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INNOVATION AND ECONOMIC GROWTH: WHAT IS THE ACTUAL IMPORTANCE OF R&D?

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Abstract

This paper deals with the relationship between innovation and economic growth in the context of developed world. After examining the correlation between economic growth and R&D (research and development) intensity, and given that the impact of R&D on economic growth is mediated by the rate of growth of technology, we proceed trying to assess the linkage between R&D outlays and economic growth, through the use of the condition of free entry into R&D. Confronted with data, our argumentation shows that the optimism of the endogenous technological change models is not confirmed for countries situated below the technological frontier. Next, based on other economic and technological indicators, a succinct comparison between the Irish and Swedish cases is made. This comparison reveals the importance of investments not classified as R&D, particularly the ones that enhance the external competitiveness of the economy. We conclude that innovation policy must always consider the complexity of the economic growth process and the other ways, besides the ones based on formal R&D indicators, in which technology has an impact on growth.

Keywords: R&D, economic growth, technological change, innovation policy.

JEL Codes: O30, O32, O33, O38.

INNOVATION AND ECONOMIC GROWTH: WHAT IS THE ACTUAL IMPORTANCE OF R&D?

1. INTRODUCTION

This paper deals with the contribution of research and development (R&D) to the growth of advanced economies. Both theoretical and empirical literatures have shown that investments in R&D are crucial for economic growth. In the theoretical front, a lot of models (Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992, to name only the most quoted) illustrate the function of R&D as a growth engine, and demonstrate the reason why government must have a role in achieving an optimum level of R&D. In the empirical front, several authors also show the importance of the R&D returns. For example, in his survey about R&D spillovers, Griliches (1992) reported 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, responsible 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. Consequently, investments in R&D seem to have very high social returns and to be a key component of economic growth and development.

Accordingly, though with very different results, several governments have vastly increased their policy commitment to innovation with significant impacts on levels of R&D expenditures of their countries, relying basically on the impact of science and technology on economic performance. However, such procedure risks to enlarge R&D intensity beyond the optimum level since there are some reasons to believe in cumulativeness in R&D outlays whatever its type: public or private (Yoo, 2004).

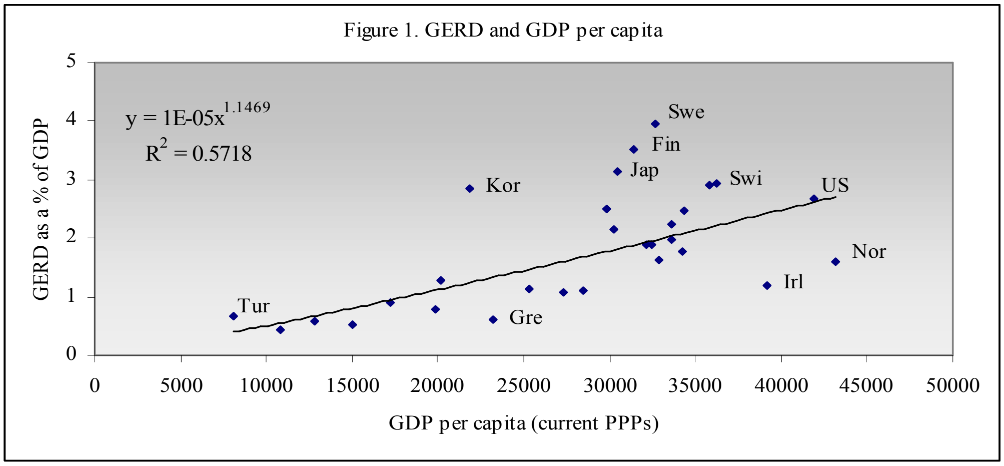
The public support to R&D expenditures is rationalized in economic terms by the existence of positive externalities. These externalities can appear in the production of the final output or in the R&D process. Production externalities arise because the development of one innovation has an effect on aggregate labour productivity beyond its contribution to the capital stock (i.e. it affects the Solow residual). When innovations are embodied, firms enjoy production externalities to the extent that they use the new goods. In the R&D process two kinds of externalities may be present. One kind is related to the R&D workers and the other is associated to the existing stock of economic useful knowledge. As has been argued by several authors (e.g. Stokey, 1995; Jones and Williams, 2000), alongside positive externalities in the R&D process like 'stand on the shoulders', there is also the possibility of some others being negative ('fishing out hypothesis', 'stepping on toes effect', 'creative destruction', etc.), which makes the empirical assessment of the contribution of R&D to economic growth very doubtful if it relies on the calibration of parameters that symbolize such externalities. Of course there is always the possibility of assessing the dimension of externalities through regression methods, like in Pessoa (2005), but this method has also problems (spurious regressions, endogeneity, etc.). So, the present paper follows a different path: the use of the free entry condition into R&D to assess the link between R&D outlays and economic growth.

The purpose of present paper is twofold. On the one hand, we aim to show that the increase of R&D intensity is not an assured means of improving economic growth, particularly in countries situated below the technological frontier. On the other hand, we try to show that there are other ways in which technology impacts on growth besides the ones based on formal R&D indicators.

So, the remainder of the paper is structured as follows. Section 2 deals with the relationship between R&D and economic growth. In section 3, we analyse one implication of the free entry into R&D, in a model of R&D-driven growth. In Section 4 we compare the Irish case with the Swedish one in terms of R&D and economic growth relationship. Section 5 concludes.

2. R&D AND GROWTH: WHAT DOES DATA TELL US?

Innovation policy has frequently relied on a 'linear model' of the impact of science and technology on economic development. The main assumption underlying this model is that R&D carried out by researchers/scientists leads to a new idea, which becomes a new product, for which a production process is developed by industrial engineers, and for which a marketing plan is then set up, conducting to its increasing demand in the market. This linear model is often empirically supported on the positive correlation between Gross Domestic Expenditure on Research and Development (GERD) and the level of development measured by GDP per capita.



Source: Based on data from OECD (2006)

In figure 1, the R&D intensity measured by GERD as a percentage of GDP in 2004[1] is plotted against the GDP per capita in 2005 for 29 OECD countries[2]. Although there is a positive relationship between the level of development and R&D intensity the correlation is far from perfect, indicating that there are other factors affecting the level of the country's development. But even if there was a strong correlation we should keep in mind that correlation is not causation. Furthermore, there are many factors omitted in the regression that affect simultaneously TFP (total factor productivity) growth and the incentives to invest in R&D, such as all those that enhance disembodied productivity. All those factors, like the managerial and organizational practices, learning by doing, etc., have a clear effect on TFP and, at the same time, induce firms to invest in R&D[3]. So, R&D outlays seem rather a proxy of the level of development than a cause of it. Partly because of this, when we search for the actual relationship between R&D

[1] Or where data are not available for 2004, the nearest year with availability of data.
[2] All OECD members except Luxembourg.
[3] There is some supportive evidence of the potential importance of this bias. For instance, Jones and Williams (1998) verify that the effect of R&D on TFP growth almost vanishes after including fixed effects in their econometric model.

intensity and GDP growth, the picture is not very confirmative of the positive effects of the former on the latter.

In fact, as depicted in figure 2, where every point identifies one of 29 OECD countries, each being represented by the average annual volume percentage change of GDP and by the GERD intensity (both measured as deviations from the OECD average), there is no positive correlation between average growth rate of GDP between 1995 and 2005 and GERD as a percent of GDP in 2004[4].

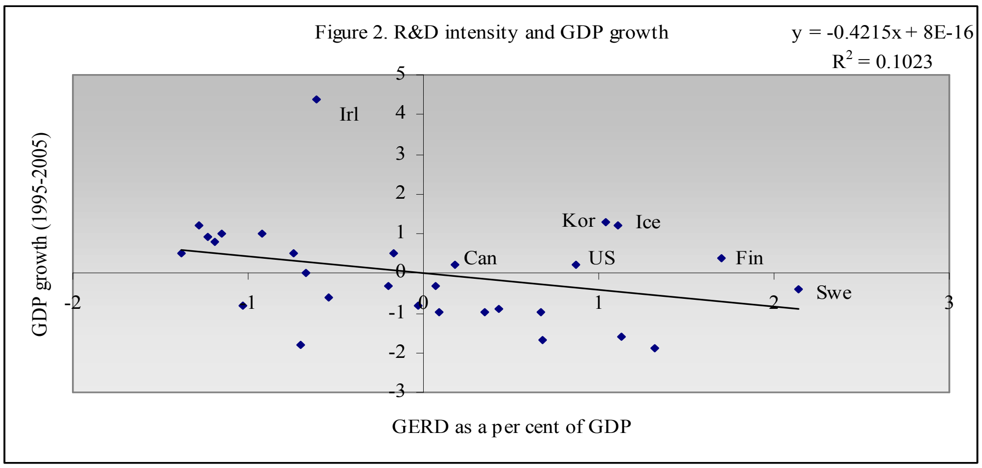


Figure 2. R&D intensity and GDP growth

Source: Based on data from OECD (2006).
Notes: The rates depicted are deviations from OECD average.

As it is apparent from the figure, among 14 countries that experienced R&D intensity above the OECD average, only 5 (the USA, Canada, Finland, Iceland and South Korea) show a GDP growth rate higher than the OECD average. The figure also makes the contrasting positions of Ireland and Sweden apparent. While the former presents the highest rate of growth, gaining in that way the qualification of 'Celtic Tiger', with low R&D intensity, the latter illustrates an example where the highest R&D intensity coexists with a rate of output growth below the OECD average, originating the idea of a 'Swedish Paradox'[5].

[4] Some may argue that there must be a lag between increase in R&D and economic growth. So, we have also regressed the economic growth rate of 1995-2005 period on the R&D intensity both for the middle of 1990s and for 2000. But the results, available from the author upon request, are very similar to the ones found for 2004.

[5] Although the paradox idea has had different versions, all of them share the common fundamentals that high Swedish R&D outlays do not produce sufficient economic results (see, Kander and Ejermo, 2006).

The fact that we don't see a positive correlation between R&D intensity and growth doesn't mean per se that technology doesn't positively affect economic growth. It only shows that the link between the two variables is complex, with the efficiency on the use of outlays classified as R&D as a mere aspect of that complexity. Moreover, if we add the complementarity between R&D and other inputs (for instance, equipment, level of schooling of labour force, qualification of business management) one can suppose that the absence of correlation is due rather to these factors than to the absence of the positive effects of technology. On the other hand, assessing the technological effects through indicators of R&D outlays is not the only possible path to evaluate the economic impact of the innovation process.

As was already argued (Pessoa e Silva, 2001), patent counts[6], albeit with limitations[7], constitute the measure of the output of research that better represents the capacity for using inventions with economic purposes. In fact, 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. Consequent to this examination, a patent is only granted if three conditions are simultaneously fulfilled[8]: 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.

So, the positive correlation between the growth of patent counts, or even between the number of patents weighted by some indicator of the country dimension, and the growth rate of GDP per capita (figure 3) it is much more likely than the correlation between R&D intensity and economic growth.

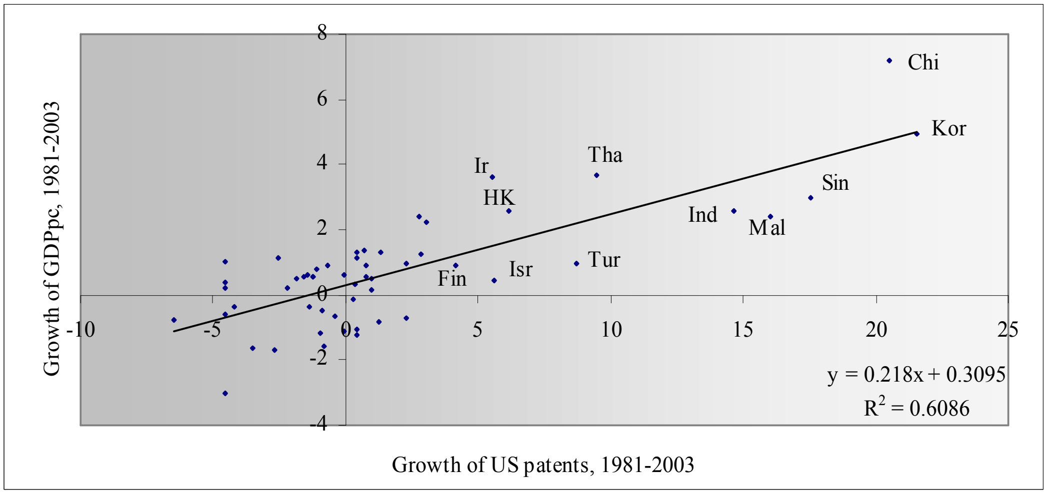
[6] Patent statistics are used with various functions. For the functions of patent counts as economic indicators, as well as for the difficulties that arise in their use and interpretation, see Griliches (1990).

[7] Among other limitations, the most frequently cited respect to the fact that: a) patent counts overlook the real economic importance of a particular patent, b) different technologies are differently patentable; and c) because applying to a patent has specific costs, which accrue to the research costs, many firms prefer the secret to the patent as a protecting device.

[8] In fact, there is another condition: the subject of invention must be accepted as "patentable" under the country's law. In many countries, scientific theories, mathematical methods, plant or animal varieties, discoveries of natural substances, commercial methods, or methods of medical treatment (rather than medical products) are not patentable.

Figure 3.

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 3 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, for the 1981-2003 period. However, in spite of the positive correlation expressed in the figure, and in spite of the optimism of the growth models with endogenous technology, there are yet many questions awaiting the right answer. In the next section, we'll use the free entry in R&D to assess the link between R&D outlays and economic growth.

3. FREE ENTRY INTO R&D

In this section we exploit an attribute of the ideas-driven growth model and calibrate it for the US, Ireland and Sweden. Our main assumption is that there is free entry into R&D. This implies that, in equilibrium, the value of the resources devoted to R&D equals the value of the newly developed technologies.

Let's denote by A_t the level of technology associated with R&D investments. In the horizontal differentiation model (Romer, 1990; Grossman and Helpman, 1991, ch. 3), this is the number of capital varieties. To compute the R&D contribution to productivity growth, we can use a production function to relate the growth rate of A_t to the growth rate of labour productivity. All over the paper we use $\dot{X}$ to designate the time derivative of variable *X*, and $\hat{X}$ to denote the growth rate of variable *X*. So, let equation (1) represent the Cobb-Douglas production function of the economy:

$$Y_t = A_t^{\sigma} Z_t K_t^{\alpha} L_t^{1-\alpha} \qquad (1)$$

where Y_t denotes the economy-wide output, Z_t is the level of disembodied productivity, K_t and L_t symbolize capital and labour respectively and where α is the capital share, and σ is the elasticity of Y_t with respect to A_t (i.e., the production externality).

From equation (1), we can calculate the elasticity of productivity growth with respect to R&D-driven technology growth (i.e., $\sigma + \alpha \partial K/\partial A$), and the contribution of R&D to productivity, $(\sigma + \alpha \partial K/\partial A)\hat{A}$, but this calculation depends on the value of the productivity externality, which is unknown. As in the present note we intend to avoid the calibration of both externalities in the production and in the R&D process[9], we alternatively start by investigating the relationship between the amount of resources devoted to R&D, $R_t Y_t$, and the growth rate of technology $\hat{A}_t$, where R_t denotes the share of resources devoted to R&D.

Let P_A symbolize the market value of a design paid by a firm to produce a variety of capital[10]. The free entry condition implies that innovators make zero profits in equilibrium; as a result the cost incurred to develop the patents (*Pat*) is equal to the market value of the flow of new technologies ($P_A \dot{A}$).

$$Pat = P_A \dot{A} \qquad (2)$$

[9] See Pessoa (2005) for references and for some tentative evidence on the estimates of R&D externalities.
[10] For the sake of simplicity, in the remainder of the paper we suppress the subscript $_t$ in parameters and variables.

Which is the condition of free entry.

This condition can be rewritten as in equation (3), where we can see that the relationship between the share of resources devoted to R&D and the growth rate of technology is arbitrated by the value of innovations.

$$\frac{Y}{A} = \frac{P_A \hat{A}}{R} \qquad (3)$$

Because successful innovators earn a patent from the blueprint, they can charge a mark-up (η) above the marginal cost of production. Whatever the value of the mark-up, the instantaneous profits earned by an innovatory firm, which produces intermediates, are:

$$\pi = \frac{\eta - 1}{\eta} \alpha \frac{Y}{A} \qquad (4)$$

But, what is the market price of an innovation? Suppose for simplicity, as in Romer (1990)'s model, that patents are infinitely lived and that innovators are not overtaken by new innovators with more sophisticated capital goods. Then the value of an innovation, P_A, must satisfy the following equation:

$$\rho P_A = \pi + \dot{P}_A \qquad (5)$$

where ρ is the relevant discount factor.

In steady state, all variables grow at constant rates. From equation (3), this implies that

$$\hat{P}_A = \hat{Y} - \hat{A} \qquad (6)$$

Substituting the variables of equation (5) by their expressions in equations (6), (4) and (3) and transferring $\hat{A}$ to the left-hand side we'll obtain the following expression for the growth rate of technology in terms of R:

$$\hat{A} = \frac{\rho - \hat{Y}}{\frac{\eta - 1}{\eta} \frac{\alpha}{R} - 1} \qquad (7)$$

There are two important observations to be made from this expression. First, $\hat{A}$ in expression (7) does not depend directly on the size of the externalities in R&D or on the degree of the diminishing returns to aggregate R&D investments. This implies the assumption that small innovators wanting to understand the market price of their innovations (P_A) do not consider the effect of their investment decisions on aggregate variables, such as the interest rate or the growth rate of output. Given that the externalities appear through these aggregate variables, we do not need to calibrate them once we control for $\hat{Y}$ and ρ. Second, the quantitative result of this section comes from the fact that, if $\hat{Y} < \rho$, $\hat{A}$ is increasing in R. The link between these two variables does not come from a production function for technology; it follows from the positive relationship that the free entry condition (3) identifies between $\hat{A}$ and R.

It is useful to give some values to these parameters in order to access the growth rate of R&D driven technology ($\hat{A}$). As it is apparent in table 1, we have estimated $\hat{A}$ based on the value of the parameters (η, α, ρ) and in the actual figures of $\hat{Y}$ and R. We have chosen the figures for the parameters in the following way: i) for α we have used 1/3, which is the capital share usually applied to the US' economy; ii) for the discount rate, ρ, we have considered 0.07, which is the average real return of the stock market in the last hundred years[11]; and iii) for the mark-up η we have chosen an intermediate value (1.2) of the empirical estimates which range from 1.05 to 1.4 (see Norrbin, 1993; and Basu, 1996). For $\hat{Y}$ and R we have used data from OECD (2006).

Table 1. Parameters and growth rate of R&D driven technology

	η	α	ρ	$\hat{Y}$	R	$\hat{A}$
Ireland	1.2	1/3	0.07	0.075	0.012	-0.00138
Sweden	1.2	1/3	0.07	0.027	0.0395	0.10616
US	1.2	1/3	0.07	0.033	0.0268	0.03455

The values presented in table 1 imply that $\hat{A}$ is about 0.0346 for the US, 0.1062 for Sweden and –0,0014 for Ireland. But the ideas growth model (Romer, 1990; Grossman and Helpman, 1991) predicts that in the long run, once attained the steady-state path,

[11] See Mehra and Prescott (1985).

$\hat{A} = \hat{Y}$. So, from this point of view, while the US' estimate is very realistic (from 1995 to 2005 GDP increased at a 0.033 average growth rate, but that rate increased for 0.034 if all the post-war period is considered), the story is very different for the other two countries, where the highest growth rate, $\hat{Y}$, is associated to the lowest $\hat{A}$, and vice versa. Why are there such discrepancies in Ireland and Sweden? While a complete explanation of the reasons is outside the scope of this note, our argument shows that if $\hat{Y} > \rho$, $\hat{A}$ decreases with increases in R. Of course we don't know if we are using the correct values for the parameters, but we can see that estimates for $\hat{A}$ that match with $\hat{Y}$ will imply that ρ must be equal to 0.14 for Ireland and equal to 0.04 for Sweden. But it is difficult to find a reason for such a discrepancy in discount rates if we keep in mind that the reported long-term interest rate is 0.041 for Ireland and 0.039 for Sweden (OECD, 2006).

Growth of productivity is not only the result of technological change, but depends, among other factors, on the efficiency with industrial firms and other organizations do work (Griliches, 2000). Although formal R&D activities are an important input for *technological* innovation, they are not the only one, and so other determinants of technological innovation have to be investigated as well.

On the other hand, besides *technological* innovation there are other forms of innovation: marketing, design and engineering capabilities, training and learning (e.g., learning by doing), development of new production facilities, and organizational investment and change (Dosi, 1988; Kline and Rosenberg, 1986; OECD, 1997; Rosenberg, 1976) are examples of non-R&D activities that are acknowledged to play an important role in a firm's innovation efforts and performance. This *informal innovation*, that is innovation not explicitly planned and budgeted and consequently largely hidden in (aggregate) innovation data can be contrasted to formal R&D activities that are traditionally considered as a systematic and organized activity by innovation or R&D surveys (cf. OECD, 1963, 1997, 2002).

The informal innovative activities that take place during production could have a significant impact on productivity growth (Dosi, 1988; Rosenberg, 1982), although the systematic evidence about informal R&D is hard to measure (Rosenberg, 1982: 121-

122) and very scarce (Griliches, 2000, p. 88). Even if these ideas are not new, they are often forgotten with the pressure for formalization.

4. INFORMAL R&D AND THE INTERNATIONAL TECHNOLOGY FLOWS

Intermediate goods flow internationally: in an increasingly globalised world, new technologies invented in country A can be acquired by country B and used to produce a final good in country C. This has two implications for the growth models standard analysis. On the one hand, worldwide R&D investments can be more relevant than the domestic investments for calibrating the R&D of a given country. On the other hand, an innovator can sell his/her innovation all over the world and so it is necessary to consider the effect of the enlarged market in the value of innovations. These considerations turn the analysis more difficult, and show how simplistic an assessment of the R&D effects is, as was the case with the one of the previous section.

Table 2.
The "Celtic Tiger" vs. the "Swedish Paradox". Economic and technological indicators

	Ireland	Sweden
GDP per capita (current PPPs), 1999, (OECD=100)	113	103
GDP per capita (current PPPs), 2005, (OECD =100)	135	113
Average growth of GDP, in volume (1995-2005)	7.5	2.7
Expenditure on educational institutions (public and private) in percent of GDP, 1998	5.00	6.90
Expenditure on educational institutions (public and private) in percent of GDP, 2002	4.38	6.86
Gross Domestic Expenditure on R&D (GERD), in percent of GDP, 1997	1.43	3.85
GERD in percent of GDP, 2004	1.20	3.95
Business enterprise expenditure on R&D (BERD), as a percent of value added in industry, 1997	1.34	4.35
Business enterprise expenditure on R&D (BERD), as a percent of value added in industry, 2004	1.07	4.64
Business sector capital/output ratio, 1999	1.5	2.0
Business sector capital/output ratio, 2003	1.9	2.9
Exports in percent of imports:		
High-Tech industries	234	136
Medium High-Tech industries	192	135

Source: OECD (2000, 2006).

So, using another type of indicators alongside with ones that measure “formal” R&D, table 2 gives a more accurate picture of the technological influence on economic growth and illustrates the reason why some talk in the Celtic Tiger and the Swedish Paradox.

Although in economic terms both Ireland and Sweden have increased their weight in the OECD average, it is difficult to support these gains with the “formal” R&D. In fact Sweden presented higher than Ireland R&D intensity in 1997, both in GERD and BERD, and from 1977 to 2004 Sweden increased those figures. Ireland, on the contrary, decreased both indicators from 1977 to 2004[12]. Similar behaviour was visible in education expenditures.

However, the apparently reduced impact of R&D doesn’t mean that technology and innovation don’t play an important role in the “Irish Miracle”. The new products and processes as well as new ways of organization generally evolve in a gradual path and in ways little or not at all related to what we associate to “formal” R&D[13]. In fact, a short analysis of the trade content shows that, in terms of penetration in foreign markets, Ireland presents a clear advantage in high and medium high technology.

From where did that advantage come? From a more efficient use of R&D and education expenditures? From positive externalities associated to a higher dynamism of exports combined with the international technology transfer? From other factors not covered by statistical indicators and, for that reason, omitted in quantitative studies?

While a complete answer to these questions is outside the scope of this paper, because it is impossible to carry it out without a historical analysis (Griliches, 2000), for now it is worth noting that Ireland is a “Tiger” probably because it succeeded in the articulation of several positive factors associated not only to the questions of the previous paragraph but also to others that only an exhaustive investigation can uncover. Among them, are some “informal” R&D (Griliches, 2000), which are not apparent in statistics, and some tacit knowledge in the sense used by Hayek (1945, p. 521): “knowledge of particular circumstances of time and location”.

[12] This does not mean that the actual level of R&D has decreased. The high growth rate of Irish GDP allows a decrease in relative terms with a stability or even with a slight increase in absolute terms. Identical comments can be made concerning education expenditures.

[13] An example is suficient to ilustrate this sentence: The resources used by Henry Ford to invent mass production and assembley lines didn’t correspond at the time, or even nowadays, to the oficial definition of R&D.

5. CONCLUSION

Economic progress occurs because we learn new forms of combining capital and labour in a more efficient way. This learning may be either the result of investment efforts directed towards the improvement of productivity or a side-effect of other activities not intentionally focussed on increasing productivity. In this paper our purpose has been the assessment of R&D contribution to productivity growth. However, the measured impact of R&D to growth is at odds with the potential contribution that results from theoretical literature, because either theoretical models are poorly formulated or the concept of R&D is poorly translated in the data. In this paper we have addressed both hypothesis.

Respecting to the first hypothesis, taking in account that the effect of increasing the R&D outlays on the growth rate of GDP (the impact of R on $\hat{Y}$) is mediated by the growth rate of R&D driven technology ($\hat{A}$), we begin by investigating the dimension of ($\hat{A}$). From the free entry condition into R&D and from the fact that R&D innovations are embodied, we have obtained an estimate for ($\hat{A}$) that is very different from the record of economic growth both in Ireland and in Sweden. This finding allows us to conclude that the link between measured R&D and economic growth is not so strong as some studies and policy commitments declare.

The failure in finding a close relationship between R&D intensity and economic growth increases the probability that other investments directed at improving productivity can be more important. For instance, investments in organization, management, financial engineering, and training, should usually be in larger scale and, because the innovations that result from them are disembodied, not patentable, and subject to a quicker diffusion, the externalities associated with them are probably much larger and, consequently, may have more impact on economic growth than the effect of the R&D outlays.

If these comments were associated to an increasing preoccupation in the entrance in world market, where the decisive pattern is one of competitivity, then it is probable that the positive externalities can come in from outside, with positive repercussions in output per capita and productivity. So, the innovation policy doesn't have to rely only on measures that increase the R&D formal indicators. Furthermore a policy that provides R&D incentives can have the perverse effect of reclassifying as R&D investment the expenditures that previously had other designations.

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