

THE EFFECTS OF GOVERNMENT SUBSIDIES ON BUSINESS R&D EMPLOYMENT: EVIDENCE FROM OECD COUNTRIES

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Existing evidence suggests that government subsidies stimulate business R&D expenditure. However, most studies fail to address the possibility that part of the observed increase in expenditure may be due to higher R&D wages. We consider the impact of different government subsidies on R&D workers in 25 OECD countries and find that the short run tax-price elasticity of R&D employment is marginally higher than existing estimates of the elasticity of expenditure with respect to the tax price of both labor and capital combined. We conclude that there is no evidence to indicate that wage inflation has seriously conflated past estimates of the effectiveness of government R&D subsidies.

Keywords: innovation policy, R&D tax incentives, R&D subsidies, wage inflation

JEL Codes: H25, O31, O57

I. INTRODUCTION

In this paper, we examine the effect of government subsidies on R&D employment using data on a panel of 25 Organisation for Economic Co-operation and Development (OECD) countries between 1983 and 2006.¹ A considerable body of cross-country empirical evidence suggests that government subsidies have a positive effect on the amount of business R&D expenditure (Hall and Van Reenen, 2000; Guellec and van Pottelsberghe, 2003; Bloom, Griffith and Van Reenen, 2002). However, if the supply of R&D inputs — such as skilled researchers — is inelastic, government subsidies may drive up wages rather than increase 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 percent (Goolsbee, 1998).

¹ The countries included are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Spain, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Mexico, Netherlands, Norway, New Zealand, Poland, Portugal, Sweden, United Kingdom, and the United States.

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More recent evidence — from studies using firm-level data — suggests that some of the observed increase in R&D expenditure is due to higher wages (Aerts, 2008; Lokshin and Mohnen, 2008; Wolff and Reinthaler, 2008). These findings seemingly cast further doubt over the effectiveness of government support for R&D and remind us that our focus should be on the effects of policy interventions on real R&D effort, rather than solely on R&D expenditure.² However, these studies have important shortcomings. First, as we argue below, it is difficult to identify market-wide effects using only firm-level data. Second, cross-country analysis is limited by the availability of exogenous measures of government subsidies (especially tax incentives) and the absence of suitable deflators through which to measure R&D effort,³ which have been perennial problems for analysis of the determinants of innovation (Griliches, 1979).

In the absence of cross-country R&D price deflators, we analyze the impact of government R&D subsidies in 25 OECD countries on a real (price-invariant) measure of the largest single component of R&D expenditure: the number of researchers employed in the business sector. We then compare these results with estimates of the effect of government R&D subsidies on R&D expenditure, which is the more conventional way of analyzing this issue. Although the main focus of our paper is the identification of the effects of R&D subsidies on R&D wage inflation, we also undertake preliminary analysis of the short-run and long-run effects of R&D subsidies.

An important contribution of our study is that we include a comprehensive suite of policy mechanisms for government R&D support, including tax incentives and monetary transfers. Including all types of subsidies overcomes the potential omitted variable bias that will arise if different policies are correlated. For example, governments may introduce more generous R&D tax incentives while at the same time reducing direct government R&D grants. Our second major contribution is that we have constructed a unique time-varying dataset on the various R&D tax incentives offered across OECD countries. Using these data, we are able to separately identify the effect of tax incentives directed at R&D capital from those directed at R&D labor. As a result, we are able to make some modest steps forward in assessing the degree of substitution (at the aggregate level) between labor and capital inputs in the R&D process.

Our main conclusion is that we find no evidence to suggest that wage inflation has attenuated the effectiveness of government R&D subsidies. We estimate that the short run tax-price elasticity of R&D employment is about -0.5 , which is marginally higher than existing estimates of the elasticity of expenditure with respect to the tax price (of both labor and capital combined). Our results suggest expenditure changes are most closely related to variation in tax policy relating to R&D labor. We also find that fiscal R&D subsidies and monetary transfers (direct grants and procurement) both have a positive effect on R&D employment and that, in the aggregate, R&D capital and R&D labor are gross substitutes.

² Examining the effects of policy interventions on R&D effort requires data on the skills of individual R&D workers that is currently unavailable. Nevertheless, it is important to remember that the ideal measure of performance is real R&D effort.

³ Some industry-specific R&D price deflators do exist — for example, Messinis (2004).

The paper is organized as follows. The next section provides a critical review of the existing literature. Section III outlines the analytical framework and empirical approach including data sources and variable construction. The results and analysis are presented in Section IV and Section V concludes.

II. BACKGROUND

Governments across the developed world employ a range of different policy instruments to stimulate business R&D investment.⁴ These include direct government R&D grants and procurement (which we refer to as “monetary transfers”) and a variety of different R&D tax incentives (including credits and augmented deductions). In this paper, we refer collectively to these policy instruments as “government subsidies for business R&D.” Many other scholars have tackled the difficult empirical issues associated with identification of the effects of direct R&D subsidies. Some studies focus on the effects of one type of policy instrument on firms in a single country, while others look at aggregate net effects of various policies at the country level. In this section, we provide a critical review of the literature.

One branch of the literature has analyzed the effects of R&D subsidies at the firm level in countries such as the United States, Finland, Canada and Netherlands. These studies face a number of methodological challenges. For example, in order to evaluate the effects of R&D tax incentives, firm-level studies must account for the fact that R&D investment and its after-tax cost are usually jointly determined (Hall, 1995). This can be handled using instrumental variables, although this reduces the accuracy of the estimated coefficients (Hall, 1992). With regard to examining the effectiveness of government R&D grants, different methodological approaches have been used (e.g. selection models, matching models) to address the potential endogeneity between R&D intensity and the receipt of government R&D grants (Aerts, 2008). Although these firm-level studies are not unanimous in their conclusions, the growing consensus is that R&D subsidies have a statistically significant, positive effect on business R&D expenditure (see also Eisner, Albert and Sullivan, 1984; Hall, 1992; Hall and Van Reenen, 2000; Czarnitzki, Hanel, and Rosa, 2011).

Until fairly recently, firm-level studies had failed to address the R&D wage-inflation effect. Recent studies have found evidence of a firm-level wage-inflation effect (Aerts, 2008; Lokshin and Mohnen, 2008). However, firm-level studies of the wage inflation effect face a serious limitation in that wage inflation — as described by Goolsbee (1998) — is a market-wide phenomena. As a result, it is difficult to disentangle the

⁴ In principle, government support for R&D aims to address the potential market failure arising from the public good characteristics 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 deadweight loss associated through raising tax revenue elsewhere. In this paper, we abstract from this more general question and focus on the effect of government subsidies for business R&D on real R&D effort, which we consider a necessary but not sufficient condition for policy intervention.

“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-subsidized firms. As Goolsbee (1998, p. 298) states: government spending can impact the wages of researchers “...even for firms not receiving federal support.”

To illustrate the limitations of using firm-level data to analyze this issue, consider a neoclassical market where firms recruit from a fixed number of homogeneous researchers. In this case, the consequences of a subsidy paid selectively to a sub-sample of firms are: (1) to reallocate workers from non-subsidized to subsidized firms;⁵ and (2) to raise the wage of *all* R&D workers. While this neoclassical framework is unlikely to reflect the complexities of the R&D labor market in practice, this heuristic illustrates the point that firm-level studies might observe an increase in employment in subsidized firms *even if aggregate labor supply is inelastic* since the pool of homogeneous R&D workers in this simple framework is fixed.⁶ Conversely, the absence of an observable difference in researcher wages (between subsidized and non-subsidized firms) does not rule out the possibility of aggregate wage inflation.⁷

Numerous studies analyze the impact of government subsidies for business R&D using aggregate country-level data. Although these studies are able to exploit some cross-sectional variation in the size of the subsidy — for instance, in the magnitude of the R&D tax credit — the use of cross-country data is limited in that it relies on a relatively small number of observations and that it only provides a cross-industry average effect. Nevertheless, the cross-country approach has made some inroads. Estimates of the short-run impact of R&D tax incentives based on cross-country data generally imply a tax-price elasticity of 0.15–0.30, and a long-run elasticity between 0.33 and unity (Bloom, Griffith, and Van Reenen, 2002; Guellec and van Pottelsberghe, 2003; Falk, 2006). However, none of these studies have tackled the issue of wage inflation, and may therefore have over-estimated the true effect of government subsidies for business R&D.

To tackle the wage inflation issue in a cross-country setting, Wolff and Reinthaler (2008) analyze the effect of the “aggregate subsidization rate,” which is the ratio of government-financed to own-financed business R&D expenditure, on total business R&D and number of researchers employed. They find that subsidies increase R&D expenditure by roughly 20 percent more than R&D employment, which they interpret as evidence of wage inflation. There are two limitations to their analysis. First, the authors go to considerable length to address the endogeneity of their subsidization rate,

⁵ Assuming diminishing returns to labor, the marginal product of researchers who remain employed in the non-subsidized firms will be higher and equal to the wages (inclusive of the subsidy) in the subsidized firms.

⁶ We recognize that the assumption of a fixed pool of homogeneous R&D workers is only likely to hold in the short-run.

⁷ This simple framework is essentially analogous to the capital tax outlined in Harberger’s (1962) tax incidence model. We thank an anonymous referee for pointing this out.

but robust instruments are difficult to find.⁸ Second, the result may simply reflect a shift in the composition of R&D expenditure from labor to capital. As the authors note, in the absence of data on labor and capital shares, this alternative explanation (and the degree of capital-labor substitution) cannot be tested.

III. FRAMEWORK AND EMPIRICAL APPROACH

A. Analytical Framework

The approach we adopt in this paper is to analyze the impact of government subsidies on R&D employment in the business sector, which is a real (price-invariant) measure of the largest single component of R&D investment.⁹ ¹⁰ Our focus is on the effect of subsidies on R&D inputs, not on R&D outputs.¹¹ Since expenditure on R&D equipment will independently influence the optimal level of R&D labor employed, we need to control for this to avoid omitted variable bias. Similarly, if expenditure on R&D equipment is not taken into account, we cannot distinguish between substitution toward labor (potentially at the expense of expenditure on capital) and increase in total effort. In the following, we sketch a simple dynamic model to motivate our empirical approach, the crux of which is to model aggregate labor demand as a function of the prices of R&D labor and capital.¹² Our approach therefore bypasses the need for an appropriate R&D price-deflator or data on the capital share of R&D expenditure.

Consider a firm that produces technology and final goods. Technology is produced using two inputs: R&D labor (L) and R&D capital (K). Final goods are produced using

⁸ In particular, the authors use government intramural R&D as an instrumental variable, which they find passes the Cragg-Donald test for weak instruments. However, other studies have shown that government intramural R&D is a *determinant* of business sector R&D in its own right, since intramural R&D is used to produce knowledge for use by firms in their own research and because government intramural R&D could also crowd out private sector R&D by driving up wages (Guellac and van Pottelsberghe, 2003; Falk, 2006). Goolsbee (1998) also notes that intramural R&D can affect researcher wages. However, Goolsbee (1998) does not distinguish between government intramural R&D and transfers to the private sector — he simply finds that the combined government funding affects wages. These results seem to call into question the validity of intramural R&D as an instrument. However, Wolff and Reinthaler (2008) report an over-identification test that supports its validity. Nonetheless, given the inherent limitations of testing for instrument exogeneity as well as the loss of efficiency associated with instrumental variables, we argue that an approach which avoids the need for instrumenting provides a valuable alternative.

⁹ Just over half of total R&D expenditure is reflected in the wage bill (OECD, 2002).

¹⁰ A limitation shared by all studies, including firm-level studies and existing deflators, is the inability to effectively control for changes in researcher skill. This issue is discussed further in the next section. In addition, we cannot account for the fact that some firms may re-label some existing activities to maximize the benefits offered via R&D tax incentive schemes (Hall, 1995; Griffith, Sandler, and Van Reenen, 1996).

¹¹ Measuring R&D outputs is subject to other complexities, particularly those relating to the treatment of spillovers and statistical identification in the presence of long lags between investment and indicators of technological output such as patents.

¹² Details of the derivation of the model can be found in the appendix.

the technology stock (G), according to a function $f(G)$.¹³ The firm's objective function is to maximize its discounted stream of profits over time. Changes in tax policy vary the effective prices of research inputs. Define c_L as the cost borne by the firm for each unit of labor-related R&D expenses after claiming all available tax liability deductions. For example, if profits are taxed at rate τ and the firm receives a tax credit of rate θ , then $c_L = (1 - \tau - \theta)$. Similarly, c_K is the after-tax cost of R&D capital. The firm's profit maximization problem can be described by the current value Hamiltonian given by

$$(1) \quad H = (1 - \tau)f(G) - c_K K - c_L L + \mu[R(L, K) - \delta G],$$

where $R(L, K)$ is the technology production function and δ is the depreciation rate of the technology stock. The most important insight from this simple model comes from the first-order condition that the ratio of R&D inputs is determined by their relative prices along the balanced growth path.¹⁴ This is critical to our analysis because it implies we can estimate a labor demand equation in the absence of data on R&D capital expenditure. That is, we can use data on the relative price of R&D labor and capital in place of data on the capital share of R&D investment, which are unavailable at the aggregate level.

We assume a constant elasticity of substitution (CES) technology production function, $R = [L^\rho + K^\rho]^{1/\rho}$, where $\varepsilon > 0$ captures returns to scale and $1/(1 - \rho)$ is the elasticity of substitution (with $\rho \neq 0, \rho \leq 1$). Finally assuming a Cobb-Douglas final good production function (with the output elasticity of technology stock denoted by γ), the steady-state labor demand equation is given by

$$(2) \quad L^* = \Phi \left[c_L / (1 - \tau) \right]^{\frac{1}{\gamma\varepsilon - 1}} \left[1 + (c_K / c_L)^{\frac{\rho}{\rho - 1}} \right]^{\frac{\rho - \gamma\varepsilon}{\rho(\gamma\varepsilon - 1)}},$$

where Φ is a constant comprising depreciation, discount rates, and productivity parameters.

Equation (2) illustrates that the cross-price elasticity of demand for R&D labor is theoretically ambiguous, because an increase in the price of R&D capital results in: (1) a substitution toward R&D labor (the substitution effect); and (2) a decrease in total technology stock maintained (the output effect). The substitution effect is determined by ρ and the output effect is determined by the returns to scale in the production functions (γ and ε). R&D capital and labor are gross substitutes if $\gamma\varepsilon < \rho$ (i.e., the cross-price elasticity of demand for R&D labor is positive).

Our estimating equation is reduced form in nature, but is motivated by this simple dual input convex adjustment cost investment framework. Our canonical statistical model is given by

$$(3) \quad L = L(c_L, c_K, (1 - \tau), TRANSFERS, GDP, PUBS, HERD, GOVRD, IPR),$$

where L is the number of researchers employed in the business sector (denoted by $RDEMP$); c_L and c_K are the after-tax cost of R&D labor and capital equipment,

¹³ For expositional clarity we omit time subscripts and also variable inputs to final good production.

¹⁴ Specifically, $K/L = (c_L/c_K)^\sigma$ where σ is the elasticity of substitution between capital and labor in the production of R&D.

respectively; τ is the rate at which profit is taxed; and *TRANSFERS* is the total monetary transfers (procurements and grants) provided by the government to business. We also include a vector of control variables that have been identified in the literature as important determinants of business R&D investment. These include: Gross Domestic Product (*GDP*); technological opportunity (proxied by the number of scientific publications, *PUBS*); the quality of postgraduate education (proxied by higher education R&D expenditure, *HERD*); capability building (proxied by government intramural R&D expenditure, *GOVRD*, which are R&D expenditures in the government sector during a specific time period); and appropriability conditions (proxied by the strength of national IP rights, *IPR*). The choice of control variables and their construction are elaborated below and our estimating approach is discussed in Section IV.

Our empirical approach includes the total dollar amount of transfers and tax incentives separately for two reasons. First, data on aggregate government-financed R&D do not include the value of tax incentives (OECD, 2002). We therefore constructed a new variable to measure R&D tax incentives. Second, the two forms of government R&D support may potentially affect firm behavior in different ways — particularly since the monetary transfers component includes procurement, which reflects both government finance and *demand* for technology.

B. Data and Variable Construction

In the following sections, we describe the sources and characteristics of the data used to construct the variables included in our estimating equations. The period of analysis is 1983–2006 ($t = 1, \dots, 24$), covering a cross-section of OECD countries ($i = 1, \dots, 25$). Data used to construct the variables are country-specific and time-varying. Our main dependent variable is the number of full-time equivalent (FTE) researchers in the business sector (*RDEMP*), which we collected from the OECD Main Science and Technology Indicators (OECD, 2008).

Ideally, we would include data on R&D employment quality — however, no such data exist at present so we use simple counts of R&D employment. Our empirical approach controls for average differences in skill composition between countries by controlling for country-level fixed effects. However, if the aggregate skill-share mix changes in response to variation in R&D subsidy this may introduce bias to our estimates; however, under any plausible conditions, our estimates will have advantages relative to traditional expenditure estimates of the elasticity of R&D activity.¹⁵ Moreover, the

¹⁵ Our estimates of the input elasticity with respect to subsidies will be subject to minimal bias if any of the following conditions hold: (1) different types of R&D workers enter the R&D production function in fixed proportions (i.e., the elasticity of substitution is approaching zero); (2) a specific skill type makes up a large share of total R&D labor; (3) R&D labor types have a “similar” productivity; or (4) the difference between the supply elasticities of different types of R&D labor is small. Note for example that in the year 2000 in the United States, only 10 percent of workers in science and engineering positions have doctorates, and the median wage (productivity) difference between these and the largest skill group (holders of bachelor’s degrees) is 20 percent (National Science Board, 2004).

issues of researcher quality are not treated any more satisfactorily in existing work on R&D price deflators.¹⁶

For comparative purposes we also model business expenditure on R&D (*BERD*) as a function of government subsidies in a manner similar to existing studies in the literature. Business R&D expenditure is measured in real 2000 U.S. dollars and is also taken from the OECD Main Science and Technology Indicators (OECD, 2008).

1. R&D Tax Incentives

Accounting for the variation in R&D tax policy design across countries and over time is one of the main contributions of our analysis. The construction of the R&D tax variables is consistent with the approach employed by Bloom, Griffith, and Van Reenen (2002) and the OECD's "B-index". However, the main difference between our measure and these past studies is the fact that we calculate separate measures for the after-tax cost of labor (c_L) and the after-tax cost of capital (c_K).¹⁷ Details of how the variable is constructed are provided below.

The cost borne by the firm through investing in R&D is reduced by allowable claims and deductions. The after-tax cost of R&D investment (denoted by ATC) can be expressed in general terms as $ATC = 1 - CIT \times Deduction - Credit$. This states that a firm's after-tax cost is reduced by allowable deductions multiplied by the corporate income tax (CIT) rate as well as any explicit tax credits. The value of deductions is determined by two factors: (1) the net present value of the stream of allowable claims; and (2) in countries that have an augmented deduction, the claimable amounts are multiplied by a factor greater than 100 percent. Note that firms receive an implicit subsidy if the allowable rate of depreciation is more rapid than the actual depreciation of the technology produced. For example, since R&D generally produces a stream of benefits persisting for some duration, allowing 100 percent of expenses to be deducted in the year they are incurred represents an implicit subsidy under an income tax. We calculate the after-tax cost for two categories of R&D expenditure: labor-related costs and tangible capital (e.g., R&D equipment). We identified the allowable rate of deduction as well as eligibility for additional credits for each category from a range of sources. In all cases in our sample labor expenses could be deducted at 100 percent in the year they are incurred (or more when an augmented deduction is allowable). The net present value (NPV) of deductions available for tangible capital depends on the allowable depreciation schedule, which is defined in the national tax code.^{18 19} Relevant

¹⁶ For instance, Dougherty et al. (2007) include 50 percent of the average researcher wage, implicitly assuming that differences in R&D wages are attributable to cost rather than quality.

¹⁷ Furthermore, other studies use Jorgenson's (1963) user cost of capital, whereas our preferred models incorporate the numerator and denominator of the user cost of capital separately. We experimented with different formulations including a "B-index" analogue. The results were consistent with those presented below.

¹⁸ The formulas used are: $NPV_{SL} = (1/T)[\{1 - (1+r)^{-T}\} / \{r / (1+r)\}]$ and $NPV_{DB} = d\{(1+r)/(d+r)\}$, for straight line and declining balance depreciation respectively, where r is the discount rate, or required rate of return.

¹⁹ We calculated measures for "machinery and equipment" and for "buildings and structures." We tested a range of different shares of machinery and equipment (from 60 percent to 100 percent). Results presented in the next section use machinery and equipment only. However, the findings are not sensitive to the use of different tangible capital mix.

augmented deductions are applied to the NPV determined by the allowable depreciation schedule.

A common type of policy — known as an “incremental” incentive — is where only R&D expenditure over-and-above a defined base level is eligible for credits or augmented deductions. A common way to define the base is the average expenditure in the previous three years. This type of incremental incentive complicates modeling the effective incentive power of tax policy. Firms that do not increase their expenditure receive no credit. For a firm that increases nominal spending, the marginal R&D dollar is eligible for the tax credit, but also reduces the share of *future* expenditure that will be eligible. Following past cross-country studies we model incremental incentives, where the base is defined as a trailing k -period moving average of expenditures, by multiplying the credit or deduction rate by $1 - (1/k)\sum_{i=1}^k (1+r)^{-i}$ which reflects the marginal value of an incremental incentive for a firm with increasing R&D expenditure, or equivalently the average share of eligible expenditure for a firm maintaining constant real R&D expenditure (Richardson and Wilkie, 1995).²⁰

Data for central government corporate income tax rates come from the University of Michigan World Tax Database (2007) extended to more recent years using OECD (2007). Some missing data were obtained using the KPMG Corporate Tax Rate Survey (KPMG, 2007) and World Bank World Development Indicators (World Bank, 2007).

Table 1 summarizes the tax treatment of R&D data, including the mean and range over the period of analysis for the after-tax cost of labor (c_l), the after-tax cost of capital (c_k), and the corporate income tax rate (denoted CIT).²¹

There are some limitations to our measure of R&D tax incentives. First, we assume firms have sufficient tax liabilities to fully benefit from any incentives. The extent of measurement error this assumption introduces is mitigated by the fact that firms are able to carry forward credits.^{22,23} If solvency implies that the firms earn a pre-tax profit (on average), the magnitude of this error should be small. More importantly, there is no reason to suspect that any measurement error will be correlated with unobserved factors that independently determine aggregate R&D investment. The measure also does not incorporate “caps” and “floors” or differences in the tax treatment of personal income tax, shareholder dividends or withholding taxes on international transfers of

²⁰ While it is not pursued here, an alternative approach taken by some authors using firm level data is to use the firm’s actual R&D schedule. However, this approach gives rise to endogeneity because firms can simultaneously choose both current and future R&D investment to maximize the benefit they receive from the subsidy (Hall, 1992).

²¹ Details regarding country-specific R&D tax treatment policies are available in Thomson, 2012.

²² The effective value of the subsidy is reduced, among other things, by the time cost of money (unless carry forward credits are indexed).

²³ Several countries have other mechanisms by which firms that temporarily do not earn a taxable profit can fully benefit from the tax incentive (over and above the ability to carry forward claimable credits and deductions). These mechanisms include cash rebates for loss-making firms and providing the credit directly on the companies wage bill rather than through the corporate income tax (as is the case, for example, in Norway and Netherlands). We note that these features will act to reduce measurement error though we do not model the extent to which these mitigate measurement error explicitly.

Table 1
Summary of Tax Treatment of R&D Expenditures, by Country, 1983–2006

Country	c_L		c_K		<i>CIT</i>	
	Mean	Range	Mean	Range	Mean	Range
Australia	49	26–60	55	33–69	38	30–49
Austria	55	42–69	65	47–79	40	25–55
Belgium	59	50–67	59	52–66	41	33–48
Canada	49	43–55	49	43–55	40	31–46
Czech Republic	63	48–72	72	65–80	34	24–42
Denmark	63	50–72	65	50–77	37	28–50
Finland	68	51–81	76	66–85	31	19–43
France	56	45–60	65	56–71	39	33–50
Germany	45	38–62	55	49–72	55	38–62
Greece	60	51–71	61	51–74	40	29–49
Hungary	69	60–82	79	64–85	23	16–40
Ireland	88	55–90	89	55–90	10	10–10
Italy	56	48–64	70	65–75	44	36–52
Japan	47	42–55	63	50–70	50	42–57
Korea, Republic of	64	58–70	73	69–77	29	25–34
Mexico	59	36–66	67	62–74	36	29–42
Netherlands	56	50–65	68	60–75	38	30–48
New Zealand	63	52–72	72	64–79	37	28–48
Norway	59	49–72	72	63–79	38	28–51
Poland	67	60–81	72	65–83	32	19–40
Portugal	60	44–77	71	65–80	34	23–40
Spain	45	32–57	47	35–65	35	33–35
Sweden	64	48–72	71	57–77	35	28–52
United Kingdom	62	48–70	63	48–70	37	30–52
United States	59	50–65	68	62–72	38	34–46

Source: Authors' calculations

profit.²⁴ Finally, we do not model tax based incentives offered in a few instances by sub-national governments.²⁵ Although this may introduce some measurement error (primarily affecting a few federal systems, such as the United States and Canada), there is no reason to believe that any measurement error will be systematically correlated with our key variables of interest.

2. Monetary Transfers (Competitive Grants and Procurement)

Our model includes a measure of business R&D financed by government (*TRANSFERS*) — that is, the total amount of R&D transfers to business from government for the purpose of R&D. The data come from the OECD Main Science and Technology Indicators (OECD, 2008) and do not include benefits to firms from tax incentives (OECD, 2002). Transfers include competitive grants and procurements, though it is not possible to distinguish between these two different types of government support. The total dollar amount of transfers is exogenous since governments typically budget grant and procurement expenditures in advance. However, there is no simple way to incorporate a subsidy rate that is exogenous. The national aggregate subsidy rate employed by Wolff and Reinthaler (2008) is the ratio of public to private expenditure on R&D. However since this ratio can vary due to changes in private sector R&D investment (even holding constant government subsidies), this introduces endogeneity. We therefore follow Guellec and van Pottelsberghe (2003), Falk (2006) and others in that we incorporate the total value of transfers in our model, rather than a subsidy rate. The contemporaneous figure is used because these data come from national surveys which are conducted *ex post*, so government funds actually spent in the given year are recorded.

3. Control Variables

Government intramural R&D data (*GOVRD*) were collected from OECD (2008). 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

²⁴ 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.

²⁵ Wilson (2009) shows that R&D tax credits offered by U.S. states have become increasingly generous in recent years. The average effective credit rate is approximately one half the value of the federal credit rate. To incorporate this level of detail into our analysis would require weighting tax policy against the proportion of national R&D performed in each region. State incentives often reduce eligibility for national incentives, implying that this is unlikely to be a serious limitation.

mechanism for building domestic R&D capacity. Therefore, we include government intramural R&D as an explanatory variable in the model. *GDP* is included to capture scale effects, or equivalently, this may be interpreted as a measure of domestic demand.

R&D performed by the tertiary education sector (*HERD*) is included primarily as a proxy for the quality of postgraduate research education. However, in the short run *HERD* may also crowd out private sector R&D, especially noting the relatively large share of gross national R&D undertaken in the higher education sector in our sample (22 percent across the pooled sample). *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. *HERD* data were collected from OECD (2008). This measure is superior to other proxies for the quality of postgraduate education — such as the percentage of the population with tertiary education — because it has greater coverage and more directly reflects both the number and quality of research-based degrees.

The variable *IPR* measures the strength of the intellectual property rights (IPR) regime (Ginarte and Park, 1997), which is a proxy for the appropriability conditions in each country. Patents and other types of IPR effectively represent an implicit subsidy for business R&D, though we do not attempt to report a subsidy equivalent. For each country, a score on a 1–5 scale is calculated at 5-year intervals (which were linearly interpolated) based on five features of the national patent regime: (1) coverage; (2) membership of international agreements; (3) provisions for loss of protection; (4) enforcement mechanisms (potential); and (5) duration of patent protection. Although measures based on reviews of legislation have been criticized for not sufficiently reflecting enforcement in practice (Branstetter, Fisman, and Foley, 2006), the Ginarte-Park index remains the best available means for controlling for IPR strength in cross-country empirical analysis.

We include the number of published scientific journal articles²⁶ (*PUBS*) in each country in each year to control for technological opportunity. The data come from World Development Indicators (World Bank, 2007). Journal article publication rates are an output-based measure of performance of academic research recorded by location of the institution of the author (National Science Board, 2008). While this measure has the advantage of being widely available both across countries and over time, it is a noisy measure of technological opportunities since some scientific research may have many commercial applications while other published research may have little (or no) immediate commercial value.

Table 2 summarizes the data for the country-year observations used in our analysis. Missing data for control variables are interpolated linearly.²⁷

²⁶ The measure includes articles published in the fields of physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

²⁷ Interpolation affects 38 observations, 18 of which are missing data for scientific journal articles for 1983 and 1984. A further 13 are biannual survey data for *HERD*.

Table 2
Pooled Summary Statistics

	Theory Variable	Empirical Variable	Mean	Standard Deviation
R&D employment (number of FTE researchers in the business enterprise sector, thousands)	L	$RDEMP$	103	217
Business expenditure on R&D (\$million)		$BERD$	19,854	41,031
After-tax cost of R&D labor	c_L	$LABCOST$	0.59	0.12
After-tax cost of R&D capital	c_K	$CAPCOST$	0.66	0.12
Corporate income tax rate	τ	CIT	0.36	0.11
Government grants and procurement (business R&D financed by the government, \$million)	n/a	$TRANSFERS$	2,169	6,371
Scale (GDP, \$billion)	n/a	GDP	1,181	2,013
Technological opportunity (number of scientific journal articles)	n/a	$PUBS$	25,116	42,908
Postgraduate education quality (R&D by higher education sector, \$million)	n/a	$HERD$	4,054	6,801
Capability building (government intramural R&D, \$million)	n/a	$GOVRD$	3,726	7,009
Appropriability conditions (national strength of IPR, index)	n/a	IPR	4.0	0.7

Notes: The number of observations is 374, and the number of countries is 25. The panel is unbalanced and, with some gaps, the maximum number of years of observation is 24 (1983–2006). All dollar amounts are in real U.S. dollars (base year 2000) at market exchange rates. Due to the unbalanced nature of the panel, the 374 observations included in the regression models cover the years 1983–2006 and all countries included in Table 1.

IV. RESULTS AND ANALYSIS

In this paper, our main aim is to estimate the tax-price elasticity of R&D labor in order to assess the extent of possible input price inflation. Recall that previous research indicates that the short-run tax-price elasticity of R&D expenditure in the order of 0.15–0.30, with a long-run elasticity of between 0.33 and unity (Bloom, Griffith, and Van Reenen, 2002; Guellec and van Pottelsberghe, 2003; Falk, 2006). According to some studies these estimates may be too high by 20–50 percent (Goolsbee, 1998; Wolff and Reinthaler, 2008). We hope to shed light on this issue in two ways. First, we compare our estimates of the tax-price elasticity of R&D labor with previous estimates of the tax-price elasticity of R&D expenditure. We expect that if input price inflation is evident, our estimates will be commensurately lower than comparable estimates of previous researchers using expenditure. Second, using our data, we estimate the elasticity of R&D expenditure with respect to the tax-prices of R&D capital and labor. In the absence of input price inflation we expect the labor tax-price elasticity of expenditure to be no more than 60 percent as large as the elasticity of R&D labor — since labor related costs constitute around 60 percent of R&D expenditure (Bloom, Griffith, and Van Reenen, 2002). Using these two sets of comparisons enables us to draw some conclusions about the existence and extent of any input price inflation associated with R&D subsidies.

Our estimation method is guided by the statistical properties of the data. R&D employment data are highly persistent: a Fisher panel unit-root test (Maddala and Wu, 1999) indicates that the autoregressive coefficient is statistically indistinguishable from unity.²⁸ This means that the R&D labor series is non-stationary, so shocks accumulate rather than reverting to an underlying trend. We therefore proceed with an empirical approach that can accommodate non-stationarity.²⁹ Our approach to this issue is to difference the data, which enables us to estimate the short-run impact based on regressions of stationary series while also purging the data of time-invariant heterogeneity related to unobserved country characteristics and differences in scale across countries.³⁰

There are several reasons why the long-run effect may differ from the short-run effect. In particular, even if we find evidence of input price inflation in the short-run, this may not be present in the long-run. For instance, if the elasticity of supply of skilled researchers is higher in the long-run than in the short run, then the extent of “overestimation” of the impact of subsidies on R&D activity should be larger in the short-run than the

²⁸ The Fisher test combines information from augmented Dickey-Fuller tests on each individual country sample. The T test statistic (which exhibits a χ^2 distribution with 50 degrees of freedom) was 42.4, reflecting a p-value of 0.77.

²⁹ We recognize that in a panel setting, where identification rests on variation along both T and N, that non-stationarity does not always lead to problems of spurious regression (Phillips and Moon, 2000; Hsiao, 2003).

³⁰ Differencing the data comes at a cost of some observations, since we are only able to include countries that have consecutive years of data available. However, missing control variable data are minimized via the interpolation described in Section III.B.3.

long-run. We therefore also estimate the long-run effects by augmenting the differenced model with error correction terms and a partial adjustment model.

It is worthwhile reflecting on the reasons why the short-run and long-run effects may be different. The first reason relates to supply: it is commonly asserted that the supply elasticity of researchers may be smaller in the short-run than over the long-run due to the fact that it takes time to educate and train new scientists and engineers. While this is no doubt true, it should also be noted that education is not the only source of supply of researchers. Researchers can also be recruited from other sectors of the economy and from abroad. Lee, Miozzo, and Laredo (2010) surveyed 102 people who graduated with a science and engineering PhD between 1998 and 2001 from the University of Manchester. They found that 37 percent got their first job (after graduation) in non-research or non-technical occupations, which increased to 58 percent for the most recent job.³¹ Such workers could potentially be enticed back into research positions in response to growing demand for their skills. It is also widely recognized that highly-trained scientists and engineers are globally-mobile employees (National Science Board, 2004). Indeed, Mahroum (2000) describes immigration as “an inseparable segment of national technology policies.” Second, the *demand* elasticity may be lower in the short-run than over the long-run due to frictions associated with hiring and firing research staff.³²

A. Short-Run Effects

The short-run impact of government subsidies for business R&D is estimated using a simple log-linear equation in differences

$$(4) \quad \Delta L_{it} = \alpha_0 \Delta c_{L,it-1} + \alpha_1 \Delta c_{K,it-1} + \alpha_2 \Delta TRANSFERS_{it} + \alpha_3 \Delta (1 - \tau_{it-1}) + \beta \Delta X_{it-1} + \lambda_t + \varepsilon_{it}.$$

The principal coefficients of interest are the short-run own-price elasticity of demand for R&D labor (α_0) and the short-run cross-price elasticity of demand (α_1). Year effects are denoted by λ_t (e.g., trends toward higher tax-based subsidies, technology shocks, etc.), and ε_{it} is the residual independent error term. Consistent with the approach used by Guellec and van Pottlesberghe (2003), our explanatory variables are lagged since both policy announcements and changes in inputs (*HERD*, *SJA*) are anticipated to affect investment in the subsequent period. This also reduces the potential for endogeneity.

³¹ This is broadly consistent with the figures reported in the United States by Stephan et al. (2004). Only about half of the workforce with degree qualifications in a science and engineering field are employed in science and engineering (National Science Board, 2004). Goolsbee (1998) observes that only 40 percent of people who describe their occupation as scientist, life scientist, or engineer are actually employed in R&D.

³² Furthermore, R&D undertaken as a consequence of government support might, over time, create technological breakthroughs (e.g., the internet) which in turn stimulates demand for a whole new area of private business R&D investment, an effect that has been described as the “spillover effect” (Wolff and Reinthaler, 2008). However, the impact of current research on the productivity of future R&D is the subject of some debate (Jones, 1995; Jones and Williams, 2000).

The results from our short-run analysis are presented in Table 3. In column (1) we present a parsimonious model with $\Delta RDEMP$ as the dependent variable and a set of explanatory variables. In column (2), we extend this model to incorporate additional control variables. The results are quite similar across both models. Our principal interest is in the effectiveness of government subsidies in driving real increased R&D effort. The first variable of interest in this regard is after-tax cost of R&D labor, $\Delta LABCOST_{it-1}$, the coefficient of which indicates that a reduction in the tax-price of R&D wages of 10 percent increases R&D employment by around 5 percent. This is somewhat on the high end of estimates of the short-run effect of R&D tax subsidies in previous cross-country analysis.³³ We postulate a reason for this below.

The short-run cross-price elasticity of R&D labor with respect to after-tax cost of R&D capital — as indicated by the variable $\Delta CAPCOST_{it-1}$ — is positive and significant. This means that, at the aggregate level, R&D capital and R&D labor are gross substitutes. The magnitude of this elasticity suggests that a 10 percent increase in the tax-price of R&D capital leads to a 2 percent increase in R&D employment. Although there are no other studies on the degree of substitution between R&D labor and capital, our findings seem to contradict the view that “... capital and labor are more likely to be complements in research” (Wolff and Reinthaler, 2008, p. 1410). We agree that *a priori*, one would expect the elasticity of substitution between R&D capital and labor to be low at the project level. However, we contend that this may not hold in the case of aggregate data. One reason is that there is considerable variation in the capital-labor ratio between different projects and across industrial sectors. At the economy wide level, resources can flow to different sectors and different projects, implying a greater degree of substitution in the aggregate.

Direct government R&D support in the form of grants and procurement ($TRANSFERS_{it}$) is also found to have a statistically significant positive impact on R&D employment. The short-run impact is only 0.07, which suggests considerable crowding out of private investment by government-financed business R&D. While this seems rather low, it is worth pointing out that our estimate of the impact of government subsidies to R&D on the number of researchers employed is identical to the effect on business R&D expenditure estimated by Guellec and van Pottelsberghe (2003).

The other variables included in the model are essentially control variables. However, they are also of some interest. Real research effort is found to be strongly pro-cyclical, as inferred by the fact that the coefficient of GDP growth is positive and statistically significant. The number of science and engineering articles published ($PUBS$) is significant and positive, while $HERD$ has a negative impact on R&D employment in the business sector in the short run. We interpret this as indicating that the short-run crowding-out effect dominates, which is not entirely surprising given the relatively large

³³ However, we note that in a recent study of Australian firms, Thomson (2010) found no evidence of a statistically significant effect of R&D tax policy. This may be due to the idiosyncrasies of the Australian policy (including the dividend imputation system), and general statistical issues that make observing an effect using firm-level data difficult.

Table 3
Regression Results, Short-Run Effects

Dependent Variable:	(1) $\Delta RDEMP$	(2) $\Delta RDEMP$	(3) $\Delta BERD$
$\Delta LABCOST_{t-1}$	-0.512*** (0.0819)	-0.529*** (0.0811)	-0.262*** (0.0716)
$\Delta CAPCOST_{t-1}$	0.189* (0.103)	0.202** (0.102)	0.000467 (0.0903)
$\Delta TRANSFERS_{t-1}$	0.0803*** (0.0163)	0.0717*** (0.0164)	0.0604*** (0.0145)
$\Delta(1 - CIT)_{t-1}$	0.369** (0.179)	0.351** (0.179)	0.330** (0.158)
ΔGDP_{t-1}	0.751*** (0.242)	0.735*** (0.247)	0.998*** (0.218)
$\Delta PUBS_{t-1}$		0.241** (0.100)	0.175** (0.0883)
$\Delta HERD_{t-1}$		-0.150** (0.0696)	-0.0926 (0.0614)
$\Delta GOVRD_{t-1}$		0.0751 (0.0629)	0.100* (0.0555)
ΔIPR_{t-1}		0.202 (0.199)	0.154 (0.176)

Notes: The number of observations is 374, and the number of countries is 25. All variables are in natural logarithms. Standard errors are shown in parentheses. Asterisks denote significance at the 1% (***), 5% (**), and 10% (*) levels. All models include year dummies.

share of national R&D that is undertaken by the higher education sector (22 percent for the pooled sample).

For comparative purposes, column (3) in Table 3 reports an analogous model using business R&D expenditure ($\Delta BERD$) as the dependent variable (rather than $\Delta RDEMP$). The estimates are entirely consistent with our earlier results. We find that the elasticity of total R&D expenditure with respect to changes in the tax-price of R&D labor to be -0.262, about half as large as the impact of the R&D labor tax-price on employment.

This is close to what we would expect with no wage inflation, given that labor costs typically make up about 60 percent of total R&D expenditure.

However, we do not observe any impact of variation in the after-tax cost of R&D capital on total R&D expenditure (this variable is not statistically significant). This may be due to the fact that identification is inhibited by the reasonably high correlation between the two tax-price measures (0.75 for the pooled sample). To explore this we considered a range of alternative specifications — such as including only the tax-price of capital — but we still did not observe (somewhat surprisingly) a statistically significant effect of the tax-price of capital on overall R&D expenditure.

How should this be interpreted? It might reflect the fact that measuring the tax-price of capital goods necessarily incorporates more noise than equivalent measures of the tax-price of labor since, for example, we must assume a single representative depreciation schedule for R&D equipment in each tax regime. Alternatively, it may reflect the fact that firms do not respond measurably to variation in the tax-price of capital. Although we cannot confirm which of these explanations might underpin our failure to identify a robust relationship between the tax-price of capital and expenditure, we speculate that variation in the labor tax-price is in fact the main source of variation contributing to identification of changes in expenditure. This may explain why our estimate is somewhat higher than those of Guellec and van Pottelsberghe (2003).

B. Long-Run Effects

Since we did not find evidence of input price inflation in the short-run, it is unlikely to be observable in the long run. Nonetheless, we also provide some preliminary analysis of the long-run effects. The R&D labor series appears to be integrated of order 1 which means that shocks accumulate permanently. In this case, long-run relationships between variables (where they are found to exist) are interpreted in terms of cointegration as linear combinations of $I(1)$ variables that are $I(0)$. For example, while total full time equivalent researchers employed in the private sector is non-stationary, it might be that the ratio of R&D workers to GDP (or some other linear combination of regressors) is stationary, i.e., it has a tendency to revert to an underlying trend relationship. We expect the government R&D subsidy rate to be mean-reverting and therefore stationary.³⁴ Pesaran, Shin, and Smith (2001) show that we can use a standard error correction model to identify long run relationships between groups of variables that include both $I(1)$ and $I(0)$ variables as long as the dependent and independent variables (collectively) are cointegrated.

We therefore consider two adjustment models. The first augments the difference model (4) with error-correction terms, which are the residuals of (3) estimated in levels

³⁴ For example, as the generosity of a tax subsidy increases it becomes relatively more likely that it will be reduced than increased further.

(that is, the deviation from the predicted number of researchers employed). The general form of the error-correction model is given by

$$(5) \quad \Delta L_{it} = \alpha_0 \Delta c_{L,it-1} + \alpha_1 \Delta c_{K,it-1} + \alpha_2 \Delta TRANSFERS_{it} + \alpha_3 \Delta(1 - \tau_{it-1}) + \beta \Delta X_{it-1} + \delta \hat{\epsilon}_{it-1} + \eta_{it},$$

where

$$\hat{\epsilon}_{it} = L_{it} - (\gamma_0 c_{L,it-1} + \gamma_1 c_{K,it-1} + \gamma_2 TRANSFERS_{it-1} + \gamma_3 \Delta(1 - \tau_{it-1}) + \beta' X_{it-1}).$$

With sufficient panel length, this specification provides estimates of the short- and long-run impacts of government R&D subsidies without constraining the shape of the adjustment path. In this model, the short-run impact is given by the α 's. The long run impacts, denoted by γ_n for $n \in \{0,1,2,3\}$, are retrieved by dividing the coefficient of the lagged variable in levels by the coefficient of the lagged dependent variable (denoted by δ). Since we include control variables in levels we consider time invariant heterogeneity in our estimation approach.³⁵

As an alternative we also consider a partial adjustment model given by

$$(6) \quad L_{it} = \delta' L_{it-1} + \gamma_0 c_{L,it-1} + \gamma_1 c_{K,it-1} + \gamma_2 TRANSFERS_{it} + \gamma_3 \Delta(1 - \tau_{it-1}) + \beta' X_{it-1} + e_{it}.$$

A partial adjustment model imposes an adjustment process and lacks a formal treatment of cointegration, but allows us to employ standard econometric techniques to account for dynamic panel bias. Given that dynamic panel bias diminishes quadratically in T (Nickell, 1981), dynamic panel bias may not be considered a major issue. However, for robustness, we also consider both the Kiviet (1995) corrected least square dummy variable estimates and GMM estimators. Regarding our choice of GMM estimator, since the series are I(1) the differenced GMM proposed by Arellano and Bond (1991) is not identified. However, Binder, Hsiao, and Pesaran (2005) show that levels GMM remains identified even if the series is I(1) as long as the variance of the initial observation is finite and uncorrelated to the unobserved heterogeneity.

Results for the error correction model are presented in Table 4. In column 1 of Table 4, we present a parsimonious error-correction model with a restricted set of control variables, and in column 2 we present the same model augmented with additional control variables. In column 3, we present a comparable set of estimates using R&D expenditure data rather than R& employment data. From the parsimonious R&D employment model (column 1), we find a long-run own-cost elasticity of R&D labor of -2.55 .³⁶ Although the short-run impacts are consistent with those presented above, overall the

³⁵ That is, we assume standard error components $\eta_{it} = \lambda'_{it} + \kappa_i + \epsilon'_{it}$, where λ'_{it} represents year effects, κ_i is unobserved time-invariant heterogeneity, and ϵ'_{it} is an independent noise term.

³⁶ This is calculated by dividing the coefficient of the labor tax-price variable by the coefficient of the lagged employment variable, i.e., $0.181/0.0709=2.553$.

Table 4
Regression Results, Error Correction Model

Dependent Variable:	(1) $\Delta RDEMP$	(2) $\Delta RDEMP$	(3) $\Delta BERD$
$BERD_{t-1}$			-0.102*** (0.0313)
$RDEMP_{t-1}$	-0.0709*** (0.0249)	-0.0700*** (0.0266)	
$LABCOST_{t-2}$	-0.181*** (0.0656)	-0.101 (0.0729)	-0.00484 (0.0612)
$CAPCOST_{t-2}$	0.0635 (0.0605)	0.102 (0.0629)	0.0698 (0.0571)
$(1 - CIT)_{t-2}$	0.208* (0.113)	0.0619 (0.122)	-0.0653 (0.110)
$TRANSFERS_{t-1}$	0.0168 (0.0132)	-0.00901 (0.0167)	0.00247 (0.0155)
GDP_{t-2}	-0.0721 (0.0738)	-0.162* (0.0869)	-0.127 (0.0808)
$PUBS_{t-2}$		0.0623 (0.0405)	0.0468 (0.0375)
$HERD_{t-2}$		-0.0375 (0.0434)	-0.0358 (0.0394)
$GOVRD_{t-2}$		0.00411 (0.0345)	0.0247 (0.0313)
IPR_{t-2}		0.147** (0.0746)	0.182** (0.0719)
$\Delta LABCOST_{t-1}$	-0.506*** (0.0824)	-0.497*** (0.0836)	-0.206*** (0.0755)
$\Delta CAPCOST_{t-1}$	0.186* (0.102)	0.206** (0.102)	0.0143 (0.0926)
$\Delta TRANSFERS_{t-1}$	0.0815*** (0.0170)	0.0696*** (0.0174)	0.0613*** (0.0159)
$\Delta(1 - CIT)_{t-1}$	0.508*** (0.186)	0.414** (0.188)	0.254 (0.171)
ΔGDP_{t-1}	0.809*** (0.264)	0.761*** (0.273)	1.103*** (0.249)

Table 4 (continued)
Regression Results, Error Correction Model

Dependent Variable:	(1) $\Delta RDEMP$	(2) $\Delta RDEMP$	(3) $\Delta BERD$
$\Delta PUBS_{t-1}$		0.175 (0.136)	0.181 (0.123)
$\Delta HERD_{t-1}$		-0.0979 (0.0774)	-0.0754 (0.0707)
$\Delta GOVRD_{t-1}$		0.0562 (0.0639)	0.0927 (0.0583)
ΔIPR_{t-1}		0.154 (0.249)	0.135 (0.226)
Observations	374	374	374
R-squared	0.2626	0.3006	0.3234
Number of countries	25	25	25

Notes: All variables are in natural logarithms. Standard errors are shown in parentheses. Asterisks denote significance at the 1% (***) , 5% (**), and 10% (*) levels. All models include year dummies.

error-correction model results are not strong, as few statistically significant long-run relationships can be observed. We believe we are simply demanding too much of our small data set, which of course is one of the main drawbacks with cross-country analysis.

Table 5 depicts three dynamic panel estimators of the partial adjustment model. Column 1 depicts fixed effects estimates. Column 2 depicts GMM suggested by Blundell and Bond (1998), and column 3 depicts Kiviet (1995) corrected least squares dummy variable. Column 4 presents the fixed effects estimates using *BERD* as the dependent variable.

Based on this approach, we observe a short-run elasticity of R&D labor with respect to its own after-tax cost of between -0.181 and -0.318 , and a long-run elasticity of between -1.31 and -3.29 .³⁷ We regard the latter result as quite high, which may reflect the general statistical difficulties discussed above. We note, however, that this is reasonably consistent with the estimates of the elasticity of R&D expenditure with respect to tax-price reported in Hall's (1992) seminal evaluation of the US tax credit using firm-level data. Results regarding the after-tax cost of R&D capital are statistically significant

³⁷ Long run impact factors are given by the coefficient of the tax-price divided by one minus the coefficient on the lagged dependent variable. In the case of the fixed effects estimates (column 1), this is $-0.318/(1-0.865) = -2.356$. For the Kiviet estimates (column 2), this is $-0.293/(1-0.911) = -3.292$. For the GMM estimates (column 3), this is $-0.181/(1-0.862) = -1.312$.

Table 5
Partial Adjustment Model

Dependent Variable:	(1) $\Delta RDEMP$ FE	(2) $\Delta RDEMP$ Kiviet ¹	(3) $\Delta RDEMP$ GMM ²	(4) $\Delta BERD$ FE
$BERD_{t-1}$				0.764*** (0.0323)
$RDEMP_{t-1}$	0.865*** (0.0249)	0.911*** (0.0353)	0.862*** (0.0730)	
$LABCOST_{t-1}$	0.318*** (0.0644)	-0.293*** (0.0827)	-0.181*** (0.0406)	-0.118* (0.0625)
$CAPCOST_{t-1}$	0.117* (0.0601)	0.101 (0.0737)	0.101** (0.0462)	0.0981 (0.0613)
$(1 - CIT)_{t-1}$	0.297** (0.115)	0.316** (0.159)	0.229*** (0.0503)	0.0679 (0.117)
$TRANSFERS_{t-1}$	0.0341** (0.0146)	0.0311* (0.0185)	0.0299* (0.0172)	0.0344** (0.0153)
GDP_{t-1}	-0.00152 (0.0846)	-0.0200 (0.116)	0.0460*** (0.0157)	0.143 (0.0882)
$PUBS_{t-1}$	-0.00448 (0.0372)	-0.00627 (0.0455)	0.00384 (0.0266)	-0.0376 (0.0386)
$HERD_{t-1}$	-0.00959 (0.0403)	-0.00755 (0.0507)	0.0324 (0.0203)	0.0259 (0.0413)
$GOVRD_{t-1}$	-0.0370 (0.0326)	-0.0408 (0.0479)	0.0225 (0.0217)	-0.0114 (0.0333)
IPR_{t-1}	0.159** (0.0732)	0.123 (0.0930)	0.0527 (0.0414)	0.251*** (0.0786)

Notes: The number of observations is 391, and the number of countries is 25. All variables are in natural logarithms. Standard errors are shown in parentheses. Asterisks denote significance at the 1% (***), 5% (**), and 10% (*) levels. To reduce the instrument count and ensure acceptable over-identification statistics, the instruments are limited to lags 2–5 and the “collapse” option is used (GMM estimates made using Stata 11, xtabond2), as suggested by Roodman (2006). Estimated coefficients are not sensitive to variation in instrument inclusion.

¹Bootstrapped standard errors are reported with 200 draws.

²S1 is 0.0, S2 is 0.21, and Sargan is 0.58.

at conventional levels under FE and GMM, but not Kiviet.³⁸ The short run impact is found to be about 0.1 and the long-run impact about unity. Direct monetary support of business R&D (*TRANSFERS*) is found to have a significant impact with a long-run impact of about 0.3, suggesting some crowding out of private investment is enduring.

VI. CONCLUSION

There has been much debate in the literature about the effects of government subsidies for business R&D. 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 percent” of previous estimates of the elasticity of R&D expenditure to tax-price. More recent cross-country 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 government R&D support programs — including both tax incentives and monetary transfers — on R&D employment.

There are three main conclusions from our analysis. First, we find no evidence that input price (wage) inflation has seriously conflated past estimates of the effectiveness of government R&D subsidies delivered via the tax system. Our estimate of the tax-price elasticity of R&D labor is no smaller than past estimates of the tax-price elasticity of R&D expenditure — in fact it is slightly larger. The tax-price of labor has about half the effect on total R&D expenditure as it does on R&D employment alone — which is consistent with the fact that labor expenses constitute somewhat over half of total R&D expenditure. Second, we find that government R&D subsidies delivered via the tax system or through monetary transfers (direct grants and procurement) both have a positive effect on R&D employment. Third, our estimates suggest that, in the aggregate, R&D capital and R&D labor are gross substitutes. In other words, as the price of R&D capital increases, the demand for R&D labor increases.

Since we do not find evidence of input price inflation in the short-run, we do not expect it to arise over the long-run since the elasticity of supply of skilled workers is expected to be larger in the long-run. We estimate the long-run elasticities based on the same partial adjustment framework used in the existing literature, and also using an error correction model. The long run analysis is broadly consistent with our main conclusions. Where we are able to identify a long-run effect of subsidies on R&D employment, it is also comparable to estimates of the effect of subsidies on expenditure. However, we feel that our long-run estimates should be treated with caution for a few reasons. First, the range of our estimates is quite large as a result of the statistical difficulties

³⁸ This may be due to the fact that the sample is unbalanced and when using the bootstrap, samples for each unit are truncated to the first missing value encountered (Kiviet estimations are undertaken using Stata 11; the `xtlsdvc` help file for details regarding truncation in the bootstrapping routine).

inherent in the method used. Second, our panel is relatively short and therefore it is difficult to obtain accurate estimates of long-run effects. Third, estimation of any effect of government subsidies is further complicated by the fact some of the data series used to construct our key variables exhibit strong persistence.

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APPENDIX A: DERIVATION OF STEADY STATE R&D LABOR EQUATION

We model a vertically integrated firm that produces both final goods and technology, via R&D. The firm's objective function is to maximize its discounted stream of profits over time. Final goods are produced using the technology stock (denoted as G), according to a function $f(G)$.^{39,40} Profits are taxed at rate τ . The firm also produces technology using two inputs, labor (L) and capital (K). We assume the technology production function $R = R(L, K)$, incorporates convex adjustment costs, following Uzawa (1969) and Hayashi (1982). Convex adjustment costs can be interpreted as a "progress constraint," whereby only a fraction of the R&D invested results in useful technology (Grossman and Shapiro, 1986). To keep the model tractable, we consider the case where research equipment is only useful for one period. The technology stock G depreciates at a rate δ . We can therefore summarize the accumulation restriction (where $\dot{G} = dG / dt$) as

$$(A1) \quad \dot{G} = R(L, K) - \delta G.$$

The model includes variation in the effective prices of research inputs that result from changes in tax policy.⁴¹ We define c_L as the cost borne by the firm for each unit of labor-related R&D

³⁹ Time subscripts on the time varying variables G , K , L , τ , c_L and c_K are omitted for clarity of exposition.

⁴⁰ We omit analysis of variable inputs in the production of final goods, though these do not change the fundamental results of interest.

⁴¹ For illustrative purposes, we normalize the money prices of final goods and research inputs.

expenses and c_K as the after-tax cost of R&D capital. The firm's profit maximization problem can be described by the current value Hamiltonian given by⁴²

$$(A2) \quad H = (1 - \tau)f(G) - c_K K - c_L L + \mu(R(K, L) - \delta G).$$

The relevant first order conditions are then given by

$$(A3) \quad \frac{\partial H}{\partial L} = -c_L + \mu R_L(L, K) = 0$$

$$(A4) \quad \frac{\partial H}{\partial K} = -c_K + \mu R_K(L, K) = 0$$

$$(A5) \quad \dot{\mu} - r\mu = -\frac{\partial H}{\partial G} = -(1 - \tau)f_G(G) + \delta\mu \Rightarrow (1 - \tau)f_G = (\delta + r)\mu - \dot{\mu},$$

where $R_X(L, K)$ and $f_X(G)$ represent the partial derivatives with respect to $X \in \{L, K, G\}$.

Taking the ratio of (A3) over (A4) gives

$$(A6) \quad \frac{R_K}{R_L} = \frac{c_K}{c_L}.$$

This states that along the balanced growth path, the ratio of prices must be equal to the ratio of the marginal products of each input to production. To get to the labor demand equation it remains to specify the relevant functional forms. Based on the previous discussion, we assume R is constant elasticity of substitution or $R = [L^\rho + K^\rho]^{\epsilon/\rho}$ so that $R_L = \epsilon R^{1-\rho/\epsilon} L^{\rho-1}$ and $R_K = \epsilon R^{1-\rho/\epsilon} K^{\rho-1}$ which, when substituted into (A6) gives

$$(A7) \quad K = (c_K / c_L)^{1/(\rho-1)\epsilon} L.$$

We assume Cobb-Douglas production of final goods (i.e., $f(G) = \psi G^\gamma$) in steady state, so we have (noting that in steady state $\delta G = R$)

$$(A8) \quad f_G(G) = \psi \gamma G^{\gamma-1} = \psi \gamma (\delta^{-1} R)^{\gamma-1}.$$

Substituting μ from (A3) and f_G from (A8) into (A5) and noting that at steady state $\dot{\mu} = 0$, gives

$$(A9) \quad (1 - \tau)\psi \gamma (\delta^{-1} R)^{\gamma-1} = (\delta + r)(c_L / R_L) = (\delta + r)\epsilon^{-1} c_L L^{-\rho} R^{\rho/\epsilon-1}$$

$$L^{\rho-1} R^{\gamma-\rho/\epsilon} = \frac{(\delta + r)\delta^{\gamma-1} c_L}{(1 - \tau)\psi \gamma \epsilon}$$

⁴² It can easily be seen that including variable inputs in the production of final goods will simply add another two first-order restrictions that do not affect the firm's choice over L and K , and therefore G (by the assumption that R&D labor is specific).

$$L^{\rho-1} [L^{\rho} + K^{\rho}]^{(\gamma \varepsilon / \rho) - 1} = \frac{(\delta + r) \delta^{\gamma-1} c_L}{(1 - \tau) \gamma \psi \varepsilon}.$$

Finally, by substituting in (A7) we obtain the steady state labor demand function, which is implicitly defined as

$$(A10) \quad L^{\rho-1} \left(L^{\rho} + (c_K / c_L)^{\rho / (\rho-1)} L^{\rho} \right)^{(\gamma \varepsilon / \rho) - 1} = \frac{(\delta + r) \delta^{\gamma-1} c_L}{(1 - \tau) \gamma \psi \varepsilon}.$$

Equation (2) from the paper follows.

