THE IMPACT OF R&D INVESTMENTS ON PERFORMANCE OF FIRMS IN DIFFERENT DEGREES OF PROXIMITY TO THE TECHNOLOGICAL FRONTIER

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ABSTRACT

This study analyzes the impact of R&D in the performance of companies from different degrees of proximity to the technological frontier. We consider the technological frontier as the limit of accumulated knowledge that is applied in the production in a given industrial sector. In this sense, a model of endogenous growth was built, where firms operating close to this frontier use the research resources to move it and therefore enjoy a higher return from the use of such investments. Unlike this scenario, firms that are further away from the frontiers have lower results on the use of these investments, what may be associated with different opportunity costs of using this resource. As companies advance toward the frontier, the greater use to be the return on investment in R&D, improving the performance of the companies. In order to test this hypothesis, we used a sample of companies with major investments in R&D in the world, according the 'EU Industrial R&D Investment Scoreboard'. The sample consisted of 548 companies distributed across 41 sectors and 26 countries between 2003 and 2013. Then, an indicator that measures the degree of proximity to the frontier for each sector in the sample was built. Utilizing the technique of regression with panel data, it was estimated an equation where the performance metrics of the company is conditioned by investments in R&D and the investment interacted with the proximity index to the frontiers. Thus, the impact of investments in performance is represented by two important vectors of influence: (1) the average effect of investments on performance, which can be represented as a direction of the sector in demand for investment; (2) the effect-efficiency that determines the company's strategy as its position in relation to the established frontier. The results show that firms which are nearest the frontiers obtain greater return on the use of investments, unlike the more distant firms. In this way, as the firms get closer the technological frontier, the greater the return of investment in R&D on performance. These results indicate that the advancement of economies towards the frontier or the best technological practices depends on policies that incorporate the influence of the 'development stage' in the outcome of this policy. Thus, firms located in remote economies have important opportunity costs on resource use, what demand different economic policies for investments in relation to economies where firms are closer to the technological frontiers. The absence of this understanding can lead developing economies, whose firms are predominant distant from this frontier compared to developed economies, toward a trap of non-convergence. In this case, the persistent backwardness of firms impose increasing opportunity costs on the demand for R&D, 'strangling' efforts in innovation and hence limiting the trajectory of technological convergence of firms and of economy.

Keywords: Research & Development; Technological Frontier; Investments; Efficiency.

1. INTRODUCTION

Innovation is increasingly essential in a highly dynamic market, where changes occur at ever increasing speed. In this environment, innovation is no longer an option: it is essential for firm's survival. As Freeman and Soete (2008) argue, firms that don't innovate move to death. Here, we refer to innovation as search, discovery, experimentation, development, imitation and adaptation of new products, new processes and new organizational formats (DOSI, 1988).

In this environment, the development of new skills is the only way to deal with a wide range of competitors that are seeking to develop new capabilities for all the time. Firms that don't innovate will probably, in the long term, reduce their competitiveness. According to Meeus and Oerlemans (2000), the maintenance of organizational inertia leads to lose of performance in the short and medium term and even death in the long term. In the same way, Bessant (2003) states that:

> Innovation represents the core renewal process in any organization. And unless a business is prepared to work continuously at renewing what it offers and how it creates and delivers that offering, there is a good chance that it won't survive in today's turbulent environment (BESSANT, 2003, p.761).

Thus, the dichotomy between short-term results and long-term planning should be adequate. As Katz (2003), managers should be able to mix the short-term efficiency and the development of capabilities in the long term. At the same way, as stated by Meeus and Oerlemans (2000), this is the dilemma between flexibility and stability.

In this sense, firms around the world seek to generate innovation as a means of differentiation, value creation and gain of competitiveness. Through this process, changes in market leadership positions occur for all the time (KATZ, 2003). Furthermore, there is an increasing rate of reduction in product life cycle. It leads the necessity to intensify efforts to innovate for maintaining competitiveness (ROTHWELL, 1994). Thus, while innovation investments are generally considered of high risk (particularly with respect to products), non-investment often means a worse option (COOPER, 2003). Thus, investment in research and development is essential to promote innovative gains. This is not a superfluous item of firm strategy but according to Bessant (2003), imperative for their survival.

At this way, Freeman and Soete (2008) highlight the increasing role of investment in research and development (R&D) in several segments. It is, according to the authors, the reason that promoted deep changes in products and production patterns over the last century, creating enormous social and economic changes.

So, which are the results of investments in R&D in the firm's competitiveness and specifically in its profitability? In an increasingly globalized market with an increasing number of competitors, innovate means to differentiate. This differentiation allows the firm to reduce the ability of other products to serve as a substitute for your own product. Thus, the firm develop a specificity, generating value.

Thus, the assessment of the effects of innovative activities on firm performance has been a topic of great prominence, especially in recent decades. Many researchers have focused on this field in order to build a link of how the search or effort in creating new products, processes and organizational forms have direct impact on the financial performance of firms (TEECE, 2009). In this sense, targeted policies aimed at accumulation of dynamic capabilities of firms have been treated as fundamental to the development of any economy, especially in the newly industrializing economies (AMSDEN, 2001).

Recent researches have attempted to measure the effect of innovative efforts in the performance of firms, incorporating in the analysis the concept of approaching to frontier (ACEMOGLU; AGHION; ZILIBOTTI, 2006; AGHION; HOWITT; AGHION, 2009; HALL; LERNER, 2009; COAD, 2011). These studies employ the Schumpeterian approach to competition, where firms seek to create new products, making current obsolete technologies, a process called 'creative destruction' (SCHUMPETER, 1942). In the Schumpeterian hypothesis, the most advanced firms are better able to adapt to new technology than in relation to the latest standards firms. Thus, in many cases, the most remote frontier firms are discouraged to innovate as the most advanced firms destroy their technological trajectories when moving the frontiers.

Thus, firms are embedded in different technological regimes. These technological regimes are defined, according to Breschi, Malerba and Orsenigo (2000), as a combination of technological opportunities, innovations appropriability, technical advances and cumulative knowledge base properties. Technological opportunities refer to the probability of a firm generate innovation from investments in R&D. The innovations appropriability relate to the ability the firm has to appropriate the financial results of innovation, limiting the capacity of reproduction of this innovation by other firms. The cumulative of technical progress refers to the fact that the present knowledge base is the source for the development of new knowledge in the future. Finally, the properties of the knowledge base refers to the characteristics of the knowledge base of a firm.

In accordance with these discussions, recent studies (COAD; RAO, 2006; COAD, 2008; 2011; KANCS; SILVERSTOVS, 2016; MONTRESOR; VEZZANI, 2015) have shown that investments in R&D have different results according to the different degrees of proximity to the technological frontier. Coad (2008; 2011) analyzed a sample of firms in different sectors and noted that firms located nearest the frontier had higher return on investment in R&D. By quantile regression, firms located in the upper quantiles of the conditional distribution of the market value exhibited greater return from the use of R&D in relation to firms located in the lower quantile. The study results suggest that firms closer to the technological frontier employ investments in research designed to move the border, appropriating the economic results arising from this displacement process. The 'gap' promoted by the displacement reduces the impact of investments in generating value from the remotest firms, due to the potential opportunity costs that such investments have.

Although the results are consistent with the literature of endogenous growth models, as the contributions of Aghion and Howitt (1998, 2009), the results presented by Coad (2008; 2011) fail to capture important aspects related to the true nature of the factor 'approach with the frontier'. The restriction of this study derives from an important emphasis on technique. As Daraio and Simar (2007), the linear regression techniques do not capture in a precise way, important characteristics of a technologically efficient production, even considering different points of the conditional distribution. The production structure at the fronteir can be distinguished from an average production structure constructed by a data sample. The 'best practice' does not necessarily imply an ''average practice', since it does not incorporate aspects of the economies of scale and scope.

This research contributes on this issue, analyzing the effects of the approach to the frontier through a more consistent technique. In this sense, it was estimated efficiency scores from non-parametric technique of Free Disposal Hull. Taking a sample of 548 firms that have invested most in R&D between 2003 and 2013, it was observed that the 'approach to the efficient frontier' factor has a significant influence on the relation between investment in R&D and company performance. The most efficient firms have higher elasticity coefficients in R&D in relation to the most inefficient firms, indicating that the firms more distant from efficient frontier employ investments in research with lower efficiency or tend to have higher opportunity costs in the use of these investments.

These results, although converging with the conclusions highlighted by Coad (2008; 2011) and Montresor and Vezzani (2015), its implications have greater consistency with the literature presented. This is due because in countries where prevalence of the most inefficient firms is notoriously higher than in the 'economies of the border', the investment opportunity costs can be as important restrictions on the process of technological convergence. In this case, the end-efficiency ceases to be captured appropriately in quantile regression technique, although this technique will prove important insights into the relationships of the variables as points of different conditional distribution.

2. THEORETICAL FRAMEWORK

Innovation

Discussions on what innovation is and why firms innovate is central in the quest for understanding the dynamics of these organizations. Starting from the assumption that the firm's objective is to maximize your results, either through gains of efficiency or competitiveness, it is assumed that firm’s decisions will be directed on this way. Therefore, it is supposed that the innovation is geared to generate increments in their economic results. This occurs when the firm be able to develop new capabilities to generate value through the development of new products with quality increments at lower unit costs (LAZONICK, 1992).

The discussion about the consequences of innovations for firms led, from the theoretical view, the rejection of many neoclassical assumptions. In this approach, innovation was discussed as a factor exogenous to the firm, which was embedded in an environment of perfect competition. In this market structure, the information would be symmetric and all agents would have access to any innovation. So, the innovation here does not promote increments of specificity for the firm. However, the intensification of the process of differentiation and increased inward investment in the development of new products and processes made the neoclassic view increasingly less acceptable.

It must be considered, however, that neoclassical theory was able to explain, in some way, the reality of the moment when it was designed. The period between the industrial revolution and the end of the nineteenth century was characterized effectively by a market environment with very low product differentiation and highly atomized. This period was characterized by a economic growth primarily based on three factors of production: natural resource, labor and capital. However, changes were happening. Industrial conglomerates were been organized and twentieth century represented the beginning of a time where economic growth was based primarily on a fourth factor of production: the knowledge developed and applied by firms to production. Since then, the differentiation becomes no longer the exception but the rule. The neoclassical theory would no longer be able to explain this new environment.

Embedded in this new environment, Schumpeter (1985) sought to analyze the development of the capitalist economy. Due to his neoclassical legacy, the author deals with the idea of a stationary moment (equilibrium). However, Schumpeter argues that the economy goes through periods of development when it comes out of the steady state and changes (innovations) occur.

But why firms seek innovation? For Schumpeter, the economic agent seeks to innovate towards a differentiation that allows you to get an increase in profit. The pursuit of innovation is motivated by generating value through the application of new knowledge into new products, which allow obtaining higher profits than in the stationary moment. However, in a second stage, this innovation is institutionalized and again it returns to the steady state and to the profits rate earned previously. In this sense, the search for value creation would move the entrepreneur to be always innovating in order to stay obtaining higher rates of profit. The system is always in motion. Therefore, within the changing perception of Schumpeter, it is introduced a concept of value much closer to reality: the value would be directly connected to the product and how much knowledge was embedded within it.

Hence, metaphorically, we could say that economic agents are now transacting not so much in a capitalist economy (ie, with the capital being the main factor of production), but in a knowledge economy. The quest for knowledge is an essential factor for the success of any firm.

Then, innovation becomes an essential strategy for a firm maintain or improve its competitive position. Therefore, there is a direct correlation between the strategy to be adopted and the development of new technologies (ITAMI; NUMAGAMI, 1992).

One of the most relevant mechanisms to the development of new capabilities is through investment in research and development (R&D). Such strategy, however, involves a high level of uncertainty and, therefore, risks. After all, to what extent these investments effectively represent financial returns and in how long? Accord Cooper (2003), the innovative activity, with its high failure rate, is one of the highest risk activities of the modern corporation. At the same way, Pavitt (2005) argue that:

> The process of innovation process is complex, involving many variables whose properties and interactions (and economic usefulness) are understood imperfectly. As a consequence, firms are not able to explain fully and predict accurately either of major innovations, or their acceptability to potential users (or in some cases even who the potential users are) (PAVITT, 2005, p. 100).

It is clear, therefore, a relation between risk and innovation. After all, as in any economic activity, there is a positive correlation between risk and return. For Freeman and Soete (2008), the innovative capacity of a firm is determined for its capacity to expose itself to risks. The authors discuss the possibility of risk assessment for R&D activities, seeking to demonstrate that it is an activity with a low degree of predictability.

R&D Resources as Strategic Investment

Investments in R&D inside firms became increasing throughout the twentieth century. It denotes a deep change of the production process, representing an essential aspect of the great social and economic transformation in this period. Increasingly, the knowledge became a key factor for the competitiveness of companies. Freeman and Soete (2008) define this transformation of the production paradigm as the "revolution of research". According to the authors:

> It was the specialization of the R&D function, which justified such expressions as the "research revolution" to describe what happened in twentieth-century industry, industry associations of R&D managers were created in different countries, and many large firms in the industrial countries had set up their own full-time specialized R&D sections or departments. (FREEMAN; SOETE, p.32-33).

Since the contributions of Arrow (1962), spending on R&D began to be perceived with quite peculiar characteristics compared to other investment of the firm. At a first glance, such investments are conformed to uncertainty. So, they compete with other investments (physical capital) according to the best and "safest" return. In another perspective, resource constraints by firms make investments in R&D highly selective, since the most advanced companies employ such resources more efficiently and in order to move the 'technological frontier' of the sector they operate. Regarding firms with low technological learning, the displacements of the frontiers have the effect of increasing its relative distance, increasing the opportunity costs of these investments and reducing the effectiveness of the results, as that imitative strategies increase the competition for resources (COAD, 2011).

Over the past decades, it was emphasized the importance of technology to the dynamism of the business, which has further highlighted the importance of investment in R&D for gains in competitiveness. As Hall (2002), there are large differences between investments in R&D and in physical capital. At First, the investment composition is very different: more than half of the resources are expended on paying salaries for a workforce highly skilled and trained (researchers, engineers, PhDs, etc.). Because of this organic composition (since it reflects the dynamism of technology), most of the knowledge created becomes intangible and tacitly incorporated in engineers and researchers. This fact has two related consequences: the propriety of this knowledge does not lie entirely in the firm. This encourages the development of specific contracts for these investments, aiming to keep employees with valuable company assets: the knowledge (HALL; LERNER, 2009).

This pattern of behavior is better observed in the firms located nearest to the frontier, where competition for knowledge is more intensive. Empirical evidences show that competition among the most advanced firms has the effect of forcing them to innovate as a strategy to escape of the effect of "threat to entry", whose incoming firms promote to those which are established. This strategy has a positive relation with the probability of entry, linking innovation and 'threat to entry' to a distinct pattern in relation to less developed firms. In this particular case, firms are discouraged to innovate, since firms, collectively, destroy the value of their innovations, increasing the opportunity costs of investments in R&D (AGHION; BESSENOVA, 2006).

Therefore, the results of investments in R&D are closely linked to fluctuations in relation to proximity to frontiers (ACEMOGLU; AGHION; ZILIBOTTI, 2006). For this reason, it is essential to analyze factors that reflect the innovative efforts of firms considering their effects on the establishment of technological asymmetries, especially when such asymmetries influence most of the dynamic capabilities of firms (TEECE, 2009). A dissociated analysis between these factors could result in inaccurate conclusions about the true nature of the 'paradigm of technology'.

Innovation and Economic Environment

The approach presented below consists in a variation of the methodology proposed by Aghion and Howitt (2009). It occurs on an environment where firms operate in a competition with others in a specific industrial sector. Each firm has a production function that approximates to a traditional Cobb-Douglas function:

$$Y_{it} = (k_{it})^{\alpha}(L_{it}A_{it})^{1-\alpha}, \alpha \in (0,1) \qquad (1)$$

According to equation (1), the elasticity of the stock of physical capital (k_i) of the i-th firm is represented by the parameter α. Consequently, the elasticity of the number of employees of the firm (L_i) and of technological parameter (or total factor productivity) from the firm (A_i) is represented by $(1-\alpha)$, so that the firm presents constant returns of scale. The time is limited in a horizon of T-years, t = 1,2,3,4 ... T.

The technological parameter of the firm measures the quality of the final output which is combined by the use of inputs in production. Thus, higher levels of this parameter reflects greater differentiability of the product compared to other competitors. Firms seek leadership in each sector, investing resources in R&D activities in order to increase the chances of achieving the technological frontier.

If the firm implements an innovation to market, the improvement of the product is accepted and the technological parameter consists in an advance of improvement over the previous period. If the firm does not develop an innovation, technological status will be the same of the previous period, without notice any improvement.

$$A_{it} = \begin{cases} \gamma A_{it-1};\ \mu \\ A_{it-1};\ 1-\mu \end{cases} \quad (2)$$

According to equation (2), the parameter $\gamma > 1$ corresponds to the extent of innovation and increase of the technological parameter of the firm in relation to the lagged period with probability μ of a succeed innovation. Otherwise, $1-\mu$, the firm fail in the innovation and the quality of your product do not improve over the previous period. The rate of technological progress of the firm is represented by the mathematical expectation *E(.)* in the percentage change of the technological parameter:

$$g_A = E\left(\frac{A_{it} - A_{it-1}}{A_{it-1}}\right) = \mu(\gamma - 1) \quad (3)$$

The probability of success of firm's innovation depends on the volume of funds invested in innovative activities. Thus, we can define the innovation function, which associates each investment in research applying (n) to a probability of success (μ) research, according to the following notation:

$$\mu = \theta(n_{it})^{\sigma};\ \sigma \in (0,1) \quad (4)$$

In accordance to the innovation function above, the parameter θ reflects the research productivity and is admitted to be a strictly low value in order to ensure the probability interval μ. The σ parameter represent the elasticity of research in increasing the probability of successful of innovation. The restriction to $\sigma \in (0,1)$ follows the empirical evidence presented in contributions from Aghion and Howitt (2009) and Acemoglu, Aghion and Zilibotti (2006).

The growth rate in sales of the firm consists in the following algebraic solution:

$$g_Y = \alpha g_k + (1-\alpha)(g_A + g_L) \quad (5)$$

Without a considerable loss of generality, the growth rate of capital (g_k) and workers (g_L) will be considered equal to zero. Substituting equations (3) and (4) into (5):

$$g_Y = (1-\alpha)\theta(n_{it})^{\sigma}(\gamma - 1) \quad (6)$$

From equation (6), we present the first test proposition in this study:

- **Proposition 1:** *Investments in R&D contribute to the growth of sales by increasing the likelihood of success on future innovations in the firm.*

As proof of **Proposition** 1, we can apply the concept of partial derivative in the growth rate with respect to investments in R&D:

$$\frac{\partial g_Y}{\partial n_{it}} = \frac{\sigma(1-\alpha)(\gamma-1)}{\theta(n_{it})^{1-\sigma}} > 0 \quad (7)$$

According to equation (7), the investments in R&D contribute visibly to the growth of firms. However, we may ask which firms enjoy a greater contribution to growth and which have marginally lower increments? What factors affect the elasticity of research in different contexts of firms?

To answer such 'theoretical puzzles', we will use the methodological assumption proposed by Aghion and Howitt (2009). According to the authors, for firms that are more distant from leadership of the sector, the strategies based in the implementation of technologies from the frontier tend to result in a rapid contribution on growth of these firms, what do not happen with firms located in 'the vicinity of the frontier'. Thus, the different results associated with the research activities present patterns of sensibility in relation to fluctuations in the proximity to the frontier.

In this perspective, the frontier is defined as the reference technology in the industry sector. Therefore, each firm is limited relative to the firm that own the "leadership status". On this assumption, the firm located on frontier ($\bar{A}$) is that firm which owns the reference of technology, satisfying as the limit of knowledge within the sector $A_{it} \leq \bar{A}$. Thus, both productivity and the elasticity of the research are affected by the degree of proximity to the frontier $a_{it} = A_{it}/\bar{A}$ (it is said that $\theta(a_{it})$ and $\sigma(a_{it})$ are increasing functions of the technological approach, $\theta'(a_{it}) > 0$ e $\sigma'(a_{it}) > 0$). Thus, the greater the proximity to frontier $\lim a_{it} \rightarrow 1$, the greater the contribution from productivity and from the research elasticity on the success of the innovation, because the experiences and patterns of cumulative knowledge in consolidating the technological trajectory (TEECE, 2009).

- **Proposition 2:** *The contribution of investments in R&D to the growth of sales is higher for firms located near the frontier than for the more distant firms.*

$$\frac{\partial g_Y}{\partial n_{it}} = \sigma(a_{it})(1-\alpha)\theta(a_{it})(n_{it})^{\sigma(a_{it})-1}(\gamma-1) > 0 \qquad (8)$$

Applying the partial derivative with respect to the degree of proximity to frontier, we have the marginal effect of technological approach in the contribution of investment in research on growth:

$$\frac{\partial^2 g_Y}{\partial n_{it}\partial a_{it}} = \frac{\sigma(a_{it})(1-\alpha)\theta(a_{it})(\gamma-1)}{(n_{it})^{1-\sigma(a_{it})}}[\Omega(a_{it})] > 0 \blacksquare$$

$$\Omega(a_{it}) \equiv \left[\left(\frac{1+\sigma(a_{it})ln(n_{it})}{\sigma(a_{it})}\right)\sigma'(a_{it}) + \frac{\theta'(a_{it})}{\theta(a_{it})}\right]$$

The next section outlines the development of the empirical model to test the hypothesis of innovative efforts and its relation with firm performance, incorporating the effects of proximity to the technological frontier in the results of these investments (R&D).

3. EMPIRICAL METHODOLOGY

Definition of the sample

The report "The EU Industrial R&D Investment Scoreboard" includes economic and financial data of companies with larger investments in R&D from all the world, comprising the largest investors selected and classified by the level of these investments. These data are available according to the latest available balance of these firms. The annual reports and accounts are public domain documents and organized by the department 'Industrial Research Monitoring and Analysis (IRMA)' from the European Commission. The collected data are adjusted by the corresponding exchange rates in the annual reports using as reference the rate from December 31 of each year. In addition, the monetary values for each variable are expressed in millions of euros. Except for the growth variables in the report, the proportions between the variables are expressed in percentage units. The variable that measures the stock of workers in each firm is presented through the number of employees and cataloged at the end of the fiscal period.

This sample represents an important representation of innovation efforts in the world, since the data include major firms investing in R&D, accounting for a share of 90% of all investments in research in the world (EUROPEAN COMMISSION, 2014). The total of firms in the study consisted in a set of 548 firms between 2003 and 2013. The final panel consisted of a sample of 6.028 observations.

Operationalization of variables

As discussed above, the variables provided in this study were collected in the report. The definitions and metrics involved in each variable catalog are presented below:

(i) Investments in Research and Development (R&D): It is represented for all expenditure directed to research, defined as activities conducted to develop new knowledge, whether directly related to scientific or technical level. The development perspective involves the application of resources for the production of new goods or substantially improved, devices, products, processes, systems or services. These investment are expressed in millions of euros.

(ii) Investment in capital assets (capex): It is represented for the expenditure realized by companies, focusing to acquire or upgrade physical assets such as equipment, property or industrial buildings. On the account of 'capital expenditure' is added to the asset account (i.e. capitalized), increasing the basis of the asset. Therefore, it is the tangible fixed assets of the companies. These investments are expressed in millions of euros.

(iii) Liquid sales: It corresponds to the accounting definition of sales, excluding sales tax and participations in sales as joint venture and shareholders. For banks, sales are defined as total operating income plus income from insurance. In relation to insurance companies, the sales are defined as gross premiums written plus any other banking products.

(iv) Number of employees: It is represented by the annual average number of employees or in the results presented at the end of the fiscal year.

(v) Profitability: It is the ratio between operating profit and liquid sales. Operating profits, in turn, are obtained "(...) the profit (or loss) before taxation, plus net interest cost (or minus net interest income) minus government grants, less gains (or plus losses) Arising from the sale / disposal of businesses or fixed assets " (EUROPEAN COMMISSION, 2014, p.105). Values are expressed in percentage units.

(vi) Intensity of investments in capital assets (capex intensity): It is ratio between investments in capital goods and sales. Values are expressed in percentage units.

Econometric model

The estimated model consisted of the following equation:

me.1 $$log(y_{it}) = \alpha + \beta_1 log(R\&D_{it}) + \beta_2 log(R\&D_{it}) * \theta_{it}(x,y) + \beta_3 log(K_{it}) + \beta_1 log(L_{it}) + \delta_i + \tau_t + \varepsilon_{it}$$

As me.1 equation, the variables $(y_{it}, R\&D_{it}, \theta_{it}, K_{it}, L_{it})$ correspond, respectively, to sales, R&D efficiency score, investment in capital goods and the stock of labor of the company "i" in time "t". Regarding the efficiency score, the next topic will present methodology to get it, based on the technique of Free Disposal Hull.

The variables (δ_i, τ_t) represent the fixed effects for the specific attributes of firms and temporary shocks of random nature, but which are common between firms. Finally, the term stochastic perturbation $\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2)$, which captures all the other factors that are irrelevant to the model structure. Hypothesis tests on the behavior of stochastic perturbation will be applied in order to ensure the efficiency properties of the model.

Scoring Efficiency

The measurement of the efficiency degree from a number of companies do not always consists in a simple exercise. Traditional techniques of linear regression do not capture accurately some important characteristics of a technologically efficient production. The production structure at the frontier can be different from an average production structure constructed by a data sample. The 'best practice' does not necessarily imply an "average practice", since it does not incorporate aspects relating to economies of scale and scope (DARAIO; SIMAR, 2007).

To capture the effect of the efficiency of firms, efficiency scores was obtained using a non-parametric technique, called *Free Disposal Hull*. The advantages of this technique can be summarized as follows:

(i) Non-parametric techniques, unlike the parametric assumptions, do not depend on the functional form of the production function and axioms statistical in process of data generator, making them more attractive for estimating factors or scores associated with efficiency (BADIN, DARAIO; SIMAR, 2014);

(ii) There are two important methods in the non-parametric technique:

(2.1) DEA method, where the firms' production set takes the assumptions of free disposal (or waste of potential in resources) and convexity (FLORENS, SIMAR, & KEILEGOM, 2014). This approach has been widely used since the contributions of Charnes, Cooper and Rhodes (1978). However, problems associated with the indivisibility of inputs and products, economies of scope and scale, as well as factors associated with specialization, make the assumption of convexity rather weak, leading efficiency scores bias problems in the presence of such 'anomalies' (DARAIO; SIMAR, 2007).

(2.2) In violation of convexity, a robust technique becomes more appropriate in the estimation of efficiency scores: Free Disposal Hull or FDH. This technique, based on contributions from Deprins, Simar and Tulkens (1984), consists in a more general version of the DEA estimator, including the assumption of Free Disposal in the set of production and relaxing the assumption of convexity. This has become the most attractive FDH technique in studies of effectiveness.

In this way, this study will apply FDH technique to estimate firms' efficiency scores. Considering the selected sample, it was identified 40 sectors in which firms are distributed. For each sector, in each time point was constructed a frontier of efficiency-oriented input. So, it was obtained 40 frontiers.

The variables selected for calculation of efficiency scores are presented in the following table:

Table 1: Definition of variables to calculate the efficiency scores.

variables	Definition of variables

Y	Profitability		
L	Total of employees		
K	Intensity of investments in capital goods		
	Division of variables to calculate the scores		
	output		input
	Y		L K

Source: developed by the authors.

The input-oriented method for calculation of efficiency scores assumes that companies minimize inputs for a given level of production (in this case, profitability). Thus, the calculated scores is a proportional adjustment in input to drive firms inefficient to an efficient level of use of inputs. Therefore, the scores take values in the following range: $\theta_{it}(x,y) \in [0,1]$

As the distribution of results of the scores, the closer to zero the calculated score is, $\lim\theta_{it}(x,y) \rightarrow 0\lim\theta_{it}(x,y) \rightarrow 1$, the more inefficient the company is located, and when the score approaches the opposite limit, the more efficient the company is and, therefore, nearest the frontiers is its location.

Estimation method

Depending on the data nature, the parameters will be estimated through three important techniques: (1) fixed effects; (2) random effects, and (3) OLS with pooled data (OLS Pooled).

The first technique incorporates the effects of heterogeneity of the sample (δ_i, τ_t) on the specific attributes of firms and temporal random nature shocks (CAMERON; TRIVEDI, 2005). Such factors can be correlated with the regressors, since forms of organization may induce the demand for investments and gains associated with the own efficiency. In this case, the absence of inclusion in the main model can lead to a serious error of specification, contributing to the emergence of endogeneity problems.

Otherwise, gains on the efficiency can be obtained by including such factors as uncorrelated with the regressors. These gains come from an alternative technique known as a method of random effects (HAYASHI, 2000; WOOLDRIDGE, 2010). This approach yields parameter estimates from the generalized least squares method (GLS).

To identify which technique is the most appropriate, it will be employed the Sargan-Hansen test with the null hypothesis that the fixed effects are not statistically correlated with the covariates of the model. The use of this test over the traditional Hausman (1978) is that in the former case, the test has to be more robust as the presence of problems related to heterocedasticity and autocorrelation (WOOLDRIDGE, 2010).

Finally, a comparison with the traditional technique of OLS excludes heterogeneity factors in the sample without the technical work properly to ensure the efficiency gains compared to the technique of random effects.

Robustness of estimates

To detect violations relating to heterocedasticity and autocorrelation, it was applied two important tests. In the first case, the statistic modified of Wald for models with fixed effects, which null hypothesis implies that $H_0: \sigma_i^2 = \sigma^2, \forall i \in \{1,2, \dots N\}$. In this case, the non-rejection of null hypothesis implies that the regression residuals are distributed in a homoscedastic form (GREENE, 2000, p. 598). To the pooled OLS method, it was applied the test of Breusch and Pagan (1979) under the same null hypothesis.

The second test involves checking the existence of autocorrelation in accordance with the test of Wooldridge (2002). As the test, the difference in discrepancy applied to the model excludes the effects of heterogeneity. So:

$$(\boldsymbol{Y}_{it} - \boldsymbol{Y}_{it-1}) = (\boldsymbol{X}_{it} - \boldsymbol{X}_{it-1})\boldsymbol{\beta} + (\boldsymbol{\varepsilon}_{it} - \boldsymbol{\varepsilon}_{it-1})$$
$$\Delta\boldsymbol{Y}_{it} = \Delta\boldsymbol{X}_{it}\boldsymbol{\beta} + \Delta\boldsymbol{\varepsilon}_{it}$$

which Δ corresponds to the operator of first difference.

The Wooldridge method estimates the above equation and the respective values of parameters, obtaining estimates of residues of the model, $\Delta\hat{\boldsymbol{\varepsilon}}_{it}$. If the model errors are not serially correlated, then $Corr(\Delta\boldsymbol{\varepsilon}_{it}, \Delta\boldsymbol{\varepsilon}_{it-1}) = -0{,}5$. This involves regressing the results of residues of the first equation with its lagged values and verify if parameter associated with the lag is statistically equal to $-0{,}5$. The test applied is robust in relation of the presence of conditional heteroscedasticity. Finally, to test for autocorrelation in the OLS pooled method, it was used the method proposed by Cumby and Huizinga (1992) under the null hypothesis of no serial autocorrelation of the first order.

In presence of serial autocorrelation and heteroscedasticity, variance-covariance matrix of the parameters was corrected using the broker from White (1980) with grouped residues (cluster) by cross section (firm). The two procedures are intended to ensure estimators HAC[i]

4. ANALYSIS OF RESULTS

Descriptive analysis of data

In this section, firms were classified in three groups: sectors with high-intensity of R&D, sectors with medium-intensity of R&D and sectors with low-intensity of R&D. This conceptualization was adopted in accordance to the report criteria, following definition:

Table 22: Definition of sectors per degree of intensity in R&D.

Group of sectors	Intensity in R & D (R & D / Sales)%
High-intensity	> 5%
Medium intensity	[1%, 5%]
Low-intensity	<1%
Definition of sectors	
High-intensity	Pharmaceuticals & biotechnology; Health care equipment & services; Technology hardware & equipment; Software & computer services and Aerospace & defense.

[i] For more details on the HAC estimators class, see Newey and West (1987).

Medium intensity	Electronics & electrical equipment; Automobiles & parts; Industrial engineering & machinery; Chemicals; Personal goods; Household goods; General industrials; Support services. Food producers; Beverages; Travel & Leisure; Average; Oil equipment; electricity; Fixed line telecommunications.
Low-intensity	Oil & gas producers; Industrial metals; Construction & materials; Food & drug retailers; Transportation; Mining; Tobacco; Multiutilities.

Source: Adapted from The 2013 EU Industrial R & D Investment Scoreboard, 2013 [p.27].

Table 3 shows the distribution of companies according to the three groups of sectors defined in Table 2.

Table 3: Distribution of firms by groups of intensive sectors in R&D.

Industry group	Freq. Abs.	Freq. Rel. (%)	Freq. Accum. (%)
High-intensity	202	3.35	3.35
Media-intensity	1,367	22.68	26.03
Low-intensity	4,459	73.97	100.00
Total	**6028**	**100.00**	-

Source: developed by the authors.

According to table 3, the smallest proportion of firms is distributed to the high-intensity group, with 3.35% of the sample, compared to 22.68% on average-intensity and a greater proportion of low-intensity firms, with 73.97%. This pattern reveals an asymmetry with great performance of firms with low intensity of R&D.

Table 4: Distribution of firms by type of efficiency.

Industry group	Freq. Abs.	Freq. Rel. (%)	Freq. Accum. (%)
efficient firms	1,692	28.07	28.07
inefficient firms	4336	71.93	100.00
Total	**6028**	**100.00**	-

Source: developed by the authors.
Note: The definition of the firms follow the criteria established in the methodology for efficient firms and inefficient firms. Thus, the efficiency parameter takes values in the restriction.$\theta(x,y) = 1\theta(x,y) < 1\ \theta(x,y) \leq 1$

According to Table 4, the efficient firms account for approximately 28% of the sample compared to 72% of inefficient firms. The following table ‘crosses’ the distribution of firms by efficiency and intensity of group research.

Table 5: Distribution of firms according to type of efficiency and intensity group.

Type firms	Freq.	Types of intensity in R & D			Total
		High	Average	Low	

	Abs.	26	309	1,357	1,692
efficient	Rel. Line (%)	1.54	18.26	80.20	100.00
	Rel. Column (%)	12.87	22.60	30.43	28.07
	Abs.	176	1,058	3102	4336
ineffective	Rel. Line (%)	4.06	24.40	71.54	100.00
	Rel. Column (%)	87.13	77.40	69.57	71.93
	Abs.	**202**	**1,367**	**4,459**	**6028**
Total	**Rel. Line (%)**	**3.35**	**22.68**	**73.97**	**100.00**
	Rel. Column (%)	**100.00**	**100.00**	**100.00**	**100.00**
Pearson chi2 (2) = 55.6678 / p-value = 0.000					

Source: developed by the authors.
Note: The definition of the firms follow the criteria established in the methodology for efficient firms and inefficient firms. Thus, the efficiency parameter takes values in the restriction.$\theta(x,y) = 1\theta(x,y) < 1\ \theta(x,y) \leq 1$

Based on the table above, the distribution of efficient firms has a higher proportion of low intensity research group (80.2%) versus a smaller proportion of high strength (1.54%). The same pattern is also observed for inefficient firms, where the largest proportion is concentrated in low-intensity companies (71.54%) against 4.06% in the proportion of firms with high intensity.

Comparing between the three intensity research groups, the proportion of inefficient firms overcomes efficient firms in relatively close values. Finally, the chi2 test showed a significant association between the factors ('efficiency' versus 'sector group').

Results of the econometric model

Table 6 shows the results of econometric model shown in ME.1 equation, according to each estimation method illustrated above.

Table 6: equation results me.1

VARIABLES	**(1) Robust Fixed Effects**	**(two) Random Effects**	**(3) Pooled OLS Robust**
log (R & D)	0205 ***	0154 ***	0.0751 ***
	(0.0357)	(0.0144)	(0.0150)
log (R & D) *□(X, y)	0.00955 ***	0.0399 ***	0131 ***
	(0.00363)	(0.00429)	(0.0114)
log (K)	0116 ***	0311 ***	0488 ***
	(0.0316)	(0.0121)	(0.0287)
log (L)	0261 ***	0465 ***	0391 ***
	(0.0643)	(0.0173)	(0.0389)
Constant	4288 ***	1277 ***	1268 ***
	(0589)	(0171)	(0236)
Fixed Effects			
Firm	yes	-	-

year	yes	-	-
R2	0.9975		0938
Heteroskedasticity test (chi2)	2.8e + 30		00:04
p-value	0.0000		0.8346
Autocorrelation test (§)	71 482 (A)		516 769 (B)
p-value	0.0000		0.0000
Sargan-Hansen statistic	228 618		
p-value	0.0000		
F	35.64		2112
p-value	0.0000		0.0000
chi2		5739	
p-value		0.0000	

Source: developed by the authors.
Note: (§) each autocorrelation has a distinct distribution pattern. (A) statistical Wooldridge (2002) follows a statistical F while (B) cumby and Huizinga (1992) follows a chi-square distribution.
The asterisks *, **, *** represent significance levels 10%, 5%, 1%, respectively. The 'robust' term implies that the results reported in the table was proceeded correction of the variance-covariance matrix using the estimator White (1980) grouped with waste per cross section. In this case, the estimator reported belongs to the class of the Best Linear Unbiased Estimators - BLUE.

According to the model results, the coefficient of elasticity from investments in research showed a significant increase comparing different methods, suggesting that OLS pooled technique underestimates its value to disregard the influence of fixed effects (0.2 for fixed effects from 0.075 for OLS and 0.15 for random effects, a variation of 167% for the first case and 33% for the second one).

Regarding the coefficient linked to the efficiency score, it was observed a decrease comparing the OLS pooled method with random effects and fixed effects. This aspect indicates an overestimate when the effects of heterogeneity of the sample are excluded from the main model. Comparing the method of fixed effects with random effects, the reduction of the parameter represents a variation of approximately 92%. Comparing efficient firms, the coefficient of final elasticity is 0.206% for OLS pooled and 0.215% for fixed effects (what represents an increase of 4%). We could also observe that both the capital and labor elasticity coefficients showed a significant reduction when comparing the methods of fixed effects, random effects and OLS.

Regarding the heteroscedasticity tests, the results showed a significant presence in the model of fixed effects (rejection of the null hypothesis of homoscedastic residue at 1%), unlike the method OLS pooled (non-rejection of the null hypothesis at 10%). Rather, autocorrelation tests showed evidence of autocorrelated residues in both models, rejecting the null hypothesis at the 1% level.

The Sargan-Hansen statistical presented a very high value (chi2 = 228.618), rejecting the null hypothesis at 1%. It indicates that the fixed effects showed significant correlation with the regressors of the model. Thus, deleting them in the stochastic error would be an error of specification, what could induce regressors to problems of endogeneity and, therefore, the bias in parameters. This bias is illustrated in overestimation of the parameters of capital and labor and underestimation of investments in research.

Figure 1 shows the effect that the proximity to the frontiers promote in the final coefficient of elasticity of R&D. Using a simulation based on the results of the fixed effects model, it is evident that the most efficient firms have higher elasticity coefficients of R&D.

These results are consistent with the theoretical model presented and recent researches on this field (Coad (2008; 2011), Kancs and Siliverstovs (2016) and Montresor and Vezzani (2015)).

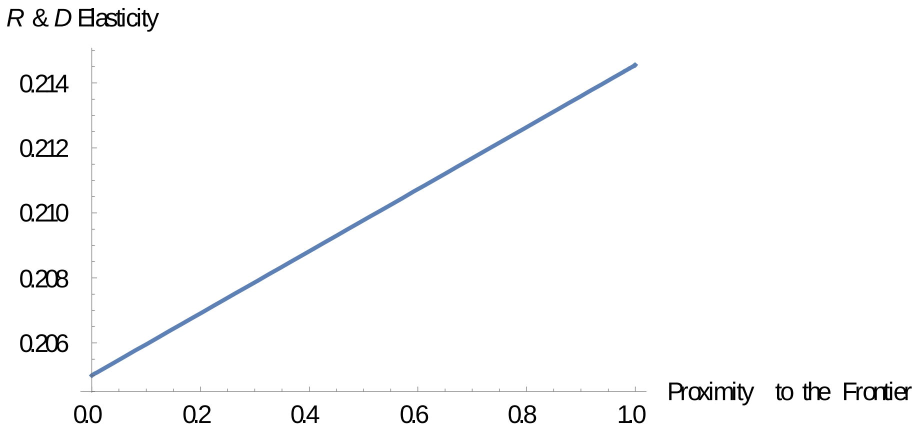

Figure 1: Effects of proximity to the frontier on elasticity, Fixed Effects.
Source: developed by the authors.
Note: The elasticity coefficient was obtained from the partial derivative of me.1 equation related to investments in R&D, $\epsilon^{R\&D} \equiv \frac{\partial log(y_{it})}{\partial log(R\&D_{it})} = \hat{\beta}_1 + \hat{\beta}_2 * \theta_{it}(x,y)$.

Figure 2 shows the relationship between R&D and sales through the scatter plot. The estimated line is reported in order to assess the degree of dispersion of data around the average. Points above and below the line can be illustrated in the model through the efficiency coefficient, which creates different 'weights' in the relation between variables.

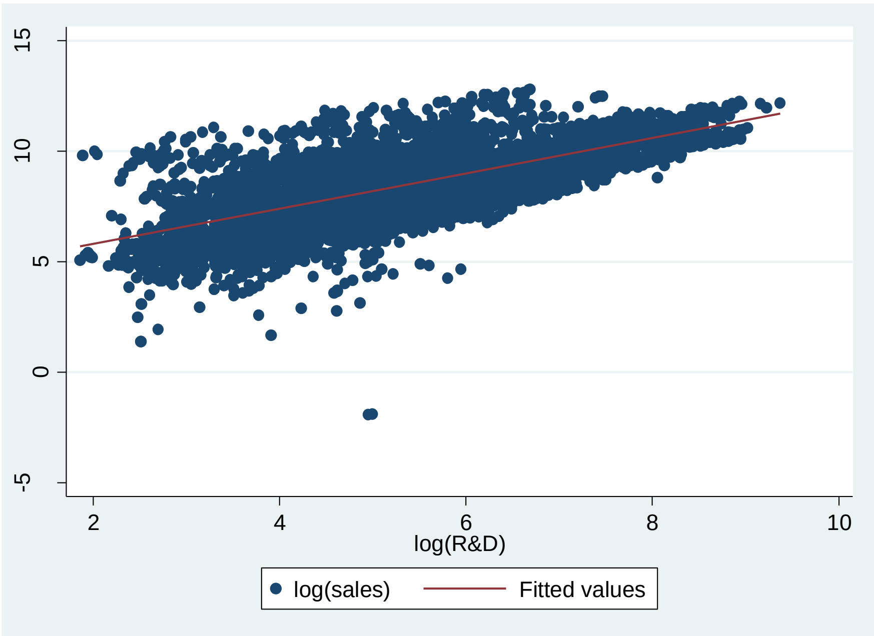

Figure 2: scatter plot, log (sales) x log (R&D).
Source: developed by the authors.

Discussion of the results with recent research

Since the contributions of Dosi (1982), the concept of "technological frontier" guided the development of studies that seek to analyze the most advanced economies conditioned the economic performance of the group "behind these frontiers." In this sense, the set of strategies that direct the demand for specifics investments became significantly influenced to the extent that we distinguish firms between more distant or closer to the frontiers.

Recent studies have shown this 'vector' of influence in different contexts of investments, especially highlighting the contributions of Coad (2008; 2011), Reinstaller and Unterlass (2012), Hall, Lotti and Mairesse (2013) and Hölzl and Janger (2014). Coad (2011) presented empirical evidence that firms located on the frontiers employ R&D resources more efficiently, generating significantly higher scores than the more distant firms.

As Hölzl and Janger (2014), perceived barriers to innovation is statistically higher for firms present in economies more distant from technological frontier. In this sense, at the same way that the percentage of innovative companies decreases with distance to the frontier, the relative number of companies that do not see importance to innovation increases.

The results corroborate with those presented evidence, since the most efficient firms and possibly operative in 'real' technology frontier demonstrate to use the R&D with greater leverage on the return in sales. This aspect may be related to the nature of the investment, since this can be more connected to the factors responsible for displacement of the frontiers. Thus, the furthest firms may have opportunity costs in the use of such investments, so that the eficient use of resource can be lower in relation to firms loccated on the frontier.

5. FINAL CONSIDERATIONS

This study examined the impact of investments in R&D in firms' sales, incorporating the efficiency effect on return of investment. Using a sample of 548 firms that invest in R&D in the world during 2003-2013, the results indicate that companies that operate in efficient levels of input-output have a higher return of such investments. To clarity these results, it was built efficiency scores from the Free Disposal Hull technical, as the 40 sectors in which the sample firms spread.

Interacting the calculated scores with investments in R&D, the results showed that the elasticity coefficients of firms on the frontier were significantly higher compared to inefficient firms. Controlling model through the effects of heterogeneity of the sample (fixed effects), the results showed gains that can be expressed as an increase in the elasticity coefficient of approximately 4% compared with the model that excludes it (Sargan-Hansen tests show that the fixed effects have correlatation with regressors).

These results can support important decisions in policies of Science & Technology, since the differences reflected between efficient and inefficient firms point to different results in the use of investments. This suggests that a policy implemented in the frontiers economies can not lead the same results in less developed economies.

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