

**RETURNS ON R&D INVESTMENT:
A COMPREHENSIVE SURVEY ON THE
MAGNITUDE AND EVALUATION
METHODOLOGIES**

**ANDREIA CARDOSO ¹
AURORA A.C. TEIXEIRA ²**

¹ INESC PORTO

² INESC PORTO; CEFUP, FACULDADE
DE ECONOMIA, UNIVERSIDADE DO
PORTO

Returns on R&D investment: A comprehensive survey on the magnitude and evaluation methodologies

Andreia Cardoso

INESC Porto

Aurora A.C. Teixeira

INESC Porto; CEFUP; Faculdade de
Economia, Universidade do Porto

Abstract

As technology and innovation seem to be contingent upon each other a great deal of attention has been given to the importance of assessing the contribution of R&D investment to firm and industry performance and, ultimately, to the economic performance of countries and regions. In industrialised societies not only private but also public agents have allocated increasing amounts of their resources to R&D activities, often considered the key path to innovativeness. At the same time, due to advances in empirical research, increasingly more focused on the micro (firms) rather than on the macro (country) level, *old myths* about the relationship between R&D, innovation and success began to fall down. Firstly, the idea that innovation is much broader than R&D has gained large support and has made it possible to identify other sources of innovation, beyond excellence in R&D, which had been largely hidden or neglected. As result, perceptions about small firms - or the so-called low-tech industries, which either do not carry out any significant R&D activities or are likely to perform them outside formal classifications - started to change. Secondly, the idea that more R&D investment is always automatically bond to success - whatever criteria one may choose to define success – has become nothing more than a utopia. In this paper we carry out an analysis of the literature on the magnitude and evaluation of R&D. We identify the methodologies used and analyse to what extent the magnitude of (eventual) R&D returns is dependent on the methodology pursued and the level of analysis - firms (micro), industry (meso), and regions/countries (macro) - considered. We conclude that methodological approaches and levels of analysis determine, to some extent, the type of results obtained and, thus, variances between them.

Keywords: Innovation and R&D indicators; Methodologies; Macro, meso and micro levels; R&D payoff.

1. Introduction

In today's knowledge-based societies the assumption that innovation plays a decisive role in the economic growth of a country or region is prevalent (Bilbao-Osorio and Rodríguez-Pose, 2004; Howells, 2005). Within this innovation-demanding environment, technology and technological advances emerge as driving forces of innovation and economic growth, which explains the reason why increasing attention has been drawn to high-tech industries by innovation policies, with the former being frequently addressed by the latter as fundamental routes to economic growth (Bender, 2006).

Firms are systematically pushed to search for growth opportunities in the market, to get to the market before their rivals and this means that they should be able to innovate at an extraordinary fast pace (Karlsson *et al.*, 2004), by developing or improving processes and products and by generating ideas likely to be converted into commercially viable and profitable products or services. The answer to all the challenges defying industries seems then to rely on *technology*, apparently the only route to successful performance (Wakelin, 2001) and, eventually, to rising standards of living, as Grossman and Helpman (1993) emphasized.

As technology and innovation seem to be contingent upon each other – even though, only apparently - a great deal of attention has been given to the importance of assessing the contribution of R&D investment to firm and industry performance and, ultimately, to the economic performance of countries and regions. Indeed, in industrialised societies not only private but also public agents have allocated increasing amounts of their resources to R&D activities (Papadakis, 1995; Walwyn: 2007), often considered the key path to innovativeness.

As it was observed by the American Office of Technology Assessment (1986: 3), “[...] economists have shown a strong positive correlation between research and development (R&D) spending and economic growth. They have estimated private returns in excess of 20 percent per year and social returns in excess of 40 percent on private sector R&D expenditures”. Thus, measuring the returns on R&D investment has become a top priority - and also a challenge, if not a dilemma - , not only for economists and firms/industries managers, but also for innovation policy decision-makers at the public level.

At the same time, due to advances in empirical research, increasingly more focused on the micro (firms) rather than on the macro (country) level, *old myths* about the relationship between R&D, innovation and success began to fall down. Firstly, the idea that innovation is much broader than R&D has gained large support (Bougrand and Haudeville, 2002; Drake *et*

al., 2006; Bogers and Lhuillery, 2006) and has made it possible to identify other sources of innovation, beyond excellence in R&D, which had been largely hidden or neglected. As result, perceptions about small firms, or the so-called low-tech industries, which either did not carry out any significant R&D activities, or performed them outside formal classifications, started to change (Hoffman *et al.*, 1998; Roper, 1999). Secondly, the idea that more R&D investment is always automatically bond to success - whatever criteria one may choose to define success – became nothing more than a utopia (Papadakis, 1995; Lefebvre *et al.*, 1998).

In the present paper we aim at surveying the literature selected on the magnitude and evaluation of R&D, and, possibly, of innovation. We began by considering journals which were likely to address these issues more systematically in their editions: Research Policy, Research Technology Management and Technovation. In a sort of *snowball effect*, the papers surveyed led us then to articles of other journals. We identify the methodologies used and analyse to what extent the magnitude of (eventual) R&D returns is dependent on the methodology pursued and the level of analysis - firms (micro), industry (meso), and regions/countries (macro) - considered.

The paper is structured as follows: in Section 2 we review the literature on R&D to analyze the spectrum of methodologies which have been employed by several authors to assess the returns on R&D investment and the different magnitudes reported by the studies surveyed. Our analysis of the literature covered is organised according to the level of analysis (micro, meso and macro) adopted by each study. In Section 3, we critically summarize the findings and highlight the implications of the present survey as regards to methodological issues and to the relationship between R&D and economic performance in traditional, low-tech industries.

2. Reviewing the magnitude of returns on R&D investment and methodologies for assessing such returns

2.1. General overview

One of the dilemmas which challenge scholars, policymakers, and business managers is how to conveniently assess whether R&D investments are coming to fruition or not. Since R&D activities still have a central place in the innovation process for many (Drake *et al.*, 2006), measuring the impact of R&D spending, tracking its effectiveness, checking whether the costs justify the expenses, are not *clichés*, but real concerns that are not to be overlooked in both public and private sectors, since R&D activities compete with other activities in the run for (scarce) resources allocation. These concerns for measurement are insightfully summarised in

the statement made by Oxman (cited in Karlsson *et al.*, 2004: 179): “[measurement is] the first step that leads to control and eventually to improvement. If you can’t measure something, you can’t understand it. If you can’t understand it, you can’t control it. And if you can’t control it, you can’t improve it”.

In result, different methodologies, ranging from more quantitative to more qualitative approaches, have been employed to estimate the return on R&D investment and to facilitate decision-making at different levels. However, consensus on how good a certain methodology is to capture the mechanism driving the relationship between R&D and economic performance is definitely lacking.

It is undeniably true that a great deal of research work carried out has found evidence of a positive correlation between R&D investment and economic performance at different levels of aggregation (Almeida and Teixeira, 2007). However, it is worth remembering that correlation does not mean causality (Hartmann, 2003), and that the reasons why several studies attempting to investigate on that relationship have led to divergent results and conclusions must be ascertained.

As regards to this last statement, we are inclined to agree with Wieser’s (2005: 587) argument that variations between studies can be partly explained by “methodological and conceptual issues”. Almost a decade before, OTA (1986: 14) also acknowledged the difficulties of describing the relationship between R&D investment and productivity growth as a causality relationship, adding that different results produced by studies on this relationship were a reflection of “the tentative and hypothetical nature of the methodologies” employed.

In this section we analyze studies that attempted to investigate on the empirical relationship between RDI investment and economic performance. The studies surveyed vary both in the *level of analysis* and in the *methodologies* selected. It follows that results and conclusions also vary accordingly. We grouped the studies into four categories: macro (country and regional level); meso (industry level), and micro (firm level).

2.2. Macro (country and regional level) perspective

In the macro-perspective, countries and regions are the scope of analysis. At this level, the aim is to analyse how R&D investment can be linked to the economic performance of a country/region or a group of countries/regions. In this subsection, we analyze 6 studies which cover different set of countries or regions and collect data from a time frame that goes from the 70s to 2001.

TABLE 1

Author	Objective	Model	Variables	Country(ies)/ Region(s)	Period	Results	R&D return
Griliches, (1980)	To relate the decline in R&D capital rate of growth to decline in productivity growth.	Econometric Analysis: estimation of the elasticity of aggregate or sectoral output with respect to changes in the R&D capital.	- R&D capital; - TFP; - LPROD; (log output per manhour);	USA	1970s	•	<i>Not specified</i>
Coe, Helpman, (1995)	To analyse the extent to which a country's TFP is dependent on domestic and foreign R&D capital.	Econometric analysis: Cointegration equations; Regression model; Inclusion of dummy variables.	- R&D capital stock (domestic/foreign) - TFP	21 OECD countries plus Israel	1971 - 1990	+	G7 countries - domestic R&D: 0.234 Other countries - domestic R&D: 0.078
Batoumi, Coe, Helpman, (1999)	To quantitatively assess the contribution of R&D spending, international R&D spillovers and trade.	Multicountry macroeconomic simulation model. MULTIMOD version consisting of 12 linked econometric models, in which TFP is endogenously determined by R&D spending, R&D <i>spillovers</i> and trade. Cobb-Douglas production function.	- TFP; - R&D capital (domestic/foreign); - R&D expenditure; - output growth ;	G7 Countries; Non-oil-exporting developing countries; Group of industrial countries.	<i>(projection)</i>	+	Short-run rate of return on R&D about 5 times as high as rate of return on physical capital.
Bilbao-Osorio, Rodríguez-Pose (2004)	To relate R&D investment and innovation and innovation and economic growth.	2 statistical models: R&D → Innovation: linear regression model; modified Cobb-Douglas function; cross-section OLS regression. Innovation → economic growth: linear regression model; cross-section OLS regression.	R&D → Innovation: - GDP; - R&D priv./pub./higher ed.; - Economic structure; - Employment rate; - Patents; Innovation → Economic Growth - Innovation and innovation growth (patents); - Skills; - Economic structure; - Employment rate; - Economic growth;	NUTS* 2 from Nine EU Member States (peripheral and non-peripheral regions) * <i>NUTS 1 UK</i>	1990 - 1998	+ peripheral regions • non-peripheral regions	R&D in private sector generates higher rates of return (0.11) than in the public sector (0.06)
Teixeira, Fortuna, (2001)	To reflect upon the human capital-innovation-growth nexus in the Portuguese economy.	Econometric Model: Vector autoregressive and cointegration analysis	- Human capital stock; - Economic growth; - Internal knowledge stock;	Portugal	1960-2001	+	Estimate of elasticity of TFP: 0.30 percentage points.
Walwyn, (2007)	To examine the return on investment from government-funded R&D	Patterson-Hartmann Model Simulating methodology	- GOVERD; - BERD; - Electrical BERD; - Electrical value added; - GDP;	Finland	1990-2001	+	0.66 (GOVERD)

It is important to notice that in almost – if not in all – of the papers surveyed the assumption of a *quasi* deterministic view that R&D investment is causatively related to the economic performance of countries/regions is practically abandoned. It is also well worth noting that here the magnitude of returns is likely to be larger than that of studies which remain at a lower level of aggregation (namely micro/firm level).

Solow's theory that economic growth could be prompted by improvements in technology led economists to draw their attention to the importance of measuring the contribution of R&D expenditure - as proxy to technological change - to productivity growth (Wakelin, 2001). This concern for R&D measurement was specially acute in the 70's, since productivity fell off across several different countries and the slowdown in R&D expenditure was rapidly taken as the main explanatory factor for such a slowdown.

In one of his earlier works, Griliches (1980) attempted to examine whether US slowing productivity in the 70's could be attributed, wholly or partly, to a decline in the growth of real R&D expenditures, taking the manufacturing sector as the scope of analysis. He assumed *ab initio* that it was not scientifically legitimate to explain US economic crisis – reflected in a productivity slowdown - as the primary consequence of R&D spending decline. This reluctance of Griliches to explain the relationship between R&D and growth through a linear and simplistic model was prompted by the fact that, according to the author's view, the 70's were not a particularly favourable period to assess the impact of R&D investment on growth, since most of OECD countries had been affected by the oil price shocks (Hall and Mairesse, 1995). Moreover, how could R&D slowdown be made the culprit of productivity slowdown, when the systems of measurement had neither been able to isolate that relationship from other influential factors nor even included in calculations R&D externalities within and across industries? (Griliches, 1980).

To support the hypothesis that no clear empirical relation could be found between R&D expenditures slowdown and the US productivity slowdown, Griliches opted for an econometric analysis and it followed that R&D coefficients declined as well as their statistical significance, reaching values very close to zero in the period of 1969-1977.

According to Griliches (1980: 347), the significant drop of the R&D coefficient in that period, could have been a reflection of the fact that “the large energy price shocks, the resulting fluctuations in capacity utilization, the substantial increase in uncertainty about future absolute and relative prices may have forced many firms away from their long-run production frontiers. What we see in the data are not movements along the technological frontier, and

hence they should not and cannot be attributed to a variable whose role is to shift this frontier outward”.

Relating this decrease to productivity slowdown in the 1970's could be reductive, given the fact that both R&D spillovers and R&D social returns had been neglected by national accounts, favouring a distortion of the real impact of R&D capital on productivity. Moreover, from Griliches's point of view, in the period covered by his study, a significant fraction of R&D investment was being diverted into defence, space exploration, health, environment and into goods and services such as computers. However, the quality improvements resulting from such expenditures were being left out of national accounts. What followed from this miscalculation, was that the “slowdown in R&D that could have had a measurable impact was not as large as the crude figures might indicate”, “since much of the slowdown in R&D” (pp. 344) had been taking place in the sectors mentioned above.

Coe and Helpman (1995) investigated the extent to which a country's total factor productivity was contingent upon its own R&D capital (domestic R&D capital) and upon foreign R&D capital. Their primary assumption was that in a world where knowledge and information met no frontiers and goods and services were traded at international scale, a country's productivity level would depend on domestic as well as on foreign R&D capital stocks. Using data from the period of 1970-1990, the authors pursued an econometric analysis, in which cumulative R&D expenditure was used as proxy for a stock of knowledge. For each country, two types of stock of knowledge were constructed: one based on domestic R&D expenditure and another, the foreign stock of knowledge, based on R&D spending of the country's trade partners. As regards to the construction of foreign R&D capital stocks, the authors used import weighed sums of trade partner's cumulative R&D spending, a procedure similar to that used by Telecky in 1974 (Goto and Suzuki, 1989) to analyze how technology flowed across industries. A calculation of the measure of TFP was made once again for each country. Finally, the effects of domestic and foreign R&D capital stocks on total factor productivity were estimated. To assess the relationship between TFP and domestic and foreign R&D capital stocks, cointegrated equations were used due to their “*attractive econometric properties*” (Coe and Helpman, 1995: 868).

Results of this study showed clear evidence that a country's total factor productivity (positively and significantly) depended on its domestic R&D capital stock as well on the R&D capital stock of its trade partners.

Four years later (1999), Coe and Helpman joined Bayoumi for a research aiming at examining quantitatively the contribution of R&D, international R&D spillovers and trade on a country's

Total Factor Productivity (TFP) and output growth. Results of the simulating multicountry macroeconometric model pursued confirmed the existence of a positive relation between R&D and growth both in industrial and developing countries.

Using similar cointegration techniques, but focusing only in one country (Portugal) over four decades (1960-2001), Teixeira and Fortuna (2004) conclude that R&D stock contributed positively and significantly for Portuguese productivity in the period in analysis, although its contribution was below that of human capital's.

Bilbao-Osorio and Rodríguez-Pose (2004) argue that the deterministic approach to R&D investment as an automatic driver to revenue has lost credibility. There are several other factors that must be taken into account when assessing the effectiveness of R&D investment, namely "*social filters*", that is, the social components of a region – type of labour market, demography and education - which can be taken as explicable factors of why not all regions are capable of turning their R&D into innovation and innovation efforts into economic growth in a similar way. These "social filters", differing from region to region, contribute to the emergence of regional disparities, since regions' capacities to profit from technology and to reap the benefits of their investment in R&D vary. In the study conducted alongside Bilbao-Osorio, Rodríguez-Pose went further with his argument on the role played by "social filters", by analyzing the major differences in the innovation and economic growth patterns between peripheral and non-peripheral regions in Europe. The analysis unfolded in two different phases. In the first one, the authors started by investigating the relationship between R&D investment and innovation, for which a standard knowledge production function was used as proposed by Griliches in 1979 and by Jaffe in 1986 and a log-log specification, except for the variables represented as a percentage. Variables included in the regression model were: patents (a proxy to innovation and, thus, the dependent variable), GDP, R&D investment as a percentage of GDP, and the so-called *social filters* (skills; economic structure and employment rate). The methodological model put forward to assess how R&D could be linked to the genesis of innovation was highly "explanatory" as stated by the authors, who conclude that the model was, however, more suitable for innovation in peripheral regions. In the second phase, the authors attempted to examine the relationship between innovation and economic growth, by using a linear regression model where innovation and innovation growth were used as independent variables and socio-economic factors were once again added to the equation. The main conclusion to be drawn from the results presented in this study is that R&D investment has different impacts on innovation and economic growth depending on the sectors or on the regions where it has been carried out.

Despite the fact that, in general, R&D activities are positively linked to the genesis of innovation, sectors and regions do react indeed differently to R&D investment. Take, for instance, the case of public and private sectors considered in the study surveyed: research activities performed by the private sector had, comparatively, higher rates of return than the research conducted by the public sector, which was not entirely surprising given the fact that the private sector is far more interested in committing itself to a sort of research that can be easily commercialized in the market (Bilbao-Osorio and Rodríguez-Pose, 2004). Another worthwhile example is that of the role played by the private and public sectors as stimuli to R&D activities and, therefore, to innovation and economic growth. As the authors suggested, it was evident that in non-peripheral regions privately-funded research “seems to be the main motor of innovation”, while in peripheral regions “it is the research conducted by higher education institutions which reports positive returns” (pp. 452).

Although it is not our intention to overestimate the weight of “social filters” or the social environment of a region, we should not dismiss Bilbao-Osorio and Rodríguez-Pose’s view about the need not to ignore that variance in innovation patterns across regions should not be dissociated from their socio-economic characteristics.

Focusing on government-funded R&D, Walwyn (2007) provides an interesting analysis of the relationship between R&D and economic growth, taking Finland, and in particular, the Finnish mobile phone industry, as the empirical context. Although the author acknowledges that it is extremely difficult – if not impossible - to establish a clear link between R&D and economic growth without taking the risk to plunge into ambiguous and not scientifically-grounded conclusions, he argues that the mobile phone manufacturing sector in Finland appears to be an exception to the rule, emerging as an interesting case study from which that relationship can be assessed. Indeed, the author pointed out that the Finnish case provided the possibility to isolate that relationship from other variables that are frequently said to exert some degree of influence. Using economic data from 1990 up to 2001, the author investigated the relationship between government-funded R&D and Business Expenditure in R&D (BERD); between electrical BERD and electrical value added and, eventually, between BERD and GDP, using the Patterson-Hartmann Model. Initially conceived to relate company-level R&D expenditure to product revenue and to allow managers to use investment and wave shapes to simulate hypothetical scenarios, more precisely, to simulate the probable outcomes of R&D budget plan and control the time-lag between investment in product development and its respective revenue (Hartmann, 2003), this model came to be rather appropriate to evaluate the impact of government-funded R&D on the growth of the Finnish mobile phone

manufacturing sector and on the growth of Finland's economy as a whole. Including parameters such as product investment wave shape, product revenue wave shape, R&D intensity, growth rate and sector or company gain, the model was quite useful not only because it incorporated lengthy time delays between investment and growth but also because it made possible to extract conclusions about the impact of both public and business R&D on economic growth (Walwyn, 2007). Among Walwyn's interesting findings, we highlight the remarkably high return on R&D investment achieved by the Finnish government. By looking at the data provided by Walwyn's research, we have to agree with the author's conclusion that government R&D-funding in a promising sector – the cell phone sector - worked as a stimulus to industry research investment in Finland, laying the framework within which the private sector came to invest in R&D.

2.2. Meso (industry level) perspective

As regards to the meso perspective, the 5 papers covered in this section take (manufacturing and non-manufacturing) industries as units of analysis. The following table summarizes the main contents of each paper, indicating that, at the meso level too, definitive conclusions about R&D and economic performance cannot be drawn.

Our analysis starts with the study by Goto and Suzuki (1989). These authors, investigating on the effects of R&D on the productivity growth of Japanese manufacturing industries, refined the approach to this relationship by introducing in their methodological model a reformulated concept of R&D capital and reached the conclusion that, for the sample considered, the marginal rate of return on R&D investment was, on average, around 40% and that social returns on R&D investment were larger than private returns. These results were obtained through a two-step analysis: first, to estimate the rate of return on R&D investment, the authors constructed series of R&D capital for the industries selected and used a Cobb-Douglas production function with R&D capital as an input along with other more conventional inputs such as capital and labour. In this model, the concept of R&D capital gained special relevance. According to the authors, using R&D capital as an input is worthwhile because “it reflects the amount of knowledge a firm or an industry has accumulated”; describes “the firm or industry's production process in terms of “R&D intensity”, and indicates “the future potential of the firm or industry to develop new products or processes” (Goto and Suzuki, 1989: 556).

TABLE 2

Author	Objective	Model	Variables	Industries/Sectors	Period	Results	Magnitude (RDI return)
Goto, Suzuki (1989)	To examine the relationship between R&D and productivity growth and to measure the impact of other industries' R&D on productivity growth of an industry.	Cobb-Douglas production function (rate of return on R&D investment). Technology flow matrix: input-output transaction (R&D spillovers).	- R&D capital; - Value-added; - Rate of external technological change; - Labour; - Physical capital - TFP - TFP growth rate	Manufacturing	1975-1986	+	Marginal rate of return: 40% Rate of return in industrial organic chemicals: 57% Rate of return in parts for electronic appliances and communications: 19%
Papadakis (1995)	To examine the effectiveness of US R&D-oriented competitiveness policies by analyzing the relationship between: R&D intensity and comparative advantage; R&D intensity and competitive performance and R&D and US-Japan bilateral competitiveness.	Typologies of performance using pattern-matching methodologies.	- R&D intensity; - Revealed comparative advantage; - competitive performance (import penetration; trade balance status); - Bilateral competitiveness (absolute volumes of R&D expenditure; rates of change in the absolute levels of spending; R&D-to-sales ratio; rates of change in R&D-to-sales ratios)	Manufacturing	1970-1986	+ - R&D and comparative advantage R&D and competitive performance/strength	<i>Not specified.</i>
Graves, Langowitz (1996)	To relate R&D expenditures (by no. of patents) to R&D productivity by international region of origin or by industry.	Econometric analysis: regression model (log-linear model, where patents or some function of patents is a measure of technological output and R&D a measure of input); addition of dummy variables.	- Patents and impact-adjusted patents; - R&D input (company's average R&D spending for a 5-year period).	- Aerospace; - Automobiles; - Chemicals; - Computers; - Electrical products; - Food; - Fuel; - Health/Pharmaceuticals; - Heavy Industry; - Telecommunications	1978-1981	- / +	42% - 45.7%
Jacobsson, Philipson (1996)	To reflect on methodological limitations of technology indicators.	Estimation of revealed technological comparative advantage (RTCA) using different technology indicators (R&D and patents).	- R&D expenditure; - Patents - RTCA	- Metal/mechanical/engineering; - Electrical engineering /electronics/computer science; - Chemistry; - Pharmaceuticals	1981-1989	<i>Ambiguous</i>	
Hsieh, Mishra, Gobeli (2005)	To compare the rate of return on R&D investment to the rate of return on fixed assets investment in pharmaceutical and chemical industries.	Econometric analysis: time-series, cross-sectional and regression models. 3 models are benchmarks for comparison with the 4 th model, developed by Parks to respond to heteroscedasticity, serial and contemporaneous correlation problems	- Performance variables (net margin; operating margin; sales growth, Tobin's Q); - R&D intensity and capital	- Manufacturing; - Non-manufacturing		+	19%

Some remarks should be made, however, about the implications of using a model as the one put forward in the study. First, time lag adjustments should be introduced, as “a certain length of time is requested before R&D is completed and the product embodying the technology is sold” (pp. 599). This time length varies from industry to industry. Second, difficulties in the access to data that would allow the authors to distinguish R&D capital from other forms of capital and R&D personnel from other types of workers have resulted in a double-counting problem. Therefore, it is to conclude that “the rate of return should be interpreted as the excess rate of return” (pp. 559). As regards to assessing the impact of other industries’ R&D on the productivity growth of an industry, the authors built a technology flow matrix based on Terleckyj’s matrix to weight R&D spillovers between and within industries, and therefore, how transferable technological knowledge would be. This transference may either occur through knowledge diffusion or spillover or through a transaction. Results showed that the technology flow matrix used by Goto and Suzuki and made up of R&D expenditure of supplying industries presented a larger coefficient than each firm’s private R&D expenditure when estimating TFP growth, leading the authors to conclude that the social return on R&D investment exceed by far the rate of return on R&D private investment.

Just as an aside, in the debate on R&D payoff we should be aware that a significant part of the effects of R&D investment is not always appropriated by firms’ accounts - and thus not measured by them - so conclusions drawn from merely looking at statistical figures at firm level may be misleading. As Bernstein (1989) underlines, a feature of R&D is that firms cannot capture all of the benefits emanating from their own investment. It is to presuppose that the R&D of a given input-supplying industry will affect the productivity growth of buyers, which will certainly capture and incorporate some of the fruits of the former through the so-called technology flow (cf. Goto, Suzuki, 1989; see also Bernstein, 1989). The R&D payoff may not have been fully captured by the R&D intensive-industry, but the technology externalities of that R&D will tend to favour the economic performance (e.g. productivity growth) of the industries which purchase the products or services embodying the other industry’s R&D. It is relevant to underline as well that due to the public good nature of knowledge not all R&D benefits are reaped by the firm which makes the investment and sells the goods. Some industries can have access to new knowledge without costs, that is to say, without having carried out any kind of transaction with the industry or the industries which have brought about a new technology.

Papadakis (1995) conducted a research aimed at exploring some questions related to the assessment of the effectiveness of US R&D-oriented competitiveness policies. The author brought to the fore the risky implications of relying on the too deterministic view which related R&D efforts to a country's capability to be competitive. Papadakis was aware that the analytic models available to assess the relationship between R&D and economic performance imposed severe limitations to prevent from any misleading interpretations. One of them was related to the fact that current R&D as an empirical measure was only capturing the first stage of technological change – the invention stage – neglecting the commercial adoption and diffusion stages. Given this limitation, and in order to examine the relationships referred in Table 2, the author developed a model which assumed the existence of a functional link between a country's industrial R&D efforts and its competitive performance. Three different types of data were used and revealed comparative advantage, competitiveness and R&D spending were calculated for the US industrial sectors. In the analysis R&D intensity, “is represented [...] by the categorization of industries into high, medium and low technology groupings. The particular classification scheme employed here is used pervasively by OECD and is based upon the R&D-to-output ratios of each industry. Thus, high-tech industries are the most R&D intensive industries and low-tech industries the least R&D intensive” (pp. 573). As regards to the relative strength of US and Japanese R&D efforts, it is important to mention that four separate indicators of R&D activity were introduced in the analysis: absolute volume of R&D expenditure, rates of change in the absolute levels of spending; R&D-to-sales ratios and rates of change in R&D-to-sales ratios. A ranked typology of R&D effort was then built. One of the main findings of the bilateral analysis contradicts the widespread assumption that R&D-intensive industries demonstrate always the strongest competitive performance. Indeed, in Papadakis's sample analysis, several high-tech industries reflecting higher commitment to R&D were non-competitive. In a comparison between Japan and the United States, figures showed, for instance, that “Japan's competitive industries do not have any systematically superior R&D effort relative to the US, and in two sectors, electronics and instruments, Japan's industrial R&D efforts are well below those of the United States. Moreover, there are two Japanese industries which demonstrate superior R&D effort but are nonetheless noncompetitive [...]”. (1995: 576).

Papadakis's conclusions bring to the fore the need to reject the common and fallacious idea that considers high-tech, research-intensive and science-based industries as industries where more prospects of economic growth seem to lie.

The PILOT report stated these types of industries tended to be regarded “as the main source of highly sophisticated products that are not easily imitated elsewhere and, therefore, the policy conclusion is that high-cost industrialised countries should concentrate their efforts on promoting these industries.” (Bender, 2006: 6); on the other hand, non-research-intensive, low-tech and medium-low tech industries tend to be marginalised by policy decision-makers, as they are “presented as being less important as agents for change in major industrialised countries”. (pp. 14). Under this logic, it is assumed that industries can only have better market performance if they are able to constantly introduce innovation in their processes and/or products, in a way that should not be easily replicated by other industries. Since in a knowledge-based society technology is often taken as a prerequisite for innovation, the emphasis is usually placed on the role of research-intensive industries as key drivers of economic growth.

In the 90s, Graves and Langowitz focused their attention on the productivity of R&D expenditures from a global multi-industry perspective. What they observed - by taking patents and impact-adjusted patents as measures of innovative output and then by examining their relationship with R&D spending - was that returns to scale in R&D decreased regardless of country of origin or industry. Nonetheless, the rate of decreasing returns and the level of returns to R&D differed across industries and also across regions. Just to mention, according to the research carried out by the two authors, the chemical industry had always presented a significantly higher level of returns than other industries. The authors put forward that this could mean “that chemicals are inherently a more fertile ground for patentable research than are other industries. Or it may mean that chemical companies consider patents to be of greater importance to their survival, thus generally pursuing and receiving patents at a markedly higher level than general industry, i.e., they have a higher propensity to patent”. (pp. 134). This remark leads us to a study by Hsieh et al. (2003), which reported for the chemical and pharmaceutical industries an average rate of return from R&D investment to operating margin significantly higher than the industry cost of capital (ranging from 9% to 11%) and found evidence that investment in R&D improves more significantly a firm’s market value than investment in fixed assets. In this study, in order to investigate the linkage between R&D spending level and four measures of company performance (net margin, operating margin, sales growth and Tobin’s Q), the authors have constructed a sample of 39 firms from the pharmaceutical and chemical industries, for which the data set required could be easily available so as to avoid “estimation difficulty”. (pp. 143). Four different regression models

were then used. By implementing this methodology, which allowed “control for both contemporaneous and firm specific serial correlation, as well as the feedback between firm profitability and investments” the authors were able to “compare the rate of return from a dollar investment on R&D to a dollar investment on fixed assets in pharmaceutical and chemical industries” (pp. 148).

As regards to measures of R&D and economic performance, it is worth looking at the study by Jacobsson and Langowitz (1996), which brought to the fore some of the methodological implications of using R&D and patents as technology indicators. By selecting these two indicators to analyse the country’s technological specialization, they aimed at assessing if patents and R&D expenditure, when used separately, were consistent with the common depiction of Sweden’s technological profile. Although this study is apparently not related to the purposes of our paper, since the authors’ main point is not to evaluate the returns of R&D expenditure but to reflect on the methodological limitations of using some technology indicators to infer the technological profile of a country, we still believe that it is relevant to be aware of the potentialities and drawbacks of opting for certain indicators in a methodological model trying to assess the relationship between R&D and economic performance. After estimating revealed technological comparative advantage (RTCA), using R&D and patents as technology indicators, the authors found that it was particularly risky and misleading to take a single technological indicator to assess the technological position of a firm or country. This argument results from the fact that when the authors used R&D and patents separately these indicators diverged significantly with respect to Sweden’s position in pharmaceuticals: while the R&D data suggested a strong Swedish position, the patent data indicated the opposite.

2.4. Micro perspective

In this sub-section, we will take an insight into the relationship between R&D and economic performance from a firm perspective. The studies surveyed date from the late 1990s onwards – thus, more recent than the studies considered in the two previous sub-sections. This may be symptomatic of the fact that, increasingly attention is being given to the impact of R&D on the performance of firms, challenged by today’s knowledge-oriented economy. Here again, findings vary as showed in the following table:

TABLE 3

Author	Objective	Model	Variables	Country (ies)	No. of Firms (Sample)	Period	Results	R&D return
É. Lefebvre, A. Lefebvre, Bourgault (1998)	To provide a better comprehension of the relationship between R&D-related capabilities and export performance of firms.	Factorial analyses; TOBIT regression models.	- groups of exporters; - export intensity; - size; - R&D intensity; - Technocratization; - R&D strategy; - Collaborative R&D	Canada	101		•	
Roper (1999)	To highlight that conventional R&D measures can produce misleading information about a firm's R&D activity.	Postal survey – Product Development Survey (comparison with official surveys).	- R&D employment; - Firm size; - Existence of R&D departments - R&D expenditure	Netherlands, Italy, Germany, UK	3096	1994-1995		
Freel (2000)	To analyze whether and to what extent small innovating manufacturing firms outperformed non-innovative manufacturing firms.	Postal questionnaire addressing innovation and organisational characteristics. Mann-Whitney U test; Chi-square test	- Innovation; - Profitability; - Firm growth; - employment growth; - export propensity; - absolute profit - profit margins - productivity levels - productivity growth	UK	228	1994-1996	+/•	<i>Not specified</i>
Wakelin (2001)	To relate R&D expenditure to productivity growth and innovation records to R&D rates of return.	Regression model: Cobb-Douglas production function; regression equations using OLS; inclusion of ten sector dummy variables.	- R&D intensity; - Productivity growth; - Capital intensity - Labour	UK	170	1945-1992	+/0	27%
Bougrain, Haudeville (2002)	To assess how SME's internal research capacities help them to exploit external scientific and technical knowledge and to use networks of innovators.	Selection of 313 public-financed innovative projects in SMEs; Logistic regression models.	- R&D intensity; - Project results	France	247	1980-1987	•	
Del Monte, Papagni (2003)	To ascertain the importance of R&D as determinant of size growth.	Econometric analysis: Gibrat's Law test; Regression model (random effect regressions; Generalised Method of Moments)	- KR&D; - Information technology; - rate of growth of industry real value-added; - firm growth - size; - growth rates; - productivity; - productivity growth rate; - profitability	Italy	884 - 496	1986-1997	+ Growth rate and research intensity • R&D and other performance variables	49%
Hartmann (2003)	To put forward a model to help managers to simulate R&D budget plans, by linking R&D spending to revenue growth	Extension of Marvin Patterson's model	- Percentual annual growth; - R&D intensity					

As we have seen in the literature surveyed so far, the impact of R&D and innovation efforts can be assessed using different variables. One of them is export performance. Lefebvre et al. (1998) used this variable in a multidimensional conceptualization to study to what extent export performance – measured by volume of sales and by final destination of those sales - could be dependent on specific R&D-related capabilities in SMEs. Indeed, one of the authors' most important contributions is that of the notion of R&D-related capabilities, because it provides an interesting approach to R&D efforts as something more encompassing than investment in R&D projects or staff. The core conclusion of the study is that firms need to build on or diversify a set of complementary capabilities – previously identified by the authors - to take fully advantage of that investment. These capabilities explain different export performances. The argument presented is far-reaching, because it supports the idea that R&D spending, although important, is not a sufficient condition to differentiate the export behaviours of firms. On the other hand, it redirects the attention to the role played by other determinants of those behaviours. At a certain point, firms are pushed to develop, beyond traditional efforts, some R&D-related capabilities, such as network or collaborative R&D engagement – a push which is, particularly, omnipresent in firms exporting to global markets.

Another study to be taken into consideration is that of Wakelin (2001), who studied the contribution of a firm's R&D expenditure on its productivity growth for a sample of 170 UK firms for the manufacturing sector. Although the author acknowledged that examining this relationship at a firm level implied one severe limitation, related to data quality and availability, one of the advantages of taking firms as units of analysis is that their own R&D efforts can be, in principle, isolated from “the technological improvements and advances that are general to the sector” (pp 1079). Based on this assumption, the methodological model pursued unfolded in three different steps: first, a Cobb Douglas production function including R&D intensity was applied for a sample of 170 UK firms, for which data on R&D expenditure were available, and several regression equations were estimated using OLS. Results accounted for the existence of a positive relationship between R&D expenditure and productivity growth. From the beginning, the author also assumed that the innovation history of a firm could be determinant to its productivity growth, as, in principle, innovative firms are “qualitatively different from non-innovating firms” (pp. 1079). Therefore, according to their innovation background, firms were then divided into innovative firms and non-innovative firms and then productivity growth was estimated for each group separately, using the model which had been previously run. Results showed that the rate of return to R&D was

significantly higher for innovative than for non-innovative firms, leading the author to conclude that “being an innovator does appear to be an important factor in influencing the rate of return to R&D expenditure” (pp. 1084). Nonetheless, the author found evidence – through the inclusion of sector dummy variables - that the sector to which a firm belonged appeared to have a very important role in determining the level of returns to its own R&D expenditure, which means that sector specificities may exert a significant degree of influence in productivity growth. Indeed, firms belonging to sectors which were net users of innovations presented higher rates of returns than firms located in other sectors.

In a research on SMEs internal research capacities, Bougrain and Haudeville (2002) showed that R&D intensity, as an indicator of in-house innovative capability, failed to set the barrier between failure and success for two main reasons: the first had to do with the type of expenditures included by firms in R&D, which could vary from country to country; the second was related to the limited amplitude of R&D as an indicator of innovation, especially within small firms. As the authors argue, “R&D is only one source of innovation” (2002: 744). This arguments is even more important to SMEs which tend to carry out research activities in a less formally organized way, because, given the fact that these activities do not fit official definitions of R&D activities, they will not be accounted for as so, leading to an underestimation of R&D investment. This brings the author to conclude that R&D intensity “cannot be satisfactory to analyse SME’s ability to innovate” (2002: 744). As a matter of fact, the problems posed to these firms by conventional statistical definitions had been reported earlier in a study by Kleinknecht (1987), and later by Stephen Roper (1999) in a cross-international study on the impact of under-reporting of R&D in small firms. Roper argued that the conventional indicators used to measure R&D at firm level– usually R&D expenditure and employment – neglected the real level of R&D activity undertaken in small firms. Moreover, since R&D classification and accounting were still very dependent on the internal procedures of companies, the way was paved for distortions in international comparative studies on business investment in R&D. Two of the reasons why R&D may be hard to track in small firms are that: firstly, the type of R&D performed by them is usually more developmental than fundamental research and, therefore, is more likely to be disseminated throughout operational areas rather than in formal units; secondly, if we call on OCDE’s definition of formal R&D, which places emphasis on “R&D performed inside an R&D department and involving at least one full-time researcher” (Roper, 1999: 131), it becomes difficult to frame small firms’ R&D within that definition, since their R&D tends to be less

formally organized. Under-estimation will be then likely to occur in firms where at least one of the above mentioned situations happens, producing misleading data about R&D investment. The conclusion is drawn from a comparative study between Germany and the U.K., where R&D in small firms is organized differently. The study provides empirical evidence that the differences regarding organizational settings of R&D in small firms will have a (positive or negative) impact on the estimation of their R&D investments according to official indicators.

Another interesting question posed by a research conducted by Mark S. Freel (2000) was whether and to what extent small innovating firms outperformed their non-innovative counterparts. The question was not novel either to academic literature or to industrial policy, both echoing a loud *yes* as an answer, which leads us to ask ourselves whether the relationship between innovation and performance within small firms has been oversimplified by equivocal premises. Having defined innovation as “the number of new products introduced [...] as a proportion of the firms product base” (2000: 196), Freel determined then a set of measures to be employed in the study in order to clarify how innovation acted upon firm growth and performance: growth in sales turnover and employment growth were selected to address firm growth; and growth in employment, growth in profits, absolute profit, profit/head, profit margins, productivity levels, productivity growth and export propensity to measure firm performance. The author’s point of departure was appropriately summarized in the affirmative answer to the rhetorical question posed above; indeed, in light of the literature and empirical studies surveyed, Freel hypothesized that small innovation firms would present superior performance compared to less innovative small firms in all measurement parameters considered. In some cases, however, results ran counter premises or were ambiguous, revealing the need for further research. Revisiting the main hypotheses put forward by the author and comparing them with the sample data it is possible to suggest that innovative small firms revealed superior performance in some parameters. As Freel argued there is robust evidence to claim that “small innovating firms are marked by higher rates of growth than small non-innovators” (2000: 207). Nonetheless, in other cases, results either differed from previous assumptions or remained unclear. Take for instance sales growth: although small innovative firms were likely to experience greater sales revenue than their less innovative peers, results did not hold that they were more likely to grow. At the same time, findings showed that there was either no significant or clear relationship between innovation and export intensities, profitability and productivity levels. Therefore, once similar studies on larger firms are taken into consideration, one of Freel’s main conclusions is that returns to

innovation may depend, to a certain extent, on firm size. This means that the common assumption that innovation always pays off should be cautiously apprehended by firms, which should be made aware of the nature of returns on innovation that they are more likely to have and of the myriad of circumstances which can play a decisive role on their growth or performance.

In a more recent empirical study on a panel of Italian firms, it was examined whether Italian firms highly committed to R&D also presented higher rates of growth when compared to those less or absolutely not engaged in R&D activities (Del Monte and Papagni, 2003). According to the authors, it could be presumed that a positive relationship between R&D and market performance existed: in this sense, a firm which deployed substantial resources to R&D would be more innovative than others, and thus, more successful in the market, reaping higher profits. Notwithstanding, the authors assumed as well their cautiousness by rejecting the too deterministic view that investing in R&D translated necessarily into better market performance. As they argued, in low-technological opportunity environments, such as those of traditional sectors, neither the intensity of R&D nor the R&D investment of a firm blocked, in general, the entry of new imitating firms in the market. As a result, the competitive advantage of the most R&D-committed firm would be rapidly reduced, with other firms arriving to the market and following the technological track of the former. The same idea that R&D investment is not a sufficient condition for successful performance in the market applies to sectors belonging to high-technological-opportunity environments, although in this case the explanation differs. The authors stated that firms from sectors with high technological opportunities could not always “introduce new technologies, deliver new products and introduce organisational innovations at the pace required” (pp. 1006) in order to obtain a competitive advantage that would ultimately result in a growth of profits. Prior to an econometric assessment of the relationship between innovation and performance of Italian firms, the authors attempted to analyze whether there were structural differences between R&D firms and non-R&D firms. Therefore, a sample of 810 firms, made up of firms which declared to conduct R&D and firms which did not - was constructed. A Student’s t-test on the difference of means was carried out and variables such as size, growth rates, productivity, productivity growth rate and profitability were included in the analysis. Results confirmed the presumed assumption that R&D had a positive impact on a firm dynamics (pp. 1007). To better estimate the relationship between innovation and performance of Italian firms, the authors moved on to an econometric analysis, in which a regression model was used making it

possible to include major control variables. This analysis was carried out in two different steps: first, a panel unit root test was implemented to verify if Gibrat's Law occurred; as results confirmed that firm size had a stochastic trend, it was then estimated the importance of R&D as a determinant of the size growth of firms, for which a regression model was adopted. The number of firms covered by the sample was reduced several variables measuring innovation were added. Findings showed evidence that a relationship could be on average established between variables measuring research intensity and the rate of growth. Nonetheless, and as regards to the rate of profits, in particular, the authors observed that R&D did not generate barriers to market entry, and, therefore, the increase in the market share of the innovative firm did not mean necessarily more profits to the innovative firms. Even more interesting and surprising was to ascertain that the effect of research on firm growth was greater in the traditional sectors than in the more research-intensive ones, a result that, according to the authors, could be somehow explained by the "*peculiarity*" (pp. 1012) of the Italian industrial system, which still denoted a strong specialization in traditional sectors, more competitive in relation to foreign firms. The idea that the type of *technological-opportunity environment* – a term first coined by Scherer (Audretsch, 1995) - to which a firm/industry belongs affects its behaviour towards innovation and R&D, in particular, has not indeed been left out of the debate by authors. As mentioned, the concept was first used in the 60s by Scherer, who argued that not all industries were equally innovative and that this could be explained by the technological environment they belonged to. Later in the 80s, Acs and Audretsch (1988) reaffirmed the assumption that variations in the innovation activity of large and small firms were contingent upon different economic and technological regimes.

So far, our literature review has focused on empirical studies carried out at firm level. Nevertheless, it is well worth making again a short reference to Hartmann's analytic forecast model, an extension of Marvin Patterson's model, according to which a causal linkage between a firm's R&D investment and its revenue could be established. According to Hartmann, the model proposed, which reflected, to a certain extent, a slight deviation from the Patterson's model, would allow managers to use investment and wave shapes to simulate hypothetical scenarios, more precisely, to simulate the probable outcomes of R&D budget plans and control the time-lag between investment in product development and its respective revenue, since returns, whatever their nature, are likely to manifest themselves not until some years after product launch.

3. Conclusions

By taking an insight into the literature on R&D assessment we intended to highlight that by tackling the issue from a wide spectrum of perspectives, with different definitions, variables, methodologies and indicators, results and conclusions to be drawn on R&D and innovation payoff are likely to differ as well, sometimes rather significantly. The main implication of this argument is that the nature of the relationship between R&D and any other variable one might considerer to assess R&D payoff is far more complex than the relationship common sense and also academic knowledge have tended to depict. Perceptions in the academic field about this relationship have changed however: most - if not all – of the articles surveyed were cautious when it came to support the idea that R&D investment should be made at all costs.

Reinforcing the idea of complexity underlying the relationship between R&D and economic performance and the skepticism of some studies to admit a causative linkage between them, is also the observation that, when we move from a macro into a micro analysis, the magnitude of R&D returns is less frequently mentioned, which may suggest that it is still a hard task, mostly, at this level, to track the real effectiveness of R&D investment.

Table 4: Summary of R&D returns (in %)

Level	Minimum	Maximum	Average
Macro	6.0	66.0	24.0
Meso	19.0	45.7	37.1
Micro	27.0	49.0	38.0

In the table above, we can see that R&D returns are, at the micro level, higher in all indicators (minimum, maximum and average), but we should bear in mind that only two of the studies surveyed at that level provided us with the figures for those returns. Indeed, one would expect that the magnitude of R&D returns to be higher at more aggregated levels of analysis, since the social value of R&D is usually left out of firm’s accounts.

A final – but not least important - remark to be made is that some of the articles reviewed called into question the need to redefine traditional systems of measurement in order to include *actors* – such as small and low-tech firms – whose role has been either kept apart or distorted in studies on returns on RD investment. Indeed, rethinking the role of small and low-tech firms in the innovation process will require not only a change in the way R&D payoff is

tackled, understood and measured, but also a change in the way innovation itself is perceived. We should not ignore the fact that even in some of the articles which take the concept of innovation as a core one, the operationalization of innovation takes place based on R&D indicators, something which remind us of the centrality that is still given to R&D in the innovation process, overshadowing other types of innovation measures.

References

- Acs, Z. J and Audretsch, D.B. (1988): "Innovation in large and small firms: an empirical analysis", *The American Economic Review*, Vol. 78, No. 4: 678-690.
- Almeida, A. and Teixeira, A. C. (2007), "Does patenting negatively impact on R&D investment", *FEP Working Papers*, 255: 1-43.
- Audretsch, D. B. (1995), "Firm profitability, growth and innovation", *Review of Industrial Organization*, 10: 579-588.
- Bender, G. on behalf on PILOT Consortium (2006), *Peculiarities and Relevance of Non-Research-Intensive Industries in the knowledge-based economy*: 1-92.
- Bayoumi, T., Coe, D. T, Helpam, E. (1999), "R&D spillovers and global growth", *Journal of International Economics*, 47: 399-428.
- Bilbao-Osorio, B. and Rodríguez-Pose, A. (2004), "From R&D to Innovation and Economic Growth in the EU", *Growth and Change*, Vol. 35. No. 4: 434-455.
- Bender, G. on behalf on PILOT Consortium (2006), *Peculiarities and Relevance of Non-Research-Intensive Industries in the knowledge-based economy*: 1-92.
- Bernstein, J. I. (1989), "The structure of Canadian inter-industry R&D spillovers, and the rates of return to R&D", *The Journal of Industrial Economics*, Vol. 37, No. 3: 315-328.
- Bogers, M. and Lhuillery, S. (2006), *Measuring Informal Innovation: From non-R&D to on-line knowledge production*, École Polytechnique Fédérale de Lausanne: 1-23.
- Bougrain, F. and Haudeville, B. (2002), "Innovation, collaboration and SMEs internal research capacities", *Research Policy*, 31: 735-747.
- Hall, B. H. and Mairesse, J. (1995), "Exploring the relationship between R&D and productivity in French manufacturing firms", *Journal of Econometrics*, 65: 263-293.
- Coe, D. T and Helpman, E. (1995), "International R&D spillovers", *European Economic Review*, 39: 859-887.

- Drake, P., Sakkab, N. and Jonash, R. (2006), "Maximizing return on innovation investment", *Research Technology Management*, November-December: 32-41.
- Graves, S. B. and Langowitz, N. S. (1996), "R&D productivity: a global multi-industry comparison", *Technological Forecasting*, 53: 125-137.
- Goto, A. and Suzuki, K. (1989), "R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries", *The Review of Economics and Statistics*, Vol. 71, No. 4: 555-564.
- Griliches, Z. (1980), "R&D and productivity slowdown", *American Economic Association*, Vol. 70, No. 2: 343-3458.
- Grossman, G.M. and Helpman, E. (1993), *Innovation and growth in the global economy*. Cambridge, Mass.; and London England: MIT Press.
- Freel, M. (2000), "Do small innovating firms outperform non-innovators?", *Small Business Economics*, 14: 195-240.
- Hartmann, G. (2003), "Linking R&D spending to revenue growth", *Research Technology Management*: 39-46.
- Hsieh, P., Mishra, C. S., Gobeli, D. H. (2003), "The return on R&D versus Capital Expenditures in Pharmaceutical and Chemical Industries", *IEEE Transactions on Engineering Management*, Vol. 50, No.2: 141-150.
- Ho, Y. K., Keh, H. T. and Ong, J. M. (2005), "The effects of R&D and Advertising on Firm Value: An examination of manufacturing and nonmanufacturing firms", *IEEE Transactions on Engineering Management*", Vol. 52, No. 1: 3-14.
- Hoffman, K., Parejo, M., Bessant, J. and Perren, L. (1998), "Samall firms, R&D, technology, and innovation in the UK: a literature review", *Technovation*, 18 (1): 39 – 55.
- Howells, J. (2005), "Innovation and regional economic development: a matter of perspective?", *Research Policy*, 34: 1220-1234.
- Jacobsson, S. and Philipson, J. (1996), "Sweden's technological profile: What can R&D and patents tell and what do they fail to tell us", *Technovation*, 26 (5): 245-253.
- Karlsson, M., Trygg, L. and Elfström, B. (2004), "Measuring R&D productivity: complementing the picture by focusing on research activities", *Technovation*, 24: 179-186.

- Kleinknecht, A. (1987), "Measuring R&D in small firms: how much are we missing", *The Journal of Industrial Economics*, Vol. 36, No. 2: 253-256.
- Lefebvre, E., Lefebvre, L. A., Bourgault, M. (1998), "R&D-related capabilities as determinants of export performance", *Small Business Economics*, 10: 365-377.
- Monte, A. del and Papagni, E. (2003), "R&D and the growth of firms: empirical analysis of a panel of Italian firms", *Research Policy*, 32: 1003-1041.
- Papadakis, M. (1995), "The delicate task of linking industrial R&D to national competitiveness", *Technovation*, 15 (9): 569-583.
- Roper, S. (1999), "Under-reporting of R&D in small firms: the impact on internal R&D comparisons", *Small Business Economics*, 12: 131-135.
- Teixeira, A.A.C. and Fortuna, N. (2004), "Human capital, innovation capability and economic growth in Portugal, 1960 - 2001", *Portuguese Economic Journal*, 3 (3): 205-225.
- US Congress, Office of Technology Assessment – OTA-TM (1986), *Research funding as an investment: can we measure the returns? A technical memorandum: 3-72*.
- Walwyn, D. (2007), "Finland and the mobile phone industry: A case study of the return on investment from government-funded research and development", *Technovation*, 27: 335-341.
- Wieser, R. (2005), "Research and Development productivity and spillovers: empirical evidence at firm level", *Journal of Economic Surveys*, Vol.19, No. 4: 587-621.

INESC PORTO

Campus da FEUP

Rua Dr. Roberto Frias, 378

4200-465 Porto

Tel. +351 22 2094000

Fax +351 22 2094050

E-mail www@inescporto.pt

<http://www.inescporto.pt>