R&D AND INNOVATION: AN EMPIRICAL ANALYSIS

Jaime E. Vatter*

ABSTRACT

This paper is based on the notion that R&D investment and innovation are the result of decisions taken by optimizing agents. Therefore, the premise is that the economic and institutional environments play a role in their determination. The objectives of this paper are two. The first one is to explore the relationships between economic variables and R&D investment and innovation. The second one is to analyze how R&D investment and innovation are affected by technological policies. To carry out the analysis 20 OECD countries were selected. The period under analysis is 1975 to 1985.

SINTESIS

Este trabajo se funda en la noción que la inversión en investigación y desarrollo e innovación son el resultado de decisiones adoptadas por agentes optimizadores. Por tanto, la premisa es que los entornos económicos e institucionales juegan un rol en la decisión de llevarlos a cabo. Los objetivos de este documento son dos. El primero consiste en explorar las relaciones entre las variables económicas y la inversión en investigación y desarrollo e innovación. El segundo aborda un análisis de cómo las políticas tecnológicas afectan a la inversión en investigación y desarrollo e innovación. Para efectuar el análisis se seleccionaron 20 países de la OCDE. El período estudiado abarca desde 1975 a 1985.

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1. INTRODUCTION

A great deal has been written about innovation, research and development (R&D) and technological progress as engines of growth. In recent years these terms have gained renewed popularity with the endogenous growth theory[1]. Here, in contrast with the neoclassical growth model, economic growth in the steady-state is positive and endogenous. The rate of growth of the economy depends, among other factors, on technological progress, which is the result of R&D investment. One of the merits of this theory is that it recognizes that R&D investment is not decided on in a vacuum. In particular, R&D investment is the result of different agents' optimization processes. Therefore, economic factors play an important role in determining R&D investment. Despite this fact, the economic variables that empirically affect R&D investment and innovation, at the aggregate lavel, have received less attention in the literature. This paper tries to narrow this gap by exploring empirically the economic factors that affect R&D investment and innovation[2].

So, this paper is on R&D investment, innovation and the economic and institutional factors behind them. However, a valid question is whether it is necessary to make a distinction between R&D investment and investment in the traditional sense of the word (i.e., in physical goods). If they behave similarly, then there is nothing to be gained by studying R&D investment. The same policies and institutions that produce an adequate investment rate are enough to induce an appropriate R&D investment rate. Unfortunately, this is not the case. An overview of the data shows that R&D investment behaves differently from investment in physical goods. This is summarized in Figures 1 and 2, where R&D expenditure as a fraction of GDP, as a measure of R&D investment, and the investment ratio for 20 OECD countries are compared[3].

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[1] The seminal papers are Romer (1986) and Lucas (1988). For a comprehensive approach see Grossman and Helpman (1991) and the references therein.

[2] R&D investment is an input in the production of innovation. By the latter it is understood the creation of new or improved products or processes.

[3] The countries used for this exercise, and for the rest of the paper, are Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the UK and USA.

FIGURE 1

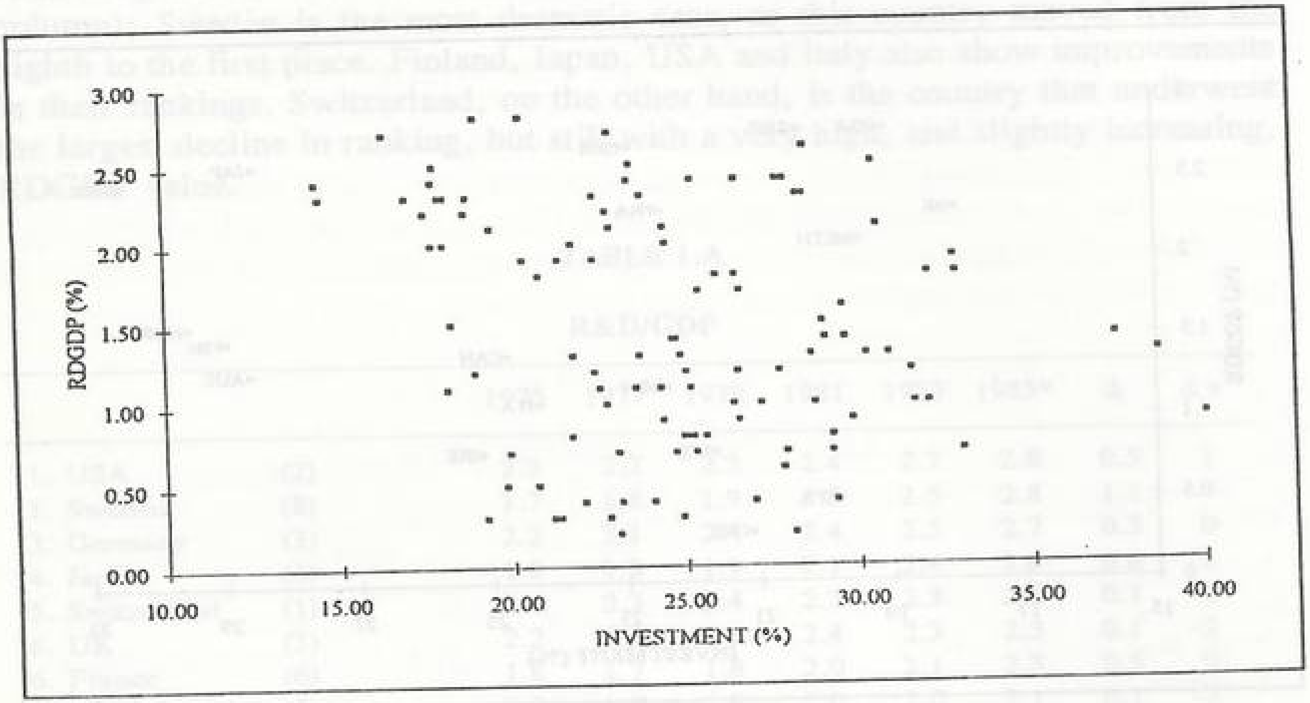


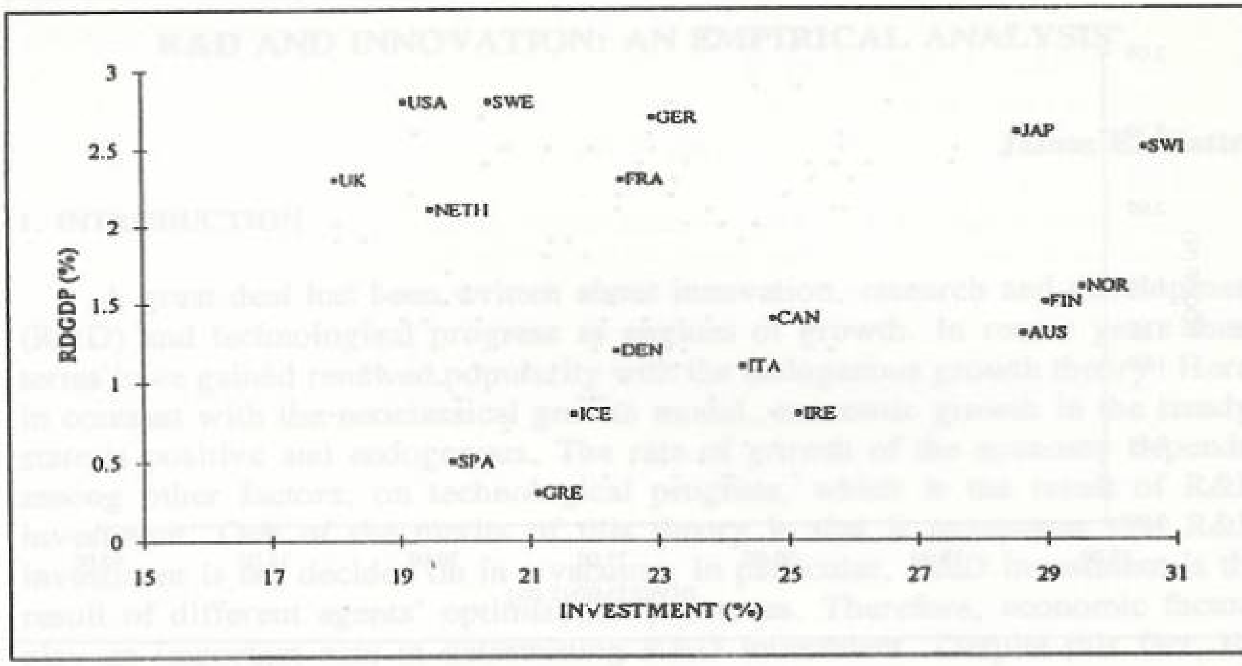
Figure 1 shows that for the whole data set no strong relationship between the two variables exists[4]. In Figure 2 the same experiment was carried out for a particular year (1985), and the outcome was the same. Also, the simple correlation between these two variables is negative and low in absolute value (-.236), showing a weak negative relation between the two.

Therefore, it is necessary to analyze R&D investment as a different type of investment. In particular, even if one could determine the "appropriate" level of investment and the policy that achieves it, then that policy will be insufficient to induce an adequate level of R&D investment. This paper shows that the economic environment plays a significant role in determining R&D investment. Also, the institutional order in which government and private sector cooperate in this field is important.

R&D investment and innovation are studied using data at the country level. As in any cross country study, the issue of data comparability is important. The R&D and patent data was obtained from OECD publications, where an effort has been made to make this data more comparable. The data used as a proxy for human capital and openness is more problematic, as explained in the Appendix and throughout the paper.

[4] There are observations for 6 years: 1975, 1977, 1979, 1981, 1983 and 1985. More about this and the selection of countries in the following section.

FIGURE 2



Data availability and the confidence on its comparability were the reasons to analyze 20 OECD countries for the period 1975 to 1985[5]. The countries selected are those with sufficient data for the whole period under analysis.

The paper is structured as follows. In the next section the data is presented and its most relevant features are described. In sections III and IV, the econometric analysis of R&D investment and innovation is carried out.

2. DATA DESCRIPTION

In this section R&D and patent data is described. The source for this data is OECD's "Science and Technology Indicators", 1986 and 1989.

There are several variables that are used to analyze R&D investment. The most commonly used is R&D expenditure as a fraction of GDP (RDGDP hereafter). This is both a direct measure of a country's R&D investment and innovative effort. In addition, this measure allows for easier across country comparisons, since it is unit free. Throughout this paper it will be used as a proxy for R&D investment. Table 1.A shows the RDGDP data. It is noteworthy that

[5] The complete data set is available only until 1985. The data from years before 1975 was not available. The R&D data is collected in surveys taken every other year.

only Iceland presents a small decrease in this variable, between 1975 and 1985. A striking fact in this table is the change in ranking observed over the period (last column); Sweden is the most dramatic case, as this country moved from the eighth to the first place. Finland, Japan, USA and Italy also show improvements in their rankings. Switzerland, on the other hand, is the country that underwent the largest decline in ranking, but still with a very high, and slightly increasing, RDGDP value.

TABLE 1.A

R&D/GDP

		1975	1977	1979	1981	1983	1985*	Δ	Δ+
1. USA	(2)	2.3	2.3	2.3	2.4	2.7	2.8	0.5	1
1. Sweden	(8)	1.7	1.8	1.9	2.2	2.5	2.8	1.1	7
3. Germany	(3)	2.2	2.1	2.4	2.4	2.5	2.7	0.5	0
4. Japan	(6)	1.8	1.8	1.9	2.1	2.4	2.6	0.8	2
5. Switzerland	(1)	2.4	2.3	2.4	2.3	2.3	2.5	0.1	-4
6. UK	(3)	2.2	N.A	N.A	2.4	2.3	2.3	0.1	-3
6. France	(6)	1.8	1.7	1.8	2.0	2.1	2.3	0.5	0
8. Netherlands	(5)	2.0	1.9	1.9	2.0	2.0	2.1	0.1	-3
9. Norway	(9)	1.3	1.4	1.4	1.3	1.4	1.6	0.3	0
10. Finland	(13)	0.9	1.0	1.0	1.2	1.3	1.5	0.6	3
11. Belgium	(9)	1.3	1.3	1.4	N.A	1.5	N.A	0.2	-1
12. Canada	(11)	1.1	1.1	1.1	1.2	1.3	1.4	0.3	-1
13. Austria	(13)	0.9	N.A	N.A	1.2	1.2	1.3	0.4	0
14. Denmark	(12)	1.0	1.0	1.0	1.1	1.2	1.2	0.2	-2
15. Italy	(16)	0.8	0.8	0.7	0.9	1.0	1.1	0.3	1
16. Iceland	(13)	0.9	0.6	0.7	0.7	0.7	0.8	-0.1	-3
16. Ireland	(16)	0.8	0.8	0.7	0.7	0.7	0.8	0.0	0
18. Spain	(18)	0.4	N.A	0.4	0.4	0.5	0.5	0.1	0
19. Portugal	(19)	0.3	0.3	0.3	0.4	0.4	N.A	0.1	0
20. Greece	(20)	N.A	N.A	0.2	0.2	0.3	0.3	0.1	0
Mean		1.4	1.4	1.3	1.4	1.5	1.7	0.3	

Source: OECD (1989).
N.A: No data available.
Countries are ranked according to 1985 value. 1975 ranking in parenthesis.
Japan's data is adjusted, see OECD (1989).
* 1986 instead of 1985 for Switzerland.
Δ is the change in percentage points between 1975 and 1985.
Δ+ is the improvement in ranking.

To see the change in each country's effort a good measure is the variation in the resources devoted to R&D. For this reason the annual growth rate of R&D expenditure in real terms (called ΔR&D) is also included in this analysis (see Table 1.B). The growing importance given to technological and competitive issues in these countries, is powerfully observed here. In real terms, the average growth rate of the 20 countries is 63.4%, that is, 5% a year. This is a significant increase during a period mostly characterized by slow economic growth. The total GDP of these 20 countries increased only 33.7% in this period[6]. Greece is the country that shows the highest growth rate. This appears to be mostly the effect of significant economic growth rather than of a reallocation of resources to R&D, since its RDGDP remains almost constant during the same period[7]. Finland, Japan and Sweden also show a significant increment in resources devoted to R&D. Also the first half of the 80's shows a renewed impulse towards R&D investment, as indicated by the increase in the average growth rate.

TABLE 1.B

R&D ANNUAL GROWTH RATE (%)

	1975-81[a]	1981-85[b]	1975-85	1985 (mill U$)
1. Greece	7.3	14.9	131.0	201.7
2. Finland	7.7	9.6	125.2	847.6
3. Japan	7.9	8.9	121.9	40064.4
4. Sweden	5.6	8.3	90.8	2946.5
5. Portugal	6.9	5.8	87.0	201.4
6. Italy	4.6	8.4	80.8	7014.5
7. Austria	6.9	4.0	74.6	1035.1
8. Spain	3.4	9.2	73.8	1552.6
9. Norway	3.3	9.2	72.8	940.2
10. Canada	4.8	5.4	63.5	5352.5
11. USA	4.2	6.1	62.2	109730.0
12. France	4.2	4.9	55.0	14571.1
13. Denmark	2.9	6.7	53.9	785.3
14. Germany	4.7	3.8	52.9	19774.0
15. Belgium	4.1	4.0	48.9	1493.7
16. Ireland	2.7	3.5	34.6	190.3
17. UK	3.1	1.6	28.0	14358.7
18. Iceland	0.7	5.2	27.7	24.3
19. Netherlands	0.9	2.8	17.8	3446.0
20. Switzerland	0.8	-0.5	3.8	1896.8
Mean	4.3	6.1	63.4	

Source: OECD (1986, 1989).
The last column shows R&D expenditure in 1985 million dollars.
[a] Greece is 1975-79.
[b] Switzerland is 1981-83.

[6] This was computed using Summer and Heston (1991). It corresponds to the growth rate of total GDP of the 20 countries, between 1975 and 1985.

[7] Some speculation is made here, because the first available data of RDGDP for Greece is 1979. Between that year and 1985, RDGDP increased only one tenth of a point.

The growing interest, in these countries, in innovation is clear from Tables 1.A and 1.B. There is a significant increase in the effort made by these countries to improve their technological capability.

A measure of a country's innovation capability is its ability to export technology. Here this is proxied by the number of "external patent applications," defined as the number of applications for patents in a foreign country submitted by residents of a given nation. Technologically more advanced countries are in a better position to patent their products in different countries. Thus, the number and growth rate of external patents are analyzed. In Tables 2.A and 2.B external patents data is presented[8]. In the former, each country's number of external patents is shown. It can be observed that the number of external patent applications increased in the period under analysis. Also, the ranking among countries remains almost unchanged, with only two exceptions: Sweden and Finland. Apparently, 10 years is not a sufficiently long period to have significant changes in this ranking.

TABLE 2.A

EXTERNAL PATENTS

		1975	1977	1979	1981	1983	1985
1. USA	(1)	93042	95749	104723	126990	135532	149707
2. Germany	(2)	60810	59517	70870	82601	76700	93974
3. Japan	(3)	27666	29047	37901	49315	55312	74363
4. UK	(4)	24402	23202	26706	31230	33648	37553
5. France	(5)	23433	22967	27390	31386	34346	36773
6. Switzerland	(6)	19729	18786	21237	21259	21689	24790
7. Italy	(7)	10080	9616	12182	13373	13537	16596
8. Sweden	(9)	9328	8643	10333	12399	13508	15219
9. Netherlands	(8)	9908	9879	11203	12146	12703	13496
10. Canada	(10)	5063	4670	4528	5137	5628	6426
11. Austria	(11)	3277	3400	4075	4610	4779	6176
12. Belgium	(12)	3197	2717	3441	3677	3871	5001
13. Denmark	(13)	2297	2568	2450	3244	3805	4480
14. Finland	(15)	1345	1899	1908	2562	3216	4373
15. Norway	(16)	1252	1351	1091	1494	1500	2271
16. Spain	(14)	1759	1607	1746	1848	1540	1785
17. Ireland	(17)	168	332	286	527	426	585
18. Greece	(17)	168	132	97	137	119	169
19. Portugal	(19)	656		10	5	10	93
TOTAL		297580	296082	342177	403940	421869	493830

Source: OECD (1986, 1989).
Countries are ranked according to 1985 value. 1975 ranking in parenthesis.

[8] There is no patent data for Iceland.

In Table 2.B the annual growth rate of the number of external patents is presented. Except for Portugal, which displays"strange" data, all countries show an increase in the number of external patents. In particular, the numbers for Ireland, Finland and Japan are remarkable. Doubtlessly, Japan is the most exceptional case since it continued its fast growth, even though it already had 9% of this market in 1975[9]. Finland started with a very low share and still produces less than 1% of the total, but it presents an increasing growth rate, with 14% per year in the last sub-period. Should its growth continue at this rate, it is likely to shortly displace Denmark, Belgium, Austria and Canada. Another case to keep in mind is Norway, which accelerated its growth rate from only 3% to 11% a year, in this period. As in Finland's case, Norway is still a small "producer" of external patents. In any event, any attempt to displace the top three patent exporters (USA, Germany and Japan) seems unlikely in the near future. The top three produce almost two thirds of all external patents in this group.

TABLE 2.B

EXTERNAL PATENTS ANNUAL GROWTH
(%)

	1975-81	1981-85	1975-85*
1. Ireland	20.99	2.64	248.21
2. Finland	11.34	14.30	225.13
3. Japan	10.11	10.81	168.79
4. Denmark	5.92	8.40	95.04
5. Austria	5.85	7.58	88.47
6. Norway	2.99	11.04	81.39
7. Italy	4.82	5.55	64.64
8. Sweden	4.86	5.26	63.15
9. USA	5.32	4.20	60.90
10. France	4.99	4.04	56.93
11. Belgium	2.36	7.99	56.43
12. Germany	5.24	3.28	54.54
13. UK	4.20	4.72	53.89
14. Netherlands	3.45	2.67	36.21
15. Canada	0.24	5.76	26.92
16. Switzerland	1.25	3.92	25.65
17. Spain	0.83	-0.86	1.48
18. Greece	-3.34	5.39	0.60
19. Portugal	-55.64	107.67	-85.82
TOTAL	5.22	5.15	65.95

Source: OECD (1986, 1989).
Countries ranked according to 1975-85 growth rate.
* Total growth in percentage.

[9] That is, the market composed by the 19 countries under analysis.

A different type of data that I will use throughout the paper are two measures of the environment related with R&D. These two variables capture in some respect the technological policy that each country follows, as discussed in detail in Vatter (1992, Chapter 3). The two variables of interest here are the ratio of business to government financed R&D (BSGOVRD) and the percentage of R&D performed in the government sector (RDINGOV).

In Table 3 the ratio of business to government financed R&D is shown. Note that in 1985, in more than half of these countries private funds were more important than public funds for R&D. Moreover, only three countries showed decreases in this ratio, between 1975 and 1985.

TABLE 3

BUSINESS TO GOVERNMENT FINANCED R&D

	1975	1977	1979	1981	1983	1985	Δ*
1. Japan	1.94	1.98	2.00	2.31	2.72	3.28	1.34
2. Switzerland	4.13	3.64	3.14	3.02	3.43	3.27	-0.86
3. Sweden	1.46	1.55	1.59	1.44	1.66	1.86	0.40
4. Germany	1.06	1.20	1.30	1.43	1.50	1.62	0.56
5. Finland	1.02	1.10	1.16	1.13	1.31	N.A	0.29
6. Norway	0.63	0.58	0.63	0.70	0.88	1.11	0.48
6. Netherlands	1.11	1.02	0.98	0.88	0.98	1.11	0.00
8. Spain	1.24	1.05	0.95	0.87	0.99	1.10	-0.14
9. UK	0.70	0.86	0.84	0.84	0.84	1.06	0.36
9. Denmark	0.72	0.78	0.84	0.80	0.93	1.06	0.34
11. Austria	0.92	N.A	N.A	1.07	1.01	1.02	0.10
12. Ireland	0.52	0.55	0.62	0.67	0.82	0.97	0.45
13. USA	0.79	0.82	0.89	0.99	0.99	0.95	0.16
14. Italy	1.18	0.99	1.24	1.06	0.86	0.86	-0.32
15. Canada	0.50	0.48	0.65	0.84	0.74	0.85	0.35
16. France	0.72	0.79	0.86	0.77	0.78	0.78	0.06
17. Greece	N.A	N.A	N.A	0.20	0.36	0.36	0.16
18. Portugal	0.29	0.15	0.40	0.48	0.50	N.A	0.21
19. Iceland	0.07	0.09	0.07	0.07	0.24	0.30	0.23

Source: OECD (1986, 1989).
N.A: Data not available.
Countries ranked according to 1985 value.
Portugal's data is for 1976, 78, 80, 82 and 84.
1986 instead of 1985 for Switzerland.
1978 instead of 1977 for Spain and the UK.
There is no data for Belgium.
* Δ is the percentage change points between 1975 and 1985.

Also, the importance of R&D carried out in the government sector is declining, as observed in Table 4[10]. Only two countries show an increase in the percentage of R&D investment performed in this sector, between 1975 and 1985. Finally, only four countries conducted more than 30% of their R&D investment in the government sector, in 1985.

TABLE 4

R&D PERFORMED IN GOVERNMENT SECTOR

(% of total R&D)

	1975	1977	1979	1981	1983	1985	Δ*
1. Greece	N.A	N.A	83.60	63.10	52.20	53.20	-30.40
2. Iceland	73.80	65.70	59.60	60.70	50.90	50.20	-23.60
3. Portugal	56.80	66.70	47.30	43.60	41.30	N.A	-15.50
4. Ireland	48.90	46.80	40.20	39.30	34.80	30.10	-18.80
5. Spain	35.70	35.80	33.20	33.80	30.50	25.40	-10.30
6. France	23.10	22.80	23.60	23.60	26.40	25.30	2.20
7. Canada	31.00	30.40	26.60	24.90	26.30	24.30	-6.70
8. Italy	22.40	24.60	24.10	25.70	23.60	23.90	1.50
9. UK	25.10	N.A	20.90	22.10	22.10	20.10	-5.00
10. Finland	25.60	26.30	26.10	22.50	21.10	19.50	-6.10
10. Denmark	24.00	22.90	22.00	22.60	20.80	19.50	-4.50
12. Netherlands	20.70	20.80	21.00	19.60	18.80	18.30	-2.40
13. Norway	20.10	18.40	18.70	17.70	17.40	14.40	-5.70
14. Germany	16.50	16.10	14.50	13.70	13.50	12.90	-3.60
15. USA	15.50	15.00	14.10	12.10	12.30	12.40	-3.10
16. Japan	13.60	13.30	13.60	12.00	10.40	9.80	-3.80
17. Belgium	8.90	11.40	9.40	N.A	N.A	N.A	0.50
18. Austria	8.50	N.A	N.A	9.00	N.A	8.40	-0.10
19. Switzerland	6.30	6.80	6.00	5.90	5.10	5.00	-1.30
20. Sweden	8.00	8.60	8.50	6.40	5.30	4.60	-3.40

Source: OECD (1986, 1989).
NA: Data not available.
Countries ranked according to 1985 value.
1986 instead of 1985 for Switzerland. 1978 instead of 1979 for the UK. 1976 instead of 1977 for Spain. Portugal's data is for 1976, 78, 80, 82 and 84.
*Δ is the percentage points change.

These two pieces of information, i.e., Tables 3 and 4, suggest that governments are more active on the financing rather than on the performing side

[10] The government sector includes state owned firms, laboratories and research agencies. It does not include higher education.

of R&D. Even in those countries where the government finances more than half of the total R&D investment, it performs less than a third of all the projects.

In summary, a significant increase in resources devoted to R&D is observed at the aggregate level. This statement holds for most countries. Moreover, this is not only true in absolute value but relative to GDP as well. Also, the number of external patents increased significantly during the period under analysis. Despite this overall trend, the behavior of the countries analyzed here, when one looks at these variables, differs in some aspects. Japan's performance is outstanding in all variables shown here and consistent with its economic rise. Other countries that show significant improvements are Sweden, Finland and Norway, but only in some of the variables described here.

3. ANALYSIS OF R&D INVESTMENT

In this section I will first explore the economic variables that empirically affect R&D investment. Then I will include two proxy variables for policy environment. This will be a first attempt to measure the impact of technological policy on R&D investment. To do this a panel data of 20 OECD countries for 1975, 1977, 1979, 1981, 1983 and 1985 is used.

3.1. Economic variables

1. Choice of variables

What economic variables may affect R&D investment? As indicated earlier, the objective is to explore empirical relationships, rather than to test a specific model of R&D and innovation. Even though the variables and the expected sign of the relationship are not derived from any specific model, they are partially based on the one developed in Vatter (1992, Chapter 2). There, a model of innovation and imitation at the firm level was presented. The firm has three alternatives: keep the current technology, imitate a technology produced elsewhere (external technology) or invest in R&D. The firm chooses the option with the highest value and the R&D alternative is modelled as a search problem. Different shocks affect each option's value and thus the firm's decision. Since this is a partial equilibrium model, it is difficult to make aggregate predictions from it. However, the model illuminates some relationships between economic factors and R&D investment.

One variable that affects R&D investment is market size, measured by GDP. That is, the focus is on the demand side, in opposition to the supply side as analyzed by Grossman and Helpman (1991)[11]. It is argued that market size has a positive effect on R&D investment. The reason is that in larger markets the expected future cash flows associated with the new technology, and therefore the expected net value of the project, are also larger. The key element is that the expected value of the new technology produced in the firm, increases more than the value of the current and external technologies. Thus, for a given number of firms, the increase in market size implies a rise in R&D investment. Also, if the market size grows, then more firms enter the market, reinforcing this positive relationship.

Another variable that affects R&D investment is the degree of openness of the economy. The effect of increasing openness on a firm with comparative advantages is theoretically ambiguous. There are two forces that counteract. First, there is a reduction in external technology's adoption cost, which induces more imitation and less R&D investment. An important source of imitation is through capital goods imports which increase with a more open economy. On the other hand, innovation goes up due to the increase in the relevant market size. A larger market size, as seen above, induces more R&D investment. As discussed in Vatter (1992, Chapter 2), if the economy is small and/or technologically developed, then the market size effect dominates. Since it is sensible to assume that OECD economies are technologically developed, the degree of openness has a positive effect on R&D investment made in firms with comparative advantages. However, for firms with comparative disadvantages the opposite is true. These firms face the reduction in adoption costs and a decrease in market size. Thus, R&D investment decreases in this case.

If the number of firms with comparative disadvantages investing in R&D is relatively small, then the increase in openness has an insignificant effect here. This is a reasonable assumption because these firms are declining, so they probably will not invest in R&D. The planning horizon becomes shorter, so the return from R&D investment is smaller. The option of keeping the actual technology is more attractive for these firms. Then, this characteristic of firms with comparative disadvantages, coupled with a positive effect on firms with comparative advantages, implies that openness affects R&D investment positively[12].

Also, the openness argument can be analyzed from another perspective. A more open economy creates a more competitive environment that encourages innovation to thrive. Thus, openness should be positively related with R&D

[11] In their Chapter 5, the effect of market size over R&D is discussed. However, they focus on the amount of resources, arguing that larger economies have more resources. A positive relationship between size and R&D investment is expected.

[12] Using a general equilibrium approach, Grossman and Helpman (1991) also find ambiguous effects of the opening of the economy (Chapters 6 and 9).

investment. Openness is measured in the standard way, exports plus imports over GDP.

A third variable discussed in the model presented in Vatter (1992, Chapter 2) is human capital. It is argued that more human capital implies more R&D investment. The underlying force behind this result is the improvement in expected returns from innovation, due to a more educated work force. Human capital is proxied by enrollment in the third level of education. That is, the number of students enrolled in post-secondary education programs, divided by the population between 20 and 24 years old[13]. This positive relationship between human capital stock and R&D investment is also predicted by Grossman and Helpman (1991).

Finally, economic instability also plays a role, because R&D investment is a long term project. More stable environments encourage all types of investment, including R&D. Instability is measured either by the inflation rate or GDP variance.

2. Econometric analysis

From the previous discussion the following equation, estimated using OLS, is used as the benchmark:

$$RDGDP_{it} = \beta_0 + \beta_1 OPENEC_{it} + \beta_2 INFLA_{it} + \beta_3 TOTRGDP_{it} + \beta_4 EDUC3_{it} + \mu_{it} \qquad (1)$$

where RDGDP is R&D expenditure as a fraction of GDP; OPENEC is exports plus imports over GDP, as a measure of openness; INFLA is the yearly inflation rate, as a proxy for instability; TOTRGDP is GDP in 1985 dollars; and EDUC3 is enrollment in the third level, as a proxy for human capital[14]. All variables are for annual periods.

From the previous discussion it is expected that OPENEC, TOTRGDP and EDUC3 have a positive effect on RDGDP, while INFLA's effect should be negative. The result of this regression is shown in the first column of Table 5. There it can be seen that only EDUC3 has the unexpected sign, but is not

[13] The comparability issue is of relevance here. As seen in the Appendix, this variable is computed using an estimate of each country's population. Also, the definition of the denominator (people between 20 and 24 years old) may be inappropriate for some countries.

[14] Variable's sources are in the Appendix.

statistically significant. The other three variables have the expected signs and are statistically significant at the 5% level.

The problem with the above formulation is that the effect of each variable is assumed to be the same in each country. That is, it is assumed that these countries are homogeneous, at least to the extent that they bear the same coefficients. However, some type of heterogeneity among countries is expected. Even though all countries under analysis are classified as developed, they do differ in the degree of industrialization and development achieved, as well as in geographical, cultural and sociological aspects. One way to handle this problem is to include dummy variables, one for each country. This allows for different intercepts for each country. This method is called "least squares dummy variables model" or "fixed effects model" (see Judge et al. (1988), Chapter 11). The result of this regression is shown in the second column of Table 5. The null hypothesis that the constant term (β_0) is the same for all countries is rejected at the 1% significance level (the observed F ratio is 80.68). Thus, the least squares dummy variables model is more appropriate than the OLS specification.

Before analyzing the results of the least square dummy variables estimation, it is necessary to check an alternative method to handle the heterogeneity problem. A different approach to analyze panel data is to assume random rather than fixed effects (see Judge et al. (1988), Chapter 11). This alternative is especially attractive when the time span is short, because then the "dummy variables estimator" may be inefficient. Since the number of periods is small in this case, the random effects (or error components) model is estimated. To do this a feasible GLS method is used and its results are presented in the third column of Table 5. First, it is necessary to check whether the null hypothesis (same coefficient for all countries) can be rejected when this formulation is used. Then, and if the null hypothesis is rejected, it is necessary to discuss which of the two formulations (fixed or random effects) is "better." In this case, as before, the null hypothesis is rejected, the observed F is 52.60. This suggests that the assumption regarding constant intercepts should be abandoned.

Which model, the fixed or the random effects, should be used? A close look at the results indicates that, in this case, it does not really matter. Note that the coefficients do not differ significantly between the two specifications. The reason for the similarity of the results is that the correction factor $\hat{\alpha}$ is close to 1 ($\hat{\alpha}$ = .895). In the random effects case the regression is between differences with respect to a corrected mean ($x^* = x - \hat{\alpha}E[x]$), while in the dummy variables model it is between differences with respect to the mean. In terms of parameter estimation the two specifications are equivalent, when $\hat{\alpha}$ is close to 1. Moreover, the statistical significance of the coefficients is not affected either.

Therefore, the analysis is carried out with the coefficients estimated using the least squares dummy variables method, due to of their robustness with respect to the model specification. With this formulation all coefficients but OPENEC have the expected sign. Also, all coefficients are statistically significant at least at the 10% level. The negative sign of OPENEC is persistent across different specifications. That is, using VARGDP (variance of GDP as a proxy for instability) instead of INFLA or excluding variables affects neither the sign nor the significance of the OPENEC coefficient.

TABLE 5

DEPENDENT VARIABLE: RDGDP

Variable	OLS	Dummy LS[a]	GLS[b]
Constant	1.195		0.125
	(4.797)		(4.922)
OPENEC	0.0065	-0.0043	-0.003
	(3.481)	(-2.983)	(-2.088)
INFLA	-0.027	-0.0066	-0.0078
	(-5.521)	(-2.225)	(-2.711)
TOTRGDP	5.2E-10	7.42E-10	4.93E-10
	(4.904)	(4.654)	(3.943)
EDUC3	-0.003	0.0146	0.0132
	(-0.362)	(2.828)	(2.542)
# of obs.	109	109	109
R^2	0.470	0.969	0.448
Adj. R^2	0.450	0.960	0.420
D-W stat	0.399	1.542	1.235
SSR	30.447	1.509	1.847
F-stat	23.085	114.683	15.932

t-statistics in parenthesis.
[a]Dummy variables for each country not included.
[b]Random effects model.

In particular, when USA and Japan (two relatively less open countries, with high RDGDP) are excluded, the result does not change. This is presented in the first column of Table 6, where it is shown that OPENEC's sign is still negative. Also, the other parameters' signs and t-statistics were not affected significantly by these changes. Only INFLA's t-statistic is reduced significantly.

TABLE 6

DEPENDENT VARIABLE: RDGDP[a]

Variable	Model 1[b]	Model 2	Model 3
OPENEC	-0.0040	-0.0027	-0.0032
	(-2.937)	(-1.856)	(-2.105)
INFLA	-0.0042	-0.0049	-0.0062
	(-1.460)	(-1.649)	(-2.131)
TOTRGDP	2.2E-09		7.57E-10
	(3.599)		(4.822)
RGDPCH		0.0001	
		(5.053)	
EDUC3	0.0108	0.0034	0.0115
	(2.107)	(0.585)	(2.158)
INV			-0.012
			(-1.936)
# of obs.	97	109	109
R^2	0.971	0.970	0.970
Adj. R^2	0.963	0.962	0.962
D-W stat	1.378	1.325	1.489
SSR	1.377	1.732	1.718
F-stat	118.665	118.979	113.61

t-statistic in parenthesis.
[a]All models are dummy variables least squares. Dummy variables for each country not shown.
[b]Model 1: USA and Japan excluded.

Another approach followed was to replace TOTRGDP by per capita GDP (RGDPCH), since the former is correlated with OPENEC, whereas RGDPCH is not[15]. In this case, the second column of Table 6, the parameters' signs remained unchanged.

Also, in Table 6, another alternative specification is presented. In the third column investment as % of GDP (INV) is added to the benchmark model. Since the simple correlation between INV and RDGDP is negative (see the Introduction), it is argued that both types of investment are substitutes. Moreover, this relation is maintained when controlling for other variables. Its coefficient is negative, although significant only at the 15% level. Thus, it is argued that both types of investment are substitutes, though not very strong ones. Note also that including INV does not affect the other parameters' signs and significance.

[15] The correlation coefficients between TOTRGDP and OPENEC, and RGDPCH and OPENEC are -0.48 and 0.11, respectively.

All this implies that OPENEC's sign, as well as the other parameters' signs, are robust with respect to different formulations of the same model. This leaves few possible answers for the sign of OPENEC. One alternative is that this variable is either a poor measure of openness, or that even though it is a good proxy for openness it is measured with errors. In this second case the estimation is biased, thus leaving the possibility of a negative sign even though the "true" coefficient is positive. A second alternative is that the theoretical sign should be negative. As said above, this is an exploratory study and not the test of a specific model. Moreover, it was also argued that the prediction about the sign of the relationship between openness and R&D investment is ambiguous. Under some circumstances, reasonable for OECD countries, the expected sign is positive. However, if those conditions are not satisfied the sign could be negative.

Therefore, it is concluded that the market size and human capital stock of the economy affect R&D investment positively. These two effects are the predicted ones. On the other hand, economic instability and openness affect R&D investment negatively. The former is an expected result, but the latter is not. Moreover, the negative sign of OPENEC does not wash away when different specifications are tried. An interesting case is when investment in physical goods (as % of the GDP) is added. Its coefficient is negative, although not strongly significant. This indicates that both types of investment are substitutes. It is noteworthy that the overall fit of all the specifications discussed above, when using the dummy variables model, is very high and significant. The adjusted R^2 is around 0.96 and the F statistics is above 110.

3.2. Technological policy variables

Two variables that are related to the orientation of the technological policy are used here. I also call them "environmental variables." They show how the environment effects R&D investment, which in turn is affected by the technological policy of the country. As argued above, the variables are the business to government financed R&D ratio and the percentage of total R&D performed in the government sector. The former measures the government's involvement in financing R&D, the latter is the degree of involvement in the performance of R&D.

A high business to government financed R&D ratio indicates that the government's participation is either low in relative terms or indirect (e.g., via tax credits, information policies or general climate measures). As argued in Vatter (1992, Chapter 3), all these countries have some type of technological policy, therefore a high ratio suggests an indirect policy rather than no policy at all. If the policy is primarily composed by climate measures, the cost of such measures is not charged as R&D investment. Japan is a good example of active technological policy and high business to government financed R&D ratio. Also, a low ratio may indicate that the financial market is not well developed. If the financial system is not well developed, then several R&D projects do not receive funds, leaving their financing to the government. However, this may be the case only in few of the countries analyzed here.

On the other hand, a high percentage of total R&D carried out in the government sector, shows that the government plays an active role in the production of new technologies. This can be the result of an incipient industrial sector, which man hold only for a few countries, or for one where the industrial sector is made up mainly by small firms. It may also be the result of a government who has an active role on the production sector. Finally, it may reflect the orientation of the policy. It can be argued that the private sector has less incentives to conduct basic research, and that therefore it is the government's role to perform it. Consequently, if there is a preference towards basic research, then the percentage of total R&D investment made within the government sector will be higher.

What should be expected from the econometric analysis, by including these two policy variables? One should expect that the business to government financed R&D ratio has a positive impact on R&D investment. On the other hand, the expected effect which the percentage of total R&D carried out in the government sector has on R&D investment is ambiguous.

The reasons for the first expected effect are diverse. First, it is argued that an indirect and non-distorting policy is better for this type of investment. That is, "climate" measures are preferred. A less active government, on the financing side, leaves more space to the private sector, thus inducing more R&D investment. Second, some type of "crowding-out" may occur. An increase in government funds for R&D displace private funds and do not induce more aggregate R&D investment. Also, if the value of the ratio is determined by the development of the financial system, a positive relationship should exist as well. A less developed financial system implies a higher participation of the government on the financing side. It also implies less R&D investment, due to the same reasons whereby any type of investment is negatively affected by a financial system that does not work properly. Therefore, R&D investment and government participation on the financing side are negatively related. However, in this case the ratio of business to government financed R&D does not reflect the technological policy of the country.

Now, some arguments are given for the second expected result. First, assume that government facilities perform mainly basic research and "Big Science," because the private sector is neither interested in nor capable of performing these types of R&D[16]. Second, assume that basic research is similar to a public good, with significant positive externalities. Then, an increase in the fraction of R&D investment carried out in the government sector implies higher spillovers, which positively affect the private investment in R&D. Thus, a positive relationship between R&D performed in the public sector and total R&D investment is obtained.

Of course, if any of the assumptions is violated, then this result does not hold. The first assumption is weaker, since it is probable that government facilities also perform industrial R&D. If these types of projects dominate, then a negative effect appears. In this case a private firm would not want to compete with the government at the innovation stage, because some type of unfair competition may arise. Also, in this case, a problem of crowding out arises, since some types of projects conducted in the public sector displace them from the private sector. Thus, these two effects imply a negative relationship between R&D performed in the government sector and total R&D investment. Therefore, the final result is ambiguous.

Econometric analysis

The benchmark model is

$$RDGDP_{it} = \beta_{0i} + \beta_1 BSGOVRD_{it} + \beta_2 OPENEC_{it} + \beta_3 INFLA_{it} + \beta_4 TOTRGDP_{it} + \beta_5 EDUC3_{it} + \mu_{it} \quad (2)$$

where BSGOVRD is the ratio of business to government financed R&D. Here, as in section III.1, the model used is the least squares dummy variables (note that the constant term is country dependent). The null hypothesis that all countries have the same intercept is rejected and the random effects model yields similar results.

In Table 7 the results of two different specifications are presented. The benchmark model is shown in the first column. Again only OPENEC shows an unexpected sign, confirming the sign obtained in section III.1. The other variables have the expected sign, but INFLA is not significant. In particular, the BSGOVRD parameter is positive and significant at the 5% level. Therefore, a higher participation of the private sector in financing R&D is "good" for R&D investment. This suggests that indirect policies to support R&D, "climate" measures, are better than a government that is too active financing R&D.

[16] "The essential feature of Big Science was that research at certain frontiers of science absolutely required access to equipment and instrumentation of unprecedented costliness." (Mowery and Rosenberg (1989), page 151)

TABLE 7

DEPENDENT VARIABLE: RDGDP*

Variable	Model 1	Model 2
RDINGOV		0.00034
		(0.091)
BSGOVRD	0.2469	
	(2.993)	
OPENEC	-0.0034	-0.0043
	(-2.093)	(-2.879)
INFLA	-0.0046	-0.0066
	(-1.607)	(-2.184)
TOTRGDP	6.07E-10	7.43E-10
	(3.773)	(4.569)
EDUC3	0.0113	0.0148
	(2.181)	(2.568)
# of obs.	104	107
R^2	0.972	0.969
Adj. R^2	0.964	0.960
D-W stat	1.542	1.503
SSR	1.539	1.794
F-stat	116.038	105.91

t-statistic in parenthesis.
*Both models are least squares dummy variables. Dummies not shown.

RDINGOV (the percentage of R&D performed in the government sector) is used instead of BSGOVRD in the model presented in the second column of Table 7. There it is shown that the sign of the other variables is not affected. In particular, OPENEC continues to be negative. The fact that RDINGOV is positive, but not significant, and that OPENEC is negative is not washed away when other specifications are tried.

An interesting element to consider here is that when BSGOVRD or RDINGOV are included, the signs and significance of the other coefficients remain unchanged, thus signalling their robustness. Also, the goodness of fit, already high in the estimations of section III.1, is improved slightly with the inclusion of BSGOVRD, but not when RDINGOV is added.

These results imply that when it comes to induce R&D investment it is more important who finances R&D than who performs it. That is, a higher fraction of R&D investment financed by the private sector induces a higher overall R&D investment. As pointed out above, several reasons can be given to explain this result. In the first place this suggests that indirect measures to support R&D

investment are more effective. Second, a crowding-out effect may occur. That is, an increase in government funds implies a decrease in private financing. Moreover, more government involvement in financing R&D signals a more active government, which has a negative effect over all types of investment. The financial system hypothesis explains this result as well. As stated earlier, the degree of development of the financial system is not an element of the technological policy. However, the role it plays here is consistent with Nelson's (1984) argument about the importance of policies and institutions that support economic growth to induce R&D investment. Finally, assuming a given public budget for R&D, a better economic environment induces more investment in general and in R&D in particular. This implies an increase in the business to government financed R&D ratio and in total R&D investment[17].

The result that RDINGOV is positive, but not significant, was to some extent expected. As said above, from this perspective, who perform R&D projects is not relevant. One reason why RDINGOV plays no role in R&D investment is that the technological policy is not well designed, in the sense described before. That is, the government sector carries out not only basic, but also applied research. Alternatively, the policy may be well designed but no significant spillovers exist.

As argued above, if the government sector also performs industrial R&D projects, then R&D conducted in the public sector will have mixed effects on total R&D investment. On one hand there is a positive effect (spillovers), but on the other a negative effect arises, through crowding out and unfair competition problems. Therefore, keeping the spillovers assumption, this result suggests that governments perform not only basic research projects at their facilities, but also industrial projects. Given the mix of projects that the government sector performs, RDINGOV has no effect on the aggregate level of R&D investment. However, as it was argued earlier, if the government sector carries out the "right" mix of projects, RDINGOV has a positive effect on R&D investment.

In summary, the environment plays an important role in R&D investment, indirect measures are more effective, and the policy's main objective should be to improve the general economic environment. Encouragement of private participation, especially on the financing side, is also required. This last characteristic is particularly important, as seen in the econometric analysis and also by analyzing Table 3. There it was shown that, in general, successful countries have a higher business to government financed R&D ratio. Another important characteristic is that projects performed in the public sector should be those that the private sector is either unwilling or unable to perform.

[17] In this case the causality is the inverse. For a fixed amount of public resources devoted to R&D, if private investment in R&D increases, then the ratio goes up and the expected relationship holds.

4. ANALYSIS OF EXTERNAL PATENTS

In this section, external patents, as a measure of a country's innovation capability, are analyzed. The focus is first on the economic and then on the technological policy variables that may affect the number of external patents.

4.1. Economic variables

It is necessary to determine which variables affect the innovation capability of a country. Though no formal model is addressed here, some heuristic explanations are given.

It is expected that the number of external patents increase with R&D investment, an input in the production of new technologies. Of course, not all new technologies are patentable and not all R&D investment is successful. In any event, a positive relationship between the two variables is expected. Human capital should have a positive impact on the number of external patents as well. In order to produce new technologies, it is necessary to have a well educated work force, including researchers and engineers. A country's wealth should have a positive impact on the number of external patents. The reason is that applying for a patent in a foreign country is an expensive procedure and countries with lower wealth are less willing to do so. Wealth is measured by GDP in total and per capita terms. Finally, the degree of openness may affect the dependent variable as well, because a more open economy has more links with other countries, thus making the patenting process easier. Therefore, the basic equation to be tested is:

$$\begin{aligned} EXTPAT_{it} = \beta_{0i} + \beta_1 RDGDP_{it} + \beta_2 RGDPCH_{it} + \\ \beta_3 EDUC3_{it} + \beta_4 OPENEC_{it} + \epsilon_{it} \end{aligned} \qquad (3)$$

where EXTPAT is the number of patent applications in a country other than the inventor's. All variables are annual. From the previous discussion it is inferred that all parameters should be positive.

In all specifications analyzed, and not shown here, the null hypothesis thatll countries have the same constant term is rejected. Therefore the results presented in Table 8 are those of the dummy variables model. In the first column the benchmark model is presented. The overall fit is very high and only EDUC3 shows an unexpected sign, although not significant. The other three coefficients are positive, as expected. If EDUC3 is excluded, second column in Table 8, the overall fit is unaffected (they have the same adjusted R^2) and only the coefficient and significance of RGDPCH are reduced significantly (although it remains positive). In any event, RDGDP remains statistically significant at the 5% level.

TABLE 8

DEPENDENT VARIABLE: EXTPAT*

Variable	Model 1	Model 2	Model 3
RDGDP	24629.95	24053.2	15024.92
	(5.036)	(4.905)	(5.513)
RGDPCH	2.397	1.8277	
	(2.148)	(1.745)	
TOTRGDP			0.000055
			(12.167)
OPENEC	124.40	124.006	33.489
	(1.928)	(1.910)	(0.839)
EDUC3	-345.87		-73.875
	(-1.414)		(-0.531)
# of obs.	103	103	103
R^2	0.972	0.971	0.989
Adj. R^2	0.964	0.964	0.987
D-W stat	1.288	1.228	1.694
SSR	2.87E+09	2.94E+09	1.07E+09
F-stat	126.03	130.326	345.815

t-statistic in parenthesis.
* All models are dummy variables least squares. Country dummies not shown.

The unexpected sign of EDUC3 is not washed away when different specifications are tried. As suggested before, this result may be driven by the fact that EDUC3 is not the "best" proxy for human capital, especially when the focus is on R&D. Moreover, the relationship between innovation (external patents) and human capital (enrrollment in the third level) may be lagged. That is, patents in period t are explained by enrrollment of five years before.

The fact that economic development affects both human capital and innovation is another explanation for the negative, but not significant, sign of EDUC3. This can be seen by looking at the simple correlation between EDUC3 and RGDPCH (or TOTRGDP), and EDUC3 and EXTPAT. The simple correlation between EDUC3 and RGDPCH (human capital and real GDP per capita) is 0.67, between EDUC3 and TOTRGDP (human capital and real GDP) it is 0.72 and between EDUC3 and EXTPAT (human capital and innovation) it is 0.59. Thus, the GDP variable may be capturing the effect of human capital on external patents, in addition to its own effect.

An interesting variation is obtained when one uses TOTRGDP as a proxy for wealth, rather than RGDPCH. Even though individual wealth is measured more accurately by per capita GDP, if the objective is to appraise the wealth of a country, then total GDP becomes a better measure. The result of this specification is presented in the third column of Table 8. TOTRGDP has the expected sign and is significant at the 5% level. The parameter of RDGDP becomes smaller but remains positive. Though EDUC3 and OPENEC show a significant reduction in their parameters (the former in absolute value), the effect of both variables is negligible. These changes suggest that TOTRGDP captures some effects that were previously captured by the other variables.

These results suggest that external patents depend crucially on R&D investment and a country's wealth, measured by per capita or total GDP. The importance of R&D investment needs no further comments. The country's wealth plays an important role because applying for an external patent is an expensive procedure. Also, since the wealth of a country correlates positively with its human capital, and EDUC3 may have measurement errors, the former may be capturing some of the latter's effects. That is, TOTRGDP measures not only wealth but also human capital.

In the previous section it was argued that the dummy variables and the random effect models yield the same result, when the correction factor is close to 1. In models 1 and 3 discussed here $\hat{\alpha}$ is 0.85, thus making unnecessary the GLS estimation[18]. The coefficients estimated in the previous part are robust to this specification change.

Therefore, it is concluded that R&D investment, openness of the economy, per capita and total GDP, affect external patents positively. Human capital, as measured by EDUC3, has a negative but not statistically significant effect. These results are robust to different specifications.

4.2. Technological policy variables

As in section 3.2, two variables are used here. They are the ratio of business to government financed R&D and the percentage of total R&D performed in the government sector. If these two policy variables are included, what can be expected from the econometric analysis? One should expect that the ratio of business to government financed R&D has a positive impact on external patents. On the other hand, the percentage of total R&D carried out in the government sector should have a negative impact on it.

[18] The correction factor was not computed for model 2, since it is only slightly different to model 1.

A larger business to government financed R&D ratio indicates that the private sector is the one with the highest responsibility in the innovation field. This sector is the one that has the incentives to patent its innovations. If the government sector finances a project, it may have less incentives to patent, especially if strategic projects are developed. Some publicly financed R&D projects may produce strategic innovations, then the government has the right to request secrecy. No patent will be produced in this case. When R&D is financed by the private sector, secrecy is unnecessary once the new product is ready to go into the market. Moreover, a project's results are usually better protected with a patent than without one.

The negative expected impact of the percentage of total R&D carried out in the government sector on external patents can be explained using two different arguments. In a well designed technological policy the government sector performs mostly non-patentable projects, for example basic research. Then, a higher percentage of R&D investment made in the government sector implies that a higher fraction of the research carried out is non-patentable. From this argument a negative relationship between R&D conducted in the government sector and external patents is obtained. The second argument comes along the lines that argue that the private sector is more efficient than the public sector. Therefore, the same project carried out in the business sector has a greater probability of successful commercial exploitation, and to receive a patent, than a project performed in the public sector. From this argument a negative relationship is expected as well.

Econometric analysis

The benchmark formulation is the following

$$EXTPAT_{it} = \beta_{0i} + \beta_1 RDGDP_{it} + \beta_2 RGDPCH_{it} + \beta_3 BSGOVRD_{it} + \beta_4 EDUC3_{it} + \beta_5 OPENEC_{it} + \epsilon_{it} \quad (4)$$

Here, as in Section IV.1, the model used is the least squares dummy variables. The null hypothesis that all countries have the same intercept is rejected and the random effects model yields similar results.

In Table 9 the results of two different specifications are presented. In the first column the benchmark model is shown. There EDUC3 is the only variable that has an unexpected, but non-significant, sign. The other variables show the expected sign, and BSGOVRD in particular has a positive coefficient. Therefore, a higher participation of the private sector in financing R&D is "good" for external patents.

TABLE 9

DEPENDENT VARIABLE: EXTPAT*

Variable	Model 1	Model 2
RDGDP	22037.04	24597.3
	(4.328)	(4.932)
RGDPCH	2.2351	2.4101
	(2.002)	(2.112)
RDINGOV		-0.6378
		(-0.003)
BSGOVRD	8420.87	
	(2.269)	
OPENEC	182.122	122.136
	(2.529)	(1.831)
EDUC3	-279.065	-340.409
	(-1.133)	(-1.289)
# of obs.	98	101
R^2	0.975	0.972
Adj. R^2	0.967	0.963
D-W stat	1.230	1.294
SSR	2.56E+09	2.87E+09
F-stat	123.231	115.528

t-statistic in parenthesis.
*Both models are least squares dummy variables. Dummies not shown.

Using RDINGOV instead of BSGOVRD yields the model presented in the second column of Table 9. There it is shown that the signs of the other variables are not affected, and EDUC3 in particular continues to be negative and not significant. Also, RDINGOV has the expected sign but is not significant. The fact that RDINGOV is not significant and that EDUC3 is negative is not washed away when other specifications are tried.

Including BSGOVRD or RDINGOV does not affect the sign of the other coefficients, thus indicating that the specification is robust. Moreover, if BSGOVRD is included the significance of OPENEC is improved. As in the previous case, the goodness of fit is slightly improved with the inclusion of BSGOVRD, but not when RDINGOV is included.

Using TOTRGDP instead of RGDPCH yields the same results discussed in Section IV.1 (this result is not shown here). Particularly, BSGOVRD continues to be positive.

These results suggests that external patents are affected positively by a more active private sector on the financing side. This result was expected for the reasons given above. With a more active private sector on the financing side, the probability of increasing the number of external patents, which reflects the innovation capability, goes up. This is because the private sector appears to be more efficient in developing applied projects and because it is to its best interest to patent its innovations. However, this capability is not affected by the degree of intervention of the government sector on the performing side of R&D investment. This result was unexpected and may indicate that the government sector does not perform non-patentable projects alone. As argued above, a negative relationship between RDINGOV and EXTPAT was expected. However, if government facilities carry out the same mix of R&D projects than the whole economy and if they are as efficient as the private sector, then no relationship between the two variables should be observed. This reinforces the idea that to be efficient government laboratories and agencies should be autonomous but subject to periodic performance evaluations. If this is not the case, a negative relationship will appear. As already pointed out, communication with the private and education sectors is also required.

In summary, the environment also plays an important role in enhancing external patents applications, which measures a country's innovation capability. Indirect and climate measures are preferred in this case as well. As in the previous case, the government should encourage private participation, especially on the financing side.

5. CONCLUDING REMARKS

This paper has tried to narrow the gap between theoretical models of R&D and innovation and the empirical facts. This was the main objective.

The simple explorative approach of this paper proved to be useful. Strong evidence that market size and human capital affect R&D investment was found. Economic stability plays an important role as well. More unstable economies have lower R&D investment rates. The effect of the degree of openness of the economy on R&D investment turned out to be negative. This may reflect some measurement problems, although this sign cannot be discarded as theoretically correct.

External patents, used as a proxy for innovation capability, depend positively on R&D investment, openness and total wealth of the economy. Human capital played no role here, probably because its effect is captured by real GDP (total or per capita). Moreover, as already argued, the data used as a proxy for human capital presents some problems of comparability. In fact, ways to construct a good and comparable proxy for human capital would be the subject of another paper.

The analysis of the effect of the environment on R&D investment and innovation, as a measure of technological policy, was interesting. Some evidence was found to the effect that, to induce more R&D investment and external patents, the technological policy should primarily encourage private participation. This is especially true on the financing side. Climate measures, e.g., stable macro environment, well designed patent and licensing laws, incentives to the dissemination of information, etc., are preferred. Within these lines, fiscal incentives to R&D investment and diffusion should be non-discriminatory across sectors. If the government becomes too active it may cause a reduction in total R&D investment.

Therefore, technological policies are important. Yet, their most important role is to promote the participation of the private sector. The government's role is crucial in promoting a stable environment, an adequate legal framework and a fluent communication between the different players. Government funds should be oriented to R&D and basic research in universities and government agencies. However, these bodies should mostly perform projects that the private sector is either unwilling or unable to carry out. From this perspective, a good communication channel between the industry, universities and government facilities is a must.

APPENDIX

This appendix describes the sources of the data and the name of the variables used in the paper. The two main data sources are Summer and Heston Mark V data set and OECD Science and Technology Indicators (1986 and 1989). Unfortunately the data set is incomplete as some variables have several missing values. The R&D data is surveyed bi-annually and I have it from 1975 to 1985, i.e., 1975, 1977, 1979, 1981, 1983 and 1985. Therefore the data set consists of 120 observations.

The economic data is taken from Summers and Heston Mark V (S&H), for the years already mentioned. Enrollment in the third level is taken from UNESCO's Statistical Yearbooks. Unfortunately this data is not very reliable, because it is based on estimations of each country's population. This is especially true for secondary enrollment where "dramatic" changes are observed between one issue and the next one (see for example the enrollment in Germany for several years). The enrollment in the third level is mainly consistent across publications for data from 1975 to 1985 (Statistical Yearbooks 1980 to 1988), which were used as a first approximation for human capital. Finally, inflation data is taken from IMF's International Financial Statistics Yearbook 1990.

Variables' Names and Sources:

BSGOVRD: Ratio of Business to Government financed R&D; OECD.

EDUC3: Enrollment at the third level as percentage of population in 20-24 years group; UNESCO.

EXTPAT: Number of patent's applications made in a foreign country; OECD.

INV: Investment share of GDP (1985 prices); S&H.

INFLA: Yearly inflation rate measured by CPI; IMF.

OPENEC: Openness (Export + Import)/CGDP (current prices); S&H.

PATGROW: Annual growth rate in the number of external patents; own construction based on OECD.

RDGDP: Ratio of total R&D expenditure to GDP; OECD.

RDGROW: Annual growth rate of R&D expenditure in real terms; OECD.

RDINGOV: Percentage of total R&D performed in the Government sector; OECD.

RGDPCH: Real GDP per capita in constant dollars using Chain (1985 international prices in PWT5) (see Summer and Heston 1991 for a discussion of the relative merits of this measure of real product); S&H.

TOTRGDP: RGDPCH*Population (in thousands); own construction based on S&H.

VARGDP: Variance of 5 previous years of RGDPCH relative to actual RGDPCH, i.e., Var($RGDPCH_{t-5}$...$RGDPCH_{t-1}$)/$RGDPCH_t$; ownconstruction based on S&H.

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