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Understanding R&D Policy: Efficiency or Politics?

Fidel Perez-Sebastian*

Abstract

This paper searches for the determinants of government-funded R&D. The goal is to disentangle whether the efficiency considerations overwhelmingly emphasized by the theoretical literature are indeed the main driving force behind public R&D expenditures. Another goal of the paper is to assess whether other types of innovation policy such as the degree of patent protection can have an impact on private R&D. I find that there are important differences between rich and poor nations at this respect. In particular, R&D-specific efficiency factors are not significant to explain public R&D in rich nations, whereas related variables such as the access to private credit and knowledge spillovers are important in less developed economies; in rich countries, public innovation effort can be better explained by the political economy variables that determine the size of governments. Private R&D, on the other hand, depends in high income economies on R&D policies that try to improve R&D efficiency, but is highly determined by goverment size in less income nations. Results suggest that more research on political economy theories of innovation is essential to understand R&D investment.

Keywords: R&D, policy, market failures, political factors.

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1 Introduction

The seminal work of Robert Solow (1956, 1957, and 1962) concluded that technological change is key to sustained economic growth. Over the years, the recognition of this fundamental result has pushed innovation to the forefront of the policy agenda. Innovation consists on the discovery of new products and processes, and requires R&D investment in most instances. Governments, therefore, design policies to increase the amount of R&D in the economy. One the one hand, policies such as anti-brain-drain measures, financial market reforms, improvement of the patent protection system, and tax reliefs, among others, try to incentive private R&D. Government-funded R&D, on the other, allocates resources directly to the inventive activity.[1]

We could say that the theoretical literature explains R&D policy based on efficiency considerations. There are many market failures related to R&D investment. Following Arrow (1962) and Nelson (1959), the possible failure of perfect competition to achieve an optimal allocation of resources is a consequence of the increasing returns, inappropriability, and uncertainty that surround the invention process. Papers such as Romer (1990), Jones and Williams (2000), and Agnion and Howitt (1992, 2006) have analyzed in detail their consequences on the allocation of R&D. Empirically, these market failures make that papers like Griliches (1992) and Jones and Willians (1998), among others, find evidence that the social return to R&D is well above its private counterpart.

The last paragraph implies that we already know quite a bit about the normative side of Government funded R&D. But what about the positive side? There is no paper in the literature that tries to disentangle the forces that determine R&D policy in reality.[2] This is an important gap because efficiency considerations are not the only potential determinant of government's policy. There is an important literature on the political economy of the size of governments (see below), which suggests that public intervention in R&D could be also a consequence of political pressure. If the last force

[1]An example of the importance of R&D policy is given by the European Union (EU) objectives of the 2002 Barcelona Council: Increasing R&D in the EU from 1.9% to 3% of GDP by 2010 to become one of the most competitive and dynamic knowledge based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion.

[2]Within the literature that tries to test whether public R&D complements or crows out private R&D, there are some papers that estimate reduced form equations for government-funded R&D using firm- and industry-level data; see David *et al.* (2000) for a review. The goal of these equations is, however, generating predicted values for public R&D that can be used as an instrument in the private R&D expression.

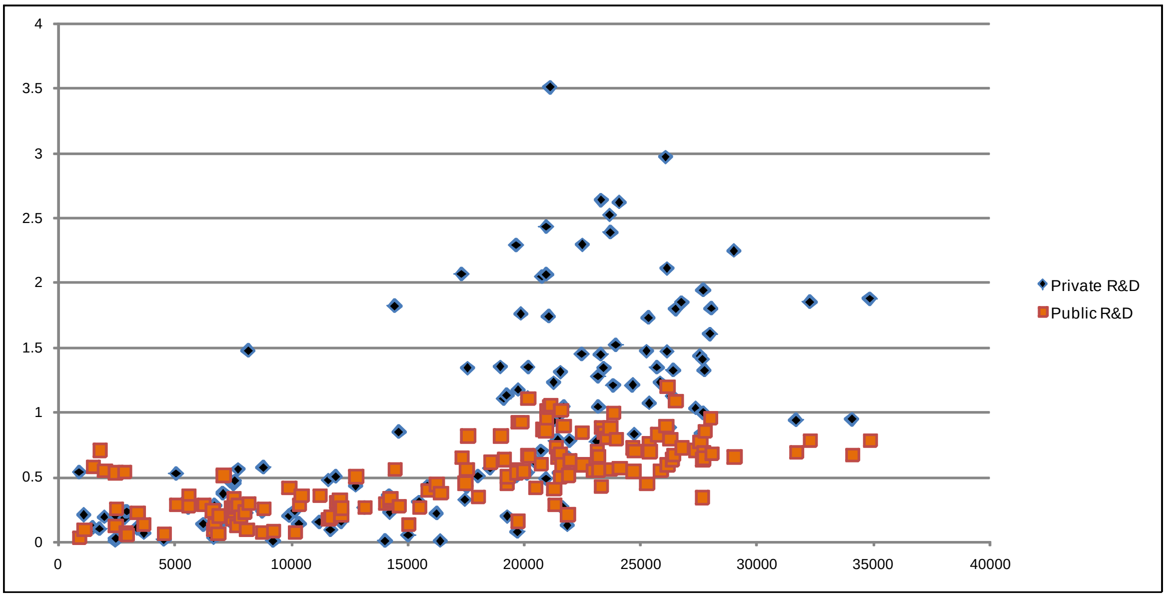
ends up being important, it should lead the theoretical literature to seriously think of introducing it into our models of R&D, and policymakers to rebuild innovation policy more closely linked to efficiency considerations.

This paper sheds light on this issue. More specifically, I address the following questions. What are the determinants of government-funded R&D? Which theory receives more support? Does private R&D respond to innovation policy in the expected direction? Does R&D policy look optimal? In addition, given that most empirical papers at the aggregate level focus on total R&D but private and public R&D can respond differently to incentives, another contribution of the paper is studying whether previous results hold when we split both components.

The key finding is that the answer to those questions is different for different country groups. More specifically, public R&D is mainly related to political factors such as budgetary pressure, political rights, government size and Wagner's law in rich nations. In less developed countries, however, public R&D is associated to the size of the economy and the size of the government, but also to efficiency considerations such as the relative lack of private credit and knowledge spillovers. Private R&D, on the other hand, is in rich nations mainly a response to efficiency variables that include market size, access to credit, patent protection, and distance to the frontier. In developing countries, private innovation effort is highly determined by the size of the public sector; thus suggesting that the public sector in those economies is required to build the knowledge, human and physical capital bases necessary for successful R&D effort.

I proceed as follows. The next section briefly revises the R&D data. Section 3 introduces a well known model of optimal R&D investment and discusses different theories of R&D and the size of nations. Section 4 describes the empirical model, the data employed in the estimation exercise, and the econometric methodology. Results are presented in section 5. Section 6 concludes.

Figure 1: R&D as percentage of GDP, 5-year averages, 1981-2005, 44 nations



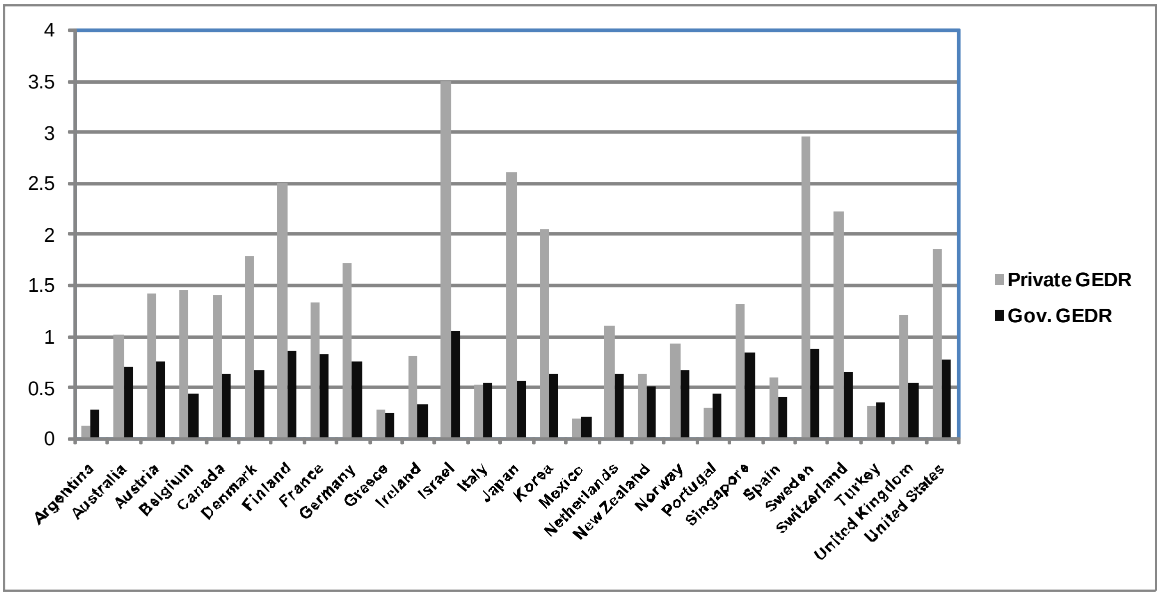
2 R&D Data

R&D investment, both at the public and private levels, differ substantially across nations. Figure 1 shows 5-year averages for the period 1981-2005 for a sample of 44 nations against their level of income.[3] We see that both private and public R&D display positive trends. That is, economies, on average, allocate more and more resources to the inventive activity as they become richer. However, the cloud of points for private R&D highlights a steeper trend and is more heteroskedastic and dispersed. For example, the slope coefficient of the straight line that better fits the data is $6E$-05 and the coefficient of variation is 0.86 for this variable, whereas the same numbers become $2E$-05 and 0.54 for the public R&D cloud. For low levels of development, the government is the main source of R&D funds. Private financing becomes relatively more important as income per capita rises.

The same patters are obtained if we look at particular nations. Figure 2 shows

[3] These nations are Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Canada, Chile, Cyprus, Denmark, Ecuador, Finland, France, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Malaysia, Mauritius, Mexico, Netherlands, New Zealand, Norway, Pakistan, Panama, Portugal, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Thailand, Tunisia, Turkey, Uganda, United Kingdom, United States, and Venezuela.

Figure 2: R&D as percentage of GDP, average for 2001-2005



R&D data for a set of OECD and middle income nations. Rich countries, the ones that are closer to the technology frontier, are usually the economies that invest more in R&D. In Figure 2, countries that invest at least 2.5% of GDP include only Finland, Israel, Japan, S. Korea, Sweden, Switzerland, and the USA. South Korea and Israel belong to the set of emerging economies that are making a big effort in R&D. Singapore is another example of these emerging economies. We can see in the Figure that Singapore allocated to invention and innovation a larger fraction of its GDP than richer economies like Italy and Spain.

Latin American nations are on the other side of the spectrum presented in Figure 2. They invest a relatively small fraction in R&D. Argentina and Mexico show the lowest private investment (0.13) and public investment (0.23), respectively. If we sum up both components, the minimum total R&D investment is the 0.42% of Argentina, compared to the maximum of 4.6% of Israel. There are clearly other nations in the world that invest even less in R&D. For example, in our original 44 country sample, the economies that show the lowest average R&D shares (close to 0.28%) for the 2001-2005 interval are Pakistan, Bolivia, and Uganda.

3 R&D Theories

There are several theories that highlight possible determinants of invention effort and could help explain the above general patterns. If we focus on public R&D, they emphasize market-failures. The special nature of ideas implies that several market failures surround their production. Ideas are non-rivalrous and, therefore, their production generates important externalities. Among them, *knowledge spillovers* across firms (Howitt 1999) and time (Romer 1990) generate positive effects on the social value of R&D. On the other hand, profit stealing coming from new products on old vintages, that is, the Schumpeter's (1942) *creative destruction* impact formalized by Agnion and Howitt (1992), and *duplication* of R&D effort across independent firms represent negative externalities. Another negative externality is present in contexts where the adoption of foreign technology is important. R&D directed to adapt technology to local conditions can suffer from *diminishing imitation opportunities* (Barro and Sala-i-Martin 1997).

As an example to illustrate these market failures, consider an economy similar to the one in Romer (1990). The economy is populated by utility-maximizing infinitely-lived consumers endowed with one unit of labor that they supply each period inelastically. There are three types of activities: consumption goods production, intermediate goods manufacturing, and R&D investment. The latter is intended to learn new designs for new types of producer durables, being the source of technological progress. When a new design is learned, an intermediate goods producer acquires the perpetual patent over the design that allows monopoly pricing. The other two sectors obey perfect competition.

At any given point in time, the final goods sector produces a homogeneous output Y employing a variety of intermediate capital goods x_i according to the CES technology

$$Y = L^{\alpha} \left[\int_0^A x_i^{(1-\alpha)\gamma} di \right]^{\frac{1}{\gamma}} \quad , \quad 0 < \alpha < 1 \ , \ \ \gamma > 0 \ ; \tag{1}$$

If $\gamma < 1$, intermediate goods are complementary; they are substitutes if $\gamma > 1$. This function displays constant returns to scale over capital and labor inputs.

The economy increases the mass of producer durables types that can be used, A, either by inventing new designs or by imitating them from a country-specific international pool of ideas A^w whose size increases exogenously at rate g_{A^w}. The increase in the total amount of producer durables varieties used in production at a given point in time t is given by the following aggregate R&D technology:

$$(1+\psi)\dot{A} = \mu\ A^{\phi}\ \left[R_I^{\lambda} + \left(\frac{A^w}{A}\right)^{\beta} R_C^{\lambda}\right]\ ;\ \lambda \in (0,1);\ \beta, \psi > 0;\ A \leq A^w; \qquad (2)$$

where A^w is the worldwide stock of all ideas that can be used in production if they are learned, regardless of where they originated; and R_I and R_C are the amounts of output that the economy invests in R&D related to innovation and imitation, respectively. This R&D technology follows Jones and Williams (1998, 2000) and Perez-Sebastian (2000, 2007).

In equation (2), ϕ weights a knowledge spillover effect from learning new designs today to future learning productivity. This effect can be positive or negative depending on whether the parameter is larger or smaller than zero, respectively. The parameter λ controls for the fact that two or more researchers can come up with the same idea either by chance or because of R&D races. Since $0 < \lambda < 1$, a *congestion externality* or, in other words, duplication of effort is present. The ratio A^w/A incorporates an advantage of *backwardness* similar to the one in Parente and Prescott (1994) and in Barro and Sala-i-Martin (1995, 1997), implying that the cost of imitating foreign designs decreases as the worldwide stock gets relatively larger. Since A is in the denominator, the imitation technology displays diminishing imitation opportunities, which cause a negative externality: higher levels of R&D effort today may decrease the relative size of the international pool of ideas, thus making copying more costly in the future. The parameter ψ captures a creative destruction effect, and follows Jones and Williams (2000). It is assumed that firms have to adopt new technology in packages composed of these $1+\psi$ designs. Only one of those designs is really new, whereas the other ψ represent *upgrades* that replace the same number of existing A types of durables goods.

It is well known that (for ψ sufficiently small) the markup η charged by intermediate-goods producers will be determined by the elasticity of substitution, $\eta = 1/[\gamma(1-\alpha)]$. It is also well known that production function (1) takes on the Cobb-Douglas form $Y = A^{\xi} L^{\alpha} K^{1-\alpha}$ at the aggregate level; where $K = \int_0^A x_i\, di$ is the country's stock of physical capital, and $\xi = \frac{1}{\gamma} - (1-\alpha)$.

Define g_A and r as the rate of change of parameter A and the interest rate, respectively. Standard methods allow obtaining the optimal steady-state allocation to R&D as a fraction of final output (S_R) delivered by the social-planner (sp) and decentralized-economy (de) solutions:

$$S_R^{sp} = \frac{\lambda\,\xi\,g_A}{r^* - (g_Y - g_A) - g_A\left[\phi - \ \beta\,\frac{(A^w/A)^{\beta/1-\lambda}}{1+(A^w/A)^{\beta/1-\lambda}}\right]}, \tag{3}$$

and

$$S_R^{de} = \frac{\frac{\eta-1}{\eta}(1-\alpha)(1+\psi)\,g_A}{r^* - (g_Y - g_A) + \psi g_A}. \tag{4}$$

Expressions (3) and (4) summarize the influence of market failures associated with the non-rilvalrous nature of ideas on the R&D decision. Unlike the social planner, firms do not take into account the existence of diminishing returns in learning due to duplication of effort. They equate marginal costs to average, instead of marginal, R&D productivity. As a consequence, S_R^{sp} increase with parameter λ, but S_R^{de} does not. The markup induced by monopoly pricing is irrelevant in the central planner's solution, but raises the decentralized economy's R&D investment. The terms ξ, ϕ, and $\beta\,(A^w/A)^{\beta/1-\lambda}\,/[1+(A^w/A)^{\beta/1-\lambda}]$ capture the effect of current R&D on future final-output and R&D productivities, which the decentralized economy does not internalize. The third term, in particular, represents the negative externality caused by diminishing imitation opportunities. As we see, this last external effect pushes up S_R^{sp} as the economy approaches the technology frontier. The creative-destruction parameter ψ, on the other hand, is irrelevant for the social planner. It appears twice in equation (4). In the numerator because more designs allow for higher profits, and in the denominator because a larger probability of patent destruction diminishes the market value of patents. The net influence of ψ on S_R^{de} is positive as long as the interest rate is larger than the growth rate of the economy. Notice as well that the rate g_A weights the incidence of all these externalities because they depend on future investment. This will prove useful later on when the econometric model is specified.

Besides the ones related to non-rivalness, there exist other market failures due to credit rationing (Hall 2005) and partial excludability of ideas (Romer 1990). Both of them produce underinvestment in R&D. If R&D needs external financing, the market will not finance all projects that are socially profitable. The problem is amplified by the uncertainly of invention if investors can not buy protection against it (Arrow 1962). This last effect diminishes as financial markets develop. Solving the partial excludability problem, on the other hand, requires the design of effective property rights such as a patent system.

So far, I have taken into account only efficiency considerations. The design of policy can be, however, a consequence of political pressure. There is an important literature on the political economy of the size of governments that tries to explain the flow of resources generated by the public sector (e.g., see Drazen 2000), and government-funded R&D can be considered simply part of this flow. Probably, the most basic political theory of government intervention is the Wagner's hypothesis. Adolph Wagner (1967) defended that the public sector share in GDP will grow continually as nations industrialize. Wagner provided several reasons for this observation. First, as national income increases, industrialization and urbanization generates additional needs for government services beyond the traditional national defense and legal system, like cultural and welfare expenditures. Second, government spending may increase in activities that complement the private sector funding for long-term investments related to economic development and changes in technology.

Other authors argue that the degree of political rights is an important determinant of the size of the public sector. Meltzer and Richard (1981), in particular, offer a theory that implies that extensions of the franchise increase the public sector size, measured as the share of income redistributed in cash or in services. Increasing openness can also be a source of public demands for government intervention. It is clear, for example, that the sophistication of nations like China, South Korea, or Taiwan have raised concerns about the future international competitiveness of firms and job losses in certain industries; thus increasing social demands for government intervention. At this respect, R&D investment is perceived as a way to avoid this problem (Fagerberg 1988). Openness, however, can also increase budgetary pressure and make more difficult finance subsidies (e.g., see Schulze and Ursprung 1999 for a review of the literature).[4]

Several of these variables can also affect private R&D investment. Financial depth mitigates the uncertainty and fund availability problems contributing to more invention investment. A more developed patent protection system raises private expected profits, although its impact on R&D is not clear (Howitt 2004). Openness can in-

[4]Empirically, Easterly and Rebelo (1993) find that democracy does not matter but Wagner's law does for explaining the share of government revenue on GDP. Some papers on the Political Sciences literature such as Avelino *et al.* (2005) find positive association of some non-R&D-related components of government spending with democracy. Regarding tests of the effect of openness on government expenditures, the main message is that there is no robust impact (see Dreher *et al.* 2008 for a recent contribution).

crease incentives to invest in R&D due to a larger market size, higher competition levels, and a larger flow of knowledge (e.g., Rivera-Batiz and Romer 1991). Finally, a more stable political environment may generate higher expected returns to a long-run activity such as R&D.

Empirically, some of these variables that can affect R&D have received support. For example, Coe and Helpman (1995) and Eaton and Kortum (1996), Lederman and Maloney (2003), and Acemoglu and Linn (2004) find that the flow of ideas, financial depth, and market size matter positively for innovation, respectively. Varsakelis (2001) estimate that the degree of patent protection encourage R&D investment, although openness does not matter. Agnion *et al.* (2005) estimate that the degree of market competition has an inverted U-shaped effect on innovation. Varsakelis (2006) using patent counts finds that political rights affect positively innovation output.

4 The Model, Data, and Estimation Method

I estimate the following R&D regression:

$$R\&D_{it} = \gamma_0 + \gamma_1 Dummies_i + \gamma_2 Controls_{it-5} + \gamma_3 Focus_{it-5} + \varepsilon_{it}. \qquad (5)$$

Regression (5) searches for the determinants R&D. The main goal behind this empirical exercise is to test which of the theories described in the previous section receive support in the data. Proxies for those theories are the ones called *Focus* variables. *Controls* represent other variables that can have an impact on R&D investment. Finally, I add *Dummies* that try to capture country fixed effects to mitigate a potential omitted variable bias. Each variable is indexed by country i and time t.

The dependent variable is R&D as a fraction of GDP. We use three different R&D measures: government-funded R&D, private R&D, total R&D; all of them represent expenditure in millions of constant 2000 dollars valued at purchasing power parities. The first measure is employed to search for its determinants. The second one, to see whether policy can have an impact on private R&D. Total R&D is considered for comparison. Missing observations were interpolated. I employ two different data sources. The first one is the OECD Main Science and Technology Indicators (S&T), which provides figures from 1981 for OECD nations and a set of non-OECD members such as Argentina, Israel, and Singapore. The second one is UNESCO.[5]

[5]Using investment in basic research as another proxy would be interesting because this component

Dummies are of two types: regional, and legal origin. More specifically, I consider Middle east region, East Asian region, Latin America region, German legal origin, French legal origin, and UK legal origin. Gallup *et al.* (1999) and La Porta *et al.* (2008), among many others, argue that these type of variables have power to predict economic performance. They have the ability to capture a variety of country-specific fixed effects related to religion, culture, climate, and the regulatory and institutional environments. A dummy variable that controls for the R&D data source is also added.

Proxies for efficiency considerations in government intervention are: relative total factor productivity (TFP), the growth rate of TFP, credit to private sector, and patent protection. As argued above, the technology gap can affect negatively the socially-optimal allocation to the adaptation of innovations to local conditions. I then include a measure of relative TFP in the regression. Expressions (3) and (4) suggest as well the introduction of the TFP growth rate, because it weights the incidence of non-rilvalness-related externalities. Assuming that relative TFP captures well the negative external effect associate with it, the estimated coefficent on TFP growth should tell us whether government-funded R&D is affected by other market failures. In particular, a positive sign would say that knowlege spillovers are behind public R&D, whereas creative destruction and duplication of effiort would be behind a negative sign. Notice that these two variables can also affect private R&D. Closeness to the technology frontier can favor the discovery of new inventions. TFP growth, on the other hand, is related to the impact of created destruction on the market value of patents, expression (4).

In terms of measurement, TFP is computed relative to the U.S. using as a country's technology level the residual not explained by physical capital and labor in a Cobb-Douglas aggregate production specification. Capital stocks are built employing investment rates from Penn World Tables 6.2 (PWT) and the perpetual inventory approach. The elasticity of capital is taken to be 1/3. Relative TFP can also affect the private R&D decision.

To see if credit rationing matters in the private and government R&D decisions, the regressions incorporate total credit by deposit money banks and other financial institutions to the private sector as percentage of GDP from the 2007 update of Beck

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is the one that probably suffers the most from market failures. S&T offers data for this variable. However, there are a relatively large number of missing years, and the type of costs included are not always the same across nations. This makes impossible to put together a reasonable sample.

et al. (2000). To proxy for inventor's appropriability issues, I include Park's (2008) patent protection index. This is an update of Ginarte and Park's (1997). These authors construct a patent rights index using a coding scheme applied to national patent laws. They examined the following categories: (1) extent of coverage, (2) membership in international patent agreements, (3) provisions for loss of protection, (4) enforcement mechanisms, and (5) duration of protection. With this information, they offer an index that ranges from 0 to 5 with the higher values indicating stronger levels of protection. Theory suggests that the estimated coefficients related to the last two variables should be positive for private R&D but negative for public R&D, except for patenting that do not have a clear effect on private innovation effort.

Four variables also proxy for political factors: political rights, GDP per capita, size of government, and openness. Political rights data try to test whether voting rights matter, as suggested by Meltzer and Richard (1981), and are provided by Freedom House. Freedom House constructs a discrete index that ranges from 1 to 7. Countries that receive a lower rating are those with less corrupt and more stable governments, a larger degree of freedom and fairness in elections, with an opposition that plays a more significant role in the political system, and citizens that enjoy more self-determination. Because of that, a negative estimated coefficient will imply a positive effect of political rights.

To test the Wagner's hypothesis, I use the level of GDP per capita and the government share in GDP, both from PWT. With this, I want to see whether R&D investment follows other types of government spending or, put differently, whether is just a consequence of the government's willingness and capacity to mobilize resources.[6] Finally, openness can capture political pressure from agents that see their revenues threaten, but also budgetary considerations. Its estimated coefficient, according to theory, can be then positive or negative. As a measure of openness, I employ imports plus exports as a fraction of GDP from WPT.

The control variables included are average years of schooling and population. Schooling and population are variables that can have an impact on the productivity of R&D - the former one weights the efficiency of the labor input, whereas the latter affects the size of the domestic market. Educational attainment comes from Barro and Lee (2001), and is the sum of the average number of years of primary, secondary and tertiary education in total population aged 15 and over. Total population is

[6] According to results in la Porta *et al.* (1999), the size of government could also proxy its quality.

thousands of inhabitants and is uploaded from PWT.

Data are averaged over 5 years for the intervals 1981-85, 1986-90, 1991-95, 1996-00, and 2001-05 to abstract from business-cycle influences, and alleviate potential measurement problems. For the schooling variable and the patent protection index that supply only one observation every five years, in 1980, 1985, ... 2000, I use the year within the interval. After excluding nations that do not offer data on all variables, big oil producers, ex-communist nations, and small economies like Iceland and Cyprus, I end up with an unbalanced panel with 38 nations and 146 observations.[7] The scale of varibles is chosen to facilitate the interpretation of estimated coefficients. In particluar, shares of ouput and growth rates are included in percentage terms, other continuous variables are taken in logs, discrete variables – the dummies and the political-rights index – are not modified.

Endogeneity, and common latent variables that determine jointly the dependent and explanatory variables can be a source of bias. For example, both forms of R&D and the patent system can respond to variations in the existing technological opportunities. To try to minimize this potential problem, I use first lags of the explanatory-variable 5-year-averages as regressors.[8] Given this, the number of data points available for the estimation exercise reduces to 119. Descriptive statistics of the different variables are offered in Table 1.

5 Results

Estimation is carried out separately for the whole sample, the S&T sample, and excluding the 22-OECD economies. The S&T group is compused of 27 rich and middle income economies. The non-22-OECD set includes the 17 poorest economies in the original sample.[9] OLS estimated coefficients are in Tables 2 and 3. The Tables also report white-heteroskedasticity-corrected standard errors in parenthesis. The last rows indicate that all regressions are able to explain a large fraction of the

[7] The nations are the ones in footnote 3 excluding Cyprus, Ecuador, Hungary, Iceland, Mauritius, and Uganda.

[8] Because private and public R&D most likely suffer severely from these simultaneity problems, I do not include public R&D as a regressor when private R&D is the dependent variable, even though the literature has found it an important determinant (e.g., see David *et al.* 2000).

[9] The 22 OECD group is the one first considered by Mankiw, Romer and Weil (1992). The S&T sample adds to those (excluding Iceland) Turkey, Israel, Singapore, South Korea, Mexico, and Argentina. Actually, the S&T economies are the ones listed in Figure 2. Estimation on the 22-OECD sample added no new results.

Table 1: Descriptive statistics

	Whole sample				S&T group				Non-22-OECD nations			
Variable	Min.	Max.	Mean	St. de.	Min.	Max.	Mean	St. de.	Min.	Max.	Mean	St. de.
Total R&D	0.14	4.57	1.57	0.94	0.28	3.87	1.82	0.80	0.14	4.57	0.99	1.00
Private R&D	0.02	3.51	1.01	0.75	0.09	2.97	1.18	0.66	0.02	3.51	0.61	0.80
Public R&D	0.06	1.20	0.56	0.26	0.19	1.20	0.64	0.22	0.06	1.06	0.38	0.26
Population	2943	1042020	70837	170506	3526	291213	39971	61067	2943	1042020	142001	286024
Schooling	3.64	12.05	8.36	2.13	3.85	12.05	9.10	1.79	3.64	10.84	6.67	1.87
Openness	13.66	410.33	72.39	57.17	14.50	179.51	65.74	34.60	13.66	410.32	87.72	88.72
Pol. right index	1	6	1.58	1.17	1	1.6	1.01	0.08	1	6	2.87	1.45
Govern. share	7.89	35.70	18.13	5.40	7.90	27.66	17.64	4.21	8.05	35.70	19.26	7.42
Real GDP	1772	34856	18397	7938	11700	34856	22238	4879	1772	27752	9545	6410
Priv. credit share	0.10	2.27	0.89	0.43	0.30	2.27	0.97	0.40	0.10	1.44	0.71	0.43
Relative TFP	0.24	1.05	0.69	0.18	0.57	1.05	0.78	0.10	0.24	0.82	0.49	0.16
Patent pro. index	1.03	4.87	3.64	0.89	1.67	4.87	3.91	0.72	1.03	4.28	3.04	0.95

Table 2: Regression results for the R&D share in GDP

Sample	Whole sample			S&T group			Excluding 22-OECD		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variables	Total	Private	Govern.	Total	Private	Govern.	Total	Private	Govern.
ln(Popu)	0.164***	0.147***	0.177***	0.143***	0.211***	0.055*	-0.060	-0.122	0.132
	(0.039)	(0.054)	(0.040)	(0.038)	(0.057)	(0.032)	(0.094)	(0.105)	(0.142)
ln(School)	0.724***	1.075***	0.380*	0.543***	0.682***	0.393*	-1.282**	-0.878	-1.188*
	(0.184)	(0.310)	(0.207)	(0.183)	(0.253)	(0.205)	(0.450)	(0.586)	(0.628)
Open	0.001	0.001*	0.000	0.001**	0.002***	-0.001	0.002**	0.004***	0.002
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Poli. Rights	0.017	0.008	0.030	-0.014	-0.100*	0.155***	-0.038	-0.025	-0.037
	(0.027)	(0.040)	(0.027)	(0.043)	(0.059)	(0.045)	(0.026)	(0.037)	(0.030)
Gov.Sr.	0.019***	0.018***	0.017***	0.015***	0.013**	0.019***	0.037***	0.047***	0.026***
	(0.003)	(0.004)	(0.003)	(0.004)	(0.006)	(0.003)	(0.006)	(0.009)	(0.008)
Credit	0.052	0.122**	-0.016	0.087**	0.097**	0.065**	-0.044	0.328*	-0.182
	(0.035)	(0.053)	(0.036)	(0.035)	(0.046)	(0.031)	(0.126)	(0.189)	(0.138)
ln(Patent I.)	0.388**	0.707***	0.001	0.486***	0.682***	0.270*	0.156	0.301	-0.136
	(0.185)	(0.281)	(0.187)	(0.167)	(0.254)	(0.148)	(0.229)	(0.268)	(0.272)
ln(Re.TFP)	0.726***	0.980***	0.715***	0.965***	0.753**	1.389***	0.956***	0.933**	1.285***
	(0.186)	(0.267)	(0.184)	(0.281)	(0.367)	(0.246)	(0.351)	(0.388)	(0.476)
TFP growth	0.018	0.017	0.013	-0.002	-0.002	0.004	0.009	-0.019	0.035*
	(0.011)	(0.014)	(0.011)	(0.012)	(0.015)	(0.010)	(0.017)	(0.027)	(0.019)
Observ.	119	119	119	94	94	94	36	36	36
R^2	0.813	0.831	0.695	0.854	0.846	0.732	0.844	0.889	0.707
$\bar{R}^2$	0.784	0.805	0.647	0.826	0.816	0.681	0.727	0.805	0.488

* Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level. Regional, legal origin, and data source dummies were also included. White-heteroskedasticity-corrected standard errors are within parenthesis.

Table 3: Regression results for the R&D share in GDP (cont'd)

Sample	Whole sample			S&T group			Excluding 22-OECD		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variables	Total	Private	Govern.	Total	Private	Govern.	Total	Private	Govern.
ln(Popu)	0.164***	0.146***	0.178***	0.145***	0.209***	0.063**	-0.153*	-0.201	0.002
	(0.039)	(0.054)	(0.039)	(0.038)	(0.056)	(0.030)	(0.082)	(0.119)	(0.088)
ln(School)	0.721***	1.115***	0.269	0.526***	0.707***	0.319	-2.282***	-1.726***	-2.577***
	(0.195)	(0.314)	(0.201)	(0.185)	(0.249)	(0.200)	(0.432)	(0.620)	(0.517)
Open	0.001	0.001*	0.000	0.001**	0.003***	-0.001*	0.002**	0.003**	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.01)	(0.001)
Poli. Rights	0.017	0.005	0.040	-0.012	-0.103*	0.164***	-0.027	-0.015	-0.021
	(0.028)	(0.041)	(0.025)	(0.042)	(0.060)	(0.041)	(0.022)	(0.035)	(0.024)
Gov.Sr.	0.019***	0.018***	0.020***	0.016***	0.013**	0.021***	0.050***	0.058***	0.045***
	(0.003)	(0.005)	(0.003)	(0.004)	(0.006)	(0.003)	(0.007)	(0.011)	(0.007)
ln(RGDPp)	0.015	-0.222	0.624**	0.179	-0.262	0.779***	1.407***	1.193***	1.954***
	(0.283)	(0.366)	(0.263)	(0.186)	(0.272)	(0.159)	(0.337)	(0.419)	(0.398)
Credit	0.051	0.141**	-0.069*	0.075**	0.114**	0.013	-0.193*	0.202	-0.389***
	(0.040)	(0.063)	(0.039)	(0.036)	(0.049)	(0.027)	(0.103)	(0.146)	(0.104)
ln(Patent I.)	0.385**	0.755***	-0.134	0.423**	0.774***	-0.005	0.072	0.230	-0.251
	(0.192)	(0.301)	(0.200)	(0.172)	(0.252)	(0.139)	(0.274)	(0.297)	(0.307)
ln(Re.TFP)	0.710**	1.217***	0.050	0.775**	1.031**	0.559*	-0.567	-0.357	-0.828
	(0.357)	(0.403)	(0.358)	(0.349)	(0.469)	(0.302)	(0.506)	(0.568)	(0.529)
TFP growth	0.018	0.018	0.011	-0.002	-0.001	0.003	0.001	-0.025	0.023*
	(0.011)	(0.014)	(0.011)	(0.012)	(0.015)	(0.009)	(0.013)	(0.024)	(0.014)
Observ.	119	119	119	94	94	94	36	36	36
R^2	0.813	0.832	0.713	0.855	0.847	0.770	0.899	0.909	0.848
$\bar{R}^2$	0.782	0.804	0.665	0.825	0.815	0.722	0.813	0.831	0.720

* Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level. Regional, legal origin, and data source dummies were also included. White-heteroskedasticity-corrected standard errors are within parenthesis.

variance of the dependent variables; in particular, around 80% for total and private R&D, and 70% for public R&D.

For the time being, I do not include GDP per capita as a regressor, this is done for comparison. Table 2 reports the results. Let us focus on total R&D – columns (1), (4) and (7). Schooling, government spending, and relative TFP appear significant in all samples and, except for schooling in the non-22-OECD group, with strong positive sign. Population and the patent index also show positive power with the exception of the same country group. This is true as well for openness, with the exception of the whole sample. Private credit is only important in the set of rich and middle income economies. Finally, political rights and TFP growth show no explanatory power.

The picture is, however, different when more disaggregated data form the dependent variables. This evidences the value added of splitting total R&D in its two components. Leave aside for a moment results with the non-22-OECD sample (columns (7) to (9)) that are distinctly different. As with total R&D, population, the government share, and relative TFP are strong positive determinants of private and public R&D, and TFP growth shows no power. Schooling, private credit, and the patent index have positive sighs when they are significant, but show clearly more power to explain private R&D than public innovation effort. Political rights and openness have different effects on both R&D components. On the one hand, openness affects positively private R&D, but has a negative non-significant impact on public R&D. Political rights, on the other, depicts in the S&T sample (column (5)) where rich nations dominate at a larger extent two opposing significant effects – positive for the former R&D component and negative for the latter. Summarizing, we could say that there are some interesting patterns: in general, efficiency proxies show stronger power to predict private R&D, and some political-economy variables have opposing effects on R&D components.

Focusing next on the non-22-OECD nations, these patterns do not hold. Efficiently variables do not seem to be more impotant to predict private effort, and there are no opposing effects. In particular, private R&D is positively associated with the degree of openness, credit, government spending, and relative TFP. These last two variables are also strong and positive determinants of public R&D. But TFP growth and schooling also contribute to explain the public component, the latter with a negative sign.

We have not employed yet GDP per capita as a regressor. Results when we include it are presented in Table 3. This exercise will help us disentangle whether some variables show power just because there are correlated with GDP. This is important because the Wagner's hypothesis establishes that GDP per capita is a main determinant of the public-expenditure share.

The main finding in Table 3 is that the general patterns found previously obtain additional support, although there are important differences between poor and rich nations. It becomes evident that real GDP per capita is an important determinant of the government-funded R&D share. Notice that, compared to Table 2, the significance of efficiency related variables, that is, private credit, patent index, relative TFP, and TFP growth do not change in the private R&D regressions (columns (2) and (5)), whereas their significance highly diminishes and the estimated coefficients sometimes flip signs in the public R&D specifications (columns (3) and (6)). The exception is the non-22-OECD sample, where efficiency variables loss all significance to explain private R&D, whereas TFP growth and credit (the last one with a negative sign) remain important to explain public R&D. The significance and sign of the other variables' coefficients, in particular, population, schooling, openness, political rights, and the government share do not change much. Exceptions are schooling and openness that become negative and significant for public R&D in the non-22-OECD sample and for private R&D in the S&T group, respectively.

6 Conclusion

This paper searches for the determinants of government-funded R&D. Its main goal has been to disentangle whether the efficiency considerations overwhelmingly emphasized by the theoretical literature are indeed the main driving force behind public R&D expenditures. Another goal of the paper has been to find out whether other types of R&D policy can have an impact on private R&D.

The paper finds that private and government R&D are, in general, driven by different forces, and that these forces vary as well between country groups. When we exclude low income countries, results imply that private R&D responds to efficiency considerations, whereas public R&D mainly to political factors. Market size proxied by population, labor-force schooling levels, the degree of openness, private credit to the private sector, the distance to the technology frontier, and the patent protection levels predict well private innovation expenditures, and their impact is positive.

Government spending and political rights also affect positively private R&D in the rich and middle income economy set. This can imply that the government supplies services that increase the productivity of the private R&D sector, like effective legal protection and basic infrastructure, and that the quality of the service increases with political freedom in those economies.

Public R&D, on the other hand, is positively determine by GDP levels, as the Wagner's hypothesis suggests, population, and also by the government share in GDP. The first two imply that R&D expenditures carried out by government can be associated with the perceived additional needs for government services brought about by the process of industrialization and urbanization. Its relationship with government size, in turn, suggests that public R&D varies with the capacity of government to mobilize resources. Political rights also have a strong impact on public effort, but this effect is negative, that is, the opposite to what Meltzer and Richard's (1981) insight suggests. The effect of political rights on public R&D is then not driven by redistributed forces. Finally, openness shows a weak negative association with public R&D, suggesting that budgetary preassure might be having an effect.

In developing economies, however, efficiency considerations play a more clear role in public innovation effort. Along with the size of government and GDP per capita, the lack of private credit and knowledge-spillovers considerations are positively related to public R&D. The fact that, in this country group, schooling shows a negative sign may mean that governments try to fight against the lack of formal education through investment in R&D that should help to form new scientists.

In light of the results, R&D policy is effective at promoting R&D investment. However, the types of policy measures that are effective can differ across countries. Measures directed to improving credit access, patent protection, and getting closer to the technology frontier fosters private R&D in rich nations, but are not a driving force in developing countries. In these last economies, private R&D responds mainly to public efforts, which most likely helps to build the knowledge, human and physical capital bases necessary for successful R&D.

Evidence then suggests that governments do not implement optimal policy, but a second best due to political distortions. This has some important implications. Possibly the main one is that more research on political economy theories of innovation is essential to understand and improve R&D policy. From the point of view of policymakers, the lesson is that direct R&D interventions need to be reassessed to make it closer to efficiency considerations. In addition, results warn that the standard argument that a country's government should spend more in R&D just because other countries spend a relatively higher share of GDP in R&D is not well founded, because politics and not efficiency is the dominant force. Further research is necessary to address these and other important related issues.

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