.[3] Estimates of the short-run impact of tax incentives based on cross-country data generally imply a short run elasticity of tax price of somewhere between 15 and 30 per cent, and a long run elasticity of between 33 per cent and unity (Bloom et al., 2002; Guellec and van Pottelsberghe, 2003). However, if the supply of R&D inputs is inelastic, government support and fiscal incentives may serve to inflate their cost, rather than drive increases in real R&D effort. Existing studies that have examined the effectiveness of tax policy on R&D expenditure using cross-country data have not tackled this issue and may therefore have over estimated the true effect.

In their macro study of direct government support to private sector R&D, Wolff and Reinthaler (2008) find that R&D expenditure increases by roughly 20 per cent more than R&D employment in a panel of 17 OECD countries. They interpret this as evidence of wage inflation. An alternative possibility, which should be considered, is that it reflects a shift in the composition of expenditure (from labour to equipment). Further, they focus on the effects of R&D grants and procurement, and do not take into account fiscal subsidies (R&D tax incentives). Failure to include this in their estimation may well introduce omitted-variable bias. Since it is highly likely that alternate mechanisms of support for private sector R&D (tax incentives, grants, procurement etc) are policy substitutes, Wolff and Reinthaler's (2008) failure to include R&D tax incentives means they may have overlooked an important component of the puzzle..

[3] Existing efforts to examine the efficacy of fiscal incentives have employed R&D expenditure series discounted using a GDP deflator (Guellec and van Pottelsberghe, 2003) or a weighted mix of GDP deflator and general wages (Bloom et al., 2002).

3. Methodology and theoretical framework

One of the persistent problems in understanding the determinants of innovative activity relates to determining appropriate deflators for R&D expenditure, as highlighted for example by Griliches (1979). In the absence of R&D-specific price deflators,[4] the OECD (2002a) (Frascati) recommend using PPP and GDP deflators for international comparisons, but they acknowledge that one limitation of this is that PPP "…reflect the opportunity cost of the resources devoted to R&D rather than the 'real' amounts involved" (p. 22). In particular, the goods on which PPP is calculated are not likely to be representative of the mix of R&D inputs. Similarly the application of a general price deflator will not reflect inter-industry differences, so measures are inaccurate if research is relatively more expensive (than other goods/sectors) in one country than another. Recent estimates using R&D-specific inter-spatial and inter-temporal deflators are significantly different to those based on GDP PPPs, suggesting that market rates give a more accurate picture of real R&D effort (Dougherty et al., 2007).

Given that about half of total R&D expenditure is the wage bill, developing price deflators for labor costs is an important task for researchers comparing R&D investment activity across countries (OECD, 2002a). However, in the absence of widely available R&D deflators covering the countries and years required, we adopt a lateral approach: rather than considering R&D expenditure, we consider the impact of public subsidies on the number of full-time equivalent workers employed in R&D in the business sector. In adopting the approach, we bypass the issue of finding an appropriate deflator and exchange rate. This means that our

[4] Some industry-specific R&D price deflators do exist – for example, Messinis (2004) estimates a pharmaceutical industry R&D price deflator for fifteen OECD countries.

independent variable is a natural real measure, which is robust to variation in price.[5]

To motivate our approach and estimating equation we begin by outlining a simple model in which demand for researchers is derived from demand for technology stock, which in turn is derived from demand for final goods. Tax incentives on researcher wages effectively reduce the cost of R&D labour. Similar incentives are often provided for scientific and research equipment, a complementary input to the production of technology. Since tax treatment of equipment and labour is often correlated, it is necessary to consider the interaction between changes in the tax price of (and investment in) researchers employed, and that of complementary scientific and research equipment. Furthermore, by considering the effect of tax incentives directed at research equipment separately to those directed at R&D labour we are able to make some tentative steps in assessing the degree of substitutability between these inputs to the R&D process at the aggregate level. A better understanding of which is an important input to effective R&D tax policy design.

Our model consists of a vertically integrated firm which produces both final goods and technology, via R&D. The firm's objective function represents the discounted stream of profit. Final goods are produced using technology stock (denoted as G), according to a function $f(G,.)$.[6] For illustrative purposes, we normalize the price of final goods, and assume profits are taxed at rate τ. Technology stock is assumed to depreciate, or become obsolete, at rate δ and is subject to the accumulation restriction given by:

$$\dot{G} = R(\quad) - \delta G \qquad (1)$$

[5] One important caveat of our approach is that it does not reflect changes in human capital or researcher quality. However, issues of researcher quality are not treated any more satisfactorily in existing work on R&D price deflators. For instance, in their price series, Dougherty et al. (2007) include 50 per cent average researcher wage, implicitly assuming R&D differences in wages relate strictly to cost rather than quality.

[6] We omit analysis of variable inputs in the production of final goods, though these do not change the fundamental results of interest.

R&D (i.e., technology stock) is produced using two inputs. These are labour (denoted as L) and research equipment (denoted as E). To keep the model tractable, we consider the case where research equipment is only useful for one period.[7] Technology (research output) is then produced via a research function given by $R = R(L, E)$.

Our main concern in specifying R( ) is to allow for two complementary inputs to the R&D process. However, incorporating investment output as a non-linear function of inputs also allows us to incorporate convex adjustment costs into the model as suggested by Uzawa (1969), who incorporates convex adjustment cost via a concave investment production function in the accumulation restriction (in his case including only one input).[8] In the case of R&D, convex adjustment costs have been interpreted as a 'progress constraint' whereby only a fraction of the R&D invested results in useful knowledge. Or equivalently, that progress exhibits "decreasing returns to effort at any point in time" (Grossman and Shapiro 1986 p.4).[9] We therefore introduce a progress constraint by assuming R is homogeneous of degree less than one.

We define A_l as the cost borne by the firm for each dollar of labour-related R&D expenses, after claiming all available tax liability reductions associated with the expenditure. For example, if a firm is able to deduct all R&D labour-related expenses and also receives a tax credit of rate θ, then we have $A_l = 1 - \theta$. Similarly, we define A_e as the cost borne by the firm for each dollar of equipment purchased after claiming all available tax liability reductions

[7] That is, we begin by abstracting from equipment as accumulable capital.

[8] See also seminal contribution by Hayashi (1982), which relates Tobins Q to a neoclassical investment model with convex adjustment costs, and demonstrates the assumptions under which marginal and average q are equivalent. Again, convex adjustment costs are incorporated via a concave investment production function in the accumulation restriction.

[9] Grossman and Shapiro (1986) model R&D investment as a dynamic optimisation problem for investment in discrete R&D projects. The firm invests to reach a 'prize' of current value W that is 'distance' L away. This essentially reflects a convex adjustment cost investment model which is recast such that the firm minimises cost to reach an exogenously given target K (˜the distance to the prize) and returns are wholly delayed to an optimally chosen termination date T. Adjustment costs are incorporated in the manner proposed by Uzawa (1969) as a 'progress constraint'.

The firm's profit maximization problem can be described by the current value Hamiltonian given by:[10]

$$H = (1-\tau)\, f(G,.) - A_e E - A_l L + \mu(R(\ ) - \delta G) \tag{2}$$

The relevant first order conditions are then given by:

$$\frac{\partial H}{\partial L} = -A_l + \mu R_L(\ ) = 0 \tag{3}$$

$$\frac{\partial H}{\partial E} = -A_e + \mu R_E(\ ) = 0 \tag{4}$$

$$\dot{\mu} - r\mu = -\frac{\partial H}{\partial G} = -(1-\tau)\, f_G(\ ) + \delta\mu \Rightarrow (1-\tau)\, f_G = (\delta + r)\mu - \dot{\mu} \tag{5}$$

where $R_X(\ )$ and $f_X(\ )$ represent the partial derivatives of R and $f(\ )$ with respect to $X_{\in\{L,E,G\}}$. These first order conditions, in conjunction with the assumed production functions and the technology accumulation restriction, implicitly define the demand for R&D labour.

With some additional assumptions we can derive a steady state labour demand equation from these first order conditions. For illustrative purposes we normalize all prices (labour, equipment and final goods). While it is not essential to the model, we allow for diminishing returns to technology stock the production of final goods, which can be interpreted as reflecting partial market power on price.[11] A simple production function $f(\ ) = \psi G^{\gamma}$ .where ψ is the part of production dependent on other inputs, which the firm treats as a constant for the purpose of choosing R&D inputs.

Finally, it remains to assume a functional form of the R&D production function. We assume a constant elasticity of substitution (CES) R&D function (i.e.,

[10] It can easily be seen that including variable inputs to the production of final goods will simply add another two first order restrictions that do not affect the firms choice over L and E, and therefore G (by the assumption that R&D labour is specific)

[11] We abstract from modelling market structure explicitly.

$R=\left[L^{\rho}+E^{\rho}\right]^{\frac{\varepsilon}{\rho}}$ where ε captures returns to scale and $\frac{1}{1-\rho}$ is the elasticity of substitution). Noting that in steady state $\delta G=R$ we can derive an explicit form of the steady state labour demand, which is given by:

$$L^{*}=\left[\left(r+\delta\right)\frac{\delta^{\gamma-1}}{\gamma\varepsilon}\frac{A_{l}}{1-\tau}\left(1+\left(\frac{A_{e}}{A_{l}}\right)^{\frac{\rho}{1-\rho}}\right)^{\frac{\rho-\gamma\varepsilon}{\rho}}\right]^{\frac{1}{\gamma\varepsilon-1}} \tag{6}$$

This simple formulation demonstrates some key aspects of the way tax incentives directed at labour or research equipment are predicted to affect the demand for each, and the technology stock maintained. Steady state labour demand is defined so long as $\gamma\varepsilon<1$. Considering the partial derivative of L* with respect to A_{e} (the tax price of equipment) reveals that the cross price elasticity of demand for research labour is positive if $\gamma\varepsilon<\rho$, which ensures the substitution effect (determined by ρ) dominates the output effect (determined by the returns to scale in each of the production functions) of the increased tax price of equipment. The actual sign of cross-price elasticity is therefore theoretically ambiguous.

We view our estimating equation as fundamentally reduced form in nature, but as motivated through the simple extension of a dual input convex adjustment cost investment framework, outlined above and summarized (in steady state) by equation (6). We considered two approaches to formulate an estimating equation (6). First, log linearising gives:

$$\ln(L)=\omega_{0}+\omega_{1}\ln\left(\frac{A_{e}}{A_{l}}\right)+\omega_{1}\ln\left(\frac{A_{l}}{1-\tau}\right) \tag{7}$$

where ω_{x} are appropriately defined constants incorporating various parameters. Note that we parameterize the estimating equation as a function of two tax policy determinants of R&D labour demand: $b=\frac{A_{l}}{(1-\tau)}$, which is the tax price of researchers and $q = \frac{A_e}{A_l}$, which is the relative subsidy implied by the tax system to equipment versus researchers. Since in practice A_e and A_l are highly correlated, controlling for the relative tax price of equipment rather than the absolute level is more likely to give a stable estimate of the effect of variation in $A_l / (1-\tau)$,[12] which is the primary variable of interest.

We also considered an estimating equation based on the total differential of equation (6); i.e., $dL = \frac{\partial L}{\partial q} dq + \frac{\partial L}{\partial b} db$. Which we operationalised as estimating an equation in differences, again augmented with additional control variables. Since the results for either approach turned out to be very similar, we present only the simple linearized model.

4. Empirical model

Our aim is to assess the determinants of full-time-equivalent researchers in the business sector from the OECD Main Science and Technology Indicators (OECD, 2008b). Our estimating equation begins with equation (7) and is augmented with additional lags of tax policy variables, a lagged dependent variable and additional explanatory variables, which have been identified in the literature as being important determinants of R&D investment (in the framework above, these can be interpreted as capturing some of the inter-temporal variation in productivity parameters). Our main estimating equation is given by:

$$L_{it} = \beta L_{it-1} + \sum \alpha_s b_{it-s} + \sum \beta_s q_{it} + \sum \gamma \beta_s S_{it-s} + \psi X_{it} \quad (8)$$

where *b*, *q*, and L_t are defined as above S_t is direct government support for R&D via cash subsidies and grants (i.e., subsidies provided directly rather than via

[12] i.e., it minimizes multicollinearity while controlling for the complementary input to R&D.

the tax system); and X a vector of additional control variables, specifically given by: $\psi X_{it} = \psi_0 SJA_{t-1} + \psi_1 HERD_t + \psi_2 RDFGOV_t + \psi_3 GOVRD_t + \psi_4 GDP_t$

Where GDP_t is Gross Domestic Product; ΔGDP_t is GDP growth; SJA_{t-1} is the lagged number of scientific journal articles; $HERD_t$ is the R&D expenditure by the higher education sector; and $GOVRD_t$ is Government intramural R&D. The dynamic structure of the preferred model was chosen to reflect the statistical properties of the aggregate R&D series. The LDV can be interpreted as a proxy for replacement investment. The persistence of the dependent variable may also reflect the hypothesis that firms will smooth R&D spending over time, to avoid adjustment costs associated with hiring new staff and because when researchers leave or are laid off the firm loses the tacit knowledge workers embody (Hall, 2005; Guellec and Pottelsberghe, 2000). The lag structures for b_t, q_t and S_t were determined by including multiple lags and paring down sequentially those that were insignificant.

Estimating the equation is subject to the familiar challenges associated with dynamic panels. Unobserved time-invariant heterogeneity[13] is correlated with the LDV and hence OLS will result in inconsistent, biased estimates. Under the FE transformation, the estimated coefficient on the LDV will be biased downward (Nickell, 1981), though given the length of the panel this may not be a substantial problem. The small sample size (width), panel length and persistence of the dependent variable make commonly applied dynamic panel GMM estimators less appropriate. For instance, as R&D is a persistent series, lagged levels will be weak instruments for current differences and for this reason Bond et al. (2002) caution against using GMM estimators in the context of highly persistent series.[14] As the number of instruments employed by these estimators are quadratic in T, these

[13] This may be due to cultural factors, natural resource endowment or geographic factors including distribution of economic activity within the country.

[14] If the series is I(1)[14] the difference GMM (Arellano and Bond, 1991) fails because the autoregressive coefficient is not identified (Bond et al., 2002).

estimators can suffer problems associated with many weak instruments (See Stock et al 2002; and also Roodman 2006) when applied to panels of this length. For these reasons, we present both FE estimates as well as the Kiviet (1995) corrected least square dummy variable estimates. Year dummies are included to control for global technology shocks.

4.1. Measuring government support for R&D

A primary contribution of our empirical analysis is that a complete range of public support programs for business R&D are included. Governments support private sector R&D in three principal ways: grants, procurements and tax incentives. These policies effectively reduce the cost of R&D investment to private firms, though they do not do this in a manner that is neutral between firms and research projects.[15] Ideally, we would like to separately identify these three components of government support.

Unfortunately, available data do not allow us to distinguish between grants and procurement. Nor do they enable us to distinguish between the component paid towards research labour or research equipment. We therefore include R&D financed by government (RDFGOV) which includes both procurement as well as direct grants. RDFGOV data are compiled from the OECD Main Science and Technology Indicators (OECD, 2008b).

Tax incentives for private sector R&D more closely resemble ad valorem subsidies and have the perceived benefit that they are allocated by the market. R&D tax policies vary considerably between countries. In the Appendix, we provide a detailed account of the relative generosity of the R&D tax schemes in each country in our panel. Variation in the variables b and q comes from both changes in tax credits and allowances, and also from variation in CIT.

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[15] For example, grant programs are typically allocated according to the specific policy objectives underpinning the program. Government procurement means that the government owns the outputs of the R&D (unlike grant recipients who own the IP they create).

The first of these variables, *b*, is equivalent to Jorgenson's (1963) user cost of capital, which is the traditional workhorse for investigating the influence of tax policy and investment in physical as well as intangible (R&D) capital. Intuitively, the variable reflects the price a firm is willing to pay for the marginal R&D worker. It is similar to the measure employed by Bloom et al. (2002) and the "B-index" published periodically by the OECD and employed by Guellec and van Pottelsberghe (2003) in their study of tax policy and R&D investment. The approach is very flexible and can accommodate a wide range of different tax policy designs.

Our methodology for calculating this variable is based on the approach employed by these previous studies. However, unlike previous studies, our measure focuses exclusively on tax policy affecting R&D labour (i.e., researchers employed). The second of the variables is derived by calculating the 'tax price' of research equipment and buildings and structures in an analogous manner, and then taking the ratio with the first (R&D labour tax price). Details of the calculations are outlined below, and details of the national tax regimes are provided in the appendix.

R&D tax policy designs vary considerably between countries.[16] Tax credits reduce tax liabilities directly by some fraction of allowable expenditure (e.g., assuming current expenditure is written off, $A = 1 - \tau - \theta$, where θ is the rate of credit). Another form of incentive is variously called, deduction allowances, tax concessions or enhanced deductions. Under this policy firms are allowed to deduct an amount greater than the actual expenditure on R&D, thereby shielding a portion of profits from corporate income tax (e.g., $A = 1 - \gamma\tau$, where $\gamma > 1$ is the rate of deduction allowable). To benefit from either deduction allowances or

[16] In this section we discuss explicit incentives. Additionally, in each country considered R&D labour costs can be deducted from current taxable income immediately, which represents an implicit subsidy to intangible capital relative to other forms of capital. Indeed, an implicit subsidy is made wherever the rate of depreciation of an asset allowable for tax purposes is greater than the rate of economic depreciation.

credits, firms must be earning a taxable income. However, under a rebate policy (also known as offset or 'extended access' schemes), firms receive a cash refund irrespective of their profit status. Finally, in a few cases incentives are provided as a reduction on labor-related taxes directly,[17] which similarly does not require a firm to earn profit to benefit.

A common type of policy – referred to here as an 'incremental scheme' – is where only increases in R&D above a defined base level are eligible for tax incentives. For example, in an incremental scheme with a three-year moving average base, only expenditure that is over and above expenditure in the previous three years is eligible to receive the tax incentive. The intent of incremental schemes is to direct the subsidy at marginal (new) R&D investment and to avoid subsidizing R&D that would have occurred anyway.

To model the value of an incremental scheme, where the base is defined as a trailing k period moving average, the credit or deduction rate is multiplied by (see Richardson and Wilkie 1995): $1-\frac{1}{k}\sum_{i=1}^{k}(1+r)^{-i}$ which reflects the marginal value of an incremental incentive for a firm with increasing R&D expenditure.[18]

To calculate the tax component of the user cost of scientific and research equipment, we collected data on the eligibility of expenditure on 'machinery and equipment' (M&E) and also 'buildings and structures' (B&S) for special tax treatment. We calculated the 'tax price' of these two complementary componants separately and considered weighted averages in the regression analysis. We considered shares of M&E ranging from 60 per cent up to 100 per cent (e.g., the tax price of buildings has a zero weighting and the measure reflects only the tax price of M&E). This range covers the approximate composition of expenditure reported in industrial surveys and is also consistent with past the ratios used by

[17] For example, in the Netherlands and Norway.

[18] This is also equivalent to the average effective subsidy rate to a representative firm which grows at the nominal discount rate and investing a constant share of its revenue in R&D (i.e., undertakes a constant amount of R&D in NPV terms)

past cross country empirical work. (see for e.g., McFetridge and Warda 1983; Bloom, Griffith et al. 2002). The results do not vary greatly, however the relative tax price (i.e., q_t) exhibited the strongest significance when we used the measure reflecting only tax treatment of machinery and equipment.

To calculate these, depreciation for tax purposes is calculated on a straight line (SL) or declining balance (DB) basis, and this is stipulated by the tax system. The formulae used for these are given by: $NPV_{SL} = \frac{1}{T}\frac{1-(1+r)^{-T}}{r/(1+r)}$ and $NPV_{DB} = d\frac{(1+r)}{(d+r)}$ for SL and DB depreciation respectively, where r is the discount rate, or required rate of return.

To make the computations manageable, our measure includes some obvious limitations. For example, the calculations assume that firms can benefit fully from the incentive, i.e., it assumes firms have sufficient tax liabilities to claim the full amount of R&D tax incentives in the current year. Maximum and minimum claims, known as caps and floors, are also ignored. The measure does not incorporate differences in tax treatment of personal income tax, shareholder dividends or withholding taxes on international transfers of profit.[19] The policies considered are only those provided at the central government level. Special schemes requiring collaboration with universities or those available only to small firms are not included, primarily because there is no obvious way to model these in a comparable manner. In some cases sub-national governments offer R&D tax

[19] Policies aimed to avoid double taxation of profits reduce the effective value of R&D tax incentives to shareholders. For example, with complete dividend imputation, taxpaying shareholders are indifferent to R&D tax incentives provided on company income. This is because a decrease in CIT liabilities, resulting from an R&D tax incentive policy, can lead to a direct increase in the tax paid on dividends. In this case tax incentives do not affect the cost of equity capital. Such a system is in place in Australia, New Zealand, France and Canada. A similar 'washing out' of the tax incentive can result where multinational enterprises repatriate profits and tax liabilities in the home country are reduced by the amount of tax paid to host country governments (as is the case in the USA).

incentives, particularly in the case of federal systems of Canada and the United States.[20]

4.2 Control variables

Government intramural R&D may crowd out private investment by driving up input costs, or by directly crowding out private investment from a finite pool of investment opportunities. However, in the longer term, government-financed R&D may act as a mechanism for building domestic R&D capacity. We include government intramural R&D (GOVRD) from OECD (2008b).

Basic scientific knowledge is an important input for new commercial technology. Academic research is thought to have played a role in observed increases in industrial innovation in the United States in the 1980s and 1990s (Branstetter and Ogura, 2005). To control for technological opportunity, we include an explanatory variable (SJA) based on a count of articles published in international journals on science and engineering, taken from World Development Indicators (World Bank, 2007), in the model. Journal article publication rates are an output-based measure of performance of academic research and these are recorded by location of the institution of the author (NSF, 2008). Scientific and technical journal articles refer to the number of scientific and engineering articles published in the fields of physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

Scientific journal articles are commonly cited as prior art for patents (see Branstetter and Ogura, 2005), providing strong evidence that these represent a meaningful measure of this source of technological opportunity. While this measure has the advantage of being widely available both across countries and over time, it is acknowledged to be a somewhat noisy measure of R&D investment

[20] Using sub-national incentive rates would then require weighting tax policy against the proportion of national R&D performed in each region. Often state incentives reduce eligibility to national incentives, meaning this is unlikely to be a serious limitation.

opportunities. This is because some scientific research, such as advances in material science or biochemistry, may have many commercial applications while other published research, say in theoretical physics or pure mathematics, may have little (or no) immediate commercial value. A further limitation of this measure is an English language bias which, like other time-invariant heterogeneity, must be taken into account when estimating the model.

Controlling for academic output, R&D performed by the tertiary education sector (HERD) provides a proxy for the quality and extent of postgraduate research education. HERD includes research by students at the PhD level, including supervisory costs, but does not include expenditure in relation to coursework degrees and teaching-related activities (OECD, 2002a). This measure is superior to the per centage of the population with tertiary education because it has greater coverage and will more directly reflect both the number and quality of research-based degrees, which is of primary interest.

The neoclassical investment model identifies growth in output as a key determinant of investment; this is known as the accelerator effect. It is also important to control for economic scale. In our empirical model, GDP is included to capture scale effects, or equivalently, this may be interpreted as a measure of domestic demand. We therefore simultaneously control for GDP level and growth.

Table 1. Pooled Summary Statistics

Variable	Abbreviation	*Mean*	*Std. Dev.*	*Min*	*Max*
Researchers in the business enterprise sector	L	101,237	214,134	655	1,156,000
Tax price of researchers	b	0.92	0.12	0.50	1.00
Relative tax price of equipment	q	1.26	0.25	0.77	2.30
Business R&D Financed by the Government	S	2,506	7,176	2	44,311
GDP ($m US)	GDP	1,368,132	2,170,247	45,332	12,400,000
GDP Growth	ΔGDP_t	0.03	0.02	-0.07	0.11
Scientific Journal Articles	SJA	24,668	42,501	196	202,075
R&D by Higher Education Sector	HERD	4,437	6,922	48	44,494
Government Intramural R&D	GOVRD	4,191	7,584	69	38,432
IPR		4.01	0.71	1.67	4.88

Number of observations (N)=391.

The data used to construct the variables in this model were compiled from a range of sources (described above) including the World Bank and the OECD. Missing data for control variables are interpolated linearly. In all but a few cases, this interpolation bridges biannual survey data of series which are in any case very persistent. The dependent variable is not interpolated in this way. Table 1 summarizes the data for the country-year observations used in our estimates.

5. Results and analysis

Fixed-effects estimates of equation 11 are presented in column (1) of Table 2. Recall the dependent variable is the number of full-time equivalent researchers employed by the business sector, which proxies real R&D effort. Overall the model fits the data reasonably well, with most coefficients estimated displaying the expected sign. As anticipated, the autoregressive coefficient is very high, reflecting that using fixed effects downward-biases this estimate. As discussed, economically this can be interpreted as a replacement component which reflects firms' incentives to smooth R&D spending. In addition, Rho is very large, reflecting the fact that a lot of variation is due to unobserved fixed effects. We interpret this as evidence of the strong dependence of R&D investment on (largely unobserved) country-specific attributes such as institutional and cultural factors.

Our preferred estimates, using the Kiviet (1995) corrected least squares dummy variable, are presented in column (2) of Table 2. The bias-corrected estimate of the autoregressive coefficient shows it to be very close to unity. This supports the intuitively appealing notion that policies which alter national aggregate R&D effort have strong persistence in the trajectory of national innovative performance. The coefficients of other variables are similar to those using fixed-effects.

Our principal interest is in the effectiveness of subsidies in driving real increased R&D effort. The first variable of interest in this regard is the tax price of R&D wages (*b*), which is estimated to have a statistically significant effect on the number of researchers employed. In particular, a reduction in the tax price of R&D wages of 10 per cent increases R&D employment by around 3 per cent. These estimates are broadly consistent with the short-run effect on real expenditure estimated in previous cross-country analysis.[21]

Table 2 Regression Results

Dependent Variable: FTE Researchers	*(1)*	*(2)*
L_{t-1}	0.878***	0.925***
	(0.0235)	(0.0315)
b_t	-0.325***	-0.337***
	(0.116)	(0.119)
b_{t-1}	0.0497	0.0833
	(0.117)	(0.126)
q_t	-0.145	-0.157
	(0.103)	(0.107)
q_{t-1}	0.203*	0.199*
	(0.106)	(0.108)
S_t	0.0807***	0.0803***
	(0.0164)	(0.0201)
S_{t-1}	-0.0848***	-0.0912***
	(0.0155)	(0.0196)
GDP_t	-0.0442	-0.0848
	(0.0790)	(0.108)
ΔGDP_t	1.146***	1.196***
	(0.263)	(0.284)
SJA_{t-1}	0.0252	0.0266
	(0.0347)	(0.0390)
$HERD_{t-1}$	-0.00748	-0.00752
	(0.0368)	(0.0451)
$GOVRD_{t-1}$	0.00799	0.00646
	(0.0308)	(0.0470)
IPR_{t-1}	0.0575**	0.0483*
	(0.0228)	(0.0280)
Observations	391	391
Number of countries	25	25
Rho	0.86	.

[21] We note that no statistically significant effect of tax policy was found in a recent paper by one of the authors (Thomson 2010) which considered Australian firm-level data. In the paper (ibid) a number of reasons for this are discussed, the idiosyncrasies of the Australian context (including the dividend imputation system); general statistical and measurement issues which make observing an effect using firm level data particularly difficult.

The elasticity of R&D employment with respect to the contemporaneous relative tax price of R&D equipment is not significant. However, after a one-year lag, the estimate is positive and weakly significant (at 10 per cent) with a magnitude suggesting a 10 per cent increase in the tax price of R&D equipment leads to a 2 per cent increase in the number of researchers employed. This provides some evidence that, at least on aggregate, equipment and researchers are reasonably substitutable. This is an important result for the design of R&D tax incentives – if researchers and equipment were not substitutes, incentives directed only towards labour costs (as is the case in the Netherlands) would be less effective.

The second key variable of interest is government-financed R&D performed by business (*S*). These results are somewhat more puzzling, since we find that an increase in total government-financed R&D is associated with a statistically significant (positive) effect on contemporaneous R&D employment – but a negative effect of a similar magnitude after one year lag. This is suggestive that R&D employment reacts primarily to a *change* in the subsidy rate (controlling for lagged R&D employment). That is, the results suggest that an increase in total government-financed R&D of 10 per cent results in a contemporaneous increase in the number of researchers employed in the private sector of 0.8 per cent, but that there is no long run effect.

Coefficients on the other explanatory variables generally conform to our priors. Real research effort is found to be strongly pro-cyclical, as inferred by the fact that the coefficient on GDP growth is positive and statistically significant. The variable which controls for scale (the level of GDP) is found to be insignificant. Moreover, the number of science and engineering articles published (SJA) is also insignificant. Both government intramural R&D and HERD are both found to have an insignificant effect on private sector R&D activity. This is consistent with our prior since, on the one hand we would anticipate some crowding out from these activities in the short term, at the same time they contribute to building R&D capacity in the long term. We experimented with including additional lags of these variables, though they were never significant. It may be that the longer term relationship is hard to identify, given that the effect of HERD on private sector R&D will be dispersed over time.

Finally, we find a weak but positive effect of IPR strength as measured by the Parke and Ginarte (1997) index. While it is difficult to interpret the magnitude of the impact implied by the coefficient, the fact that it is positive and significant conforms to our prior. Interestingly, this is not a universal result in the existing literature; note for example that a number of past studies at the micro and macro level did not observe a positive effect of IP rights on R&D investment (see for example Lerner 2002; Sakakibara and Branstetter, 2001).

We found the main results to be robust to reasonable variation in the basic model. As noted previously we considered a differenced model with errors clustered by country. We also experimented with additional lags of each explanatory variable.

6. Conclusion

There has been much debate in the literature about the effects of public R&D support. Some studies have analyzed this issue from a macro perspective, but have failed to consider the possibility that wage inflation has attenuated the effects of R&D subsidies on R&D expenditure (e.g. Guellec and van Pottelsberghe, 2003). Goolsbee (1998) claimed that wage inflation may account for "as much as 50 per cent" of previous estimates of the elasticity of R&D investment to tax price. At the same time, other macro studies (e.g. Wolff and Reinthaler, 2008) have accounted for wage inflation but have not considered the possibility that different R&D policies may be substitutes. In this study, we have attempted to unify these two streams of the literature by analyzing the effects of a comprehensive set of R&D subsidies on real R&D effort (as proxied by R&D employment).

Our results suggest that the number of researchers employed in the business enterprise sector responds to public subsidies in a similar manner to the response observed in aggregate R&D investment. In other words, we find no evidence that input price inflation has seriously conflated past estimates of the effectiveness of R&D subsidies delivered via the tax system. Our results also suggest that subsidies delivered via the tax system or by direct grants are both effective in increasing real R&D effort. Additionally, we have provided some tentative evidence that, at least in aggregate, equipment and researchers are reasonably substitutable. This latter result suggests policy makers can be flexible in terms of the manner in which fiscal incentives are provided.

Determining the best policy instrument for a particular objective may therefore depend on other consequences of the different modes of delivery. Direct funding of R&D can provide governments with greater control over the direction of research undertaken (i.e., technological field). This may be seen as either a positive or a negative relative to allowing the market to allocate resources, depending on the level of uncertainty about the social benefits of the R&D project, and the likelihood of success.

References

Aerts, K. 2008. *Who writes the payslip? Do R&D subsidies merely increase researcher wages?* Unpublished mimeo, Katholieke University Leuven.

Arellano, M. and Bond, S. 1991. Some tests of specification for panel data - Monte-Carlo evidence and an application to employment equations. *Review of Economic Studies* 58(2): 277-297.

Bloom, N., Griffith, R. and Van Reenen, J. 2002. Do R&D tax credits work? Evidence from a panel of countries 1979-1997. *Journal of Public Economics* 85(1): 1-31.

Blundell, R. and Bond, S. 1998. Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics* 87(1): 115-143.

Bond, S., Nauges C. and Windmeijer, F. 2002. *Dynamic Panel Data Models: A Guide to Data Methods and Practice.* The Institute of Fiscal Studies. CeMMAP Working Paper (CWP09/02).

Branstetter, L. and Ogura, Y. 2005. *Is academic science driving a surge in industrial innovation? Evidence from patent citations*. NBER Working Paper No. 11561, Cambridge MA.

Chirinko, R., 1993. Business fixed investment spending - Modeling strategies, empirical results, and policy implications. *Journal of Economic Literature* 31(4), 1875-1911.

Czarnitzki, D., Hanel, P. and Rosa, J. 2004. *Evaluating the impact of R&D tax credits on innovation: A microeconometric study on Canadian firms.* ZEW Discussion Paper No. 04-77.

Dougherty, S.M., Inklaar, R., McGuckin, R.H. and van Ark, B. 2007. *International comparisons of R&D Expenditure: Does an R&D PPP make a difference?* NBER Working Paper No. 12829, Cambridge MA.

Eisner, R., Albert, S., Sullivan, M. 1984. *The new incremental tax credit for R&D: Incentive or disincentive?* National Tax Journal 37(2), 171-184.

EC 2002. *European Trend Chart on Innovation. Theme-specific Country Report: Portugal.* (http://cordis.europa.eu/en/home.html), European Commission, Community Research and Development Information Service

ETAN 1999a. *An International Compendium of Indirect Schemes and Measures for Supporting Research and Technological Development in Enterprises,* European Commission, European Technology Assessment Network. (http://www.cordis.lu/etan/src/topic-7.htm).

ETAN 1999b. *An International Compendium of Indirect Schemes and Measures for Supporting Research and Technological Development in Enterprises. Supplementary Report,* European Commission, European Technology Assessment Network. (http://www.cordis.lu/etan/src/topic-7.htm).

Falk, M. 2006. *What drives business Research and Development (R&D) intensity across Organisation for Economic Co-Operation and Development (OECD)* countries? *Applied Economics* 38(5), 533-547.

Genser, B. 2001. *Corporate Income Taxation, In The European Union: Current State And Perspectives,* Centre for Tax System Integrity Research School of Social Sciences Australian National University Working Paper No 17.

Ginarte, J.C. and Park, W.G. 1997. Determinants of patent rights: A cross-national study. *Research Policy* 26(3), 283-301.

Goolsbee, A. 1998. Does government R&D policy mainly benefit scientists and engineers? *American Economic Review* 88(2), 298-302.

Griliches, Z. 1979. Issues in assessing the contribution of Research and Development to productivity growth. *Bell Journal of Economics* 10(1), 92-116.

Grossman, G. M. and C. Shapiro 1986. 'Optimal Dynamic Research-And-Development Programs.' Rand Journal Of Economics 17(4): 581-593

Guellec, D. and Pottelsberghe, B. van 2003. The impact of public R&D expenditure on business R&D. *Economics of Innovation and New Technology* 12(3), 225-243.

Hall, B.H. 1992. *R&D tax policy during the eighties: Success or failure?* NBER. Working Paper No. 4240, Cambridge MA.

Hall, B.H. 1995. *Effectiveness of Research and Experimentation Tax Credits: Critical Literature Review and Research Design*, University of California Berkeley & NBER.

Hall, B. and Reenen, J. van 2000. How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy*, 29, 449-469.

Hall, B. 2005. *The Financing of Innovation*, University of California at Berkeley.

Hayashi, F. 1982. 'Tobin's Marginal q and Average q: A Neoclassical Interpretation.' Econometrica 50: 213-224.

ICSTI 1998. *Irish Council for Science Technology & Innovation. Task Force Report 1998*. (http://www.forfas.ie/icsti/statements/innent/task.htm).

IRD 2000. *Research & Development Expenditure - Accounting Treatment for Tax Purposes.* N.Z. Inland Revenue Department.

JCT 1997. *The Blue Book, General Explanation of Tax Legislation Enacted in 1997*, U.S. Joint Committee on Taxation.

Kiviet, J. 1995. On bias, inconsistency, and efficiency of various estimators in dynamic panel data models. *Journal of Econometrics* 68(1), 53-78.

Koga, T. 2003. Firm size and R&D tax incentives. Technovation 23, 643-648.

KPMG 2007. *KPMG Corporate Tax Rate Survey*, KPMG.

Lederman, D. and Maloney, W. 2003. *R&D and Development,* World Bank.

Lerner, J. 2002. *Patent protection and innovation over 150 years*. NBER. Working Paper Series W8977, Cambridge MA.

Lowtax.net 2008. *Ireland Information: Business, Taxation and Offshore*, http://www.lowtax.net/lowtax/html/jiroltr.html .

Lokshin, B. and Mohnen, P. 2008. *Wage effects of R&D tax incentives: Evidence from the Netherlands*. UNU-MERIT Working Paper 2008-034.

Mansfield, E. 1994. *Intellectual Property Protection, Foreign Direct Investment and Technology Transfer*, Washington DC., International Finance Corporation Discussion Paper 19.

Messinis, G. 2004. R&D Price Inflation, *Real BERD and Innovation: Pharmaceuticals, OECD 1980-2000*, Centre for Strategic Economic Studies, Victoria University of Technology, Pharmaceutical Industry Project Working Paper Series No. 18.

McFetridge, D. and Warda, J. 1983. *Canadian R&D incentives: Their adequacy and impact,* Canadian Tax Paper No. 70. Toronto, Canadian Tax Foundation.

Mulkay, B. and Mairesse, J. 2003. *The effect of the R&D tax credit in France*. EEA-ESEM Conference, Stockholm Sweden.

National Science Board 2008. *Science and Engineering Indicators 2008.* National Science Foundation, Arlington VA.

Nickell, S. 1981. Biases in dynamic models with fixed effects. *Econometrica* 49(6), 1417-1426.

NKTH 2006. *Hungarian Tax Incentives for Research and Development,* National Office for Research and Technology, Hungary.

OECD 1998. *Technology, Productivity and Job Creation. Best Policy Practices.* Paris, OECD.

OECD 2000. *STI Outlook 2000: National Policies. Country Response, Korea*, Paris, OECD.

OECD 2002a. *Frascati Manual 2002: Proposed Standard Practice for Surveys on Research and Experimental Development*. Paris, OECD.

OECD 2002b. *Tax Incentives for Research and Development: Trends and Issues.* Paris, OECD.

OECD 2006. *OECD Science, Technology and Industry Outlook 2006*. Paris, OECD.

OECD 2007. *OECD Tax Database*. Paris, OECD.

OECD 2008a. *OECD Science, Technology and Industry Outlook 2008.* Paris, OECD.

OECD 2008b. *OECD Main Science and Technology Indicators 2008*. Paris, OECD.

Park, W.G. and Ginarte, J.C. 1997. Intellectual property rights and economic growth. *Contemporary Economic Policy* 15(3), 51-61.

Rapp, R.T. and Rozek R.P. 1990. Benefits and costs of intellectual property protection in developing-countries. *Journal of World Trade* 24(5), 75-102.

Rashkin, M.D. 2007. *Practical Guide to Research and Development Tax Incentives. Federal, State and Foreign.* 2nd Ed. Chicago, Wolters Kluwer Business.

Richardson, M. and S. Wilkie (1995). 'Incremental R&D Subsidies.' Journal of Regulatory Economics 7, 161-175.

Roodman, D. 2006. *How to Do xtabond2: An Introduction to "Difference" and "System" GMM in Stata*, Center for Global Development.

Sakakibara, M. and Branstetter, L., (2001). 'Do stronger patents induce more innovation? Evidence from the 1988 Japanese patent law reforms.' *Rand Journal of Economics* 32, 77-100.

Sawyer, A.J. 2004. *Potential Implications of Providing Tax Incentives for Research and Development in NZ*, Department of Accountancy, Finance and Information Systems, University of Canterbury Christchurch, NZ.

Stock, J., Wright, J. and Yogo, M., A Survey of Weak Instruments and Weak Identification in Generalized Method of Moments. *Journal of Business & Economic Statistics*, Vol. 20, No. 4,

UN 2005. World Investment Report 2005: *Transnational Corporations and the Internationalisation of R&D.* New York, United Nations.

Uzawa, H. 1969. 'Time Preference And Penrose Effect In A 2-Class Model Of Economic Growth.' Journal Of Political Economy 77(4): 628-652.

Warda, J. 1996. *Measuring the Value of R&D Tax Provisions. Fiscal Measures to Promote R&D and Innovation.* Paris, OECD.

Warda, J. 1996b. *Background Paper for "Measuring the Value of R&D Tax Provisions"*, Provided by the Author.

Warda, J. 1999. *Measuring the Attractiveness of R&D Tax Incentives: Canada and Major Industrial Countries, Statistics Canada,* The Conference Board of Canada.

Warda, J. 2006. *Tax Treatment of Business Investments in Intellectual Assets: An International Comparison.* Paris, OECD. STI Working Paper 2006/4.

World Bank 2007. *World Development Indicators*, World Bank.

WTD 2007. *World Tax Database*, University of Michigan.

Wolff, G. and Reinthaler, W. 2008. The effectiveness of subsidies revisited: Accounting for wage and employment effects in business R&D, *Research Policy 37*, 1403–1412.

Appendix

In the following, we present a breakdown of the details of the R&D tax incentives which apply to R&D labour in each country in our panel, and a detailed breakdown of the corporate income tax rate in each country. For details regarding tax treatment of R&D equipment see Thomson (2008).

Australia. **R&D tax policy:** A 150% deduction introduced 1 July 1985 and then reduced to 125% from 1 July 1997. From 1 July 2001, companies could also claim an additional 50% (175% total) deduction on incremental expenditure above a 3 year moving average base. **Depreciation:** M&E (1980-1996) 3 years straight line (SL), (1996-) 5 years SL. B&S: (1980-1986) 3 years SL (Lattimore 1997 p.94). (1987-) 40 years SL.**CIT:**[22] 46% (1980-86), 49% (1987-88), 39% (1989-1993), 33% (1994-95), 36% (1996-1999), 34% (2000), 30% (2001-2006) (financial year begins 1 July, for example 1 July 1999- 30 June 2000 is denoted as 1999).

Austria. **R&D tax policy:** 1980-1988: 105% deduction. 1988 – 1999, 112% deduction. If the innovation was commercialised 'in house' the rate was 118% which is the rate modeled here. Cited as Tax law BGBL Nr 4/1988 in ETAN (1999a). 2000 - 2006, the concession included two parts, a 125% deduction available on the volume and 135% on increments above base expenditure defined as a three year moving average (Law BGBL 28/99). From 2005, firms could opt to take an 8% credit (modeled here). **Depreciation:** For the years 1980-1983, all fixed assets are deducted at 80% in the first year, followed by the remainder over the subsequent 4 years on a straight line basis (Warda 1983). For the period 1984-2006, depreciation is calculated over 5 and 25 years SL for M&E and B&S, respectively. **CIT:** 55% (1980-88), 30% (1989-93), 34% (1994-2004), 25% (2005-06).

Belgium. **R&D tax policy:** McFetridge and Warda (1983) observe that in 1980 a scheme was in place whereby expenditure above the average in the three years to 1976 was eligible for a 15% augmented deduction (115% of expenditure deducted from taxable income).[23] In the absence of additional information the 15% rate is applied. **Depreciation:** We assume M&E is depreciated over 3 years SL. B&S are depreciated over 20 years SL. **CIT:** 48% (1980-1982), 45% 1983-86, 43% (1987-1989), 41% (1990), 39% (1999-2002), 33% (2003-2006).

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[22] Unless otherwise stated, all CIT data applied are based on central government tax rates from University of Michigan World Tax Database (WTD 2007)extended for the more recent years using OECD (2007). Other sources include: KPMG Corporate Tax Rate Survey (KPMG 2007) and World Bank World Development Indicators (WDI).

[23] Under some conditions eligible expenditure could be scaled up, by a maximum of 50% meaning that in principle firms could deduct 122.5% of every incremental dollar (McFetridge and Warda 1983; ETAN 1993b, p.12). However, a European Commission report (ETAN 1999b) notes that "In practice, however this higher figure is never reached".

Canada. R&D tax policy: The R&D tax credit in Canada was introduced in 1966 and has undergone a range of variations since then. Between 1980 and 1982, the scheme consisted of 10% on volume as well as an incremental credit of 50% above a three year moving average base. From 1983 the credit is 20%. The R&D credit in Canada is taxable, in that current allowable deductions are reduced by the value of the credit (Bloom et al. 2002). **Depreciation:** B&S and M&E were expensed (deducted at 100%) M&E between 1979 and 1987 (Bloom, Griffith et al. 2002). Since 1987 M&E can be deducted in the year it is incurred and B&S at 4% on a declining balance basis. **CIT:**[24] 46% (1980-86), 45.5% (1987), 41.5% (1988), 38% (1989-2002), 33% (2003), 31% (2004-06).

Czech Republic. R&D tax policy: No special concessions were available between 1993 and 2005. As of 2005 a 200% deduction is available to all firms. **Depreciation:** 5 years SL for M&E and 30 years SL for B&S applied over the entire period. **CIT:** 45% (1993), 42% (1994), 41% (1995), 39% (1996-97), 35% (1998-2000), 31% (2001-03), 28% (2004), 26% (2005), 24% (2006).

Denmark. R&D tax policy: No special incentives are modeled. Denmark has had a range of concessions in place, but these have been attached to special conditions, generally relating to encouraging research collaboration both internationally and between tertiary research institutions and private business. **Depreciation:** Between 1980-1997 all fixed assets are deducted 100% in the year of expense. For the period 1998- 2006 M&E and B&S are deducted according to a 30% declining balance (DB) and 20 year SL, respectively. **CIT:** 40% (1980-85), 50% (1986-89), 40% (1990), 38% (1991-92), 34% (1993-98), 32% (1999-2000), 30% (2001-04) and 28% (2005-06).

Finland. R&D tax policy: Tax Deduction Enhancement 1983-87 allowed firms to deduct 225% on the first 4m FM and 10% on amounts above this (ETAN 1999). In addition a 50% deduction was available on incremental expenditure above the previous year. It has been suggested that the scheme was ultimately withdrawn on the basis that little impact was observed (ETAN 1999a). The calculations here apply the 10% rate on the volume plus the 50% incremental scheme to current expenditure between 1983 and 1987 inclusive. **Depreciation:** 25% DB for M&E and 20% DB for B&S. **CIT:** 43% (1980-85), 33% (1986-89), 25 (1990) 23% (1991), 19% (1992), 25 % (1993-1995), 28% (1996-1999), 29% (2000-04), 26% (2005-).

France. R&D tax policy: For the years 1983-1984, businesses in France could claim a 25% tax credit on expenditure above the previous year's expenditure (Mulkay and Mairesse 2003). This was increased to 50% in 1985. Between 1988-90

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[24] The headline central government (CG) Corporate Income Tax is applied. In Canada, the CG CIT is generally reduced by 10% (Provincial abatement) but increased by provincial (sub national) CIT. For example, the state CIT in Ontario has ranged from 12.5 to13%. Additional features include the rebate for the manufacturing sector that has varied from 2 to 7% as well as a federal surcharge which has varied from 0-5% over the period. The headline CG CIT is close to measures taking into account these additional factors that require additional assumptions.

an alternative credit of 30% on the increment above expenditure in 1987 was available (Bloom et al. 2002). In 1991, the base for calculating incremental expenditure was changed to be defined as the average of the previous two years (two year moving average) (Mulkay and Mairesse 2003). From 2004 to 2005, firms could claim 5% on volume and 45% on incremental expenditure with incremental expenditure defined as a 2 year moving average. In 2006, this was again changed to 10% on the volume and 40% on incremental expenditure above a 2 year moving average. **Depreciation:** M&E and B&S are depreciated at 4% DB and 20 years SL respectively. However, between 1983-1986 B&S used for scientific research attracted an accelerated depreciation under which 50% was deducted in the year of expense with the remainder deducted over the usual period (Bloom, Griffith et al. 2002). **CIT:** 50% (1980-86), 45% (1987), 42% (1988), 39% (1989), 37% (1990), 34% (1991-92), 33% (1993-2006).

Germany. R&D tax policy: Germany has had no special concessions **Depreciation:** Depreciation rates applied are 20% DB for M&E and 4% DB for B&S. **CIT:** 61.8% (1980-1989), 59.7% (1990-1993), 55.6% (1994), 59.0% (1995-1996), 57.5%, (1997-98), 52.0% (1999-2000), 38.0% (2001-02), 40.0%, 38.0% (2004-06), 38.3% (2006).[25]

Greece. R&D tax policy: Greece has had no special concessions available throughout this period. **Depreciation** rates of 12.5 years (SL) for buildings. For M&E immediate deduction is assumed for the period between 1980 and 1998 (consistent with Warda 1996b) and depreciation over 3 years (SL) for the period 1999 to 2006 (consistent with Warda 2001). **CIT:** 43.4% (1980-1982), 48.5% (1983-84), 49.0% (1985-1988), 46.0% (1989-1992), 35.0% (1993-2004), 32.0% (2005), 29.0% (2006).

Hungary. R&D tax policy: 1997-1999 current expenditure can be deducted at a rate of 120%. In 2000 this was increased to 200% (NKTH 2006). **Depreciation:** 3 years SL for M&E and 50 years SL for Buildings. **CIT:** 40.0% (1990-1993), 36.0% (1994), 18.0% (1995-2003), 16.0% 2004-2006.

Ireland. R&D tax policy: Between 1996 and 1998: a special 400% deduction was available on R&D expenditure above the previous year (ICSTI 1998; ETAN 1999a). Only companies eligible for the special 10% CIT were eligible.[26] The Finance Act 2004 introduced a 20% tax credit on incremental expenditure. The baseline for calculating incremental expenditure is 2003 for R&D expenditure incurred in the first 3 years of the scheme (2004 to 2006, inclusive). Thereafter,

[25] CIT Data applied for Germany from 1990 is taken from KPMG which include both central government rate and important corporate income taxes that vary by municipality. KPMG do not cover 1990 and 1992, the 1993 figure is extrapolated back as the headline CGCIT is the same in each of these years. Prior to 1990 figures are taken directly from Bloom et al. (2002).

[26] The scheme had a relatively low cap (175,000 IEP or about 350,000 USD) and according to the Irish Council for Science, Technology & Innovation "the deduction still had many restrictions and was little used by either foreign or indigenous research performers."

the base is defined as the expenditure four years previous. i.e., for 2007 the baseline will be 2004 and for 2008 the base will be 2005, and so on. **Depreciation:** Both M&E and B&S are written off in the year it is incurred over the entire period. **CIT:** Ireland introduced a special tax rate of 10% nominally for manufacturing companies in 1981. In practice, eligibility extended to most relevant firms as courts deemed businesses in a number of activities not normally regarded as manufacturing as being eligible (Lowtax.net 2008). This is the rate applied in most past studies of tax concessions. In 1980 CIT was the standard 45%.

Italy. R&D tax policy: Italy had no special tax treatment for R&D by large firms during the period of study. **Depreciation:** 10 years (SL) for M&E and 33 years (SL) for buildings. **CIT:** 36.3% (1980-1981), 38.8% (1982), 41.3% (1983), 46.4% (1984-1990), 47.8% (1991-1992), 52.2% (1993-1998), 41.3% (1998-2000), 40.3% (2001-2002), 38.3% (2003), 37.3% (2004-2006).

Japan. R&D tax policy: Japan has had a tax incentive for R&D in place since 1967 (Koga 2003). For the period 1980 to 1998 a 20% tax credit on incremental expenditure, with the base defined as the largest expenditure reported since 1967, which for the representative firm is the previous year's expenditure. Subject to a maximum cap of 10% of a company's CIT liabilities. Reform in April 1999 (Koga 2003) reduced the rate to 15% and the definition of the base was changed. From 1999 the base is as the average of the three maximum R&D expenses in the past 5 years. From 2004, the rate of the credit is 8-10% (depending on firm R&D intensity) plus an additional 2% "as an aid of overcoming depressed economic situation" (OECD 2006). The average 11% total tax credit is applied here. **Depreciation:** 50 years SL for buildings[27] and for M&E. A depreciation schedule of 18% DB for M&E for the years 1980-2003, and 50% thereafter is applied here.[28] **CIT:**[29] 53.0% (1980), 55.2% (1981-1983), 56.6% (1984-1986), 55.2% (1987-1988), 53.0% (1989), 50.4% (1990-1997), 47.2% (1998), 42.4% (1999-2006).

Korea. R&D tax policy: An incentive introduced in 1988 allowed firms to claim a credit of 25% on incremental expenditure above a 2 year moving average base and 5% on the volume expenditure (10% on volume for small firms) (OECD 1998,

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[27] This is based on (Warda 1996b) and is also consistent with available figures for b-index published by the OECD.

[28] McFetridge and Warda (1983) suggests this is depreciated "over useful life 4-7 years. - This is close NPV to the 18% DB applied for later periods.

[29] Three forms of taxation levied on corporate profits in Japan are considered: central government rate, prefectural tax and citizen's tax. Corporations operating in Japan must also pay prefectural tax. The prefectural tax rate in this study is taken as 12% (deductible). The inhabitant's tax or enterprise tax is levied as a "surcharge on national income tax." In this study, Warda (1996b) is followed, applying a rate of 20.7%. Central government rate is taken from the WTD. The eventual series is very close to the Composite CIT reported by KPMG that takes into account these sub-national taxes. However this enabled calculation of an equivalent figure for years that are not included in the KPMG database (1980-1992). There was also a different tax rate applied to retained and distributed profits prior to 1999 this is not modelled here.

p.172). Between 1998[30] and 2004 companies could choose between either the 50% on incremental expenditure or 5% on the total volume of expenditure. The 50% incremental rate is applied here as it is the more generous of the two under the current assumptions. The reforms also changed the base to the average of the previous four years (OECD 2000b; Sawyer 2004). The rate of the incremental scheme was reduced from 50 to 40% in 2003 (Rashkin, 2007). **Deprecation:** Between 1980 and 1997 depreciation rates of 22.6% and 5.6% DB are applied for M&E and B&S respectively.[31] For the subsequent decade each are depreciated over 5 years on a SL basis (Warda 1999 and subsequent OECD documents). **CIT:** 30.0% (1980-1990), 34.0% (1991-1993), 32.0% (1994), 30.0% (1995), 28.0% (1996-2001), 27.0% (2002), 25.0% (2005).

Mexico. R&D tax policy: Between 1981 and 1982 (introduced November 1980) Mexico provided a tax credit on durables of 15-20% (McFetridge and Warda, 1983). The maximum 20% rate is applied here. There was also a credit of 10% for payment for 'R&D services'. These represent contract R&D or outsourcing part of the R&D process. Warda (1983) suggests such expenditure comprises around 8% of total R&D spending. Between 1983 and 1996 no special incentives were generally available. Between 1997 and 2001 expenditures above a three year moving average were eligible for a 20% credit (Sawyer 2004). Since 2002 a 30% credit has been available on expenditure (OECD 2006). Credits are untaxed; i.e., they do not reduce standard deductions. **Depreciation:** The depreciation rates applied are 3 and 20 years on a SL basis for M&E and B&S, respectively.

CIT: 42.0% (1980-1986), 35.0% (1987-88), 37.0% (1989), 36.0% (1990), 35.0% (1991-1993), 34.0% (1994-1998), 35.0% (1999-2002), 34.0% (2003), 33.0% (2004), 30.0% (2005), 29.0% (2006).

Netherlands. R&D tax policy: Netherlands represents an important case study for the effectiveness of R&D tax incentives. From 1994, R&D wages attracted a tax credit of 40% of the first 72,000 ECU and 12.5% of above (Hall 1995b). The 12.5 rate is modeled. This credit applies to salaries and these are assumed to constitute 60% of total representative R&D expenditure. The value of the concession increased to 13% in 2001 and to 14% from 2004. **Depreciation:** Depreciation rates applied are 5 and 25 years on a SL basis for M&E and B&S, respectively. **CIT:** 48.0% (1980-1983), 43.0% (1984-85), 42.0% (1986-88), 35.0% (1989-1995), 37.0% (1996), 36.0% (1997), 35.0% (1998-2001), 34.5% (2002-2004), 31.5% (2005), 29.6% (2006).

New Zealand. R&D tax policy: No special concessions or tax credits have been available during the period 1980-2005. The rules for deducting 'current' R&D

[30] Associated with the 'Special Law for S&T' enacted in 1997.

[31] This is consistent with Warda (1996b) and others. However, Warda (1983) notes 50% of these assets are depreciated up front with the remainder depreciated "over their useful lives". In the absence of further guidance, the 1996 information on asset deprecation has been applied back to 1980.

expenditure including wages have been subject to some uncertainty, particularly prior to 2001. While the situation prior to 2001 was somewhat ambiguous, a discussion paper prepared by the New Zealand Inland Revenue Department observes that "…although the tax treatment of R&D expenditure is uncertain, taxpayers are immediately deducting almost all of their R&D costs" (IRD 2000). Separate provisions (DJ 9 ITA 1994 and earlier s 144 ITA 1976) existed, allowing deductions for expenditure relating to scientific research. Provisions under ITA 1976 suggest a similar capital test. **Depreciation:** Following Warda (2006) a representative depreciation schedule of 22% (DB) is applied for M&E, and 4% (DB) for B&S.

CIT: 45.0% (1980-1985), 48.0% (1987-88), 28.0% (1989), 33.0% (1990-2006).

Norway. R&D tax policy: 1980-2001 no special concessions. 2002 - current 18% tax credit (OECD 2006). **Depreciation:** M&E and B&S depreciated at 20% and 5% (DB) respectively. **CIT:** 50.8% (1980-1991), 28.0% (1992-2006). Before the reform in 1992, basic CIT in Norway was 27.8% as cited in WTD. Corporations also paid municipal income tax (21% in 1989) and an additional 2% surtax (Genser 2001). McFetridge and Warda (1983) also cite the total rate as 51%.

Poland. R&D tax policy: From July 2005, large firms receive a 30% tax credit on expenditure "incurred to purchase new technologies" (IBFD online database). Accessibility is limited to firms which obtain at least 50% of their income from R&D, the law "enables entrepreneurs to deduct from their tax base expenditures on purchase of new technologies from research units" (OECD 2006, p.71). As such, it appears this incentive is not available for all 'in house' R&D. The purchase of R&D services is assumed to constitute 8% of R&D costs - analogously to the scheme in Mexico in 1980-82 (discussed above). **Depreciation:** prior to the 2005 reform, in principle, successful R&D expenditure is classified as an intangible asset and had to be depreciated over 3 years on a straight line basis (IBFD 2004). M&E and B&S did not attract any special treatment and are depreciated over 4 years and 40 years, respectively (IBFD online database 2007). After the reform in 2005 'current' R&D are expensed. **CIT:** 40.0% (1991-1997), 36.0% (1998), 34.0% (1999), 28.0% (2000-2002), 27.0% (2003), 19.0% (2004-2006).

Portugal. R&D tax policy: From 1997 to 2000, current R&D expenditure attracted a tax credit of 8% on the volume and 30% on incremental expenditure above the average expenditure in the previous 3 years (EC 2002).[32]. In June 2001 the credit was increased to 20% on volume and 50% on incremental expenditure (Decree law no 197/2001). It understood that the base changed to a 2 year moving average (OECD 2002b). 2004 No scheme in place (OECD 2006). From 2004 expenditure attracts a tax credit 20% on volume and 50% on incremental expenditure (IBFD online database). **Depreciation:** Depreciation schedule of 4 and 20 years (SL) for M&E and B&S, respectively is applied (consistent with Warda

[32] Decree law no 292/97, and prolonged to cover 2001, 2002 and 2003 by Article 60 of Law no 3-B/2000.

1996b and others).[33] **CIT:** 23.0% (1980-81), 40.0% (1982-1986), 35.0% (1987-88), 36.5% (1989-90), 36.0% (1991-1997), 37.0% (1998), 34.0% (1999), 32.0% (2000-01), 30.0% (2002-03), 25.0% (2004-06). WTD (2007) series show jumps in CIT to 39.6% in 1995 and 1997. These appear to be the sum of the 36% base tax rate and the 10% local surcharge. A rate of 36% is applied in these years.

Spain.[34] **R&D tax policy:** 1981-83 10% credit on all expenditure. Between 1984 and 1991, a credit of 15%. 1992-95, 15% credit on volume and 30% on incremental expenditure above a 2 year moving average. 1996-2000, 20% credit on volume and 40% on incremental expenditure Between 2001 and 2006, only current expenditure was eligible for the credit at a rate of 30% of volume and 50% on increment above the 3 year moving average. **Depreciation:** M&E costs are expensed, B&S 7 years SL 1980-1995, 10 years 1996 and 33 years 1997-2006.

CIT: 33% (1980-1983), 35% (1984-2006).

Sweden. R&D tax policy: 1980-1983 Special Deduction allowances of 10 % on wage payments grossed up by two thirds. i.e. 16.7% total wage payments (Warda 1983). In addition, a 20% deduction was available on the increment on the previous year's expenditure (wages). Effective 1 Jan 1982, the base credit was reduced from 10% to 5% applied to 250% of wages, implying a 12.5% concession on wages (i.e., 112% of wage costs are deducted). With this change the incremental component was also increased to 30%. No other special concession at other times. **Depreciation:** Depreciation rates 30% DB for M&E with B&S over 25 years SL.**CIT:** 40.0% (1980-1983), 32.0% (1984), 52.0% (1985-1989), 40.0% (1990), 30.0% (1991-1993), 28.0% (1994-2006).

Switzerland. R&D tax policy: Switzerland offered no special concession over the period covered by this study. **Depreciation:** Representative depreciation schedules applied are 40% and 8% (DB) for M&E and B&S respectively. **CIT:**[35] 30.2% (1980-1989), 28.5% (1990-1997), 27.5% (1998), 25.1% (1999-2000), 24.7% (2001), 24.5% (2002), 24.1% (2003-04), 21.3% (2005-06)

United Kingdom. R&D tax policy: 1980-2000 no special concessions. From 2000, 125% deduction on current expenditure is available for small companies with a turnover below 25m GBP (not modeled). From 1 April 2002, a similar concession was introduced for large firms of 125% deduction (IBFD 2007). **Depreciation:** Both M&E and B&S are deducted in the year of expense.

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[33] Note Warda (1983) applies 3 years for M&E however without knowing the exact year the laws were changed, or if this results from alternate interpretation of the same depreciation guidelines, to avoid erroneous temporal variation the same rate is applied across the whole time.

[34] Information for Spain was provided by J. Warda (personal communication).

[35] Switzerland CIT should consider the effect of the cantonal tax rate for Zurich. For 1993-2005, KMPG data is used. KPMG report a jump of 5pp to 29% for 2006, however the OECD tax database series suggests no change between 2005 and 2006. Prior to 1993, the CIT is calculated based on the CG rate from WTD and adding the last known cantonal rate (18.5 pp, inferred from the difference between WTD and KPMG and constant for the period 1993-1997).

CIT: 52.0% (1980-1983), 50.0% (1984), 45.0% (1985), 40.0% (1986), 35.0% (1987-1991), 33.0% (1992-1997), 31.0% (1998-1999), 30.0% (2000-2006).

United States. R&D tax policy: From 1981-1985 a 25% tax credit was available on incremental expenditure. The base is defined as the average of the previous three years with a maximum allowable credit of 50% of total R&D expenditure. In 1986, the credit is reduced to 20% of incremental expenditure. Until 1988, the credit itself was untaxed. In 1989 it was 50% taxable and from 1990 onwards it is 100% taxable. In 1990, the definition of the base expenditure was changed to reflect R&D to sales revenue over the period of 1984-88 (see Hall 1995b; JCT 1997). We model this identically to a trailing 4 year moving average base, which is the case for a representative firm with constant R&D expenditure and constant real R&D/sales ratio. **Depreciation:** applied is 5 years SL for M&E and for Buildings: 15yrs SL (1980-1984), 18yrs SL (1985), 19yrs SL (1986) and 39 years thereafter. The method for calculating depreciation was changed from 1987 with the introduction of the Modified Accelerated Cost Recovery System. **CIT:** 46.0% (1980-86), 40.0% (1987), 34.0% (1988-1992), 35.0% (1993-2006).