PATTERNS OF R&D AND GROWTH PERFORMANCE: CAN A TECHNOLOGICAL FOLLOWER BE CONVERTED INTO AN ECONOMIC LEADER?

Argentino Pessoa
Faculdade de Economia do Porto
Rua Dr. Roberto Frias
4200-464 Porto, Portugal
Email: apessoa@fep.up.pt

Mário Rui Silva
Faculdade de Economia do Porto
Rua Dr. Roberto Frias
4200-464 Porto, Portugal
Email: mrui@fep.up.pt

Abstract

In this paper we rely on the literature on R&D-based growth models in order to examine the patterns of development in national innovative capacity. Focusing on the country level investments in R&D, and in the examination of the patent counts, in a broad sample of countries that include the leaders and the followers in catching up to the world's leading countries, we put forth three main conclusions that could be extensive to the growth of sub-national regions: i) the most successful economies are those where increases in aggregate R&D efforts are induced by the action of the business sector; ii) the R&D efforts must go hand by hand with concerns of efficiency; iii) high growth rates of patents are closely associated to high growth rates of economic growth.

Keywords: *Economic growth, R&D, National innovative capacity, Technological catch-up, Patents.*

1. Introduction

It is well known that researchers in several traditions have argued that innovation is essential to ensure countries' economic growth (Schumpeter, 1912; Freeman, 1987; Pavitt, 1982; Romer, 1990; Jones, 1995). At the same time, other researchers have stressed the role of imitative capacity in economic catching-up (Abramovitz, 1986; Fagerberg, 1987). Simultaneously, for a great lot of countries economic growth has become one of the most significant policy commitments. Accordingly, though with very different results, several countries have vastly increased their economic and policy commitments to innovation and have made investments in their innovative capacity, and in their levels of R&D expenditures.

As a matter of fact, theoretical and empirical literature shows that investments in R&D are important for economic growth. In the theoretical front, a great deal of models (Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992, to name only the most quoted) have illustrated the function of R&D as a growth engine, and demonstrated the reason why governments must have a role in achieving an optimum level of R&D. In the empirical front, several authors also show the importance of R&D returns. For example, in his survey about R&D spillovers, Griliches (1992) reports a wide range of estimates for the social return of R&D, with values that cluster in the range of 20 to 60 per cent, making R&D a major source of growth, accounting for at least half of all increases in per capita output. Additionally, Jones and Williams (1998) found that optimal R&D investment is at least four times greater than actual spending.

The activity of research and development is an important issue in the recent endogenous growth literature. The models included in this R&D-based growth literature (Romer, 1990; Grossman and Helpman, 1991; and Aghion and Howitt (1992) though differing from each other in important ways, all share the idea that entrepreneurs conduct R&D to gain monopoly power made possible by patents and other intellectual property rights. In these models technological change occurs due to deliberate and costly investments carried out by firms that intend to profit from monopoly power that results from successful innovation, and so increases in economically useful knowledge must imply an increase in the efforts made by firms in financing and performing R&D.

In R&D-based endogenous growth models there are two widely used strands: the varieties model, which builds on foundations placed by Dixit and Stiglitz (1977), Ethier (1982), and Romer (1990), and the quality ladders model developed by Aghion and Howitt (1992), and Grossman and Helpman (1991). In a closed economy, growth is sustained in the varieties model through the assumption that the creation of new products expands the knowledge stock, which then diminishes the cost of innovation. As more products are invented, both the costs of inventing new products and the profits of subsequent innovators are lower because of increased competition, since no products disappear from the market in this model.

By contrast, the quality ladders model assumes that consumers are willing to pay a premium for higher-quality products. As a result, firms always have an incentive to improve the quality of products. The important assumption that sustains growth in both models is that every successful innovation allows all firms to study the attributes of the newly invented product and then improve on it. Patent rights restrict a firm from producing a product invented by some other firm but not from using the knowledge (created due to R&D) that is embodied in that product. Thus, as soon as a product is created, the knowledge needed for its production becomes available to all; such knowledge spillovers ensure that anyone can try to invent a higher-quality version of the same product[1]. However, we must insist on the idea that instantaneous knowledge spillovers only exist if firms use patents as a mode of protection. If firms use other forms of protection, like secret, the immediate availability of knowledge doesn't exist. So, from the endogenous growth perspective the R&D performed by business sector in percent of GDP (BERD/GDP) can show the commitment of firms to conduct R&D to gain monopoly power.

Furthermore, R&D intensity, the structure of R&D expenditures and the productivity of R&D outlays show a remarkable diversity across countries. Our paper uses this diversity and the lessons of the past three decades to shed some light on the relationship between productivity and technological change, and aims to answer the following questions: How was the productivity in economic miracles propelled by a technological change? What are the reasons why it seems so easy for some few countries — and so difficult for a lot of others — to catch-up with the levels of productivity of the world technological frontier?

[1] From this viewpoint applied research and experimental development are the most important forms of using R&D for promoting wellbeing and sustaining growth.

So, in this paper we investigate the patterns of development in national innovative capacity, focusing on the country level investments in R&D, and in the examination of the patent counts, in a broad sample of countries that includes the leaders and the followers in catching up to the world's leading countries.

The remainder of the paper is structured as follows: Section 2 aims to search patterns for R&D intensity and the structure of R&D expenditures; section 3 analyses patent counts; Section 4 relates BERD with patent counts in a selected group of countries; Section 5 concludes.

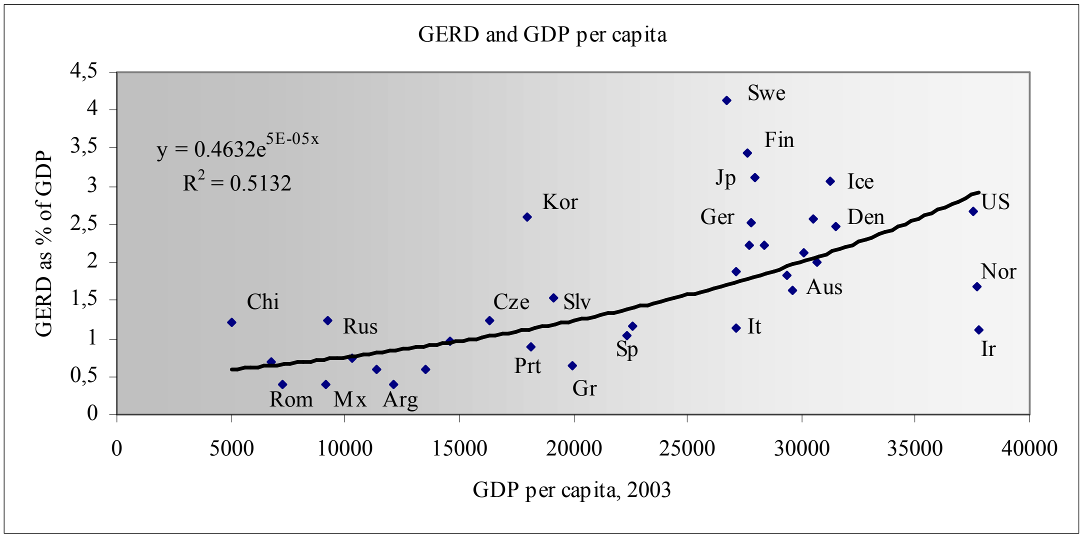
2. Patterns of R&D intensity

It is well known that theoretically not all the activities of research and experimental development are reported in statistics. There are many informal actions performed in firms, which in spite of being effectively R&D, escape computation in statistics. However, we need to use figures and the figures we use in this paper come from statistical databases. With these considerations in mind, let's begin by analysing the Gross Domestic Expenditure on Research and Experimental Development **(GERD)** in a sample of 35 countries[2]. As it is usually recognized there is a positive association between the level of development measured by GDP per capita and the intensity in efforts of R&D, measured by GERD as a % of GDP (GERD/GDP). Figure 1 illustrates such an association.

The figure shows considerable dispersion of both GERD/GDP and GDP per capita, but the dispersion of technological efforts is higher than the dispersion of levels of development, as measured, for instance, by the respective standard deviation (SD) of the sample. For the 35 countries depicted in figure 1, the SD of log GDP pc (per capita) measured as per cent of US GDP pc is 0.23 while the SD of GERD/GDP is 0.28. If investments in R&D are a key component of economic growth and have very high returns, as was shown above, the higher dispersion of R&D efforts across-countries may have an effect on the catching-up process.

[2] The sample is compound by countries that reported data on R&D included in the OECD database (see OECD, 2005).

Figure 1
Association between GERD and GDP per capita



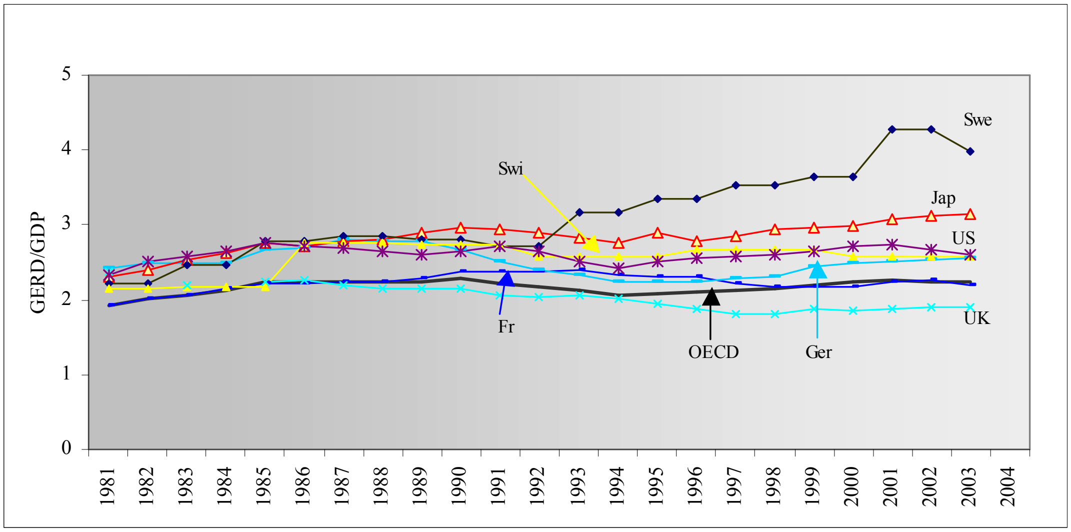
Source: Based on data from OECD (2005) and World Bank (2005).

As is apparent from figure 1 the relationship between the two variables is likely not to be linear indicating that as one country moves towards the technological frontier the "advantages of backwardness", as mentioned in the "technological catch-up theory" (Gershenkron, 1962; Abramovitz, 1979, 1986; Maddison, 1987) are getting lower and lower. The decrease of those "advantages of backwardness" as the level of development increases makes mandatory that in order to grow countries must create inside their boundaries new knowledge through R&D activity.

The cross-section depicted in figure 1 provides a static picture of the statistical relationship between level of development and intensity in efforts of R&D. But, how does GERD/GDP evolve along time? The analysis of the longitudinal trend of GERD/GDP can illustrate an important point: there is a much more variability in GERD/GDP across-countries than along time in the same country. We interpret this finding as evidence that there are important national factors influencing GERD behaviour.

Among countries that present data from 1981 there are three different patterns of evolution. Some countries (which we label as the technological leaders in 1981) began with a GERD/GDP percentage above the OECD average and have kept this position. The exception is the United Kingdom (while OECD average have been increased, UK has decreased its percentage). Of course, the behaviour of the other leaders was not uniform. Some of them have augmented its percentage (with Sweden ahead) while France ends the period with a similar position to the initial one (see figure 2).

Figure 2.
GERD above the OECD average

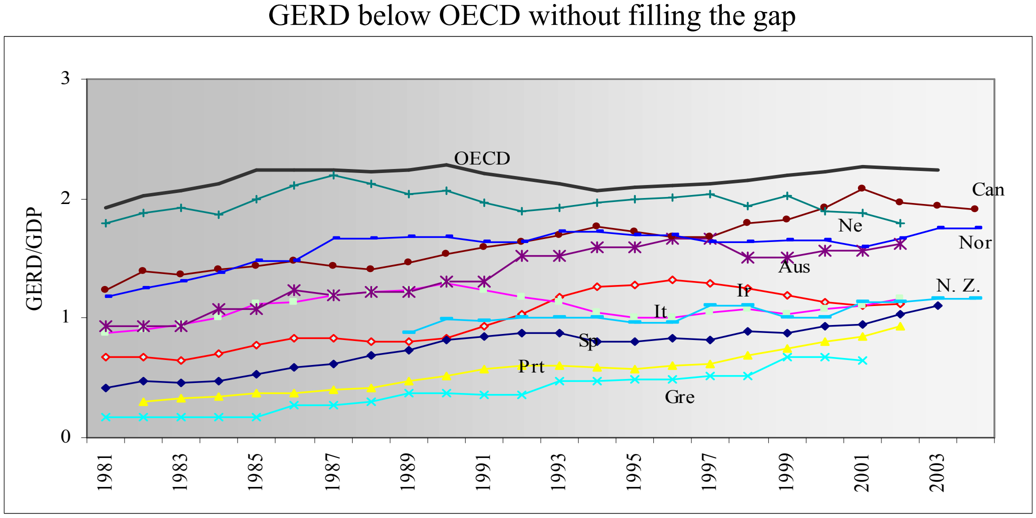


Source: Based on data from OECD (2005).

As is apparent in figure 2, this group of countries ends the period of comparison with a dispersion of R&D efforts significantly higher than at the beginning of 1980s.

A second, and more numerous, group of countries (the laggard followers) began the 1980-decade with a GERD/GDP percentage lower than the equivalent OECD average, and remain at present without filling the gap (figure 3).

Figure 3.
GERD below OECD without filling the gap

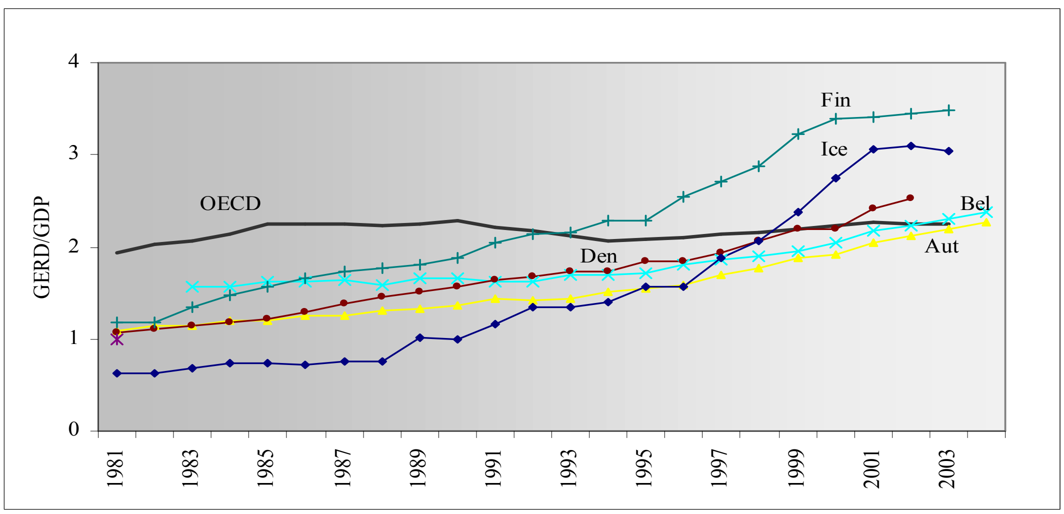


Source: Based on data from OECD (2005).

Again, there is a diversity of performance, which enables us to make a distinction between two clusters: the four countries that were nearer OECD average at the beginning of 1980-decade do remain nearer, and the six laggards keep their position well below the OECD average. This latter group of countries, having started well below the OECD average, have timidly increased their percentage, apparently converging to a point that is situated below the OECD average.

A third group of countries (the succeefull technological catchers) began the 1980-decade with a GERD/GDP percentage lower than the OECD average but have increased their R&D efforts and are successful in overcoming the gap. The most spectacular performance in this group has occurred with Finland and Iceland. Two other countries, Taiwan and South Korea not included in figure 4 due to paucity of data, have a similar performance in terms of GERD/GDP.

Figure 4
GERD below OECD average and filling the gap

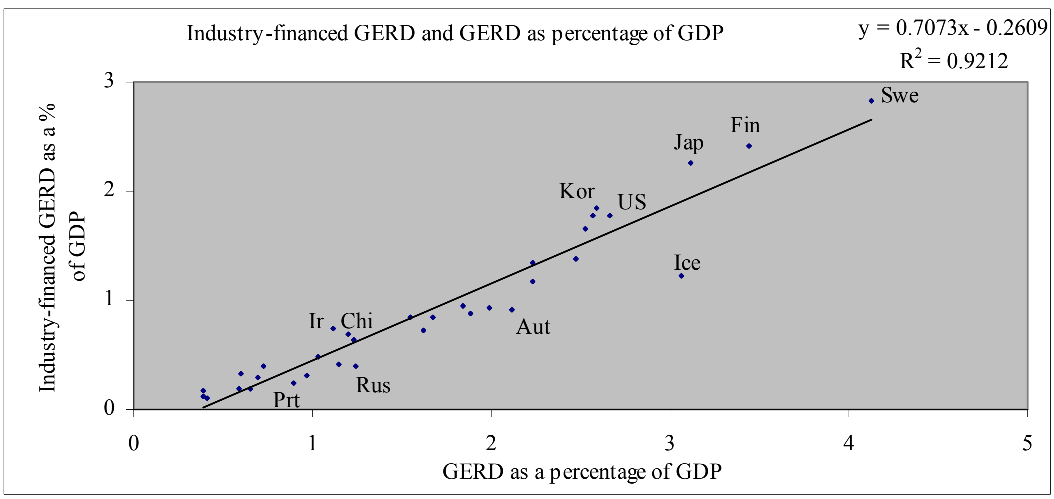


Source: Based on data from OECD (2005).

Even though GERD/GDP may be a good indicator of society's commitment to R&D, it is also a very opaque indicator. First, GERD, being a very aggregative category overlooks significant details about the agents that perform the R&D activity, about the source of funds and more importantly about the adequacy of the mechanisms used to boost the R&D intensity. Inside GERD there are different types of R&D: applied research and experimental development (i.e. product-related research) usually mostly performed by the business sector; fundamental (i.e., basic) research most funded by government (including Higher Education).

Although much governmental R&D is for specific government needs, government funding is crucial to economic growth because market failures induce firms, which act in their own best interests, to underinvest in R&D from society's perspective. However, if the government cannot identify the exact amount of spillovers, governmental funding as a form of solving market failures in R&D is much more likely to lead to inefficiency, and an increase in GERD/GDP can lead to a higher waste of resources and not to an enforcement of the technological capacity. Because there is a close association between industry-financed GERD and GERD/GDP (figure 5), an increase in the GERD/GDP ratio can be the simple result of an increase in industry-financed GERD, and a significant percentage of GERD financed by business sector is of course an important indicator of the commitment of firms in the benefits of R&D.

Figure 5
Association between industry-financed GERD and GERD/GDP



Source: Based on data from OECD (2005).

As it is apparent from figure 5, there is a positive correlation between industry financed GERD as a % of GDP and GERD/GDP. But there are also some dissonant patterns. Respecting the share of GERD financed by industry, there are some countries that push up the OECD average while others contribute to its decrease. In the group of the former technological leaders, Sweden and Japan had pushed the increase of the OECD average of the industry-financed GERD, while France and the UK had shown the opposite behaviour (see figure A1, in Appendix).

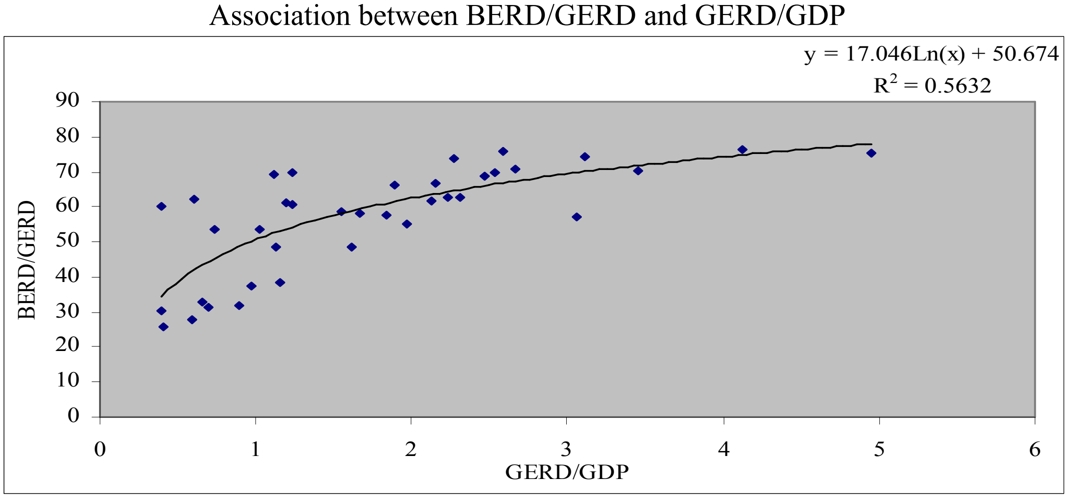
In the 5 countries that have successfully filled the GERD gap (with the exception of Austria and Belgium whose performance follow the evolution of OECD average) there was a substantial increase in industry-financed GERD as a percentage of GDP, as it is apparent from figure A2 in Appendix. Among the countries of this group, the most notable performance came from Finland.

Contrasting with the performance of these countries, the GERD laggards (i. e., the follower countries that fail in filling the GERD gap) do not show a sustainable convergence to the OECD average in industry-financed GERD (figure A3, in Appendix). The increase in the percentage of GERD financed by industry in the Netherlands was reversed in the middle of 1980's and the corresponding Irish boost was finished in the middle of the 1990s.

The analysis made till now shows that the successful catching-up in GERD is associated to an increase of the industry-financed GERD. This is not an astonishing fact because the increase in industry-financed GERD shows that the business sector sees in R&D outlays a profitable investment. Accordingly, an increasing share of business funds directed to R&D shows that a structural change is occurring: the transformation from an economy based on fixed capital to a more knowledge-oriented economy.

On the other hand, the sector where R&D is carried out must be also considered because there is a positive correlation between BERD/GDP and GERD/GDP (figure 6). As expected, likely because there are governmental financial inducements, this correlation is higher than the correlation between industry-financed GERD and GERD/GDP (0.98 vs 0.96, respectively).

Figure 6
Association between BERD/GERD and GERD/GDP



Source: Based on data from OECD (2005).

Nevertheless, the association between BERD/GERD and GERD/GDP as depicted in figure 6 shows that there is more dispersion for low levels of GERD/GDP, than for higher levels. This differential dispersion is indicative of the disparity in the capacity in introducing the R&D activities in the routines of the business sector. Although this lack of capacity would bee experienced by a significant lot of economies it is usually more present in the ones with lower GDP per capita.

The analysis of BERD by groups of countries shows a picture that essentially is not much different from the figures of industry-financed GERD: in the group of countries of the early technological frontier only the UK and France finished the period with a BERD/GDP lower than OECD average (figure A4, in Appendix); in the follower countries all the ones that fail in filing the GERD gap, finished the period of analysis with a BERD/GDP below the OECD average level (figure A5); in contrast countries that succeeded in filing the GERD gap (only with the Austrian exception) show a significant increase in BERD/GDP (figure A6, in Appendix).

From the above analysis, a 1st conclusion can be drawn. Countries that have succeeded in catching the efforts in GERD/GDP coincide with those where industry financed GERD has consistently increased, and are also the ones that improved significantly the BERD/GDP ratio. However, the previous analysis only considers the input side the R&D activities: the financial resources used with alleged R&D purposes. So, because R&D numbers may be overestimating the real growth in inventive input, a more accurate analysis makes the use of other indicators mandatory. In this respect, indicators that permit to assess the efficiency with whicu R&D expenditures are spent are particularly useful. Respecting the business sector the most obvious indicator for that endeavour is patent counts.

3. Patents

A patent is a document, supplied by a certified governmental agency, granting the right to exclude anyone else from producing or trading a specific new product, device, or process for a stated number of years[3]. The settled purpose of the patent system is to encourage invention and technical progress both by providing a temporary

[3] Patent statistics are used with various functions. For the functions of patent counts as economic indicators, as well as for the difficulties that arise in their use and interpretation, see Griliches (1990).

monopoly for the inventor and by forcing the early disclosure of the information necessary for the production of the patented item or for the operation of the new process. From the endogenous growth viewpoint this latter reason is essential, because the immediate availability of knowledge is a condition for the continuous role of the engine of growth[4].

Patents are the measure of the output of research that better represents the capacity for using inventions with economic purposes. In effect, a patent does correspond to a minimal amount of invention that has passed both the trial of the investment of effort and resources by the inventor and his institute or firm into the development of this idea, product or process, and the examination of the patent office. As a matter of fact, a patent is only granted if four conditions are simultaneously fulfilled: i) industrial applicability — the invention must be of practical use; ii) inventive step — the invention must not be merely deduced by a person with average knowledge of the technical field; iii) novelty, that is, the invention must show some new characteristic which is not known in the bulk of existing knowledge in its technical field; iv) the subject of invention must be accepted as "patentable" under country's law[5].

In general, an application for a patent must be filed, and a patent shall be granted and enforced, in each country in which one looks for patent protection for its invention, in accordance with the law of that country. Although in some regions, a regional patent office (for example, the European Patent Office or the African Regional Intellectual Property Organization) accepts regional patent applications, or grants patents, which have the same effect as applications filed, or patents granted, in the member states of that region, the patent system has a national basis.

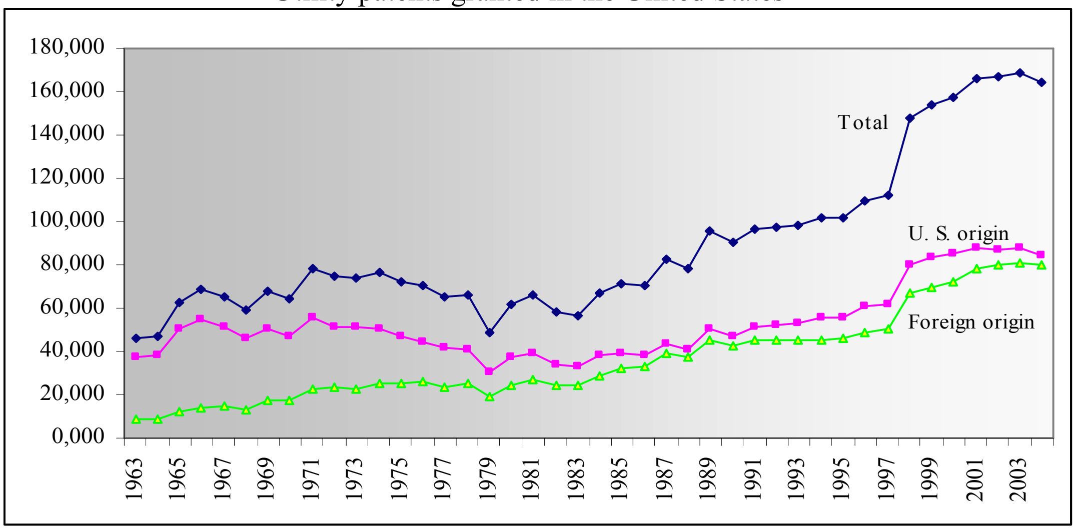
The granting rate of patents (which ultimately shows the stringency of patent office examination) varies greatly across countries. As was demonstrated by Griliches (1990), this variability is largely associated with differences in the procedures and resources of the various patent offices, implying therefore also differences in the average "quality" of a granted patent across countries and along time.

[4] All patent owners are obliged, in return for patent protection, to publicly reveal information on their invention in order to improve the world bulk of technical knowledge. Such a growing body of public knowledge promotes further creativity and innovation in others. In this way, patents provide not only protection for the owner but valuable information and inspiration for future generations of researchers and inventors.

[5] In many countries, scientific theories, mathematical methods, plant or animal varieties, discoveries of natural substances, commercial methods, or methods for medical treatment (rather than medical products) are not patentable.

So, if we intend to evaluate the inventiveness of various countries through patent counts we must use figures generated by the same criteria for the analysed sample of countries. This necessity of comparativeness implies using patent counts granted in the same reference country. In this paper we'll use figures of patents granted in the USA by USPTO (United States Patent and Trademark Office). Figure 7 shows the number of utility patents (i. e., patents of invention) granted to residents in the US and to residents in all the other countries around the world, from 1963 to 2004.

Figure 7
Utility patents granted in the United States



Source: Based on data from USPTO (2006).

As it is apparent from the figure, the evolution of the number of patents along time was not linear. On the other hand, there is an important discrepancy in the evolution of the number of patents according to the origin of inventors: for instance, the convergence between foreign origin and US origin, particularly visible from 1966, is interrupted around the end of the 1980's. This stoppage in the patent counts convergence anticipates the interruption of the European catching up process initiated after the 2nd world war.

Table 1 shows the results of the simple regression of the annual change in Gross Domestic Product (measured in million current PPP$) and the numbers of US patents for a panel of countries separated in two samples: a large sample compounded by all the countries included in the database we have used in the R&D analysis (OECD, 2005), and a restricted sample where we include only the countries that were analysed in the preceding section[6].

Table 1
GDP change and patent counts, 1982-2004

	Large sample				Restricted sample			
	Pooled LS		GLS cross section weights		Pooled LS		GLS cross section weights	
	(1)	(1')	(2)	(2')	(3)	(3')	(4)	(4')
Coefficient (t-1)	4.40* (14.00)	2.09* (3.29)	4.40* (14.00)	2.71** (2.52)	4.50* (13.96)	2.07* (3.25)	5.24* (5.41)	3.09** (2.07)
T N Obs	22 39 743	22 39 743	22 39 743	22 39 743	22 22 484	22 22 484	22 22 484	22 22 484
R^2	0.50	0.89	0.50	0.89	0.83	0.91	0.81	0.90
Coefficient (t-2)	4.47* (14.03)	1.71* (3.36)	4.47* (14.03)	2.54* (2.67)	4.58* (14.00)	1.70* (3.31)	5.41* (5.20)	2.92** (2.14)
T N Obs	22 39 750	22 39 750	22 39 750	22 39 750	22 22 484	22 22 484	22 22 484	22 22 484
R^2	0.50	0.89	0.50	0.89	0.81	0.91	0.79	0.90

Source: Calculations based on OECD (2005).
Notes: *t* tests are shown in brackets: *significant at the 1 percent level; **significant at the 5 percent level; Standard errors and covariance matrix are White (1980) heteroskedastic corrected.

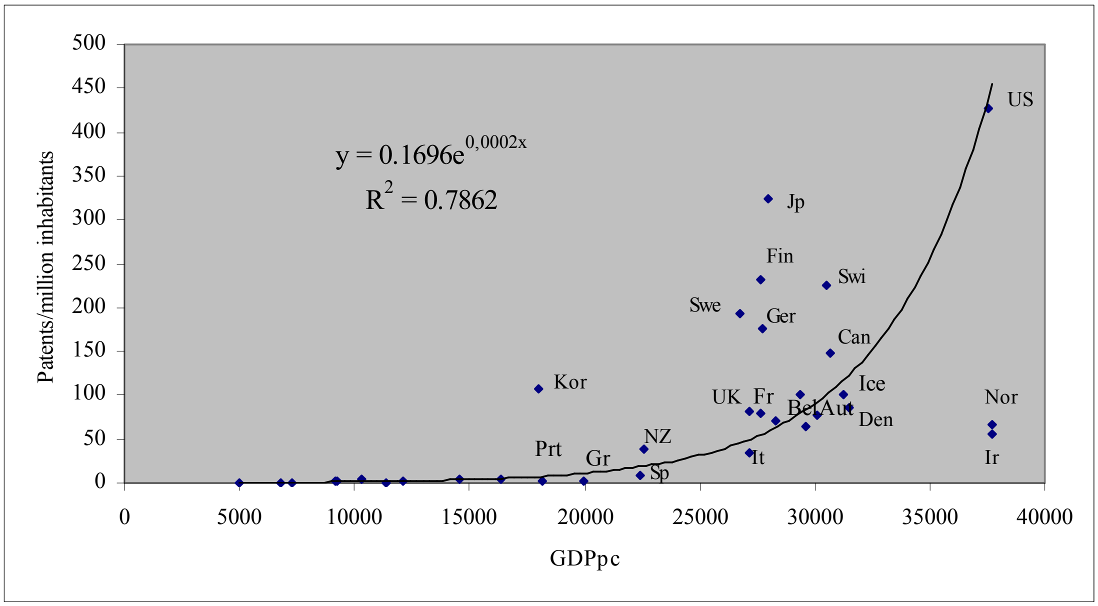
In table 1 we show the estimates calculated by two different methods and for two time lags: we regress the change in GDP on the number of patents of one and two years before. Columns 1, 1', 3 and 3' show estimates that are obtained by Pooled OLS. This specification estimates the model using system OLS method, and has implicit the verification of the assumptions of the classic linear regression model. So, it is only appropriate when the residuals are contemporaneously uncorrelated and time period and cross-section homoskedastic. But because when the residuals are cross-section heteroskedastic and contemporaneously uncorrelated it is more appropriate to use cross-section weights, the table reports GLS estimates, too (columns 2, 2', 4 and 4')[7]. The first of each pair of columns presents estimates with a common constant; the second presents estimates obtained by a fixed effects model.

As is apparent from the table there is a strong relationship between the change in GDP and the number of patents received across countries and along time, as the usual

[6] For a different approach of the use of patents in testing ideas-driven models, see Pessoa (2005).
[7] We have also calculated Seemingly Unrelated Regression (SUR) estimates (Zellner, 1962). SUR is the feasible GLS estimator when the residuals are both cross-section heteroskedastic and contemporaneously correlated. The results, not very different from the reported in table 1, are available from the authors upon request.

criteria for assessing the statistical significance show: R^2 typically high, and high levels of significance measured by the *t* tests. However, the number of patents also depends on the level of development of the country as it is shown in figure 8, where the number of US patents per million inhabitants is depicted as a function of the level of development.

Figure 8
US patents per million inhabitants



Source: Based on data from OECD (2005) and World Bank (2006).

Figure 8 shows an image similar to the depicted in figure 1, where the association between GERD and GDP per capita is represented: a non linear relationship between the variables. However, in contrast with the GERD behaviour the dispersion around the expected value is much concentrated in the high levels of development. On the one hand, Norway and Ireland show patent counts evidently poorer than expected given their level of development. One the other hand other countries, like Japan and Finland, had patent counts clearly greater than it would be expectable owing to their level of GDP per capita.

Countries that significantly increased GERD/GDP (Finland, Iceland, Denmark, Austria and Belgium) are countries that have already a considerable number of patents per million inhabitants (from 17.3 in Iceland to 39.8 in Finland) in 1981. Furthermore, these countries, excepting Iceland, have experienced an annual average growth rate of the number of US patents higher than the world average, from 1963 to 1980: Denmark (4.75), Belgium (6.20), Austria (6.66) and Finland (11.21). In addition, after World War

II, almost all the countries that have benefited from long periods of economic sustained growth have also experienced high growth rates of patents.

Table 2 presents the annual average growth rates of US patents from 1981 to 2002, and the number of US patents per million inhabitants in 2002, in a sample of 36 countries. Table 2 shows that the highest growth rates of patent counts correspond to countries which we can include in one of two situations: either countries that have significantly increased the GERD/GDP ratio (Iceland, Finland), or countries that have previously initiated a practice of relying on patents as a mechanism of technological change (Korea, Singapore). China, at the top of the list, fulfils, both criteria.

Table 2
Average growth rate of US patents

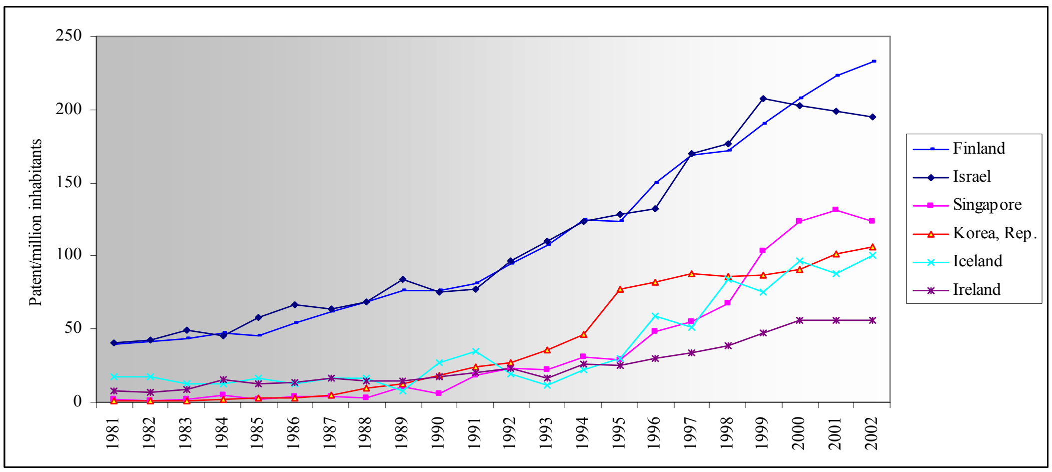
US patents per million inhabitants								
Country	**Growth***	**Value****	**Country**	**Growth***	**Value****	**Country**	**Growth***	**Value****
China	23.19	0.53	Argentina	5.14	1.54	Germany	3.60	175.49
Korea, Rep.	21.53	106.53	Japan	5.02	323.31	Poland	3.15	0.78
Singapore	20.45	123.20	Norway	4.96	66.77	Austria	3.13	76.37
Ireland	9.09	56.23	Denmark	4.88	86.90	U. Kingdom	3.07	81.56
Iceland	8.18	100.69	Australia	4.71	63.67	Netherlands	3.01	100.90
Turkey	7.89	0.33	U. States	4.43	426.53	France	2.94	78.74
Finland	7.59	232.54	N. Zealand	4.06	37.57	Switzerland	1.08	224.83
Israel	6.84	194.94	Greece	4.05	1.82	Russian Fed.	0.95	1.28
Portugal	6.13	1.45	Sweden	3.79	193.75	South Africa	0.76	3.53
Spain	5.97	7.97	Italy	3.79	34.74	Luxembourg	0.30	94.70
Canada	5.27	148.56	Romania	3.76	0.28	Czech Rep.	-0.01	3.92
Belgium	5.23	71.13	Mexico	3.63	1.10	Hungary	-2.95	5.32

Source: Computation based on data from OECD (2005)
Notes: * Annual average growth rate, 1981-2002; ** US patents per million inhabitants, 2002.

As it is apparent from table 2 (and from other figures below), Asia presents the highest rates of growth of US patents, but in some Asian countries the level of US patents per million inhabitants is still very small, and in some of them (*v. g.,* China) the efficiency of BERD is also very low. However, if these countries (China, Malaysia, Thailand and India) follow the path of other Asian countries (South Korea, Taiwan, Hong-Kong and Singapore), as figure 10 seems to indicate, we'll subsequently have new waves of Asian Tigers.

Figure 9 shows the most significant cases of growth of US patents per million inhabitants, from 1981 to 2002. Of course, there are other economies with higher growth rates of patent counts (*v. g*., China, Turkey, Portugal) that the figure doesn't consider. The main reason for this exclusion lies in their very small level of patents per million inhabitants, which is insufficient to constitute a ground for cumulativeness, according to the models of knowledge-driven growth. However a high growth rate of patents, if sustained, is an important indicator of a potential technological and economic change in the near future, as was demonstrated with the first generation of Asian Tigers (Hong-Kong, Taiwan, South Korea, and Singapore). Additionally, if patent counts can be taken as an indicator of the number of economically useful ideas, their high rate of growth is critical. According to the models of knowledge-driven growth (Romer, 1990; Jones, 1995), in order to have growth, the number of new ideas must grow over time.

Figure 9
Most significant growth of US Patents per million inhabitants



Source: Based on data from OECD (2005) and World Bank (2006)

Although the database we have used (OECD, 2005) do not supply enough R&D data about Singapore and South Korea for the entire period, the scarce data supplied show that these countries experienced a different path in what respects to GERD/GDP, industry-financed GERD and BERD/GDP. While Korea has experienced a path similar to the Finish one in all the above features, in Singapore none of those indicators grew sufficiently in order to catch the OECD average, in spite of the significant progress made in that direction. In these aspects there are some similarities with the Irish case.

4. Efficiency of BERD

In the preceding sections we have dealt with indicators of the effort of society as a whole and of firms to conduct R&D, as well as with a potential indicator of the success of those efforts: the number of patents received. However, countries may be more or less successful in the accomplishment of those efforts. So, another important aspect must be considered: The efficiency with which R&D outlays are spent. For the business sector it matters to know the *ratio* between US patent counts and BERD

Table 3 presents the annual average in the period 1981-2002 of the *ratio* between US patent counts and BERD (measured in million 2000 dollars — constant prices and PPP) for the unrestricted sample of OECD (2005). There is roughly a positive relationship between the efficiency of BERD and the level of development. This is partly a consequence of the increasing returns associated to BERD, as was argued elsewhere (Pessoa and Silva, 2001). However, there is some national specificity that may influence the technological and economic performance of the countries and that partly outweighs some differences in R&D, as measured by the statistical indicators like GERD or BERD.

Table 3
US patents per million dollars BERD

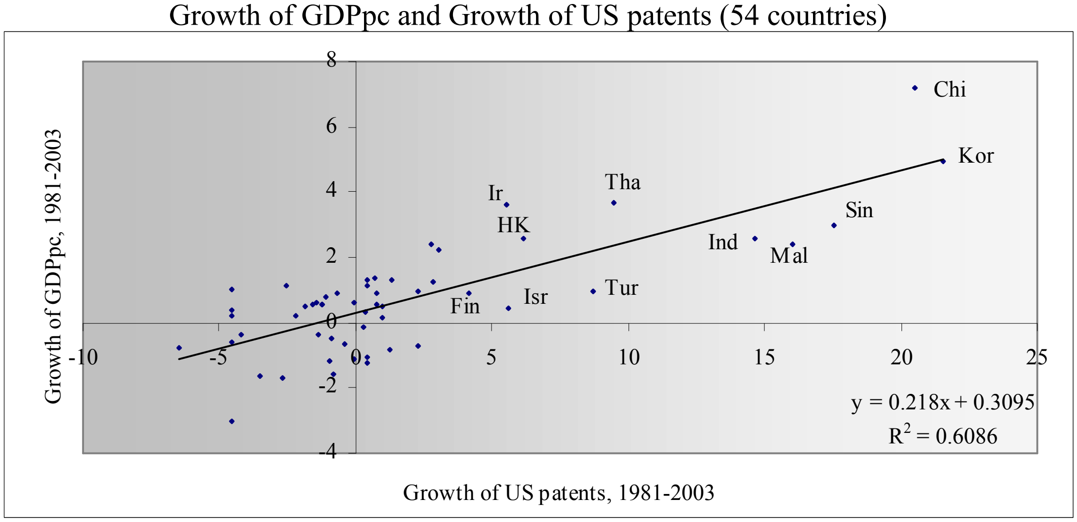
Country	*Ratio*	Country	*Ratio*	Country	*Ratio*
Taiwan	0.877	Austria	0.301	Greece	0.103
United States	0.470	Netherlands	0.298	Slovenia	0.078
Iceland	0.466	Sweden	0.275	Spain	0.077
Japan	0.465	Denmark	0.260	Portugal	0.041
New Zealand	0.445	Ireland	0.221	Czech Republic	0.029
Canada	0.412	U. Kingdom	0.202	Poland	0.027
Switzerland	0.387	France	0.197	Russian Federation	0.027
Finland	0.351	Italy	0.194	Slovak Republic	0.020
Korea, Rep.	0.327	Belgium	0.180	Turkey	0.014
Singapore	0.325	Mexico	0.174	China	0.013
Israel	0.319	Norway	0.169	Romania	0.012
Germany	0.319	Hungary	0.139		
Australia	0.317	Argentina	0.113		

Source: Calculations based on OECD (2005).

Before concluding we must say something about the relationship between productivity and technological change. The link between technology and productivity is not so evident as the commitments referred to in the introduction seem to believe. First, not all productivity growth is due to inventions or other improvements in technology, and when it happens the effects of an invention on productivity appear with a long and variable lag. In this case, it is doubtful if the available econometric procedures can identify all of them with accuracy. Moreover the aggregation of many lag structures is likely to level them out further, beyond any detection. Second, apart from technology, many other factors have an impact on productivity: for instance, the growth in the quality of the labour force, the benefits from economies of scale and the reallocation of capital among industries, to name the most usually mentioned.

However, a stylised fact can be drawn from the comparison between the growth of productivity and the growth US patents, as is shown in figure 10, which extends the number of countries used in the OECD database (OECD, 2005) using data from World Bank (2006) and the database of USPTO (2006).

Figure 10.
Growth of GDPpc and Growth of US patents (54 countries)



Source: Based on data from World Bank (2006) and USPTO (2006).
Notes: The rates depicted are deviations from world average rates.

Each one of the points in Figure 10 identifies one of 54 countries, each being represented by the deviation from the world average growth rate of both GDP pc and number of US patents. As it is apparent from the figure, the countries that experienced the highest rates of US patents are simultaneously the ones that show the highest rates of economic growth in per capita terms.

5. Concluding remarks

R&D expenditures typically constitute, for advanced economies, only a small percent of GDP. In a standard growth accounting framework, variations in the research effort will, therefore, explain very little of the differences in growth rates between countries. But the point of much of the new growth theory is precisely that if knowledge spillovers are substantial, and if knowledge exhibits dynamic feedback effects, then even small changes in the resources devoted to the production of knowledge may result in substantial changes in economic growth.

In this paper we have investigated the patterns of development in national innovative capacity, in a broad sample of countries that have included the leaders and the followers in catching up to the world's leading countries focusing on several types of indicators at country level: GERD/GDP, BERD/GDP, industry-financed GERD and patent counts. The analysis carried out has allowed us to put forth three main conclusions that could be extensive to the growth of sub-national regions:

i) The most successful economies are those where increases in aggregate R&D efforts are induced by the action of the business sector;

ii) R&D efforts must go hand in hand with concerns of efficiency;

iii) High growth rates of patent counts are closely associated to high growth rates of economic growth.

References

Abramovitz, Moses (1979), "Rapid Growth Potential and Its Realisation: The Experience of Capitalist Economics in the Post-war Period", in *Economic Growth and Resources: Vol. I: The Major Issues*, Edmond Malinvaud (ed.), London: Macmillan, pp. 1-30.

Abramovitz, Moses (1986), "Catching-up, Forging Ahead and Falling Behind", *Journal of Economic History*, Vol. 46(2), pp. 386-406.

Aghion, P. e P. Howitt, (1992), "A Model of Growth Through Creative Destruction", *Econometrica*, Vol. (2), pp. 323-51.

Dixit, Avinash, e Joseph E. Stiglitz (1977), "Monopolistic Competition and Optimum Product Diversity." *American Economic Review*, *Vol.* 67(3), pp. 297-308.

Ethier, William (1982), "National and International Returns to Scale in the Modern Theory of International Trade", *American Economic Review*, Vol. 72(3), pp. 389--405.

Fagerberg, Jan (1987), "A Technology Gap Approach to Why Growth Rates Differ", *Research Policy*, Vol. 16(2-4), pp. 87-99.

Freeman, Chris (1987), *Technology and Economic Performance: Lessons form Japan*, London: Pinter Publishers.

Gerschenkron, Alexander (1962), *Economic Backwardness in Historical Perspective*, Cambridge, Mass.: Harvard University Press.

Griliches, Zvi (1990), "Patent Statistics as Economic Indicators: A Survey", *Journal of Economic Literature,* Vol. 28, pp. 1661-1707.

Griliches, Zvi (1992), "The Search for R&D Spillovers", *Scandinavian Journal of Economics,* Vol. 94, Suplement, pp 29-47.

Grossman, Gene and Elhanan Helpman (1991), *Innovation and Growth in the Global Economy.* Cambridge, Mass.: MIT Press.

Jones, C. I. (1995), "R&D Based Models of Economic Growth", *Journal of Political Econom*y, Vol. 103(4), pp. 759-784.

Jones, Charles I. and John C. Williams (1998), "Measuring The Social Return To R&D", *The Quarterly Journal of Economics,* pp. 1119-1135.

Jones, Charles I. and John C. Williams (2000), "To Much of a Good Thing? The Economics of Investment in R&D", Journal of Economic Growth, 5, pp. 65-85.

Maddison, Angus (1987), "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment", *Journal of Economic Literature*, Vol. 25(2), pp. 649-98.

OECD (2005), *Main Science and Technology Indicators* (MSTI data base), Paris: OECD.

Pavitt, Keith (1982), "R&D, Patenting, and Innovative Activities: A Statistical Exploration", *Research Policy*, 11 (1), pp. 33-51.

Pessoa, Argentino (2005), "Ideas-Driven Growth: The OECD Evidence" *Portuguese Economic Journal,* 4, pp. 46-67.

Pessoa, Argentino and Mário Rui Silva (2001), "Padrões de I&D: Portugal no contexto da OCDE" in *Como Está a Economia Portuguesa? IV Conferência sobre a Economia Portuguesa*, CISEP — Centro de Investigação sobre a Economia Portuguesa, Lisboa, pp. 775-96.

Romer, Paul M. (1990), "Endogenous Technological Change", *Journal of Political Economy*, Vol. 98(5), pp. S71-102.

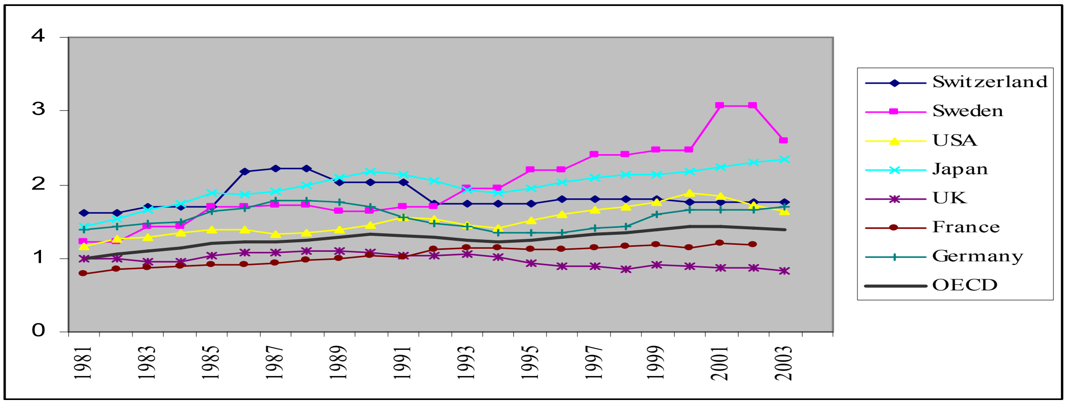
Schumpeter, Joseph (1912), *Theorie der Wirtschaftlichen Entwicklung* (2nd edition 1926), Leipzig. English version: *The Theory of Economic Development*, Cambridge, Massachusetts, 1934.

USPTO (2006), Patents by Country/State and year, United States Patent and Trademark Office, http://www.uspto.gov.

Word Bank (2006), *World Development Indicators,* CD-ROM, World Bank.

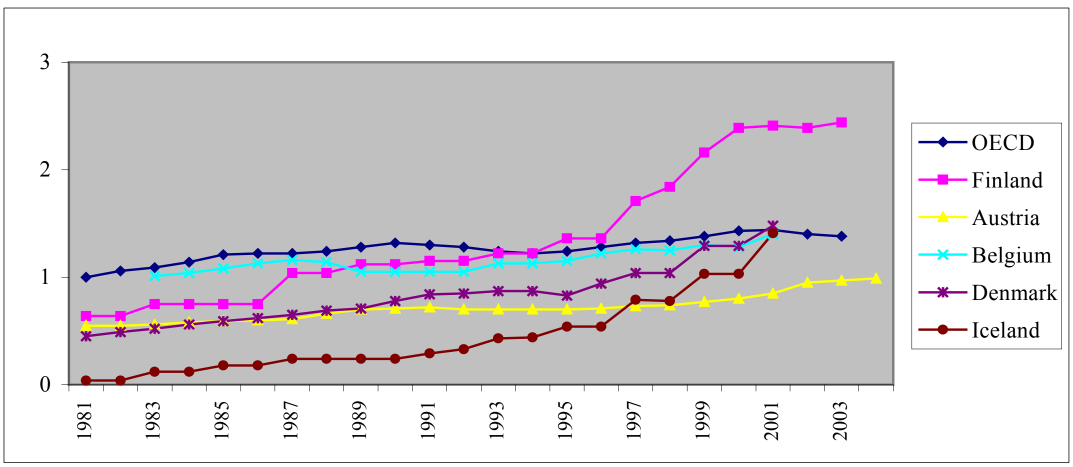
Appendix

Figure A1. Industry-financed GERD in earlier technological frontier



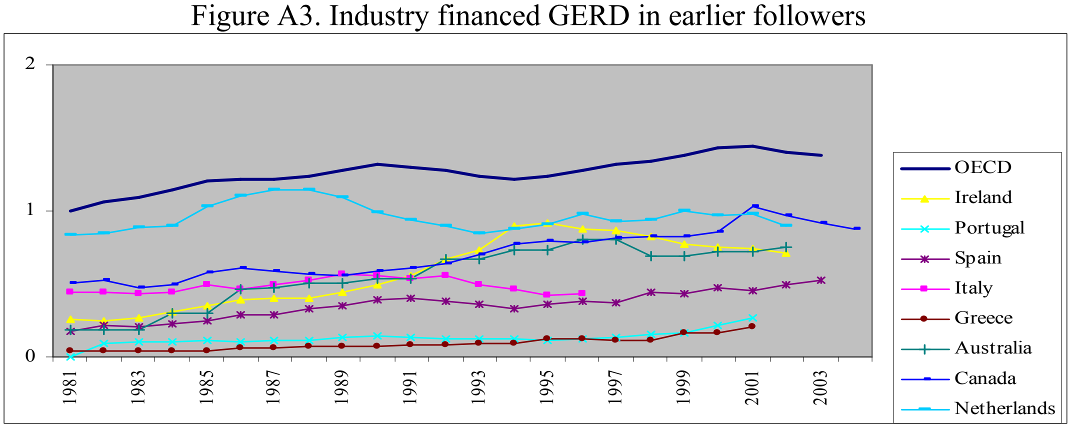
Source: Based on data from OECD (2005).

Figure A2. Industry financed GERD in well succeed followers



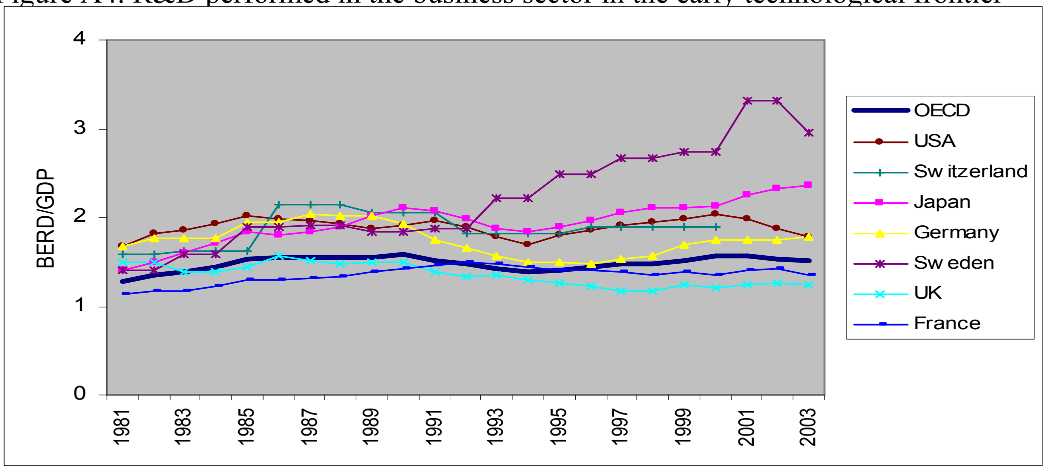
Source: Based on data from OECD (2005).

Figure A3. Industry financed GERD in earlier followers



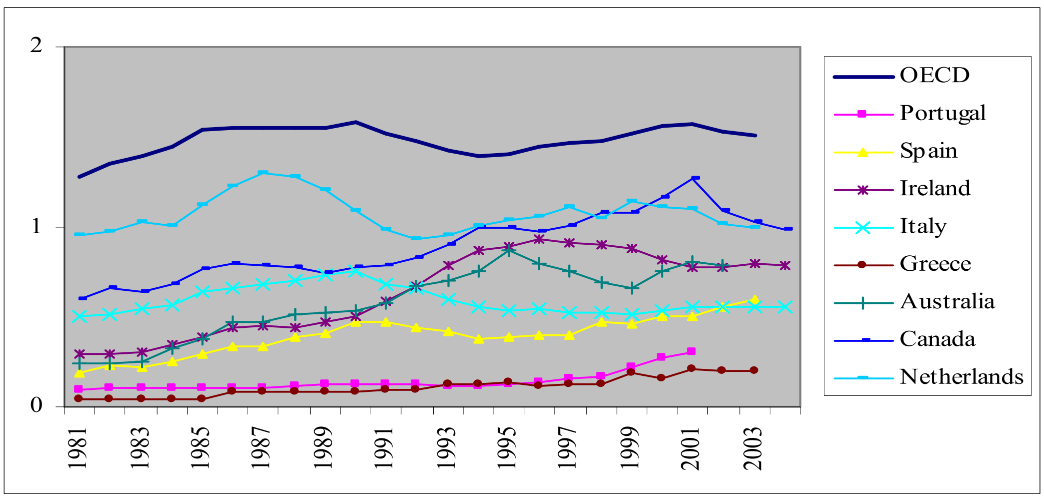
Source: Based on data from OECD (2005).

Figure A4. R&D performed in the business sector in the early technological frontier



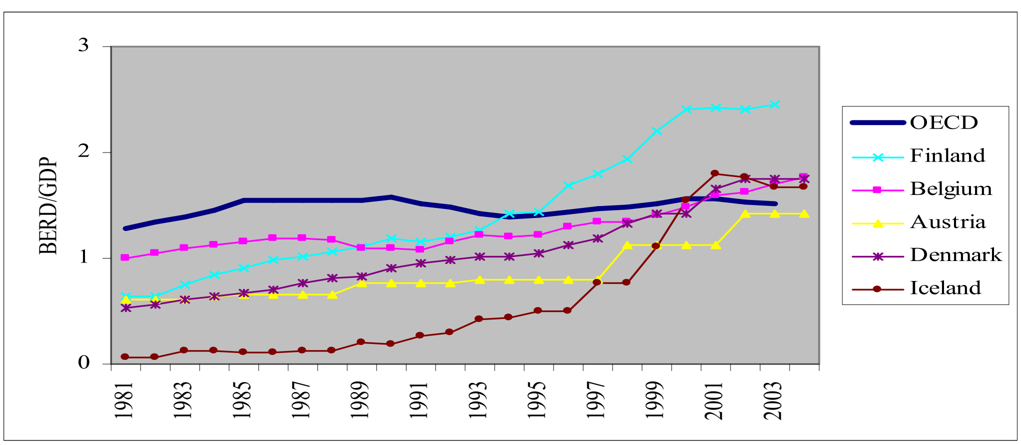
Source: Based on data from OECD (2005).

Figure A5. R&D performed in the business sector in in earlier technological frontier



Source: Based on data from OECD (2005).

Figure A6. Catching-up in BERD



Source: Based on data from OECD (2005).