Taxation and R&D: An Investigation of the Push and Pull Effects

KENNETH J. MCKENZIE AND NATALIA SERSHUN
Department of Economics
University of Calgary, Alberta

Dans cet article, nous mesurons l'impact que les subventions directes à caractère fiscal (effet « push ») et la compétitivité du système de taxe sur la production (effet « pull ») ont sur la recherche et le développement. Nous utilisons un ensemble de données recueillies au moyen d'un panel sur neuf pays pendant plus de 19 ans pour évaluer un modèle dynamique à effets fixes des activités de R-D. Les deux effets sont significatifs et importants économiquement. L'élasticité de court terme de la R-D par rapport à l'effet « push » varie de -0,12 à -0,22, alors que l'élasticité de long terme varie de -0,46 à -0,83 ; l'élasticité de court terme de la R-D par rapport à l'effet « pull » varie de -0,15 à -0,28, alors que l'élasticité de long terme varie de -0,58 to -0,83.

Mots clés : fiscalité, subventions, R-D, investissement, « push », « pull »

We investigate the extent of the impact that direct tax subsidies (the "push" effect) and the competitiveness of the production tax system (the "pull" effect) have on research and development. A panel dataset of nine countries over nineteen years is used to estimate a dynamic fixed effects model of aggregate R&D. Both effects are significant and economically important. The short-run elasticity of R&D with respect to the push effect ranges from –0.12 to –0.22, while the long-run elasticity ranges from –0.46 to –0.83; the short-run elasticity of the pull effect ranges from –0.15 to –0.28, while the long-run elasticity ranges from –0.58 to –0.83.

Keywords: taxation, subsidy, R&D, investment, push, pull

INTRODUCTION

Government policies relating to research and development (R&D) have been the subject of considerable scrutiny in Canada. This is in large part because R&D is thought to be an important determinant of economic growth. For example, Boskin and Lau (1994) estimate that R&D accounted for about 10 percent of economic growth in Canada between 1964 and 1990.

Positive knowledge spillovers thought to emanate from R&D suggest that social rates of return exceed private rates of return and that private firms may therefore under-invest in R&D. Griffith (2000) estimates social rates of return to R&D of about 100 percent compared to private returns of 25 percent. In a Canadian context Bernstein (1988, 1989, 1996) estimates that the social rate of return to R&D exceeds the private rate of return by a factor of two or more in most industries. The presence of these spillovers is perhaps the most commonly used argument to justify government subsidies for R&D.

Government intervention can take several forms including patent policy, direct funding, and subsidies offered through the tax system. Tax subsidies also come in various guises but typically include tax credits and accelerated writeoffs for R&D related expenditures. Many OECD countries offer some form of direct tax subsidy designed to lower the cost to private firms of undertaking R&D.

The presence of these subsidies raises several questions, not the least of which is how effective they are at promoting R&D activity. An extensive empirical literature has examined the impact of tax subsidies on R&D activity. Much of this research looks at the impact of the after-tax user cost of R&D capital on expenditures. Hall and Van Reenen (1999) survey this literature and find average short-run and long-run elasticities of R&D with respect to its after-tax user cost of about –0.1 and –1.0, respectively. Indicative of this research is a paper by Bloom, Griffiths, and Van Reenen (2002) that looks at aggregate data from a subset of OECD countries and estimates a short-run elasticity of R&D with respect to its after-tax user cost of –0.12 and a long-run elasticity of –0.86. The empirical evidence thus seems to suggest that direct tax subsidies that lower its user cost are quite effective at promoting R&D activity, particularly in the long run.[1]

In this paper we focus on another tax related factor that has not received much attention in the existing research: the role played by the overall tax regime imposed on production in promoting (or discouraging) R&D activity. The basic idea is simple. Direct tax subsidies that lower the cost of R&D, as measured by its after-tax user cost, reward effort and exhibit a "push" effect on R&D. High taxes on production—on the "fruits" of R&D (new products and processes)—punish success, but conversely, low taxes on production reward success (or punish it less) and exhibit a "pull" effect on R&D. Both push and pull effects should be taken into account when evaluating the overall impact of the tax system on R&D.

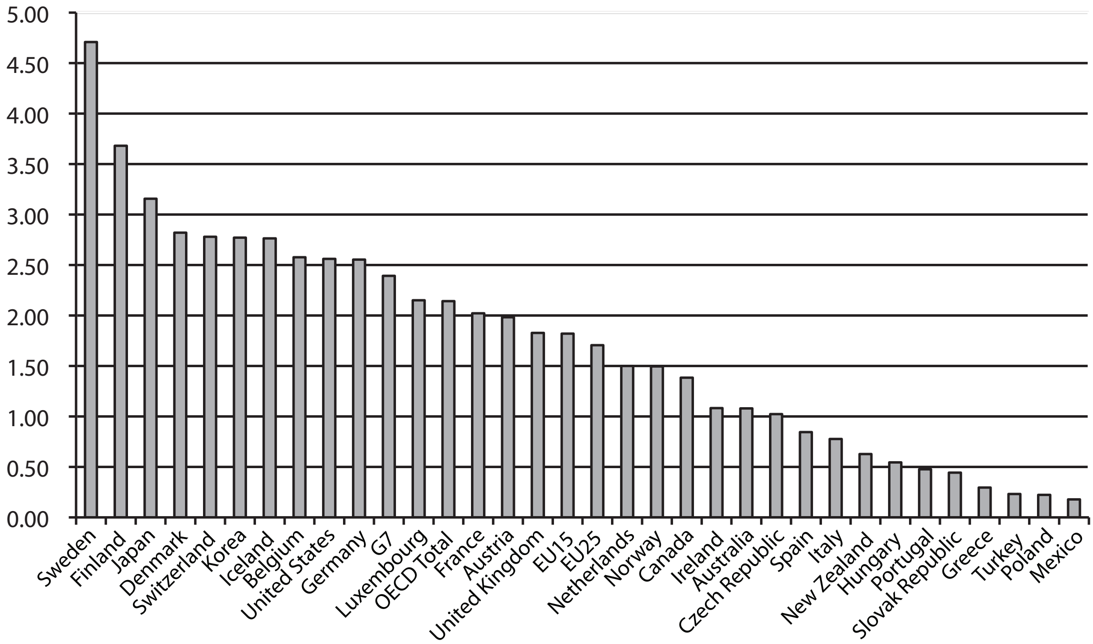
The empirical analysis utilizes an aggregate panel dataset of nine OECD countries over 19 years. After controlling for country specific and time specific factors using fixed effects techniques, the empirical results show that both push and pull tax effects are statistically significant and economically important determinants of business R&D expenditures across countries. These results suggest that some of the differences in business R&D intensity across countries can be explained by differences in their production tax regimes.

Motivation

Other studies have considered the possible complementarity between R&D and physical production capital. For example, Chiao (2000) and OECD (2001) find a relationship between R&D and investment in physical capital, in particular machinery and equipment. We are not aware, however, of any study that has investigated the relationship between overall taxes on production inputs and R&D explicitly. That is what we do in this paper.

As motivation for our approach, consider Figure 1, which reports OECD data on R&D conducted by business enterprises in selected countries as a percentage of value added by industry. As the figure shows, there is a wide range of R&D intensities across countries. In this regard Canada and Sweden offer up an interesting study in contrasts. In particular, note that Sweden is at the top of the list with business R&D at just over 4.7 percent of value added, and Canada is in the bottom half at just over 1.3 percent; the OECD average is 2.1 percent. Now consider Figure 2, which presents

Figure 1
Business Experimental Research and Development Expenditures as a Percent of Value Added, 2003



Source: OECD (2005).

OECD calculations of direct tax subsidies offered per dollar of R&D expenditures. Here we see that Canada is one of the top R&D subsidizers, while Sweden is near the bottom.

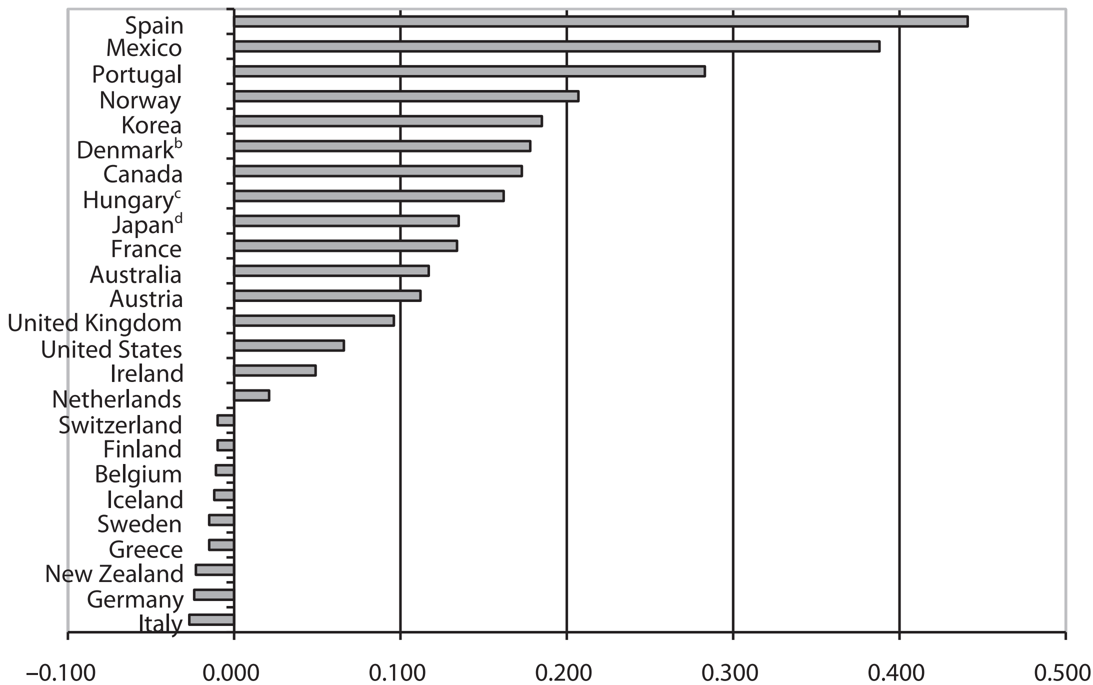
Casual inspection of these two figures raises an obvious question: if Canada offers such generous direct tax subsidies for R&D and Sweden offers so few, and if tax subsidies are an important determinant of R&D activity (as documented above), why is R&D intensity so much higher in Sweden than in Canada?

Of course several explanations are possible that have nothing to do with the tax system. For example, in testimony to the Standing Parliamentary Committee on Industry, Science and Technology, John Baldwin suggests that the share of foreign owned enterprises in Canada could be an important factor:

> it is widely known that R&D is not done intensively in Canada. The ratio of R&D expenditures to GDP is lower in Canada than in many other OECD countries. But that does not mean our industry lags behind other nations in terms of our ability to benefit from the knowledge gained from R&D.
>
> We have to recall that over half of Canadian manufacturing industries are foreign owned, and foreign-owned plants in Canada benefit from the R&D done abroad by their parents. Indeed, if we take into account both domestic R&D spending and what our plants pay for R&D done abroad, Canada increases its R&D ranking substantially. (Government of Canada 2001)

While it is possible that foreign ownership can account for Canada's low R&D intensity, in other work

FIGURE 2
Tax Subsidy Ratio OECD Countries, 2004[a]



Notes:
[a] The tax subsidy ratio equals 1 minus the B-index. The B-index is the after-tax cost of $1 spent on R&D, reflecting the present value of tax deductions and tax credits, divided by 1 minus the corporate income tax rate. See Warda (2005).
[b] The 2004 calculation for Denmark applies to the 150 percent allowance on collaborative research at universities or public research institutions. Without this incentive, the B-index is 1:015.
[c] The B-index for Hungary is based on the 100 percent R&D tax allowance for research and technology development. A 300 percent allowance is available if the company's R&D laboratory is located at a university or public research site.
[d] The 2004 B-index for Japan applies to firms with a ratio of R&D to sales of less than 10 percent. The B-index for firms with a R&D-to-sales ratio above 10 percent is 0.831. The B-index for research conducted in collaboration with universities is 0.782.

Source: OECD (2005).

Baldwin and Hanel (2000) show that multinational firms in Canada are in fact more engaged in R&D than domestically owned firms.

Baldwin goes on in his testimony to emphasize the importance of industrial structure:

> Comparison of simple R&D to GDP ratios across countries is also misleading if corrections are not made for the different industrial structures of countries. Innovation regimes differ across industries. Studies have shown that there are some industries, like electronic industries and machinery, that are at the core of the innovation system. They do a large amount of R&D and they produce more innovations ... Others, such as food products use new materials and machinery from the core sector and tend to expend money

> not on R&D, but technological and engineering, and production systems. The two sectors work together in a symbiotic relationship. Some countries have more of the former, other countries have more of the latter, and those countries such as Canada that concentrate more on the latter will simply have low R&D ratios because of that, even if they have a highly innovative industrial sector. (Government of Canada 2001)

And indeed, ab Iorwerth (2005) shows that Canada's low aggregate R&D performance hides high research intensities in some industries but that the small size of these industries leads to weak aggregate R&D performance overall.

While these factors are no doubt very important, our focus in this paper is on another factor: the overall level of taxation on production. Consider Table 1, which displays marginal effective tax rates on production capital across several countries as calculated by the C.D. Howe Institute (Chen and Mintz 2005). Here we see that Canada imposes a very high effective tax rate on production capital, almost three times higher than Sweden. Could this be a factor in explaining Canada's low level of R&D spending relative to Sweden?

Table 1

Marginal Effective Tax Rates on Production Capital by Country, 2004 (percent)

	Corporate Income Tax Rate	*METR*
China	24.0	37.7
Germany	38.4	32.7
Canada	34.9	31.3
Japan	41.9	29.8
Brazil	34.0	29.2
France	35.4	27.8
Italy	37.3	26.0
US	39.5	23.0
India	35.9	22.5
Finland	29.0	19.9
Netherlands	34.5	19.2
UK	30.0	18.7
Australia	30.0	17.8
Russia	22.0	17.6
Denmark	30.0	16.5
Mexico	33.0	12.8
Ireland	12.5	11.5
Sweden	28.0	11.2
Singapore	22.0	7.6
Hong Kong	16.0	5.7

Source: Chen and Mintz (2005).

To help answer this question, in the appendix we develop a simple theoretical model motivating the role of push tax subsidies on R&D costs and the pull effect of production taxes. This model serves not only to motivate the empirical analysis that follows but also develops the precise formulation of the push and pull tax variables that enter the empirical specification.[2] In particular, the push tax variable that emerges from the model is the standard after-tax user cost of R&D capital that is used in most other studies. The tax variable that captures the pull effect of the production tax regime is the effective tax rate on marginal production costs (ETRMC), as developed by McKenzie, Mintz, and Scharf (1997). The ETRMC aggregates marginal effective tax rates on production capital and labour into an effective excise tax rate on production costs. The key insight here is that taxes imposed on all production inputs, not just capital, can exhibit a pull effect on R&D intensity.

One issue that merits discussion is the implicit assumption that production and R&D are located in the same jurisdiction and are therefore subject to the same underlying tax regime. In a world of mobile multinational corporations, an obvious objection to this assumption is that corporations can undertake R&D in a jurisdiction with a favourable R&D tax environment and production in a jurisdiction with a favourable production tax regime, and that for these corporations the pull effect of a favourable production tax regime on R&D may not be important.

This issue can be addressed on two fronts. First, having developed the theoretical motivation for the inclusion of both effects, we are of course agnostic on how important each effect will be; at the end of the day the data will tell us the relative importance of the two effects. If the pull effect as captured by the ETRMC is insignificant, one explanation (of perhaps several) is the de-linking of production from R&D.

Second, there is reason to expect that there are limits to the extent to which production can be jurisdictionally isolated from R&D. It is generally well recognized that for successful innovating firms, R&D, product development, and production are integrated. A good deal of R&D takes place, if not literally "on the factory floor," then at least in close consultation with production engineers and personnel. Robert Gordon (2000) talks about the Toyota philosophy of *Kaizan*, which refers to continual, incremental product and production improvements emanating from the plant floor. *CIO Magazine*, which caters to chief information officers, refers to successful R&D departments "beating the clock through internal integration with line business units" (Hildebrand 1995). The need to integrate production units with R&D departments suggests a complementarity that precludes, at least to some extent, the jurisdictional de-linking of production and R&D activities.

Empirical Approach

In the previous section we argued that both the after-tax user cost of R&D and the effective tax rate on production could affect R&D. In this section we present an empirical model to estimate the relative impacts.

Data

The dataset we employ is a panel of the aggregate R&D expenditures of manufacturing industries across nine countries (Australia, Canada, Italy, Spain, US, UK, Germany, France, Japan) over 19 years (1979–97). Aggregate R&D expenditures and output for each country were obtained from the OECD's ANBERD and STAN databases.[3]

Bloom et al. (1997) present expressions for the after-tax user cost of R&D capital based on a standard neoclassical Jorgenson investment model. Tax subsidies typically take the form of accelerated depreciation deductions and/or tax credits, and they take account of both.

The net present value of the stream of depreciation allowances on a unit of R&D capital depreciated at a declining balance rate α_R is:

$$Z^R = \frac{\alpha_R}{\alpha_R + i} \tag{1}$$

where i is the nominal interest rate.[4]

Tax credits typically take two basic forms. In some countries, tax credits are non-incremental and are granted on all eligible R&D expenditures. In other countries, tax credits are incremental and are granted on R&D expenditures in excess of a moving average. In the case of incremental credits, the present value of a credit is lower than the statutory credit because it raises the moving average. Bloom et al. (1997) present a general expression for the net present value of tax credit for R&D:

$$A_R = \theta\left(a_t - \frac{1}{k}\sum_{i=1}^{k}\left(1+r\right)^{-i} a_{t+1}\right) \tag{2}$$

where θ is the statutory tax credit rate, a is an indicator variable that takes the value of *1* if the R&D is above its incremental base and zero otherwise, k is the number of years over which the moving average is taken, and r is the real interest rate.[5]

The after-tax user cost of R&D capital is then:

$$c^T = \frac{\left(1-A_R\right)\left(1-uZ_R\right)}{1-u}\left(r+\delta_R\right) \tag{3}$$

where δ_R is the economic depreciation rate on R&D.

Bloom et al. (1997) compute a weighted average after-tax user cost of R&D for several types of expenditures in several countries over time. We use the updated user cost of R&D figures reported in Bloom, Griffith, and Van Reenen (2002, Table A1).

The ETRMC for each country is calculated following the approach developed by McKenzie, Mintz, and Scharf (1997). The ETRMC requires computations of the METR on labour (τ_L) and capital (τ_K) production inputs. The METRs on labour are calculated from various issues of the OECD publication *Taxing Wages*, where an average labour tax rate is determined for the average industrial wage earner in each country. The calculations take account of personal income taxes on labour as well as payroll and/or social security taxes. The METRs on production capital are calculated from information on the basic manufacturing tax regime in each country, gleaned from the dataset presented in Klemm (2003).

In order to calculate the ETRMC on production, an assumption regarding the production/cost function is required. We assume a Cobb-Douglas production function, in which case the ETRMC is given by

$$T = \left(1+\tau_L\right)^{S_L}\left(1+\tau_K\right)^{S_K} - 1 \tag{4}$$

where S_L is labour's share of total costs and S_K is capital's share (see McKenzie, Mintz, and Scharf 1997).

Table 2 presents summary data on the variables employed in the analysis.

Specification

R&D, and in particular its reaction to changes in tax variables, is inherently a dynamic process. One way of taking this into account in a simple way is by specifying a partial adjustment model, as follows:[6]

$$\begin{aligned} R_{it} &= \alpha_0 + \alpha_1 c_{it}^T + \alpha_2 T_{it} + \alpha_3 R_{it-1} \\ &\quad + \alpha_4 Y_{it} + d_i + d_t + u_{it} \end{aligned} \tag{5}$$

The i index refers to country and t to time. The variable R_{it} is aggregate R&D expenditures by manufacturing enterprises in country i at time t, R_{it-1} is its one year lag; c_{it}^T is the after-tax user cost of R&D; T_{it} is the ETRMC; Y_{it} is a measure of country output; d_i is a vector of country fixed effect dummies, d_t a vector of year fixed effect dummies, and u_{it} an error term.

In implementing the dynamic panel specification given by equation (5), all of the variables are measured in log form.[7] Therefore the coefficients are the elasticities of R&D expenditures with respect to the tax variables. In particular, α_1 and α_2 are the

TABLE 2
Data Summary Statistics (All Countries, All Years)

	Mean	*Standard Deviation*	*Min*	*Max*
c^T	.2949	.0479	.1644	.3620
T	.1226	.0267	.0634	.2044
R/Y	.0140	.0076	.0020	.0310

Notes: c^T is the user cost of R&D; T is the effective tax rate on the marginal cost of production (ETRMC); R/Y is the R&D to output ratio.
Source: Authors' calculations.

contemporaneous tax (push and pull) elasticities, and $(1-\alpha_3)$ measures the speed of adjustment of R&D spending toward its desired level. Dividing the contemporaneous elasticities by $(1-\alpha_3)$ gives the long-run tax elasticities.

Several econometric issues arise from this specification. First, in the absence of fixed effects, the specification is quite parsimonious and potentially ignores several factors that may affect R&D. The difficulty lies in measuring these omitted effects. To the extent that these unmeasured factors differ across countries but are relatively constant over time, or differ over time but are relatively constant across countries, this can be handled via the inclusion of fixed country and year effects. In the case of country fixed effects, these unmeasured factors may include things like access to skilled labour, regulatory policies associated with R&D (patents), industrial structure, and the importance of foreign direct investment, as well as a myriad of other economic, cultural, and political factors that may affect R&D. In the case of year fixed effects, these unmeasured factors include things like technological innovations as well as worldwide business cycles. To the extent that these fixed effects are significant and correlated with the tax variables, failure to include them would result in omitted variable bias in the estimation of the coefficients on the tax variables.

As an aside, the inclusion of both country fixed and year fixed effects, along with a lagged dependent variable, can account for a good degree of the variability in cross-sectional time-series data. The estimation strategy employed here may thus be thought of as being quite conservative, in the sense that it tends to stack the deck against finding significant effects for the other explanatory variables included in the model, in our case the push and pull tax variables.

The inclusion of fixed country effects with a lagged dependent variable creates potential difficulties, however. In particular, the OLS estimate of α_3 will be biased due to the correlation of the lagged dependent variable with the country fixed effects. Since R_{it} is a function of d_i so too is R_{it-1}. Therefore R_{it-1} is potentially correlated with the error term u_{it}, rendering the OLS fixed effects estimators biased.

An approach to circumventing this problem has been developed by Arellano and Bond (1991), who suggest a generalized method of moments (GMM) approach. After taking first differences in equation (5), the fixed country effects disappear:

$$\begin{aligned}\Delta R_{it} &= \alpha_1 \Delta c_{it}^T + \alpha_2 \Delta T_{it} + \alpha_3 \Delta R_{it-1} \\ &\quad + \alpha_4 \Delta Y_{it} + \Delta d_t + \Delta u_{it}\end{aligned} \tag{6}$$

While this approach eliminates the difficulties that arise from the correlation between the lagged dependent variable and the country fixed effect, the regressor ΔR_{it} is still correlated with the error term. To deal with this, Arellano and Bond (1991) suggest following an instrumental variables approach, taking advantage of the fact that higher order lags of the dependent variable, R_{it-2}, R_{it-3}, ... are uncorrelated with the residuals and can be used as instruments. Moreover, to increase the efficiency of the estimators, orthogonality restrictions are imposed on the covariance between the regressor and the error.

Another set of issues concerns the structure of the error term u_{it} in equation (5). In panel models, hetroskedasticity must be thought of in multi-dimensional terms. The classical econometric assumptions, which generate efficient estimates when OLS is applied to the pooled data, are that the errors are homoskedastic both within and across panels. If either of these assumptions is violated, problems with the standard errors will generate inefficient estimates. Various ways of dealing with this issue in panel models, such as the use of Feasible Generalized Least Squares and panel corrected standard errors, are discussed below.

A final concern is the possible endogeneity of the tax variables. Both the user cost of R&D (c_{it}^T) and the ETRMC (T_{it}) include the real rate of interest in their derivation. However, real interest rates and R&D expenditures both tend to be pro-cyclical, and this may cause a simultaneity problem resulting in inconsistent estimates in the case of OLS. This problem too is explored below.

Results

The results are reported in Table 3. The first three columns display the OLS results with and without fixed effects. Comparing column 1 to columns 2 and 3, it is evident that the inclusion of both country and year fixed effects are important and have a significant impact on the coefficients of the tax variables and the lagged dependent variable. Looking at column 3, which includes both country and year effects, the short-run elasticity of R&D intensity with respect to the tax adjusted user cost of R&D, which measures the push effect of R&D tax subsidies, is –0.207, and the associated long-run elasticity is –0.83, which is consistent with previous studies. Importantly, the pull effect of the overall production tax regime is of a similar magnitude, with a short-run elasticity of R&D intensity with respect to the ETRMC of –0.183 and a long-run elasticity of –0.734. Ramsey tests suggest no problems with omitted variables.

As discussed above, there is a possible endogeneity issue with the user cost of R&D (c_{it}^{T}) and the ETRMC (T_{it}) due to the inclusion of the real rate of interest in both variables. We follow Bloom,

Table 3

Regression Results

	OLS (1)	*OLS (2)*	*OLS (3)*	*OLS (4)*	*FGSL(w) (5)*	*FGLS(c) (6)*	*PCSE (7)*	*ABOND (8)*
DVAR	*R*	*R*	*R*	*(R/Y)*	*R*	*R*	*R*	*R*
Y	.057	.286	.313	–	.293	.347	.313	.433
	(.016)	(.138)	(.175)		(.098)	(.074)	(.134)	(.215)
	(.000)	(.049)	(.076)		(.003)	(.000)	(.019)	(.047)
R_{-1}	.952	.786	.750	.720	.742	.714	.751	.637
	(.016)	(.047)	(.074)	(.080)	(.053)	(.045)	(.077)	(.111)
	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
c^T	–.034	–.128	–.207	–.210	–.120	–.144	–.207	–.226
	(.058)	(.078)	(.083)	(.089)	(.063)	(.054)	(.084)	(.077)
	(.560)	(.106)	(.015)	(.020)	(.057)	(.008)	(.013)	(.004)
T	–.075	–.139	–.183	–.234	–.149	–.180	–.183	–.279
	(.490)	(.930)	(.095)	(.100)	(.050)	(.033)	(.086)	(.165)
	(.127)	(.139)	(.057)	(.021)	(.003)	(.000)	(.032)	(.095)
Country FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	No	No	Yes	Yes	Yes	Yes	Yes	Yes

Notes: All variables are measured in logs. *DVAR* designates the dependent variable; *R* is R&D expenditures in the manufacturing sector (R_{-1} is its lag); *Y* is manufacturing output; c^T is the tax adjusted user cost of R&D capital; *T* is the ETRMC; *Country FE* refers to country fixed effects; *Time FE* refers to time fixed effects. The first (non-bracketed) number for each variable is the estimated co-efficient, the first number in brackets is the standard error, and the second number in brackets is the p-value. The regressions were run using Stata 8.0.

Source: Authors' calculations.

Griffith, and Van Reenan (2002) and calculate both variables holding the real rate of interest constant over time and across countries. By construction the tax variables measured in this way change only due to exogenous changes in tax policy and are therefore good candidates for potential instruments if there is an endogeneity problem. However, a Hausman test cannot reject the null hypotheses of exogeneity in both cases.[8]

Column 4 presents a slightly different specification, using R&D intensity (R&D expenditures as a percentage of output) as the dependent variable. This specification is equivalent to constraining the co-efficient on the output variable to unity. While the results are similar to the (log) levels regressions, a test of the null hypothesis that the co-efficient on output is unity is strongly rejected, and we stick to the log-levels specification in the other regressions.

Columns 5 and 6 present feasible generalized least squares estimates, allowing for different types of hetroskedasticity. In column 5, within-panel hetroskedasticity (*FGLS(w)*) is allowed for, while column 6 allows for cross-panel hetroskedasticity (*FGLS(c)*). While the short-run elasticity estimates drop slightly relative to the OLS results, they are of the same order of magnitude and remain statistically significant.

Column 7 reports panel corrected standard errors (*PCSE*). The coefficient estimates are identical to the OLS estimates in column 3 by construction, but the standard errors, which turn out to vary only slightly, are corrected using the approach suggested by Beck and Katz (1995).

Column 8 reports the Arellano-Bond (*ABOND*) estimates, as discussed above. In this case the short-run elasticities remain statistically significant (albeit at somewhat higher p-values) and are of the same order of magnitude at –0.226 and –0.279 for c_{it}^T and T_{it} respectively, with long-run elasticities of –0.622 and –0.769.

Discussion and Policy Implications

These results indicate that both push and pull tax effects are important and independent determinants of R&D. The results are quite robust across specifications. With respect to the push effect of direct tax subsidies, as measured by the after-tax user cost of R&D, the short-run elasticity ranges from about –0.12 to –0.22 and the long-run elasticity from about –0.46 to –0.83, figures that are generally consistent with previous studies. Importantly, the pull effect of the overall production tax regime, as measured by the ETRMC on production, is significant as well and of a similar magnitude: the short-run elasticity ranges from about –0.15 to –0.28 and the long-run elasticity from about –0.58 to –0.84.

It is important to remember that these elasticities control for country and year fixed effects. Thus, independently of country specific characteristics such as industrial makeup, the importance of foreign firms, and so on, the overall tax regime as it applies to production exerts an important and independent impact on the incentive to undertake R&D.

We believe the results have important policy implications. Most importantly, when considering tax policy in the context of R&D, governments should consider not only the impact of direct tax subsidies on R&D but also the impact of the production tax regime. More precisely, failing to take account of both effects may result in governments giving with one hand and taking away with the other—encouraging R&D by offering generous tax subsidies that lower the cost of undertaking research, but discouraging R&D by imposing high production taxes on the fruits of the R&D, the discovery of new products and processes.

As discussed in the introduction, Canada and Sweden provide a study in contrasts in this regard. Canada has tended to provide generous direct tax subsidies for R&D, while until recently it imposed relatively high taxes on production. Sweden, on the other hand, provides few direct subsidies for R&D

but has a very competitive production tax regime. Business R&D as a percentage of value added in Sweden is more than triple that of Canada. While much of this situation is no doubt due to the unique structural characteristics of the two countries, the results reported above suggest that some of the difference in R&D is due to differences in the production tax environment.

The results also suggest that production and R&D are not jurisdictionally de-linked in the countries included in this study, and that even in a world where capital is mobile, firms may not be completely inclined to locate their production in jurisdictions with favourable production tax regimes and their R&D in jurisdictions with attractive tax subsidies for innovation. This possibility is consistent with the notion that R&D and production are complementary in some sense and that at least some innovation emanates from the factory floor.

The finding that taxes on production discourage R&D should not necessarily be taken to mean that the best way to encourage R&D is to cut taxes on production. In this regard it is important to emphasize that our results reinforce much of the previous research that suggests that direct tax subsidies do have a significant impact on R&D. Rather, we think that the policy implications are more nuanced, and are essentially fourfold.

First, as indicated above, some of the benefits of targeted R&D subsidies can be undone by high taxes on subsequent production. This insight helps us understand why seemingly generous tax subsidies for R&D may not manifest themselves in higher expenditures if they are effectively undone by high taxes on production.

Second, the results suggest to us that a balanced approach to tax policy that does not rely overmuch on targeted subsidies but rather is geared towards overall tax competitiveness may prove to be more effective along several dimensions.

In this regard, the third insight is that changes in taxes on inputs used in production that may perhaps be motivated by other considerations will also indirectly affect R&D. For example, Canada has recently implemented several changes to both federal and provincial tax systems, most particularly cuts to corporate income tax rates, which have significantly lowered the marginal effective tax rate on production capital. The analysis undertaken here suggests that this should feed back to increased expenditures on R&D. Further on this point, the generous nature of tax subsidies for R&D in Canada are such that the marginal effective tax rate on R&D is actually negative (see McKenzie 2005). In this case a reduction in the corporate income tax rate can, somewhat paradoxically, increase the marginal effective tax rate on R&D by making it less negative. In and of itself, this suggests that corporate income tax cuts may actually discourage R&D. The analysis undertaken here suggests that this dampening effect will be undone by the reduction in the effective tax rate on production associated with the tax cut.

Finally, another interesting implication of the results follows from the insight of Goolsbee (1998), among others, that tax subsidies for R&D may translate into larger expenditures because of inflated wages for scientists and researchers rather than because of an increased level of "real" R&D. However, it seems to us that the pull effect should differ from the push effect in this respect. This is because the pull effect only translates into increased expenditures on R&D if those expenditures are fruitful—that is, if they increase, say, the probability of a discovery. Thus it could be that the pull effect is more effective at increasing real R&D than the push effect. This possibility could be investigated in subsequent research by utilizing data on "real" R&D activity (e.g., the number of registered patents).

While we do not presume on the basis of this analysis to be in a position to make a strong statement regarding the "optimal" tax regime for production inputs and R&D, we can say that our results suggest that the two need to be considered in tandem.

Summary and Conclusions

In this paper we investigate the extent to which direct tax subsidies that lower the user cost of undertaking R&D (the push effect) and the overall competitiveness of the production tax system (the pull effect) independently affect aggregate R&D expenditures across countries. The push effect of direct tax subsidies is measured by the after-tax user cost of R&D capital, and the pull effect of the production tax regime is measured by the effective tax rate on marginal production costs (ETRMC), which aggregates the marginal effective tax rates on production inputs (labour and capital) into an effective excise tax rate.

A panel dataset of nine countries over 19 years is used to estimate a dynamic fixed effects model of R&D. It is estimated that the short-run elasticity of the ratio of R&D to output with respect to the push effect of direct tax subsidies, as measured by the after-tax user cost of R&D, is significant, ranging from –0.12 to –0.22; so is the long-run elasticity, ranging from –0.46 to –0.83, depending upon the specification. The pull effect of the overall production tax system, as measured by the ETRMC, is significant as well, with the short-run elasticity ranging from –0.15 to –0.28 and the long-run elasticity from –0.58 to –0.83.

Overall the analysis suggests that governments should take a balanced approach when developing tax policy with R&D in mind. While direct tax subsidies for R&D are effective at encouraging R&D activity, just as important is the overall competitiveness of the production tax regime.

Notes

[1] This evidence has been criticized on several dimensions. One is that R&D tax subsidies may simply inflate the wages of scientists and researchers without increasing the amount of "real" R&D undertaken, particularly in the short run when the supply of innovative personnel is inelastic (see Goolsbee 1998; Griffith 2000). Another is that public subsidies to R&D may crowd out private spending. As pointed out by Wallsten (2000), most empirical studies of the effectiveness of R&D tax credits are not able to determine whether the credits stimulate more research or whether firms that do research are just better able to take advantage of subsidies.

[2] The theoretical model is not intended to be the basis for the empirical specification but rather is presented to show that both types of tax variables can affect R&D. The empirical specification in the subsequent section follows the bulk of the literature on taxation and investment; see the discussion below.

[3] The choice of countries and the time period was determined by the availability of consistent tax variables measuring the push and pull effects; see below.

[4] It is presumed that there is no inflation adjustment to the tax depreciation base, which is the case for the countries considered here. This expression is for a declining balance depreciation system. It is straightforward to incorporate other approaches, such as straight line depreciation.

[5] There are several variations on this expression, which vary from country to country, such as the interaction of the credit with the depreciable base for tax purposes, nominal vs. real discounting, etc. These are all taken account in the numerical calculations.

[6] The partial adjustment model (PAM) is a widely used approach for investigating dynamic relationships. Another common approach is the error correction model (ECM). To implement an ECM, all of the variables in the regression model must be non-stationary (i.e., possess a unit root) and co-integrated. This is not the case for the data employed here. For example, tests by Levin, Lin, and Chu (2002) for a unit root in panel data strongly rejected the presence of a unit root for R&D expenditures. This result is robust to various assumptions regarding lags, time trends, etc. For example, with two lags and a time trend, the Levin-Lin-Chu t* statistic is 4.54, which rejects the null hypothesis of unit roots in the panel data at the 1 percent level of significance. This suggests that a PAM is appropriate.

[7] The log-linear (or double-log) specification utilized here is widely used in the literature that investigates the impact of taxes on both real and intangible (R&D) investment. For example, Chirinko et al. (1999) show that a log-linear specification follows directly from a

CES production function, which can be thought of as an approximation of the true production function. Bloom, Griffith, and Van Reenan (2002), Hall and Van Reenan (2000), and Lokshin and Mohnen (2007) use a similar specification in their study of tax subsidies for R&D. J-tests were run to determine if the log-linear specification could be rejected against alternative specifications (levels, translog). The results were inconclusive (i.e., none of the specifications could be rejected against the others).

[8] In the case of the user cost of R&D, $chi^2(2)=2.99$ with $prob>chi^2=.2244$; in the case of the ETRMC, $chi^2 2(2)=-1.98$, and the model failed to meet the asymptotic assumptions of the Hausman test.

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Appendix

The complementarity between production inputs and R&D can be motivated in several ways. Here we employ an approach that allows us to focus in a particularly useful way on the various taxes levied on production and R&D. We think of the firm as proceeding in stages. First, a firm undertakes R&D (R), at a before-tax cost of c dollars per unit. The level of R&D undertaken by the firm determines the probability that a new product will be discovered. Thus, the probability of a new discovery is written as a concave function of the level of R&D expenditures, $q(R)$, where $q'(R)>0$ and $q''(R)<0$.

A fraction Z_R of R&D expenses is written off for tax purposes. This captures the idea that some R&D costs may be depreciated over time and that the present value of the deductions may therefore be less than unity (if they are immediately expensed $Z_R=1$). Full loss offsets are assumed, which is equivalent to assuming that the corporation has other income against which to write off the R&D expenditures in the case where the R&D is unsuccessful. The firm also earns a subsidy of θ per dollar spent on R&D in the form of a tax credit, which is received regardless of whether or not the R&D is successful. This tax credit is assumed to reduce the depreciable base. The after-tax cost of a unit of R&D is therefore $c(1-\theta)(1-uZ_R)$, where u is the corporate income tax rate.

The firm discovers a new product with probability $q(R)$, in which case it then undertakes production. Production takes place using capital and labour, according to a production function $F(K,L)$, and the proceeds of production are subject to a corporate tax with the standard characteristics. In particular, labour costs are expensed and subject to a payroll tax at rate t_L, while a fraction $Z_P<1$ of production capital costs are written off. Income is then subject to tax at rate u. If the R&D is unsuccessful, which occurs with probability $1-q(R)$, the firm earns zero profits but still incurs the R&D expenses. The firm's expected profits are thus

$$q(R)\left\{P(Q)Q(1-u)-w(1-u)(1+t_L)-r(1-uZp)K\right\}-c(1-\theta)(1-uZ_R)R \qquad \text{(A-1)}$$

where $P(Q)$ is the firm's inverse demand function, $Q=F(K,L)$ is output, w is the wage rate, and r is the cost of a unit of production capital.[1]

Note that the after-tax operating profits from production, contained in the braces, are realized with probability $q(R)$, which depends upon R&D expenditures, while the after-tax costs of R&D are incurred regardless because of the assumption of full loss offsetting.

It is convenient to re-express the firm's after-tax operating profits arising from successful R&D by first considering the production cost minimization problem,

$$Min_{K,L}\, w(1-u)(1+t_L)L+r(1-uZ_p)K+\gamma\left[Q-F(K,L)\right] \qquad \text{(A-2)}$$

[1] For simplicity it is assumed that the both the demand function and the production function are known with certainty. While uncertainty along both of these dimensions could easily be introduced, it would add little to the story and obfuscates the main insights.

After some manipulation, the first-order conditions for this problem can be written as

$$\frac{F_L}{F_K} = \frac{w\left(1+\tau_L\right)}{r\left(1+\tau_K\right)} \tag{A-3}$$

$$Q = F\left(K, L\right) \tag{A-4}$$

where τ_L and τ_K the marginal effective tax rates (METRs) on production labour and capital respectively, defined as

$$\tau_L = \frac{\left[\dfrac{w\left(1-u\right)\left(1+\tau_L\right)}{1-u}\right] - w}{w} \tag{A-5}$$

$$\tau_L = \frac{\left[\dfrac{r\left(1-uZ_P\right)}{1-u}\right] - r}{r} \tag{A-6}$$

In each case the numerator is the tax wedge between the gross-of-tax (the first term) and the net-of-tax (the second term) cost of the input. This is divided by the net-of-tax cost to give a METR that measures the effective excise tax rate levied on the firm's production inputs.[2]

Equations (A-3) and (A-4) give the familiar condition that inputs are employed up to the point where the marginal rate of technical substitution is equal to the ratio of the gross-of-tax user costs. Together they determine the conditional input demand functions for labour and capital as a function of the net-of-tax user costs and the METRs, $L(Q;w(1+\tau_L),r(1+\tau_K))$ and $K(Q;w(1+\tau_L),r(1+\tau_K))$. Substituting the input demand functions into the objective function equation (A-2), and manipulating, gives the firm's gross-of-tax cost function

$$\left(1-u\right)C\left(Q;w\left(1+\tau_L\right),r\left(1+\tau_K\right)\right) \tag{A-7}$$

where

$$\begin{aligned} &C\left(Q;w\left(1+\tau_L\right),r\left(1+\tau_K\right)\right) \\ &\stackrel{\text{def}}{=} w\left(1+\tau_L\right)L\left(Q;w\left(1+\tau_L\right),r\left(1+\tau_K\right)\right) \\ &+r\left(1+\tau_K\right)K\left(Q;w\left(1+\tau_L\right),r\left(1+\tau_K\right)\right) \end{aligned}$$

Using the cost function in equation (A-7), after-tax operating profits from successful R&D are

$$\left(1-u\right)P\left(Q\right)-\left(1-u\right)C\left(Q;w\left(1+\tau_L\right),r\left(1+\tau_K\right)\right) \tag{A-8}$$

[2] This definition of the METR differs slightly from the standard definition in that it is expressed as an effective excise tax rate by normalizing by the net-of-tax rather than gross-of-tax return.

The firm maximizes operating profits by choosing output, Q, which gives the first-order condition

$$MR\left(Q\right) = MC\left(Q; w\left(1+\tau_L\right), r\left(1+\tau_K\right)\right) \tag{A-9}$$

where

$$MC\left(Q; w\left(1+\tau_L\right), r\left(1+\tau_K\right)\right) \stackrel{\text{def}}{=} \frac{\partial C\left(Q; w\left(1+\tau_L\right), r\left(1+\tau_K\right)\right)}{\partial Q} \tag{A-10}$$

is the gross-of-tax marginal cost of production, and

$$MR\left(Q\right) \stackrel{\text{def}}{=} P'\left(Q\right)Q + P\left(Q\right) \tag{A-11}$$

is marginal revenue.

Following McKenzie, Mintz, and Scharf (1997), now define the effective tax rate on marginal production cost (ETRMC), T, as

$$T \stackrel{\text{def}}{=} \frac{MC\left(Q; w\left(1+\tau_L\right), r\left(1+\tau_K\right)\right) - MC\left(Q; w, r\right)}{MC\left(Q; w, r\right)} \tag{A-12}$$

where $MC(Q;w,r)$ is the net-of-tax marginal cost of production.

The ETRMC measures the percentage increase in the marginal cost of producing the good arising from the taxation of the firm's inputs. It aggregates the METRs on the production inputs, labour (τ_L) and capital (τ_K), into an effective excise tax rate on marginal production costs in an economically sensible way. Using this concept, the profit maximizing first-order condition, equation (A-9), can be written as

$$MR\left(Q\right) = MC\left(Q; w, r\right)\left(1+T\right) \tag{A-13}$$

Equation (A-13) can be solved for output as a function of the ETRMC, $Q(T)$. Substituting this output function into the expression for after-tax operating profits, equation (A-8), gives the maximized after-tax operating profits of successful R&D as a function of the ETRMC, $(1-u)\Pi(T)$. Note that after-tax operating profits are decreasing in T.

The firm's expected after-tax profits from undertaking R&D, equation (A-1), can now be re-written as

$$q\left(R\right)\left(1-u\right)\Pi\left(T\right) - c\left(1-\theta\right)\left(1-uZ_R\right) \tag{A-14}$$

The firm then chooses R&D intensity, R, to maximize (A-14), giving the first-order condition

$$q'\left(R\right)\Pi\left(T\right) = \frac{c\left(1-\theta\right)\left(1-uZ_R\right)}{1-u} \tag{A-17}$$

The left-hand side of (A-15) is the marginal benefit of undertaking an incremental unit of R&D and the right-hand side is the marginal cost, as measured by the after-tax user cost of R&D, $c^T=c(1-\theta)(1-uZ_R)/(1-u)$. Equation

(A-15) implicitly determines the optimal level of R&D as a function of the ETRMC and the after-tax user cost of R&D, $R(T,c^T)$. It is straightforward to show via implicit differentiation of (A-15) that R&D effort is decreasing in both the after-tax user cost of R&D and the ETRMC (remember that $q(R)$ is concave and $\Pi(T)$ is decreasing in T). The former captures the push effect of direct R&D tax subsidies, while the latter captures the pull effect of the production tax regime.