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Determinants of Aggregate R&D, Role of Fiscal Policy, and the Effects of Government R&D on Economic Growth

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DETERMINANTS OF AGGREGATE R&D, ROLE OF FISCAL POLICY, AND THE EFFECTS OF GOVERNMENT R&D ON ECONOMIC GROWTH

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INTRODUCTION

Research and development (R&D) and technological change have received much attention since the fifties, notable examples being Nelson (1959), Hamberg (1959), Griliches (1962), and Arrow (1962, 1969). Since that time several studies have contributed to this field, theoretically and empirically, by focusing on different issues related to R&D, such as R&D and productivity growth, the role of R&D in innovation, market structure and the rate of technological change, fiscal incentives and R&D, international R&D spillovers, R&D and economic growth, and the relationship between public and private R&D.

This dissertation focuses on three main issues in the R&D literature: determinants of R&D, the role of fiscal policy in stimulating private R&D, and government R&D and economic growth. In the first essay, we study the determinants of aggregate R&D in both developed and emerging countries. The motivation behind this study is to identify and compare between developed and emerging countries' different macroeconomic R&D determinants with special attention to the effect of patent rights protection and technology transfer. This area is somewhat new in the R&D literature since it was very difficult in the past to find data on R&D in developing countries. We are mainly interested in examining if patent protection helps R&D, and whether technology transfer takes place via trade in intermediate goods and FDI. We find that patent protection has a positive effect on R&D but excessive protection can limit access to new innovations and thus slowdown the rate of research and development. The effect of technology transfer on domestic R&D is positive only in countries that depend heavily on imports of intermediate goods and FDI.

Although the existing R&D literature emphasizes the importance of patent protection and technology transfer as determinants of R&D, this essay contributes to the literature by extending the quality ladder model to incorporate patent rights and their effects on R&D. The model then suggests and the empirics confirm the presence of a threshold in patent protection beyond which the effect on R&D weakens. And the semiparametric approach neatly captures the underlying dynamic effects of different macro variables on R&D. In addition, contrary to Lichtenberg's (2001) findings that only outward FDI flows and trade in intermediate goods affect domestic R&D, we find a threshold after which inward FDI flows and imports of intermediate goods affect domestic R&D.

In the second and the third essays, we disaggregate R&D into two major subcategories: private and government R&D. The reason behind this disaggregation is to: 1) study the behavior of each type of R&D and how they respond to different fiscal policy variables, which is done in essay two, and 2) estimate the social rate of return to government and private R&D, which is pursued in essay three. We focus on private R&D in the second essay because we believe it is an important component of R&D in decentralized market economies and is sensitive to changes in various fiscal incentives. Our interest in fiscal policy comes from the fact that it is one of the most commonly used policies to stimulate private R&D especially through tax credits, allowances, and subsidies. This is particularly relevant since the market system tends to underinvest in R&D because of non-excludability associated with the creation of new technology and knowledge, as argued by Lenjosek and Mansour (1999) and Jones and Williams (1998), among others.

Empirical results show that the effect of profit taxes on business R&D investment could be positive because of R&D tax credits. The intuition is that incremental R&D tax credit in the presence of significant tax burden on firms' profits can be effective in inducing private firms to increase their R&D. Also, it is seen that budget deficits crowd out business R&D and government capital expenditure has a positive and significant effect of on business R&D while government consumption expenditure is found to be insignificant.

We focus on government R&D in the third essay in order to examine the validity of the commonly held hypothesis that the effect of government R&D on economic growth is either zero or negative[1]. We disaggregate government R&D into civil and defense R&D to test this hypothesis. Although the third essay deals with high-income OECD countries, we think that studying the relationship between government R&D and economic growth is also important to policymakers in developing countries since almost all R&D activities in those countries are funded by the government.

Results from a dynamic panel data model show that government R&D has a positive and significant effect on GDP per capita growth which is contrary to most empirical studies that report insignificant social rate of return to total government

[1] For more details see Griliches (1980), Lichtenberg and Siegel (1991), Battelsman (1990), and Lichtenberg (1992).

R&D. Furthermore, disaggregating civil government R&D shows that both civil government R&D for economic development programs and for general university funds have positive and significant effects on economic growth. Civil government R&D for health and environment programs is found to be insignificant, which is expected since such programs produce services that most likely do not immediately appear in the GDP. However, defense R&D is found to have either insignificant or negative effect on economic growth, which supports the crowding out hypothesis associated with defense R&D. In the short run, due to limited resources, if more is devoted to defense R&D, less is available for civil government R&D and this might have a negative impact on economic growth.

ESSAY 1

DETERMINANTS OF AGGREGATE R&D EXPENDITURE IN DEVELOPED AND EMERGING COUNTRIES: A SEMIPARAMETRIC PANEL DATA STUDY

Introdution

Research and development expenditure and its relationship with productivity and economic growth have received much attention during the last three decades. Griliches (1979), (1980), (1990) Romer (1990), and Grossman and Helpman (1991) suggest that R&D expenditure is an important source of economic growth. It is well known that the majority of the existing R&D-based growth literature concentrates on the relationship between R&D and economic growth in developed countries, specifically U.S.A, Canada, Japan, and other developed OECD countries.

This paper is one of the few attempts to study the determinants of R&D expenditure in emerging countries and developed countries with special attention to the effect of patent rights protection and technology transfer. In addition, this paper also improves upon the existing literature by using a semiparametric panel data framework. The existing empirical literature uses mostly linear cross section regression. However, it is well known that a misspecification of the functional form can lead to misleading conclusions. The semiparametric model takes care of the misspecification bias problem and helps us understand the underlying dynamics of the effect of different macro variables on R&D expenditure. Country and time specific heterogeneities are also addressed by using a fixed effect panel data model.

We are particularly interested in the following questions: whether 1) patent protection helps R&D, and 2) technology transfer takes place via trade in intermediate goods and FDI. We find that: 1) patent protection has a positive effect on R&D but overly burdensome protection can limit access to new innovations and thus slowdown the rate of research and development, and 2) the effect of technology transfer on domestic rate of R&D appears only in countries that depend heavily on imports of intermediate goods and FDI. Although the existing R&D literature emphasizes the importance of patent protection and technology transfer as determinants of R&D, this essay contributes to the literature by extending the quality ladder model to incorporate patent rights and their effects on R&D. The model then suggests and the empirics confirm the presence of a threshold in patent protection beyond which the effect on R&D weakens. And the semiparametric approach neatly captures the underlying dynamic effects of different macro variables on R&D. In addition, contrary to Lichtenberg's (2001) findings that only outward FDI flows and trade in intermediate goods affect domestic R&D, we find a threshold after which inward FDI flows and imports of intermediate goods affect domestic R&D.

The sample size is twenty-one countries which are divided into two groups: the first contains six low and medium-income countries that have some record of R&D expenditure[2]; the second group contains fifteen high-income OECD countries. The paper focuses mainly on the macroeconomic determinants of R&D expenditure; therefore, the empirical model contains country level annual data over the last two decades.

[2] Due to data constrains, the low and medium-income group contains only six countries over the period 1981-1997.

In the next section we briefly discuss the relevant R&D literature. In section 3 we extend the quality ladder model of Grossman and Helpman (1991) to examine the effects of patent protection on R&D. Also, a simple model of innovation and imitation is presented to describe technology transfer. Section 4 presents the empirical model and the results. The model is estimated in different ways in order to compare between the parametric and semiparametric results. Section 5 contains the conclusion.

Literature Review

In the following few paragraphs, the key studies on research and development will be cited along with the core findings.

Studies on R&D in Developing Countries

-Lederman and Maloney (2003)

- Social rate of return to R&D in developing countries is around 78% and it decreases with development. In addition, they conclude that financial depth, protection of intellectual property rights, government capacity to mobilize resources, and the quality of research institutions are the main reasons why R&D effort rises with the level of development.

-Bebczuk (2002)

-Trade openness and investment in physical capital have a negative effect on aggregate R&D expenditure in developing countries.

Studies on International R&D Spillover

-Clemenz (1990)

Moving from Autarky to free trade stimulates R&D if the technological gap between the international competitors is sufficiently small while a temporary protection is favorable if the gap is large.

-Elj (2000)

Productivity level is positively related to its own cumulative R&D and also to other industries' technology investments due to trade in embodied technology. However, domestic spillovers are stronger than the foreign ones for all sectors and all countries.

-Coe, Helpman, and Hoffmaister (1997)

Developing countries can boost their productivity by importing a larger variety of intermediate goods and capital equipments embodying foreign knowledge and by acquiring useful information that would otherwise be costly to obtain.

-Potterie and Lichtenberg (2001)

Outward FDI flows and import flows are two simultaneous channels through which technology spills over and benefits other industrialized countries.

-Coe and Helpman (1995)

Foreign R&D, defined as the import-share-weighted average of domestic R&D of trade partners, has beneficial effects on domestic total factor productivity. These effects are stronger the more open an economy is to international trade.

Studies on Innovation and Imitation

-Perez-Sebastian (1999)

Technology imitation provides an additional growth engine that allows for rapid convergence along with interest rates, consumption, and physical capital investment shares.

-Eger, Kraft, and Weise (1991)

In a game-theoretic model of N identical players who are all engaged in a supergame and have to choose between two strategies, innovation and imitation, an equilibrium between innovation and imitation exists and is globally stable. However, equilibrium is not Pareto-efficient.

-Mukoyama (2003)

Imitation enhances innovative activity by increasing the number of innovative industries. He suggests that a subsidy to imitation might be preferable to a subsidy to innovation because the later might increase the monopoly distortion.

-Papageorgiou (2003)

Developing economies possessing sufficiently high levels of skilled labor can take advantage of existing technologies through imitation and grow rapidly for a long time.

-Wilke and Zaichkowsky (1999)

High-quality imitators are not a problem to society and may even benefit the marketplace by providing good competition and more choices for consumers.

-Zeng (2001)

A subsidy to innovation always speeds up economic growth while a subsidy to imitation always does the opposite. The subsidy to imitation decreases the marginal cost of the imitator and thus induces more employment in imitation which leads to a reduction in the marginal benefits to innovation.

-Katz and Shapiro (1987)

The firm with the higher baseline profits, the industry leader, will tend to develop major innovations if and only if imitation is difficult. They also suggest that a decrease in the transaction cost of licensing that raises the innovator's profits may lead to slower development by reducing the incentives of the losing firm to fight for the initial property rights.

Studies on Government and Private R&D

-David, Hall, and Toole (1999)

An empirical survey paper that addresses if public R&D is a complement or a substitute for private R&D. They find that one third of the cases report that public R&D behaves as a substitute for private R&D, the others find that complementarity appears more prevalent at the industry and national economy levels.

-Goolsbee (1998)

Government R&D policy mainly benefit scientists and engineers in the U.S. A significant fraction of the increased R&D spending goes directly into higher wages to R&D scientists (because of the inelastic labor supply for these scientists).

-Hu (2000)

There is significant complementarity between private and government R&D in China's enterprises.

-Tranjtenberg (2000)

Argues that government policy in Israel should be aimed at the supply side of R&D (scientists and engineers) rather than subsidizing the demand side.

The Theoretical Model

The theoretical model in this paper extends Grossman and Helpman's (1991) quality ladder model. Generally, we focus on two main determinants of R&D: patent rights protection laws and technology transfer. Assume two countries, A and B, where A is a developed country and B is an emerging country; each country has three sectors: traditional goods *(Z)*, R&D *(γ)*, and intermediate goods *(X)*. Household demand is divided between the traditional good Z and the high-tech good Y which uses X intermediate good in its production. Each sector uses two inputs: human capital *(H)* and unskilled labor *(L)*.

The utility function of a representative household takes the form

$$U_t = \int_t^{\infty} e^{-\rho} [\sigma \log C_Y(t) + (1-\sigma) \log C_Z(t)\, dt, \qquad 0<\sigma<1. \tag{1}$$

Where C_i is the consumption of good i $(i=Y, Z)$, ρ is the subjective discount rate, σ is fraction of consumer spending devoted to good Y – the high-tech product, and the remaining $1-\sigma$ is devoted to good Z, the traditional good. It is well known that the solution to this problem involves

$$\dot{E}/E=r-\rho \quad (2)$$

Where E is the aggregate expenditure in the economy and $E(t)=p_iC_i$. p_i is the price of good i, and r is the interest rate. In the steady-state

$$r=\rho \quad (3)$$

We also normalize expenditure so that

$$E(t)=1$$

With the normalization of aggregate spending, $E(t)=1$, demand for good Y equals σ/p_Y, and equals 1- σ/p_Z for good Z. In equilibrium the value of household purchases of good Y equals the aggregate cost of component intermediates p_xX. Therefore, the market clearing condition for the high tech product implies that

$$p_xX = \sigma \quad (4)$$

And the market clearing condition for the traditional good Z implies that

$$p_Z Z=1-\sigma \quad (5)$$

In the oligopoly equilibrium for product X, it is assumed that the industry leader captures the entire world market by setting a price that is λ times the unit cost of production of its closest competitor on the quality ladder. That is

$$p_x = \lambda\, C(x) \quad (6)$$

Where $\lambda>1$ and is an index of quality increments. One explanation is that each new generation of product provides λ times as many services as the product of the generation before it. This means that technological progress causes costs in that product line to fall by a factor of $1/\lambda$. The expected stream of profits for each firm engaging in R&D activity is

$\pi = x(p_x\text{-}C(x))$ (7)

Substituting *(4)* and *(6)* in *(7)* we get

$$\pi = \frac{\sigma}{p_x}(p_x - \frac{p_x}{\lambda}),$$

which reduces to

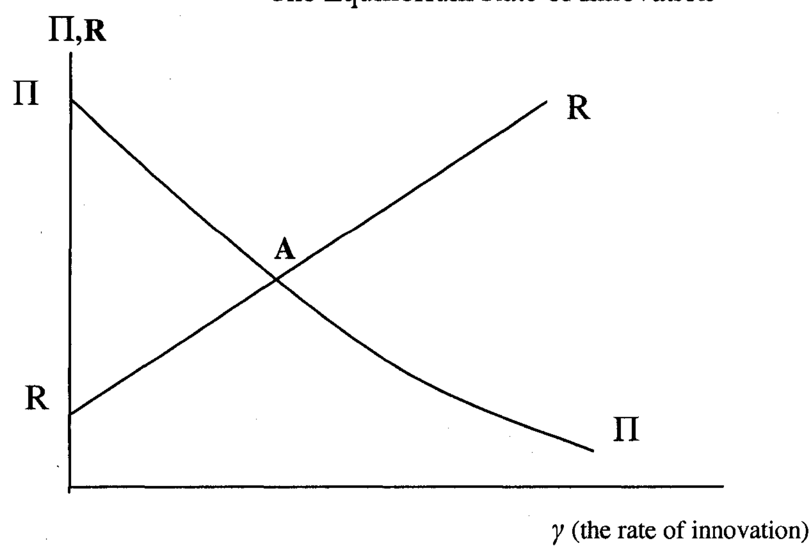
$$\pi = (1 - 1/\lambda)\,\sigma \qquad (8)$$

Now relating the profit from R&D with the total cost of R&D, *(C (γ)),* the long-run profit rate is $\frac{(1-1/\lambda)\sigma}{C(\gamma)}$. This profit rate declines with the rate of innovation because as γ increases the cost of R&D increases too. In equilibrium, the profit rate equals the cost of capital (r) and the risk of capital loss which is given by the rate of innovation (γ), because a successful innovation can replace the current market leader.

The market clearing condition takes the form

$$\frac{[(1-1/\lambda)\sigma]}{C(\gamma)} = \rho + \gamma \qquad (9)$$

Figure 1
The Equilibrium Rate of Innovation



As shown in Figure 1, ππ presents the profit rate and RR presents the required return, given by the safe asset return and the risk of capital loss. The RR curve is upward sloping since the risk rises with the rate of innovation because a successful innovation unseats the current leader which happens with probability γ. The equilibrium rate of innovation is shown at point A.

Patent Rights Protection and the Rate of R&D

We next model patent rights in the R&D race. As indicated in Park and Wagh (2000), the strength of intellectual property and patent rights in a country is based upon five criteria:(1) coverage (the subject matter that can be patented); (2) duration (the length of protection); (3) enforcement (the mechanisms for enforcing patent rights); (4) membership in international patent treaties; and (5) restrictions or limitations on the use of patent rights. Our hypothesis is that the rate of R&D is positively related with the strength of intellectual property and patent rights. Let θ be an index of the strength of intellectual property and patent rights, where $0<\theta<1$. Using an asset value equation the value of a firm engaging in R&D is determined as

$$\pi + \dot{V} - V(\gamma+1-\theta) = \rho V, \tag{10}$$

where π is the profit flow, $\dot{V}$ is the capital gains, $(\gamma+1-\theta)$ is the risk of capital loss, and ρ is the return on alternative investment in the safe asset. The risk term $(\gamma+1-\theta)$ includes both innovation and the lack of patent protection because with probability $(\gamma+1-\theta)$ the existing leader is replaced.

In the steady-state where $\dot{V}=0$, the market value of the firm is

$$V(\lambda)=\frac{\pi(\lambda)}{(\rho+\gamma+1-\theta)} \tag{11}$$

Or

$$\frac{V(\lambda)}{\pi(\lambda)}=\frac{1}{(\rho+\gamma+1-\theta)} \tag{12}$$

We explicitly write $V(\lambda)$ to examine the effect of λ on profit, market value, and innovation. The basic idea is that a firm that makes quality improvements enjoys a higher market value. From equation *(12)* we can see that as θ increases, the right hand side (the discount factor) increases and thus the left hand side should also increase provided that $V(\lambda)$ rises more than $\pi(\lambda)$. This means that λ rises with θ if the effect of quality improvements on the market value of the firm is greater than its effect on the profit flow, which is intuitive and ought to be naturally satisfied. We show next that this occurs when there is an increase in the degree of patent protection, θ.

We write equation (11) in elasticity form following a change in θ,

$$\varepsilon_{v,\lambda}\,\varepsilon_{\lambda,\theta}=\varepsilon_{\pi,\lambda}\,\varepsilon_{\lambda,\theta}+\varepsilon_{d,\theta}, \tag{13}$$

where $d=\dfrac{1}{(\rho+\gamma+1-\theta)}$ is the discount factor.

Because $\varepsilon_{d,\theta}$ is positive it follows that $\varepsilon_{v,\lambda}>\varepsilon_{\pi,\lambda}$, which means that the value of the firm responds to an increase in θ by more than the profit flow. The basic intuition for our result is that an increase in patent protection enables firms to make a bigger commitment in their R&D race, which takes the form of quality improvements. In terms of the determinants of innovation, the profit rate curve ΠΠ shifts up in response to the increase in patent protection which raises the profit flow while the RR line shifts down due to a decrease in the risk associated with R&D.

A factor that is likely to affect the cost of innovation, particularly at high levels of patent protection, is that overly burdensome protection can limit access to new ideas and slowdown innovation. This would have the effect of raising the cost of innovation. We incorporate this factor in the steady state equation as

$$\frac{\pi(\lambda)\sigma}{C(\gamma,\theta-\theta_\circ)} = \rho + \gamma + 1 - \theta \ , \qquad (14)$$

where $\theta_\circ$ is a threshold after which the R&D cost function rises with θ, i.e., $C_\theta>0$ for $\theta>\theta_\circ$, and $C_\theta=0$ for $\theta\leq\theta_\circ$. This would slow the profit rate for $\theta>\theta_\circ$, leading to a slowdown in the rate of innovation. Of course, at very high levels of θ, it is possible that the gains in profit are entirely offset by rising costs and the ΠΠ curve does not shift. A perverse effect is possible in which case the ΠΠ curve shifts in, which would have a negative effect on the rate of innovation.

Foreign R&D and Technology Transfer

The effect of foreign R&D on domestic R&D and the way technology is transmitted between countries have received much attention. Well known examples are Coe, Helpman, and Hoffmaister (1997), Coe and Helpman (1995), Bebczuk (2002), Moez El Elj (2000), Grossman and Helpman (1991), and Potterie and Lichtenberg (2001), to mention a few. The general consensus is that the important technology transmission mechanisms are through trade and FDI, especially trade in intermediate goods and outward FDI flows.

In this paper we postulate that trade in intermediate goods and FDI increase the rate of innovation in both exporting and importing countries. Let us consider a situation in which we have two countries, an LDC and a developed country. We assume that the LDC only imitates and the developed country only innovates. We are assuming also in this model that the imitation rate in the LDC is strictly less than the innovation rate in the developed country, because imitation is derived from innovation. That is $I<\gamma$, where I is the imitation rate in the LDC. Using asset value equations and ignoring patent protection issues we can state that the value of an innovating firm in the developed country, V^D, is given by

$$\pi^D + \dot{V}^D - V^D(\gamma+I) = \rho^D V^D \qquad (15)$$

where I, the imitation rate in the LDC, increases the risk of displacement of the leading firm in the developed country. Thus, in the steady state

$$V^D = \frac{\pi^D}{\rho+\gamma+I} \qquad (16)$$

We assume that the risk facing an imitating firm is given by the rate of innovation but does not depend on imitation. This can be rationalized by assuming that successful imitation occurs only once for every new technology. So the risk to a successful firm in the LDC is just the rate of innovation in the developed country.

The market value for the imitator firm, V^L, is given by

$$\pi^L + \dot{V}^L - V^L(\gamma) = \rho^L V^L \qquad (17)$$

And

$$V^L = \frac{\pi^L}{\gamma + \rho} \tag{18}$$

It follows that in the steady state the rate of innovation cannot be decreasing in the rate of imitation. If it did, both innovation and imitation would be zero because imitation is derived from innovation. In this simple model of imitation, therefore, we expect that $\gamma'(I)>0$. The transmission mechanism that enables the LDC to imitate, we assume, is increasing in imports of intermediate goods and FDI. From this argument it follows that imports of intermediate goods and FDI help imitation, which in turn raises innovation and thus R&D in both countries.

Empirical Application

This paper uses a semiparametric approach to estimate the determinants of R&D. It is well known that misspecification of the functional form can lead to biased econometric estimates, resulting in misleading conclusions about hypothesis testing. In this respect the nonparametric approach, which does not impose any restriction on the functional form of the regression model, has been increasingly popular in econometrics during the last decade or so. However, the major complication in a purely nonparametric econometric approach is that of the "curse of dimensionality". Every econometric technique has some detriment associated with it and in case of nonparametric, it is the need for a very large sample size without which accuracy is not possible. Also the size of the sample required increases with the increase in the number of regressors involved in the model. It is in this regard that the semiparametric approach has been very popular.

In a semiparametric analysis one can impose linear functional form for some of the regressors whereas the other (smaller number of) regressors may be allowed to have an unknown functional form. Effectively, the semiparametric estimation involves the use of a combination of parametric and nonparametric techniques within the same regression model. Cross sectional nonparametric and semiparametric regression analysis can be found in Robinson (1988), Hardle (1990), Pagan and Ullah (1999). Panel data with fixed and random effects in nonparametric and semiparametric frameworks have been discussed in Porter (1991), Li and Ullah (1998), Ullah and Roy (1998).

This paper attempts to apply semiparmetric panel data techniques to test the aforementioned hypotheses about the determinants of research and development expenditure. Both country and time specific heterogeneity effects are captured in the model. Moreover semiparametric estimation involves local point wise analysis and helps us find the underlying dynamics of the effect of different macroeconomic determinants of R&D.

Econometric Model

We use a fixed effect semiparametric regression model as in (19). The methodology used is very similar to that in Ullah and Roy (1998). Ullah & Roy (1998) has only individual specific fixed effect in their model. This paper follows the same methodology but incorporates time specific fixed effect in addition. The model is

$$y_{it} = \alpha_i + \mu_t + \beta x_{it} + m(z_{it}) + u_{it} \tag{19}$$

$$i=1,\ldots\ldots\ldots,n, \text{ and } t=1,\ldots\ldots\ldots,T$$

Where y_{it} is the dependent variable of individual i in time t, α_i is the individual-specific fixed effect parameter, μ_t is the time-specific fixed effect parameter, x_{it} is a vector of linear parametric regressors, z_{it} is a vector of regressors with the known functional form, $m(.)$ represents the unknown functional form, and u_{it}'s are assumed to be i.i.d with mean zero and constant variance σ^2. The identification conditions are

$$\sum_{i=1}^{n} \alpha_i = 0 \text{ and } \sum_{t=1}^{T} \mu_t = 0$$

If $m(z_{it}) = \beta z_{it}$, we get the linear parametric model. Taking a linear approximation of $m(z_{it})$ around a fixed point z we have,

$$m(z_{it}) = m(z) + \delta(z)(z_{it} - z) \tag{20}$$

Where $\delta(z)$ is the first derivative of $m(z_{it})$ at $z_{it}=z$

Thus, substituting (20) in (19) we get,

$$y_{it} = \alpha_i + \mu_t + \beta x_{it} + m(z) + \delta(z)(z_{it} - z) + u_{it} \tag{21}$$

This is the local linear semiparametric model.

Following Robinson's method (1988), both β and δ can be estimated as follows

$$\hat{\beta} = \sum_i \sum_t (y^*_{it}\, x^*_{it}) / \sum_i \sum_t (x^*_{it})^2 \tag{22}$$

Where

$$y^*_{it} = y_{it} - E(y_{it} \mid z_{it}) \text{ and,}$$

$$x^*_{it} = x_{it} - E(x_{it} \mid z_{it})$$

And thus,

$$\hat{y}^*_{it} = \hat{\beta}\, x^*_{it} \qquad (23)$$

To get an estimation of the nonparametric part of equation (21), we subtract (23) from (21) to get

$$y^{**}_{it} = \alpha_i + \gamma_i + m(z) + \delta(z)(z_{it} - z) + \mu_{it} \qquad (24)$$

And

$$\hat{\delta}(z) = \sum_{i=1}^{n} \sum_{t=1}^{T} [(z_{it} - z_{i.} - z_{.t} + \bar{z})(y^{**}_{it} - y^{**}_{i.} - y^{**}_{.t} + \bar{y}^{**} K(\frac{z_{it} - z}{h}))]/$$

$$\sum_{i=1}^{n} \sum_{t=1}^{T} (z_{it} - z_{i.} - z_{.t} + \bar{z})^2 K(\frac{z_{it} - z}{h}) \qquad (25)$$

where $z_{i.}$ is the average of z_{it} over time, $z_{.t}$ is the average of z_{it} over individuals, $\bar{z}$ is the average over all observations, $K(.)$ is the kernel smoothing function, and h is the bandwidth.

<u>Data</u>

The sample of study contains six low and medium-income countries: India, Thailand, Indonesia, Korea, Mexico, and Venezuela, and 15 high-income OECD countries: Austria, Denmark, Canada, Finland, France, Japan, Iceland, Ireland, Italy, Netherlands, Norway, Spain, Sweden, United Kingdom, USA. Data are collected from several sources: World Bank WDI, UNESCO website, Science & Technology Ibero-American Indicators Network website (RICYT). We used the patent rights index constructed by Walter G. Park and Smita Wagh (2000) that represents the strength of the patents rights laws in each country of interest. The index range is from 1 to 5; the closer the index to 5 the stronger are the patent rights laws in the country. The panel data contains an annual country level data over 17 years (1981-1997).

The variables considered are: aggregate R&D expenditure as a percent of GDP, patent rights (Pat), budget deficit as a percent of GDP (Bd), manufactured imports as a percent of GDP (Imp), foreign direct investment inflows (FDI), and log of real GDP per capita (LRGDP). The other control variables are: inflation (Inf), and secondary school enrolment as a percent of population (SE) as a proxy of human capital. FDI and manufactured imports as a percent of GDP are used to represent the prospect of technology transfer from foreign R&D. We could not find data on government subsidies to domestic R&D over our period of study especially in the low and medium-income countries, so we will study only the effect of budget deficit on the rate of R&D knowing that this deficit is not necessarily caused by an R&D subsidy. Table 1 contains the statistical description of the variables.

Table 1
Statistical Description

Variables	R&D	LRGDP	IMP	FDI	BD	SE	Inf	Pat
Mean	1.47	9.3	15.5	0.97	-3.5	87.2	9.35	3
St. Deviation	0.87	1.3	7.39	1.01	3.89	28.7	16.24	1.1
Max.	3.89	10.68	37.54	6.45	5.08	142.8	139.6	4.8
Min.	0.07	5.46	1.96	-0.85	-16	1.97	-1.44	0.3

Results

We first estimated the whole sample in a fixed effect parametric framework. The choice of a fixed effect model is based on Hausman test. The results of the parametric model are presented in the second column in Table 2. The second estimation is conducted using the semiparametric model[3]. Tests for linearity suggest that there is a nonlinear relation between R&D and all the variables of interest (patents, imports, GDP per-capita, FDI, budget deficit) and thus, the linear parametric model will not be appropriate. However, it is difficult to use nonparametric functional form for all those variables together in a regression model as it may lead to "dimensionality" problem.

Table 2
Parametric and Nonparametric Results

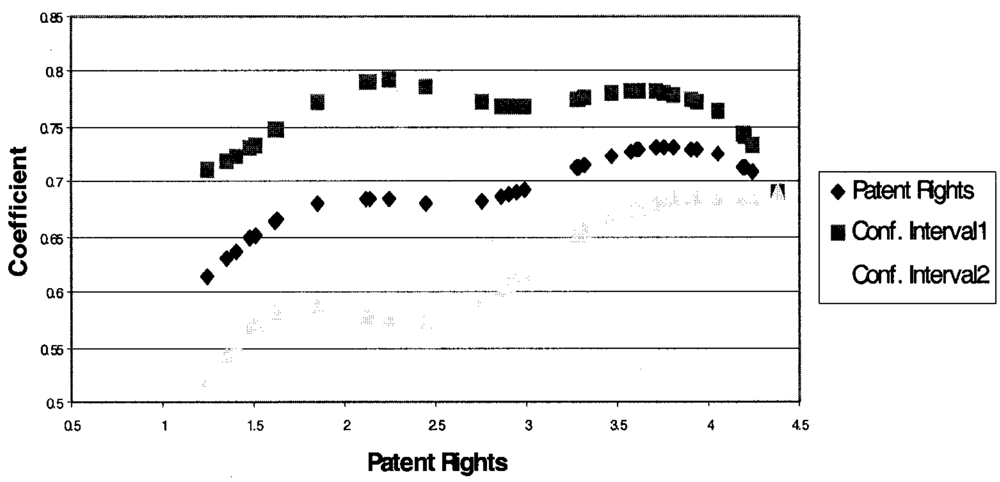
Variables	Parametric Results	Nonlinearity in Pat.	Nonlinearity in LRGDP	Nonlinearity in Imp.	Nonlinearity In FDI	Nonlinearity in Bd.
Pat	0.286 (6.332)	0.692 (22.222)	0.317 (6.619)	0.317 (6.751)	0.289 (6.281)	0.297 (6.483)
LRGDP	0.761 (7.677)	0.208 (4.267)	0.738 (33.7)	0.1845 (4.160)	0.147 (3.378)	0.159 (3.583)
Imp	-0.031 (-5.545)	-0.029 (-6.216)	-0.026 (-5.874)	0.001 (0.251)	-0.032 (-7.186)	-0.032 (-7.319)
FDI	0.035 (2.167)	0.037 (1.219)	0.083 (2.703)	0.088 (2.908)	-0.004 (-0.232)	0.052 (1.683)
Bd	-0.010 (-2.531)	0.007 (0.976)	0.002 (0.370)	-0.003 (-0.515)	0.010 (1.393)	-0.036 (-7.199)
SE	0.001 (1.577)	0.007 (4.064)	0.003 (1.867)	0.004 (2.15)	0.007 (3.811)	0.006 (3.248)
Inf	-0.003 (-4.011)	-0.007 (-3.860)	-0.005 (-2.462)	-0.006 (-3.365)	-0.007 (-3.735)	-0.008 (-4.405)
R2	0.94	0.97	0.98	0.94	0.94	0.96

Notes:
- R&D expenditure as a percent of GDP is the dependent variable.
- The total number of observations (n*T) is 357.
- t-statistic is in the parentheses.

[3] Standard normal kernel and optimal bandwidth that minimizes the mean square error have been used.

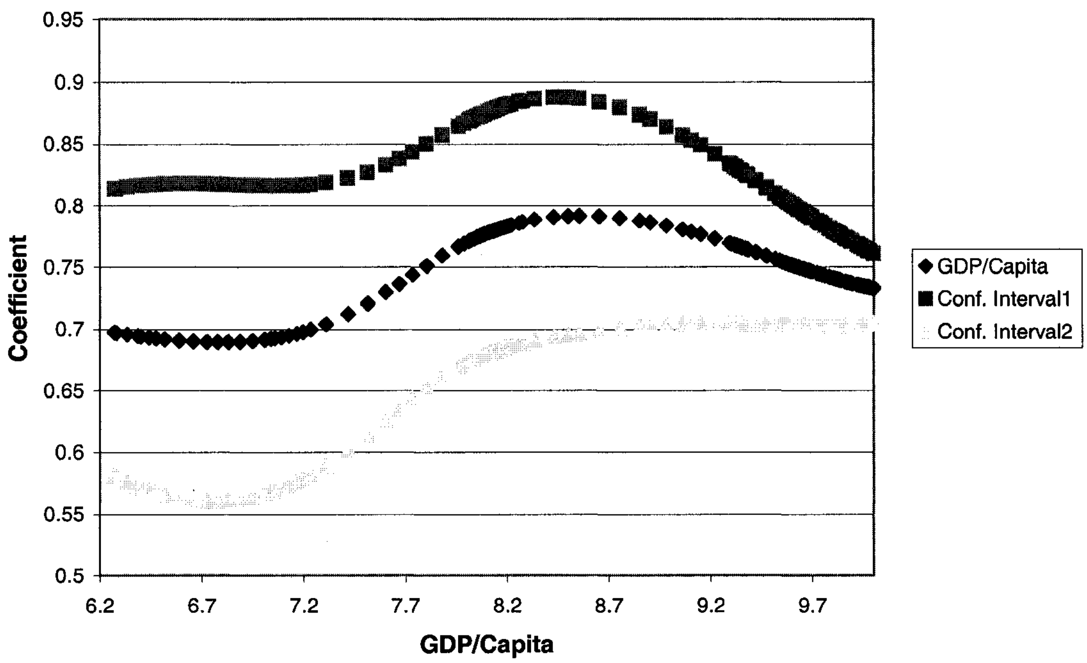
Thus, we consider different semiparametric models while focusing on different economic hypotheses regarding the determinants of R&D. For example, while focusing on the hypothesis about the effect of patent on R&D, we consider a semiparametric model with patent (z_{it}), being the only regressor with unknown function form *m(.)* and all other variables, inflation, imports, GDP, FDI, school enrolment, budget deficit (x_{it}) are assumed to have a linear form. Thus, we consider five different semiparametric regression models. The results are reported in columns 3 to 7 in Table 2 while the results for the linear parametric estimation are reported in column 2.

Figure 2
The Effect of Patent Rights on the Rate of R&D



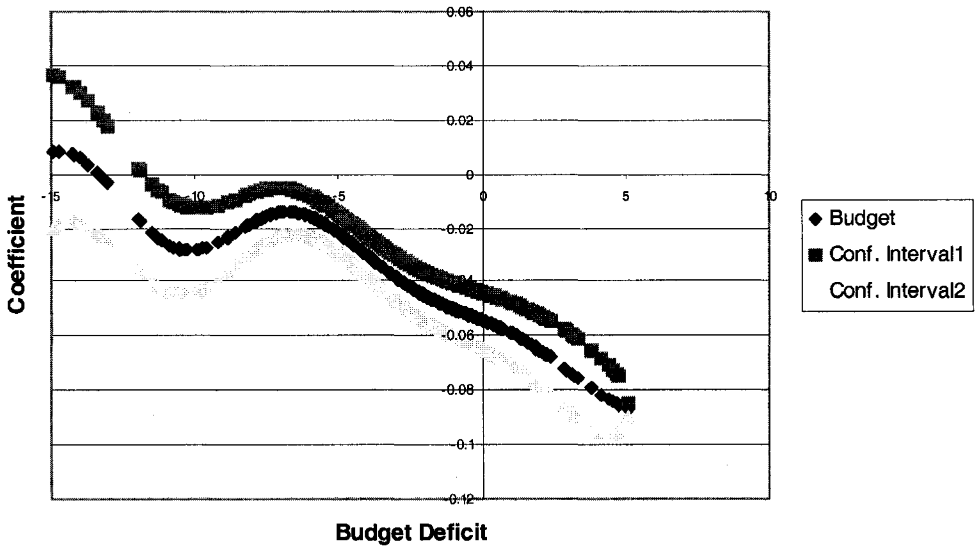
Column 3 reports the result for semiparametric regression where the unknown functional form is assumed for patent rights index only. Since the nonparametric/semiparametric estimation is a local "point-wise" analysis, the obtained slope coefficients vary with the regressors as in any typical nonlinear regression model. Based on the sample size, we obtained 357 slope coefficients. The averages of those coefficients are reported in Table 2 as the estimated coefficient for the effect of patent rights on R&D expenditure. However, in Figure 2 we present the dynamics of the effect of patent on R&D. In the horizontal axis we measure the index of patents whereas in the vertical axis we measure the effect of patent rights index on R&D expenditure, i.e., the estimated slope coefficients ($\delta(z)$ in equation 25).

Figure 3
The Effect of GDP/Capita on the Rate of R&D



A 5% confidence band for the slope coefficient $\delta(z)$ is also presented. We found that the effect of patent rights on R&D is positive and significant for all values of patents. However, the positive effect slows down after a threshold of 3.5. That is, beyond this level if the government increases the patent rights protection, the percentage of R&D expenditure increases but at a decreasing rate. This means that too much protection may cause a slowing down in the rate of R&D because now accessing the technology is very costly. Patent rights index is also found to be positive and significant in the parametric estimations (column 2).

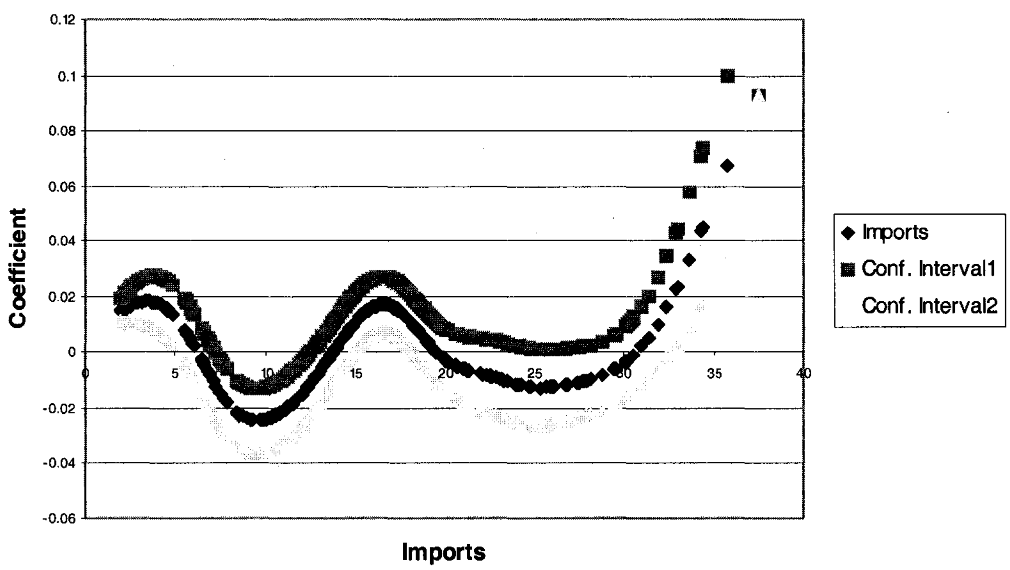
Figure 4
The Effect of Budget Deficit on the Rate of R&D



Column 4 reports the effect of GDP per-capita on the rate of R&D. The positive and significant effect indicates that richer countries are able to support a higher rate of innovation. As for the dynamics, the semiparametric estimators are presented in Figure 3. It shows that there are two thresholds in the relationship between GDP per-capita and the rate of R&D, the first one is when GDP per-capita reaches a level of 7.2 ($2900). After this level we find that the positive effect of the GDP per-capita is increasing at an increasing rate until it reaches the second threshold (8.5 which is about $4600). We then find the effect of GDP per-capita on the rate of R&D becomes weaker but still positive.

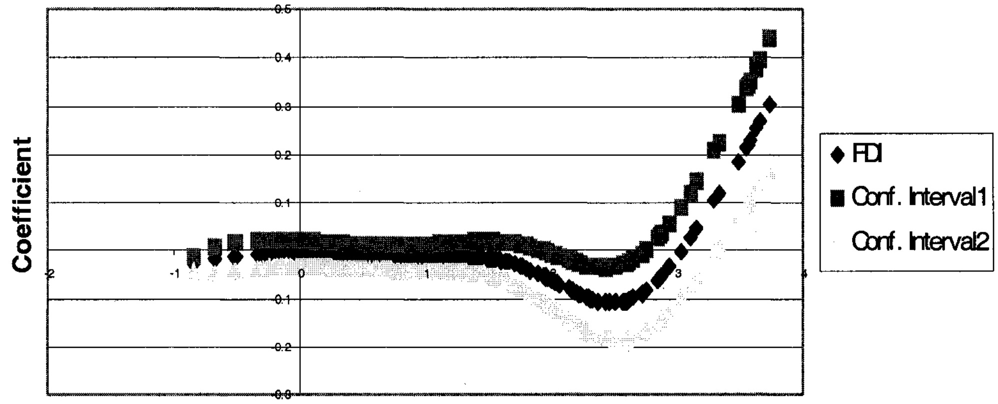
The average of the coefficients of budget deficit is reported in column 7. The nonparametric estimation shows a negative and significant impact of budget deficit on the rate of R&D. Imports and FDI nonparametric coefficients appears in columns 5 and 6 respectively. The average coefficients are insignificant for both proxies of foreign R&D. Coefficients for the parametric regression are significant and negative for both the cases.

Figure 5
The Effect of Imports on the Rate of R&D



However, when we look at the dynamics in Figures 5 and 6 we find that both variables turn out to be significant and positive after a certain threshold (30% of GDP in case of imports and 3% of GDP in case of FDI) is reached. This means that foreign technology has an effect on domestic R&D only when the country depends heavily on importing intermediate goods or inward FDI flows.

Figure 6
The Effect of FDI on the Rate of R&D



School enrollment, that has been estimated parametrically, has the expected positive sign and its effect on the rate of R&D is significant. Inflation has also been estimated parametrically and has a negative and significant effect on the research and development expenditure

Conclusion

In this paper we analyze some R&D determinants using a theoretical model and a panel data semiparametric empirical model that uses country level data of twenty-one countries, of which six are emerging, for the period 1981-1997. The theoretical model predicts that patent protection and technology transfer have positive effects on the rate of innovation. However, the effect of patent protection slows down after a certain threshold in the degree of patent protection is reached. It also predicts that technology transfers through imports of intermediate goods and FDI inflows raise the rate of innovation and imitation in both developed and less developed countries.

The dynamics of the semiparametric model capture these predictions well. We find that patent protection's effect on the rate of R&D becomes weaker, though still positive, after it reaches an index of 3.5. In addition, imports and FDI effects are positive and significant but only for countries that depend heavily on FDI and imported intermediate goods. GDP per-capita is found to have a positive effect on the rate of R&D but becomes weaker after a threshold is reached, while the effect of budget deficit is found to be negative and significant. Other control variables such as inflation and school enrolment are found to have the expected impact on research and development expenditure (negative effect for inflation and positive effect for school enrolment).

ESSAY 2
FISCAL POLICY AND BUSINESS EXPENDITURE ON R&D: AN EMPIRICAL STUDY OF OECD COUNTRIES

Introduction

Private expenditure on research and development has received a lot of attention by both researchers and policymakers since it plays a vital role in increasing economic growth and productivity. For example, Lichtenberg (1992) finds that privately funded R&D investment has a significant positive effect on both the level and growth rate of productivity. A similar result is found by Albert Hu (2000) and Jones and Williams (1998). These results motivate governments to design economic policies so that they can stimulate private R&D. In OECD countries, Dominique Guellec and Bruno Van Pottelsberghe (2000) show that governments implement several policies to support business sector R&D, which was the largest of three sectors performing R&D in the past decade in most OECD countries; the other two being higher education and government R&D. Governments support was provided either directly by funding businesses for carrying out certain research, or indirectly by providing fiscal incentives.

In the R&D literature, several studies investigate the relationship between Private R&D expenditure and fiscal policy incentives. Their purpose is to investigate whether the fiscal incentives, specifically tax credits and allowances, can be welfare enhancing by increasing the rate of R&D. In other words, they aim at comparing the tax revenue loss arising from fiscal incentives and the social benefits arising from increasing the private expenditure on R&D. Such studies have been undertaken by

Edwin Mansfield (1986) and Mansfield et al (1985), Lenjosek and Mansour (1999), Bloom, Griffith, and Reenen (2000), and Hall and Reneen (1999).

In this paper we conduct an empirical study of the effect of fiscal policy on private R&D expenditure in OECD countries. The main idea in this paper is to treat the research and development expenditure decision in the private sector as an investment decision and examine how it is affected by various fiscal policy variables. Following Barro (1990), we divide the fiscal policy variables into four categories: distortionary taxes and non-distortionary taxes (the tax side), and productive and non-productive expenditure (the expenditure side).

Our main goal is to examine the impact of the first three fiscal variables, along with budget deficit, on the private R&D investment decision assuming that private firms are provided with R&D tax incentives. The later assumption is important not only because it is a practical assumption (most developed economies offer R&D tax incentives to private firms for qualified R&D expenditure), but also because it helps us understand the behavior of private R&D investment for any increase in the marginal income tax rate in the presence of R&D tax incentives. Non-productive expenditure, such as social security and any transfer payments, is ignored in the analysis since it is expected that its impact on private R&D expenditure decision is insignificant.

The empirical study is applied to a sample of 14 high-income OECD countries over the period 1981-2000. Country and time specific heterogeneities are addressed by using a fixed effect panel data model.

In the next section we briefly discuss the relevant R&D literature. Section 3 contains the theoretical model in which we extend the quality ladder model of Grossman and Helpman (1991) to examine the effects of different fiscal policy variables on private R&D expenditure. Section 4 presents the empirical model, data, and results. Section 5 contains the conclusion.

Literature Review

The field of fiscal policy and business expenditure on R&D has been a subject for many theoretical and empirical studies. The most important of these studies are listed below.

-Hines, JR. (1997)

Tax policies influence significantly the level, composition, and location of R&D activity of US based multinational firms.

-Nadiri and Mamuneas (1997)

In US manufacturing industries, publicly financed R&D investment is more appropriate for increasing efficiency and stimulating output growth whereas R&D tax policy is more appropriate for stimulating private sector R&D investment.

-Conway (1997)

Suggests that an R&D tax deduction of 150 to 200 percent of R&D expenditure is an appropriate incentive for private firms.

-Hussinger (2003)

By adopting parametric and semiparametric selection model in cross sectional firm level data in Germany, Hussinger finds that public funding of R&D increases private firms' R&D expenditure. So the hypothesis of crowding out between public and private R&D funding is rejected.

-Lenjosek and Mansour (1999)

Their basic idea is that because technology and knowledge are characterized by both non-excludability and non-rivalry, we expect that the market system will underinvest in R&D. They conclude that R&D tax incentives are cost-effective if the ratio of incremental R&D expenditures to tax revenue forgone is greater than or equal unity and thus, R&D tax incentives will be welfare enhancing.

-Hall (1992)

During the eighties, R&D spending at the firm level in the US responds to the tax credit incentive although it took several years for firms to fully adjust.

- Bloom, Griffith, and Reenen (2000)

They constructed an empirical model to test the effectiveness of R&D tax incentives in nine OECD countries during the period 1979-1994. The main conclusion of this study is that fiscal incentives matter because it has an effect on reducing the user cost of R&D. In other words, tax changes significantly affect the level of R&D

-Mansfield (1986) and Mansfield et al (1985)

He studied the effectiveness of Canada's direct tax incentives for R&D using data from 55 firms. The econometric results show that the tax credit did increase R&D expenditures, but with modest percentages (a one-dollar loss in government revenue resulted in about 30 to 40 cents increase in company-financed R&D expenditure).

- Howe and McFetridge (1976)

The main determinants of R&D expenditure are found to be current sales, cash flow, and government incentive grants. Government R&D subsidies induced R&D expenditure in only one of the three industries investigated (electrical, chemical, and machinery industries).

-Peretto (2003)

The main point of this theoretical study of fiscal policy and long run growth in R&D-based models is that the only fiscal instruments that have steady-state growth effects are the tax on household asset income because it is a tax on saving, and the tax on corporate income because it grants an implicit subsidy to R&D undertaken by incumbents.

Some other studies were conducted on government and private R&D as follows:

-David, Hall, and Toole (1999)

A survey of econometric evidence over 35 years to figure out whether public R&D is a complement or a substitute for private R&D. They find that one third of the cases report that public R&D behaves as a substitute for private R&D.

-Goolsbee (1998)

Government R&D policy mainly benefit scientists and engineers in the U.S. A significant fraction of the increased R&D spending goes directly into higher wages to R&D scientists because of the inelastic labor supply for these scientists.

-Hu (2000)

There is a significant complementary relationship between private and government R&D in China's enterprises.

-Tranjtenberg (2000)

Israel R&D policy should be aimed at the supply side of the R&D market (scientists and engineers) rather than keeping subsidizing the demand side.

-Guellec and Pottelsberghe (2000).

Direct government funding of R&D and tax incentives have a positive effect on business-financed R&D. However, direct government funding and R&D tax incentives are substitutes: increased intensity of one reduces the effect of the other on business R&D.

The Theoretical Model

In this paper, we extend Grossman and Helpman's (1991) quality ladder model to examine the effects of fiscal policy variables on the rate of research and development in the business sector. More specifically, we focus on four main fiscal variables: taxes on income and profits (distortionary tax), taxes on expenditure (non-distortionary tax), government productive expenditure, and budget deficit or surplus. Following Barro (1990) and Mendoza et al (1997), the relevant distortion here is that the incentive to invest in physical and/ or human capital may be adversely affected. Expenditure (consumption) taxes are non-distortionary in the sense that they do not reduce the returns to invest; nevertheless, they may affect the returns to investment indirectly through the labor/education-leisure choice, which in turn affects the capital/labor ratio in production.

Budget Deficit and the Rate of R&D

As mentioned in the first paper, the steady state market clearing condition in the R&D sector states that the rate of innovation is determined by the equality between the profit rate for a representative producer $\frac{(1-1/\lambda)\sigma}{c(\gamma)}$, which is represented by ΠΠ curve in Figure 7, and the sum of the risk free rate *(ρ)* and the risk of capital loss *(γ)*, which is represented by the RR curve.

That is:

$$\frac{(1-1/\lambda)\sigma}{c(\gamma)} = \rho + \gamma \qquad (1)$$

Where λ is the quality index (λ>1), $C(\gamma)$ is the cost of R&D, and σ is the fraction of consumer spending devoted to the high-tech goods. We assume here that each high-tech producing firm engages in R&D activity.

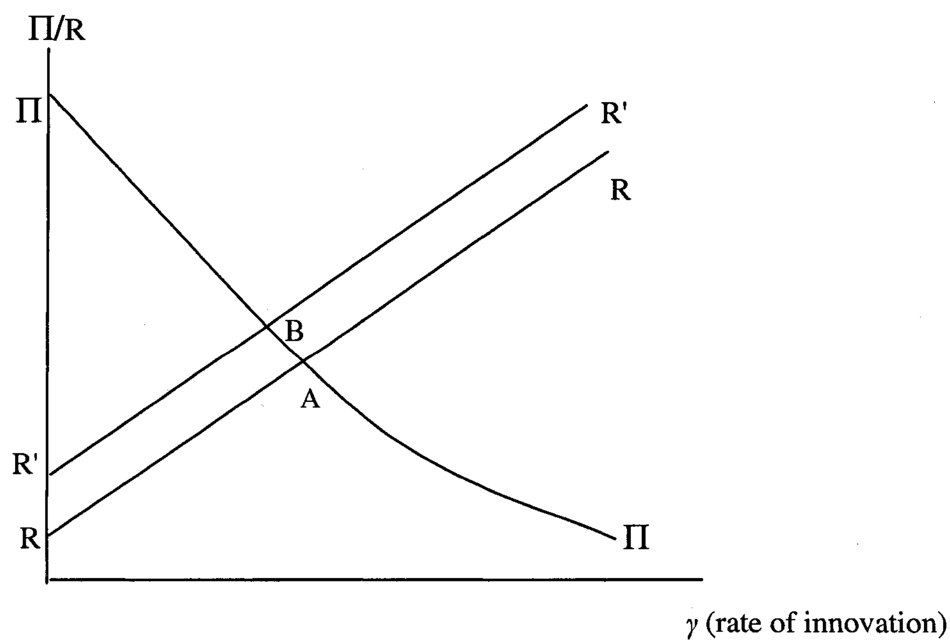
Let *S* reflect the government budget imbalance. In case of a budget deficit, *S* is negative, and in case of budget surplus *S* is positive (*S* = 0 in case of a balanced budget). Suppose that due to external effects, the government realizes a budget deficit and it chooses to finance the deficit through borrowing. The expected "transitional" effect of this policy is to change the interest rate *r* by an amount *s,* which would have the opposite sign of *S* and increases with the absolute value of *S*. This would capture the crowding out effect, for example, when *S*<0. And because $r(t) = \rho$ in our model, so the right hand side in equation (1) will increase and reflect the increase in the cost of capital associated with budget deficit. The market clearing condition now is

$$\frac{(1-1/\lambda)\sigma}{c(\gamma)} = (\rho+s)+\gamma \tag{2}$$

As s here is positive, it is clear that the RR curve will shift upward to R'R' and, as a result, the rate of innovation goes down.

On the other hand, if the government realizes a budget surplus so that it can redeem some of its debts, we expect a reduction in the interest rate. In this case RR curve will shift downward reflecting an increase in the rate of innovation. The budget imbalance index (S) is positive in this case. It is obvious that if the government realizes a balanced budget, the budget imbalance index (S) and the interest rate effect are both zero, and thus, there will be no effect on the rate of innovation.

Figure 7
The Effect of Government Budget Deficit on the Rate of Innovation



Income Taxes, Tax Credits, and the Rate of R&D

Although it is well known that taxes on income and profits have a negative effect on private investment in general, their effect on R&D investment in the business sector could be altered because of the existence of tax incentives to R&D[4]. Suppose that private firms are subjected to a profit tax rate τ so that the net profit after tax is $(1-\tau)\pi\sigma$. As implemented in most tax systems in developed countries, suppose that the government gives a tax credit to R&D investment which applies only to the incremental investment in business R&D[5]. This procedure creates more incentive for firms to increase its R&D investment especially if they are suffering from high marginal tax rates.

The direct effect of the tax credit, which is equivalent to a government subsidy in the Grossman and Helpman model, is to reduce the user cost of R&D investment. The effective after-tax credit cost of the incremental R&D is $(1-t_c)c_\gamma$, where t_c is the tax credit and c_γ is the cost of the incremental R&D investment ($c_\gamma = c(\Delta\gamma)$). Following Stiglitz (2000)[6], firms will increase their investment in R&D beyond previous year's level as long as the after-tax marginal return to R&D, $((1-\tau)MR\gamma)$, is greater than the after-tax credit cost of the incremental R&D. That is

$$(1-\tau)MR\gamma > (1-t_c)c_\gamma, \qquad (3)$$

or

[4] In their empirical paper, Easterly and Rebelo find that marginal income tax rate has a negative effect on private investment.
[5] Some countries, France for example, depend on the previous year's R&D as a base year; others take an average of the R&D expenditure over the past two or three years, as in Spain and USA.

$$MR\gamma > \frac{(1 - t_c)c_\gamma}{(1 - \tau)} \qquad (4)$$

Assuming that we start with a situation in which the firm's before-tax marginal return to R&D equals the before-tax credit marginal cost of R&D ($MR\gamma = c_\gamma$), the government has to design its fiscal policy so that it can achieve the inequality in equation (4) and thus encourage firms to increase R&D investment. This could be done by setting $t_c > \tau$ (it is clear that if $t_c = \tau$, this fiscal policy leaves R&D investment unaffected since the marginal return is reduced by the same amount that marginal cost is). The government needs to keep this inequality as long as the social benefits from R&D are greater than the private benefits[7].We must note here that the marginal tax rate on profits (τ) is bounded between zero and 1, while the tax credit can be unbounded. This means that the tax credit could reach 100% of the incremental R&D investment or it may exceed that limit[8].

In any typical year firms can maximize their benefits from the tax credit and avoid paying profit taxes by increasing R&D investment. And as long as the R&D tax credit does not exceed the firm's tax liability, we expect that increasing the marginal tax rate on profits together with the provision of the incremental R&D tax credit, but

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[6] Stiglitz shows how the investment decision is undertaken when taxes affect both the cost of capital, in the presence of tax incentives, and its return. For more information, see Joseph E. Stiglitz, "Economics of the Public Sector", 3rd edition, W.W. Norton and Company, 2000, pp 584-585.

[7] Studies of social return to R&D such as Griliches and Lichenberg (1984), Griliches (1994), and Jones and Williams (1998) find large rate of returns to R&D, suggesting substantial underinvestment in R&D. The later study estimates the optimal investment in R&D is more than two to four times the actual investment in R&D.

[8] In this case, R&D tax credit will be more effective if it is accompanied by R&D tax credit carryback or carryforward as applied in some OECD countries such as Australia, Belgium, Denmark, Netherlands, and Spain. In such countries, the carryback period is usually between 3 to 5 years while the carryforward period could be up to 10 years. For more information see: Bronwyn Hall and Van Reenen (1999).

keeping $t_c > \tau$, is an effective fiscal policy that leads to an increase in R&D investment. This works because firms find that an effective way to reduce the incremental tax burden is to increase R&D investment. Also, the mix of tax and credit helps government to balance its budget.

R&D tax credit is one of the most commonly used fiscal incentives along with depreciation allowances in developed countries to encourage firms to undertake more R&D. Nevertheless, some studies, Mansfield (1986) and Mansfield et al (1985) for example, find that R&D tax credits are not welfare enhancing because the loss in tax revenue associated with the tax credit is greater than the increase in R&D expenditure. As Mansfield (1986) indicated in his paper, firms may claim some of their expenditure as R&D to benefit from the tax incentives offered to them while in fact these expenditures are not really what informed observers would regard as R&D expenditure. This is mainly because of the vagueness of R&D definition in the tax law.

Expenditure Taxes, Government Expenditure, and the Rate of R&D

It is well known that in practice consumption (sales) taxes are levied only on the consumption of goods-such as capital goods and consumer durables- and not in such a way to conform to a comprehensive consumption tax base. We assume here that the consumption tax is levied on consumers' purchases of high-tech goods. This tax is expected to have a direct effect on σ (the fraction of consumer spending devoted to the high-tech goods). The steady-state market clearing condition will be

$$\frac{(1-1/\lambda)\sigma(1-\varepsilon t)}{c(\gamma)} = \rho+\gamma \quad (5)$$

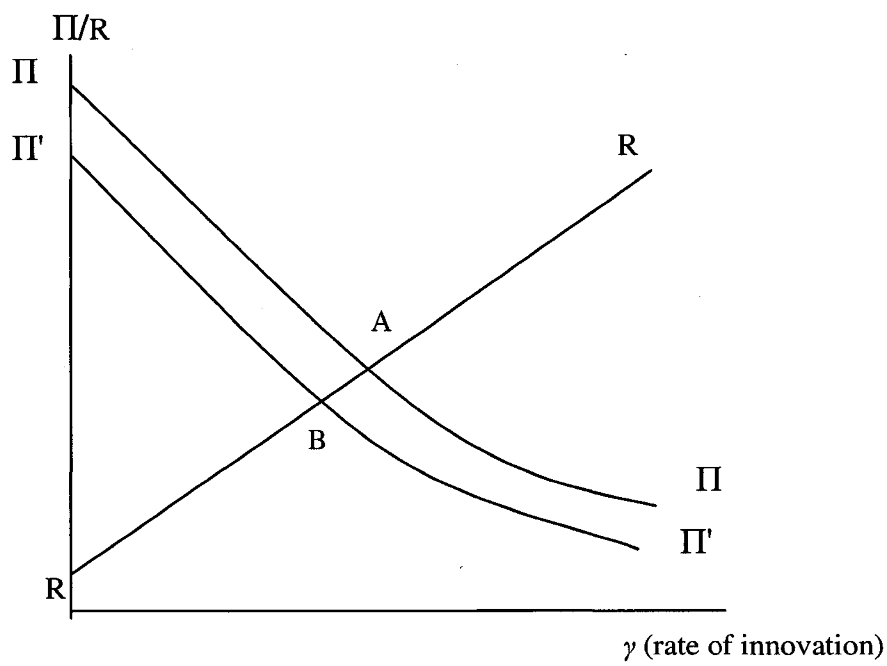
Where t is the tax rate, $0<t<1$ and ε is the price elasticity of demand, $\varepsilon\leq 0$. The consumption tax will reduce the fraction of consumer spending devoted to high-tech goods as long as $\varepsilon\neq 0$ and thus the expected stream of profits for each firm engaging in R&D activity will be reduced. The negative effect of the consumption tax will shift the ΠΠ curve down to Π'Π' which means that the rate of innovation decreases with the imposition of consumption taxes. This negative effect is expected to be large if we assumed that high-tech products are luxury goods and thus we expect that the price elasticity of demand on these products is high. Figure 8 represents this result.

The effect of government expenditure on private R&D is somewhat ambiguous. Peretto (2003) argues that a rise in the fraction of tax revenues allocated to productive expenditure, which employ labor, has a negative effect on the fraction of the labor force allocated to R&D in private firms; i. e., public employment displaces private employment. His basic idea is that the rise in public employment crowds out firms and thereby lowers the number of firms per capita which, in turn, has two contradictory effects: the first is that the typical firm, which survives in the market, has a larger market share and thus realizes more profits, the second is that, assuming R&D spending per firm does not change, since the rate of return on firms' stocks rises, households are induced to reduce consumption expenditure and increase assets holding. This reduction in expenditure leads to a reduction in firms' revenues.

Relating Peretto's argument to our model, we can say that the negative effect of government productive expenditure on the fraction of labor force allocated to R&D

is reflected in an increase in $C(\gamma)$: as labor available in the private sector is now relatively scarce the cost of R&D tends to rise. In addition, the market size variable for the typical firm, σ, is affected positively because there are likely to be fewer firms, while the reduction in consumption expenditure has a negative effect; thus the net effect of government productive expenditure on R&D is ambiguous[9]. The empirical model in the next section helps us find out whether government productive expenditure and business R&D are complements or substitutes.

Figure 8
The Effect of a Consumption Tax on High-tech Products on the Rate of Innovation



[9] Peretto argues that if the government allocates all tax revenues to transfer payments, there is no crowding out through the labor supply and consumption expenditure and the number of firms might rise.

The Empirical Model

We apply the fixed effect two stage least squares model to estimate the relationship between fiscal policy variables and business R&D investment in 14 high-income OECD countries over the period 1981-2000. The choice of a fixed effect model is based on Wald test. We apply the two stage least squares method to overcome the problem of endogeneity between business and government R&D[10]. However, we also report the OLS results to compare between the two methods. Country specific heterogeneity effects are captured in the model. The empirical model consists of two simultaneous equations: the main equation of interest is the business R&D equation; the second equation is the government R&D equation. In addition, these two structural equations explore the interrelationship between business and government R&D in the OECD countries in question. We use the explanatory variables with lagged values as instruments.

The econometric model is specified as follows:

The business R&D equation

$$BERD = \alpha_i + \beta x_{it} + \delta z_{it} + \varepsilon_{it}, \qquad (5)$$

$t=(1,\ldots\ldots\ldots,20)$ and $i=(1,\ldots\ldots\ldots,14)$

Where *BERD* is business expenditure on research and development, x is a vector of fiscal policy variables, z is a vector of control variables, α_i is the individual

[10] We tested for endogeneity of government R&D using Hausman auxiliary regression test as presented by Davidson and Mackinnon (1993) and find that it does exist which means that OLS estimation is not consistent.

specific fixed effect parameter, and ε_{it}'s are assumed to be i.i.d with mean zero and constant variance σ^2. The identification condition is $\sum_{i=1}^{n} \alpha_i = 0$.

The government R&D equation

$$GERD = \phi_i + \theta f_{it} + \sigma k_{it} + \mu_{it}, \tag{6}$$

$t=(1,.........,20)$ and $i=(1,.........,14)$

Where *GERD* is government expenditure on research and development, *f* is a vector of fiscal policy variables, *k* is a vector of control variables, ϕ_i is the individual-specific fixed effect parameter, and μ_{it}'s are assumed to be i.i.d with mean zero and constant variance σ^2. The identification condition is $\sum_{i=1}^{n} \phi_i = 0$. We must note that the fiscal policy variables and the control variables in equations (5) and (6) are not the same. The next section describes these variables.

Data

The sample of study contains 14 high-income OECD countries: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Japan, Ireland, Italy, Netherlands, Spain, United Kingdom, and USA.

Data are collected from several sources: World Bank WDI and International Financial Statistics (IFS) are the main sources for the control variables and some of the fiscal policy variables listed below whereas OECD database is the main source for business R&D expenditure. Government Financial Statistics is used for some of the fiscal policy variables. We used the patent rights index constructed by Walter G. Park and Smita Wagh (2000) that represents the strength of the patents rights laws in each country of interest. The panel data contains an annual country level data over 20 years (1981-2000)

The fiscal policy variables considered in equation (5) are: taxes on profits and capital gains as a percent of total tax revenue (distortionary), taxes on goods and services as a percent of total tax revenue (non-distortionary), government capital expenditure as a percent of GDP (this is an indicator of government acquisition of fixed assets), and government final consumption expenditure as a percent of GDP. The control variables consist of: GDP growth which represents the domestic demand on R&D, high-tech exports as a percent of total exports which represent the foreign demand on R&D (high-tech exports are the sum of exports of pharmaceutical products, office machines and computers, consumer electronics, instruments, and aerospace), the number of scientists and engineers per million of population and the number of researchers in business R&D sector which represents the supply side of R&D, patent rights index which represent the rule of law, and gross fixed capital formation as a percent of GDP which represent the investment in intermediate goods (machinery and equipments). We also included the interest rate since it represents the channel through which budget imbalances affect business R&D investment. Government R&D is included as a control variable to check for complementarity with business R&D. All variables are in log form.

For equation (6), the fiscal policy variables considered are budget balance and income taxes. The control variables are; GDP growth, high tech exports, patent rights index, the number of scientists and engineers, and business R&D.

Results

As we mentioned above, the model is estimated in a fixed effect two stage least squares framework. We estimate equation (5) in four different specifications; the first and the third include gross fixed capital formation while the second and the forth include government capital expenditure. In specifications (1) and (2) we use the total number of scientists and engineers while in specifications (3) and (4) we use the number of researchers in business R&D sector. The results of the OLS and the two stage least square estimation are presented in Tables 2.2 and 2.3 for equation (5) and in Table 6 for equation (6). Table 3 contains the variables' descriptive statistics.

Regarding the fiscal policy variables in equation (5), we incorporate taxes on profits and taxes on goods and services in all specifications while government capital expenditure appears only in specification (2) and (4). Since interest rate is the channel through which budget surplus/ deficit affect business R&D, we include it in all specifications.

Table 3
Statistical Description

Variables	Mean	Standard Deviation	Max.	Min.
Business R&D as a percent of GDP	1.12	0.52	2.41	0.19
Government R&D as a percent of GDP	0.28	0.11	0.57	0.06
Budget surplus as a percent of GDP	-3.88	3.7	4.3	-14.8
Taxes on profits and capital gains as a percent of total taxes	41.01	15.5	75.4	16.3
Government capital expenditure as a percent of GDP	6.19	2.9	18.2	1.5
High-tech exports as a percent of total exports	15	9.5	47.1	1.4
GDP growth	2.8	2.4	20.8	-6.2
Patent rights index	3.7	0.51	4.8	2.1
Gross fixed capital formation as a percent of GDP	19.8	5.7	32.1	2.4
Number of researchers in business R&D sector	1060.67	2037.05	1037.5	607
Number of scientists and engineers	2280.9	1068.8	6293	495
Interest rate	10.2	3.7	22.2	2.06

The exclusion of the budget balance variable from equation (5) and take it as an exogenous variable in equation (6), helps in satisfying the identification condition for equation (5). We also include interest rate, government capital expenditure, gross fixed capital formation, and taxes on goods and services as unique regressors in equation (5). On the other hand, the effect of government consumption expenditure on business R&D is found insignificant in every specification and thus it is dropped from the regression.

Table 4
Fixed Effects OLS Estimation of the Effect of Fiscal Policy on Business R&D
(equation-5)

Variable	(1)	(2)	(3)	(4)
Taxes on profits	0.34 (3.0)***	0.6 (3.9)***	0.3 (3.4)***	0.39 (3.4)***
Taxes on goods and services	-0.03 (-.49)	-0.07 (-0.9)	-0.04 (-0.7)	0.04 (0.7)
Government capital expenditure	___	0.21 (4.6)***	___	0.19 (5.7)***
GDP growth	0.03 (1.1)	0.02 (0.59)	0.006 (2.14)**	0.003 (1.07)
High-tech exports	0.17 (3.8)***	0.24 (5.3)***	0.013 (0.38)	0.1 (2.9)***
scientists and engineers	0.52 (8.4)***	0.47 (7.3)***	___	___
researchers in business sector	___	___	0.56 (17.3)	0.5 (14.6)***
Patent rights index	0.35 (1.98)**	0.53 (3.0)***	0.02 (1.67)*	0.13 (1.24)
Gross fixed capital formation	-0.2 (-2.2)***	___	-0.21 (-3.2)***	___
Interest rate	0.002 (0.04)	0.05 (0.8)	-0.08 (-2.7)***	-0.001 (-0.05)
Government R&D	0.02 (0.5)	-0.05 (-1.2)	0.17 (4.18)***	0.22 (5.07)***

Notes:
-Business enterprise expenditure on R&D is the dependent variable.
-t-statistics are in parentheses.
-Coefficients are significant at *** 1%, ** 5%, and * 10%.

The two stage least squares analysis shows that interest rate has the expected negative sign and it is significant most of the specifications. Government capital expenditure, which represents government spending to acquire fixed nonmilitary capital assets and includes capital grants, has a positive and significant effect on business R&D. The positive sign associated with government capital expenditure is expected since it represents the government's demand on capital goods, which stimulates R&D. This result suggests that government capital expenditure and business R&D are complements. However, when we replace the government capital expenditure with gross fixed capital formation in the first and the third specification, we get a negative and significant sign. There are two explanations for this negative sign: the first, according to Grossman and Helpman (1991), is that since gross fixed capital formation represents the intermediate goods sector, it is expected that R&D and intermediate goods sector are inversely related as both sectors depend heavily on scientists and engineers. The second explanation, proposed by Bebczuk (2002), is that countries engage more actively in R&D only after the diminishing returns of physical capital start threatening the country's growth prospects.

Contrary to the well known negative effect of income tax on private investment, tax on income and profits have a positive and significant effect on business R&D investment in all specifications. This is because of R&D tax credits offered to qualified private firms in most OECD countries. This tax credit is usually offered to firms that succeed in increasing their R&D investment over the previous years, which means that firms will not benefit from the tax credit unless they increase their R&D. Because the credit can be applied only against the tax liability, higher profit tax motivates additional R&D to find tax relief. This means that profit tax and R&D tax credit are likely to be highly correlated. The coefficients associated with taxes on income and profits capture the effect of taxes in the presence of R&D tax credit. Table 7 shows the nature of R&D tax incentives in some of the OECD countries.

Table 5
Fixed Effects 2SLS Estimation of the Effect of Fiscal Policy on Business R&D (equation-5)

Variable	(1)	(2)	(3)	(4)
Taxes on profits	0.36 (3.0)***	0.76 (4.6)***	0.32 (3.4)***	0.47 (3.6)***
Taxes on goods and services	-0.04 (-0.5)	-0.043 (-0.5)	-0.053 (-0.8)	0.062 (0.92)
Government capital expenditure	—	0.21 (4.3)***	—	0.23 (5.9)***
GDP growth	0.03 (0.9)	0.005 (1.65)*	0.007 (2.2)**	0.003 (1.73)*
High-tech exports	0.11 (2.3)**	0.18 (3.6)***	0.09 (0.23)	0.11 (2.6)***
Scientists and engineers	0.47 (7.1)***	0.37 (5.4)***	—	—
Researchers in business sector			0.55 (14.7)***	0.46 (11.07)***
Patent rights index	0.43 (2.2)**	0.58 (3.1)***	0.02 (1.47)	0.22 (1.7)*
Gross fixed capital formation	-0.14 (-3.9) ***	—	-0.22 (-2.9)***	—
Interest rate	-.02 (-1.4)	-0.1 (-2.1)**	-0.07 (-1.93)*	-0.04 (-1.71)*
Government R&D	-0.04 (-0.66)	0.03 (0.45)	0.17 (3.7)***	0.23 (4.8)***

Notes:
-Business enterprise expenditure on R&D is the dependent variable.
-t-statistics are in parentheses.
-Instrumental variables are the lagged values of the explanatory variables.
-Coefficients are significant at *** 1%, ** 5%, and * 10%

In all specifications, although taxes on goods and services are found to have the expected negative sign, they are found to be insignificant. Taxes on goods and services are non-distortionary in the sense that they do not affect the business R&D investment decision. Government R&D is found to be complement with business

R&D in the third and forth specifications: a 1% increase in government R&D leads to 0.23% increase in business R&D.

Table 6
Fixed Effects OLS and 2SLS Estimation of Government R&D Determinants (equation-6)

Variable	OLS	2SLS
Budget surplus as % of GDP	0.28 (2.2)**	0.21 (1.98)**
Taxes on profits as % of total taxes	0.12 (1.13)	0.12 (1.03)
GDP growth	0.013 (3.5)***	0.015 (3.5)***
High-tech Exports % of total exports	0.01 (0.21)	0.013 (0.26)
Number of scientists and engineers	0.03 (4.7)***	0.03 (4.8)***
Patent rights index	0.24 (1.3)	0.104 (0.51)
Business R&D	0.17 (2.2)**	0.18 (2.01) **

Notes:
-Government expenditure on R&D is the dependent variable.
-t-statistics are in parentheses.
-Instrumental variables are the lagged values of the explanatory variables
-Coefficients are significant at *** 1%, ** 5%, and * 10%

All the control variables are found to have the expected signs. Patent rights, GDP growth, number of scientists and engineers, number of researchers in business R&D sector, and high-tech exports are found to have positive and significant effects on business investment in R&D. The results of the two stage least squares did not change much compared with the ordinary least square, in terms of significancy, except for two variables: GDP growth and interest rate which become significant in most of the specifications. Table 5 shows these results.

Table 7
R&D Tax Incentives

Australia	A special depreciation allowance of 150% for R&D expenditure.
Canada	20% of total R&D expenditure.
France	50% credit on the increase over the previous year's R&D expenditure.
Japan	20% credit on R&D spending exceeding the largest previous annual R&D expenditure.
Spain	A tax credit of 20% of the level of R&D and an additional 40% tax credit of the incremental R&D over the last two years.
UK	Capital expenditure on equipment used for "scientific research" in the UK qualifes for a 100% first year allowances under the Scientific Research Allowance (SRA).
USA	20% credit on R&D spending exceeding the average of the last 3 years regular R&D expenditure, and 20% of the basic research payments.
Italy	No special tax depreciation provisions or credits are given on R&D expenditure.
Germany	No special tax depreciation provisions or credits are given on R&D expenditure.

Source: Internal Revenue Services website and Bloom, Griffith, and Reenen (2000)

Table 6 shows that government R&D is positively related to GDP per capita growth, number of scientists and engineers, and business R&D investment. The positive relationship between government and business R&D suggests a complementarity between the two types of R&D. This result is compatible with the findings of Albert Hu (2000) and about two third of the empirical studies surveyed by David et al (1999)[11]. On the other hand, budget surplus seems to have a positive and significant impact on government R&D expenditure while income taxes are found to

[11] David, Hall, and Toole (1999) find that complementarity appears more prevalent among the subgroup of studies that have investigated this relationship at the industry and national economy levels.

be insignificant in the two methods; two stage least squares and OLS. Other control variables, patent rights and high tech exports, are found to be insignificant.

Conclusion

In this paper we present a simple model of fiscal policy and business investment in research and development. In our theoretical model we study the effect of four fiscal variables on business R&D: budget imbalance, taxes on income and profits (distortionary taxes), taxes on goods and services (non-distortionary taxes), and government productive expenditure. Regarding the tax variables, it has been shown that—contrary to the normal negative relationship between taxes on profits and private investment—the effect of profit taxes on business R&D investment could be positive because of the R&D tax credits. A fiscal policy of incremental R&D tax credit with a significant tax burden on firms' profits is expected to be effective in inducing private firms to increase their R&D. Also, we show that budget deficit causes a decline in business R&D investment due to the crowding out effect. Additionally, taxes on goods and services could have an indirect effect on business investment in R&D through their negative effect on the market size of high-tech products. The empirical model in this paper is applied to a sample of 14 high-income OECD countries over the period 1981-2000. The fixed effects two stage least squares model shows that taxes on income and profits are found to have the expected positive effect on business investment in R&D since almost all OECD countries in the sample, except Germany and Italy, apply the incremental R&D tax credit. Regarding taxes on goods and services, we get the expected negative sign but the coefficients are insignificant in all specifications. The impact of interest rate, the channel through which budget imbalances affect business R&D, is found to be negative, confirming the crowding out hypothesis.

We also examine the effect of two types of government productive expenditure on business investment in R&D: government capital expenditure and government current expenditure. We find a positive and significant effect of the former while the later has insignificant effect in all specifications. In addition, government R&D is found to be complement with business R&D. Other control variables such as patent rights, GDP growth, number of scientists and engineers, number of researchers in the business R&D sector, high-tech exports, and gross fixed capital formation are found to have the expected positive sign except for gross fixed capital formation which is found to have a negative effect on business R&D.

With regards to government R&D, we find that government R&D is significantly affected by budget surplus but not by income taxes. Government R&D is positively related to GDP per capita growth, number of scientists and engineers, and business R&D investment. Again, this suggests a complementarity between government and business R&D.

ESSAY 3

GOVERNMENT R&D AND ECONOMIC GROWTH: A DYNAMIC PANEL DATA ANALYSIS OF OECD COUNTRIES

Introduction

Governments in developed economies play a vital role in stimulating research and development activities either directly by undertaking public R&D or indirectly by using fiscal policy instruments such as R&D subsidies, allowances, profit taxes and R&D tax credit. Lenjosek and Mansour (1999) and Jones and Williams (1998) show that government intervention in the R&D sector is important since the market system tends to underinvest in R&D because of non-excludability associated with the creation of technology and knowledge.

In the R&D literature, studies that aim at measuring the rate of return to R&D distinguish between the private rate of return to R&D, Griliches (1979) and Bronwyn Hall (1996), for example, and the social rate of return to R&D, Jones and Williams (1998) and Lederman and Maloney (2003). The former refers to the estimation of rate of return to R&D using a firm's own R&D as the explanatory variable (the returns to the individual or organization undertaking the R&D) while the later attempts to capture interfirm technology spillovers by focusing at the industry level[12].

The majority of empirical studies that measure the rate of return to government R&D expenditure are at the firm or industry level. Griliches (1980),

[12] Jones and Williams (1998) indicate that since productivity gains may not be reflected in the developing firm's total factor productivity and may rather show up downstream, aggregation to the industry level helps to mitigate productivity measurement problems. On the other hand, Lichtenberg (1995) shows that total factor productivity equals the marginal product of knowledge capital times

Lichtenberg and Siegel (1991), and Battelsman (1990) have found that government funded R&D has zero or negative return in firms in the U.S. Nevertheless, Mansfield (1984) and Lichtenberg (1985), among others, have found that federal R&D has a positive impact on firms' own R&D investment. Bronwyn Hall (1996) has shown that similar result hold in other countries such as Germany and Norway. One explanation behind the zero return to federal R&D at the firm or industry level is that the government is the major purchaser of the products of these industries and thus, both prices and output for these industries are expected to convey little information about true productivity. In other words, R&D is not subject to a market test, Bronwyn Hall (1996).

In a cross-country study using country level data, Lichtenberg (1992) finds that the social marginal product of government-funded research is much lower than that of private-funded research. In most of the estimates, the social marginal product of government research is insignificantly different from zero. On the other hand, Hall and Mairesse (1995) find that the returns to R&D in France were 50 percent higher for those firms for which the government funded more than 20 percent of their R&D. Few studies distinguish between civil and defense R&D and examine the effect of defense R&D expenditure on economic growth. Poole and Bernard (1992), Lichtenberg (1995), and Morales-Ramos (2002) find a negative impact of defense R&D on total factor productivity.

R&D share of GDP, and since the rate of knowledge capital depreciation rate is zero, the marginal product of knowledge may be interpreted as the social rate of return to investment in R&D.

In this paper, we measure the social rate of return to government R&D in thirteen high income OECD countries. In doing so, we first disaggregate total government expenditure on R&D into two categories: civil and defense R&D. Furthermore, we disaggregate civil government R&D into three subcategories: civil government R&D for economic development programs, civil government R&D for health and environmental programs, and civil government R&D for general university funds. This disaggregation helps us in identifying the type of government R&D, if any, that has a positive impact on economic growth and thus, to decide whether it is more useful for the country to increase the government funded R&D or it is better to replace it by fiscal incentives to the business sector engaging in the same type of R&D activities.

Following Arellano and Bond (1991), we estimate a dynamic panel model using the Generalized Method of Moments estimator (GMM) to overcome the problem of inconsistency associated with the OLS estimator of a dynamic panel model. Since we are conducting our study at the macro level, we are using country level data over the period 1981-2000.

In the next section we briefly discuss the relevant literature. Section 3 presents the theoretical background for the empirical model of R&D and economic growth, and section 4 describes the econometric model, data, and results. Section 5 contains the conclusion.

Literature Review

We briefly list some relevant papers.

-Bayoumi, Coe, and Helpman (1999)

Their simulation results suggest that R&D and R&D spillover play an important role in boosting growth in industrial and developing countries.

-Morales-Ramos (2002)

Using TSLS method, the demand-supply model results show that defense R&D crowds out growth indirectly through its negative impact on investment.

-Poole and Bernard (1992)

The SUR multiple regression analysis shows that military R&D has a negative impact on total factor productivity.

Lederman and Maloney (2003)

According to them, the social rate of return to R&D in developing countries is around 78% and it decreases with development. In addition, they conclude that financial depth, protection of intellectual property rights, government capacity to mobilize resources, and the quality of research institutions are the main reasons why R&D effort rises with the level of development.

-Lichtenberg (1995)

Both micro and aggregate estimates of social rate of return to investment in government funded, largely defense-related, R&D are insignificantly different from zero.

-Hall (1996)

She finds that the rate of return to federal R&D is measured to be zero in the US and several other countries.

-Jones and Williams (1998)

The present a conservative estimate of the social return to R&D indicate that optimal investment in R&D is more than two to four times actual investment.

-Lichtenberg (1992)

Privately funded R&D investment is found to have a significant positive effect on productivity. In addition, the social marginal product of government funded R&D appears to be much lower than that of private R&D.

-Hu (2000)

Using firm level data in China, Hu finds a strong link between private R&D and firm's productivity while the direct contribution of government R&D to productivity is found to be insignificant.

-Griliches and Lichtenberg (1984)

Industry level data show a strong relationship between the intensity of private R&D expenditure, but not federal R&D, and subsequent growth in productivity.

-Griliches and Mairesse (1984)

The cross-sectional analysis of the productivity of 133 US large firms during the period 1966-1977 shows high estimates of the importance of R&D investment at the firm level relative to physical capital.

-Griliches and Clark(1984)

R&D investment has a significant positive effect on the growth rate of total factor productivity at the business level. In addition, the fall in R&D intensity could explain about 20% of the decline in productivity growth in the high-tech sector.

-Griffith, Redding, and Reenen (1999)

They investigate the role of R&D in stimulating productivity growth in eleven OECD countries at the industry level. They find evidence that R&D plays two roles: its direct effect on productivity growth and its important role in technology transfer.

The Rate of Return to R&D

Lichtenberg (1992) extends the augmented Solow model presented by Mankiw, Romer, and Weil (1992), which includes the stock of human capital (H_t) in the production function, by proposing a further extension: the inclusion of the stock of research capital R which is accumulated via investment in research and development, I_R:

$$Y_t = A_t R_t^{\pi} H_t^{\theta} K_t^{\alpha} L_t^{\beta} \tag{1}$$

$$R_t = (1-\delta_R)R_{t-1} + I_{Rt} \tag{2}$$

$$H_t = (1-\delta_H)H_{t-1} + I_{Ht} \tag{3}$$

$$K_t = (1-\delta_K)K_{t-1} + I_{Kt} \tag{4}$$

Where Y_t is real output, A is an index of total factor productivity, K is the stock of physical capital, L is labor input, R_{t-1} is the stock of research and development in the previous period, δ_R, δ_H, and δ_K are the depreciation rates. Lichtenberg continues to maintain the constant return to scale assumption in the production function by assuming that $\pi + \theta + \alpha + \beta = 1$. L and A are assumed to grow exogenously at rates n and g and thus, the quantity of effective labor, AL, grows at rates $n+g$. Following Mankiw, Romer, and Weil (1992) (henceforth MRW), Lichtenberg defines: $S_K \equiv I_K/Y$, the fraction of output devoted to fixed investment; $S_H \equiv I_H/Y$, the fraction of output devoted to human capital; $S_R \equiv I_R/Y$, the fraction of output devoted to research and development (the ratio of R&D to GDP); $k \equiv K/AL$, capital per unit of effective labor; and $y \equiv Y/AL$, output per unit of effective labor. He also assumed that $\delta_R = \delta_H, = \delta_K = 0.03$ and $g=0.05$[13].

Without the inclusion of human and research capital, the observable sources of cross country variation in steady state income per capita (y_i^*) are variations in S_K and n[14]:

$$ln\ y_i^* = constant + \left[\frac{\alpha}{(1-\alpha)}\right] ln\ S_{Ki} - \left[\frac{\alpha}{(1-\alpha)}\right] ln\ (n_i + g + \delta_K) + u_i \qquad (5)$$

Adding human and research capital, Lichtenberg obtains a generalized version of equation (5) which includes as regressors rates of investment in human capital and research as well as physical capital:

[13] MRW assume that g, α, and δ_K are invariant across countries and that g=0.02, δ_K=0.03.
[14] MRW show that the evolution of the capital per unit of effective labor, k, is given by

$\dot{k}(t) = sk(t)^{\alpha} - (n+g+\delta_K)k(t)$, where s is the saving rate, and that k converges to a steady state value k^* defined by: $k^* = [s/(n+g+\delta_K)]^{1/(1-\alpha)}$. Substituting the later equation into the production function and taking logs leads to the steady state income per capita shown in equation (5).

$$ln\ y_i^* = constant + \left[\frac{\alpha}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Ki} + \left[\frac{\theta}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Hi}$$

$$+\left[\frac{\pi}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Ri} - \left[\frac{\alpha+\theta+\pi}{(1-\alpha-\theta-\pi)}\right] ln\ (n_i + g + \delta_K) + u_i \tag{6}$$

In this model S_R represents the total R&D investment to GDP ratio. To derive an expression for income per capita at time t, Lichtenberg assumes that income per capita at time t, $ln\ y(t)$, is a weighted average of productivity at time zero (initial productivity), $ln\ y(0)$, and of $ln\ y^*$:

$$ln\ y(t) = (1-e^{-\mu t})\ ln\ y^* + e^{-\mu t}\ ln\ y(0) \tag{7}$$

where the weights depend on t, the higher is t the closer $y(t)$ to y^*, and on the convergence rate μ which is given by: $\mu = (n + g + \delta_K)(1-\alpha-\theta-\pi)$. Substituting (6) into (7), we get:

$$ln\ y(t)_i = (1-e^{-\mu t}) \left\{ \left[\frac{\alpha}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Ki} + \left[\frac{\theta}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Hi}\right.$$

$$\left.+\left[\frac{\pi}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Ri} - \left[\frac{\alpha+\theta+\pi}{(1-\alpha-\theta-\pi)}\right] ln\ (n_i + g + \delta_K)_i \right\} + e^{-\mu t}\ ln\ y(0) + u_i \tag{8}$$

Lichtenberg also derives an expression determining productivity growth by subtracting $ln\ y(0)$ from both sides in equation (8):

$$ln\ y(t)_i - ln\ y(0)_i = (1-e^{-\mu t}) \left\{ \left[\frac{\alpha}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Ki} + \left[\frac{\theta}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Hi}\right.$$

$$\left.+\left[\frac{\pi}{(1-\alpha-\theta-\pi)}\right] ln\ S_{Ri} - \left[\frac{\alpha+\theta+\pi}{(1-\alpha-\theta-\pi)}\right] ln\ (n_i + g + \delta_K) - ln\ y(0)_i \right\} + u_i \tag{9}$$

In estimating equation (9), Lichtenberg (1992) separates R&D investment, S_R, as private and government R&D[15]. OECD data permit us to distinguish between business and government R&D and disaggregate government R&D into civil and defense R&D. In addition, civil R&D is disaggregated into three different categories: civil government R&D for economic development programs, civil government R&D for health and environment programs, civil government R&D for general university funds. Our goal is to measure the rate of return to each type of government R&D.

The Econometric Model

The following specification represents a dynamic panel economic growth model[16]:

$$\dot{y}_{i,t} = \gamma\, y_{i,t-1} + \varphi' X_{i,t} + \sigma' R_{i,t} + \mu_i + \varepsilon_t + u_{i,t} \tag{10}$$

Where $\dot{y}_{i,t}$ is the log difference of GDP per capita of country i in period t, $y_{i,t-1}$ is the log GDP per capita in the previous year, $X_{i,t}$ is a vector of control variables which includes: gross fixed capital formation as a proxy of physical investment, labor force participation rate, population growth, and credit to private sector as a proxy of financial depth, and $R_{i,t}$ is the vector of different types of research and development expenditure. μ_i is the unobserved individual country specific effect, ε_t is the

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[15] In a different study, Lichtenberg (1995) estimates the rate of return to defense and non-defense R&D by taking government funded R&D as a proxy of defense R&D and private as a proxy of non-defense R&D.

[16] We follow Coe and Helpman (1995) in estimating the model based on a difference specification, growth rate, rather than in level since various variables are clearly trended and thus the estimated relationship may be spurious if the error term is not stationary.

unobserved time specific effect, and $u_{i,t}$ captures the effect of the unobserved variables.

Following Cheng Hsiao (2002), it is known that in models with lagged dependent variables the maximum likelihood estimator (MLE) or the least square dummy variables estimator (LSDV) under the fixed effect formulation is no longer consistent because of the asymptotic bias of the MLE of γ. This bias is caused by having to eliminate the unknown individual effects from each observation, which creates the correlation between the explanatory variables and the residuals in the transformed model. Hsiao indicates that a consistent estimator of γ can be obtained by using instrumental variables.

We follow Arellano and Bond (1991) and employ lagged levels as instruments in a Generalized Method of Moments (GMM) formulation. They show that differencing a dynamic panel data model gives the transformed error a moving average structure, MA(n), which is correlated with the differenced lagged dependent variable. To overcome this problem, Arellano and Bond (1991) suggest using instruments dated t-n and earlier. In addition, Baum, Schaffer, and Stillman (2003) indicate that the advantage of GMM over simple instrumental variables' estimators is that if heteroskedasticity is present, the GMM estimator is more efficient than the simple instrumental variables' estimator, whereas if heteroskedasticity is not present, the GMM estimator is no worse asymptotically than the instrumental variables' estimators.

Data

The sample of study contains 13 high-income OECD countries: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, United Kingdom, and USA. Data are collected from several sources: World Bank WDI and International Financial Statistics (IFS) are the main source for the control variables. OECD database is the main source of government R&D and business R&D expenditure. The panel data contain an annual country level data over 20 years (1981-2000)

The main variables of interest are government R&D expenditure, which is disaggregated into two main types: total civil government R&D and defense R&D. Also, we are interested in the effect of business R&D expenditure. Moreover, civil government R&D is disaggregated into three types: 1) civil government R&D for economic development programs as a percent of civil government budget appropriations or outlays for R&D: R&D programs financed for the purpose of the advancement of agriculture, fishery, forestry; industry; energy; and infrastructure and general planning of land use, 2) civil government R&D for health and environmental programs as a percent of civil government budget appropriations or outlays for R&D: R&D programs funded for the purpose of the protection and improvement of human health; social structures and relationships; control and care of the environment; and for the exploration and exploitation of earth, and 3) civil government R&D for general university funds as a percent of civil government budget appropriations or outlays for R&D: R&D content of grants to the higher education sector. These three types of civil government R&D expenditure account for about 70% to 87% of total civil government R&D[17]. Defense budget R&D is defined as all defense R&D financed by government, including military nuclear and space but excluding civilian R&D financed by ministries of defense. R&D in the business enterprise sector covers private enterprises and institutes serving such enterprises.

Two control variables are added to the regression: labor force participation rate, and gross fixed capital formation. The effect of credit to the private sector, as a proxy of financial depth in the economy, and population growth were estimated and found insignificant in all specifications and thus excluded from the regression. Because the sample size is somewhat small (13 countries), we could not use a panel of five-year averages.

Results

We estimate equation (10) under two different specifications. In the first, we estimate the rate of return to total civil government R&D, defense R&D, and business R&D expenditure. In the second specification, we disaggregate the civil government R&D into the three categories described before and estimate the rate of return to each type in addition to defense and business R&D. Rates of return to both current and lagged values of R&D are estimated. We report only the estimates of the lagged values since it is likely that economic growth is affected more by past year's R&D

[17] OECD data give five different types of civil government R&D expenditure, but since we lack data on two types in most countries in our sample, civil government R&D for space programs and for non-oriented research programs, we focus on measuring the rate of return of the three types of civil government R&D mentioned above.

compared with current R&D. Tables 3.2 and 3.3 represent the estimation of the rate of return to lagged government R&D for the first and the second specification, respectively. The two specifications pass the Sargan test for the validity of the instruments and the Arellano-Bond test that average autocovariance in residuals of second order is zero. Table 8 contains the statistical description of the variables.

Table 8
Statistical Description

Variable	Mean	Standard Deviation	Max.	Min.
Business R&D as % of GDP	1.06	0.49	2.41	0.19
Civil government R&D as % of total government R&D	85.6	18.4	100	30.7
Defense R&D as % of total government R&D	14.3	18.6	69.3	0
Civil R&D for economic development programs as % of civil government R&D	32.3	10.03	64.3	11.6
Civil R&D for health and environment programs as % of civil government R&D	16.8	9.4	57.9	7.4
Civil R&D for general university fund as % of civil government R&D	31.2	8.2	49.2	15.2
GDP per capita growth	2.8	2.4	20.8	-6.2
Labor force participation rate	70.3	7.1	83.9	59.6
Gross fixed capital formation as % of GDP	19.1	5.4	29.4	2.4

Table 9 shows that lagged civil government R&D affects GDP per capita growth positively and significantly. The rate of return to civil government R&D expenditure equals 0.027. Since the coefficient (σ) in equation (10) is the output growth elasticity of R&D investment—a one percent increase in civil government R&D expenditure leads to 0.027 percent increase in GDP per capita growth. On the other hand, the coefficient of lagged defense R&D seems to be insignificantly different from zero. This result matches with the findings of Lichtenberg (1995). Lagged business sector R&D expenditure, which is the largest among the three sectors funding R&D activities in most OECD countries: business sector, the government, and universities, positively and significantly affects GDP per capita growth.

Table 9
GMM Estimation of the Rate of Return to Lagged Civil Government and Defense R&D

Variable	Coefficient
Lagged GDP per capita	-0.059 (-1.77)*
Lagged civil government R&D	0.027 (4.05)***
Lagged defense R&D	0.0005 (0.75)
Lagged business R&D	0.013 (7.67)***
Gross fixed capital formation	0.001 (0.63)
Labor force participation rate	0.021 (2.08)**
Sargan test (Prob > chi2)	1
Arellano-Bond test for second order autocorrelation	Z=-0.84

Notes:
-Growth in GDP per capita is the dependent variable.
-z-statistics are in parenthesis.
-Coefficients are significant at *** 1%, ** 5%, and * 10%

The rate of return to business R&D expenditure is 0.013. Labor force participation rate also positively affects GDP per capita growth, while gross fixed capital formation seems to be insignificantly different from zero. Lagged GDP per capita has the expected negative effect on current GDP per capita growth. It is useful to note that these results did not change when we use the current values of R&D variables.

The following table, Table 10, represents the estimation of lagged government R&D expenditure when it is disaggregated into the three categories mentioned above. It shows that lagged civil government R&D for economic development programs and for general university funds positively and significantly affect GDP per capita growth; the rates of return are 0.033 and 0.07 respectively. The third type of civil government R&D, lagged civil government R&D for health and environment programs, is found to be insignificant. This is somewhat expected since government R&D for health and environment programs are devoted to the production of non-economic benefits, promoting health and environment, which do not immediately appear in the GDP. Comparing these results with the estimates of the rate of return to current values of disaggregated government R&D, we find that the lagged values give us slightly better estimates in terms of magnitudes. The rate of return to lagged government R&D for general university funds is 0.07 compared with 0.002 in case of current government R&D for the same programs.

Lagged defense R&D has a negative and significant effect on GDP per capita growth. This supports the defense R&D crowding out hypothesis and the famous tradeoff between guns and butter as explained by Lichtenberg (1995): the greater the fraction of R&D a society devotes to guns (defense R&D) rather than butter (civil R&D) the lower its measured growth will be[18].

Table 10
GMM Estimation of the Rate of Return to Lagged Civil and Defense R&D: Civil Government R&D is Disaggregated into Three Categories

Variable	Coefficient
Lagged GDP per capita	-0.27 (-3.06)***
Lagged civil government R&D for economic development programs	0.033 (5.3)***
Lagged civil government R&D for health and environment programs	0.006 (1.01)
Lagged civil government R&D for general university funds	0.07 (6.44)***
Lagged defense R&D	-0.001 (-2.72)***
Lagged business R&D	0.012 (7.89)***
Gross fixed capital formation	0.013 (1.07)
Labor force participation rate	0.06 (4.57)***
Sargan test (Prob > chi2)	1
Arellano-Bond test for second order autocorrelation	Z= -1.7

Notes:
-Growth in GDP per capita is the dependent variable.
-z-statistics are in parenthesis.
-Coefficients are significant at *** 1%, ** 5%, and * 10%.

[18] The defense R&D crowding out hypothesis implies that due to scarcity of resources, an increase in defense R&D affects negatively other activities in the economy assuming resources are fully and efficiently employed. For more details see Morales-Ramos (2002), "Defense R&D Expenditure: the Crowding-out Hypothesis", Defense and Peace Economics, Vol. 13(5), pp. 365-383.

This negative impact is presumably reduced by spillovers from the defense R&D sector to the private R&D sector which are not captured in our model. The rate of return to business R&D is found to be very close to its figure in the first specification and equals to 0.012.

Conclusion

This paper is an attempt to estimate the rate of return to government and business R&D when the former is disaggregated into different subcategories. We extend Lichtenberg's (1992) work to include disaggregated data of high-income OECD countries in order to estimate the social rate of return to civil government R&D and defense R&D. In addition, we also measure the rate of return to the three major categories of civil government R&D: civil government R&D for economic development programs, civil government R&D for health and environment programs, and civil government R&D for general university funds.

Using the Arellano-Bond (1991) technique of employing lagged levels as instruments in a Generalized Method of Moments (GMM) formulation, we estimate a dynamic panel data model that consists of 13 high-income OECD countries over the period 1981-2000. The results show that contrary to most empirical studies that report a social rate of return to total government R&D expenditure to be insignificantly different from zero, this paper finds that civil government R&D expenditure has a positive and significant effect on GDP per capita growth. Furthermore, when we disaggregate total civil government R&D into the three categories mentioned above, we find that both civil government R&D for economic development programs and civil government R&D for general university funds have positive and significant effect on economic growth. Civil government R&D for health and environment programs is found to be insignificant, which is expected since such programs produce services that most likely do not appear in the GDP. The results did not change much when we use the current instead of lagged values of the disaggregated R&D variables.

Lagged defense R&D is found to have either insignificant or negative effect on economic growth. This result supports the crowding out hypothesis associated with defense R&D. In the short run, due to limited resources, if more is devoted to defense R&D, less is available for civil government R&D and this might have a negative impact on economic growth. It would be interesting to study the effect of defense R&D on economic growth in the long run, which this paper doesn't address. Finally, business R&D is found to have a positive and significant effect on GDP per capita growth in all specifications.

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