The impact of financial constraints on tradable and non-tradable R&D investments in Portugal

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Abstract

We develop a directed technical change model with two sectors, tradable and non-tradable, and dynamic firms' decisions to invest in R&D in the presence of financial constraints. The model establishes a linkage between R&D decisions, product and process innovations, future productivity, profits, and credit constraints. The model is estimated using Portuguese firms' data of the tradable and non-tradable sectors. We find that the previous R&D investments raises the innovating probabilities, the innovating probabilities are higher in the tradable sector, and the startup costs of innovation tend to be higher than the maintenance costs. The results also show complementary between the R&D benefits and the firm's financial strength, diminishing marginal returns to capital on innovation benefits, and high heterogeneity of the innovation costs across industries. Finally, when the firms' financial strength and the trade-off between tradable and non-tradable goods are considered, the R&D benefits in the non-tradable sector do not compensate its cost given the higher productivity and innovation probabilities of the tradable sector. As a result, the R&D investments in the tradable sector illustrates a misallocation of financial resources.

keywords: Credit constraints, firm-level data, productivity, R&D, tradable and non-tradable goods.

JEL Classification: O31, O32.

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1 Introduction

Economic recessions are in general characterized by a strong reallocation process. On the one hand, inefficient firms are encouraged by the recession to reorganize their activity, innovate, reallocate their resources, search for new markets, or exit the market (Carreira and Teixeira, 2008, 2016). On the other hand, recessions are also periods in which the opportunity cost of long-term investments is less than in the boom periods, (Hall, 1993; Gali and Hammour, 1992; Bloom, 2007). These two effects during the economics recessions should lead to more efficient economies, more productive firms, and an increase in the R&D investment and economic growth.

To reorganize their activity and innovate, firms need funds. Firms' cash flows are usually insufficient and most firms need to borrow funds in the financial market. However, during economic recessions, the financial crisis tends to be more pronounced, the scarcity of funds is high, the liquidity is limited, and the cost of borrowing is also high. In other words, the access to financial funds by firms is more difficult, costly, and subject to tighter credit conditions. As a consequence, the firms' investment might decline leading to a more and deeper economic recessions. Thus, the firms' R&D investment choices are determined by opposite forces. The empirical evidence has shown that R&D investments might be pro-cyclical for firms with high financial constrains Aghion et al. (2012); Cerra and Saxena (2008); Abiad et al. (2009).

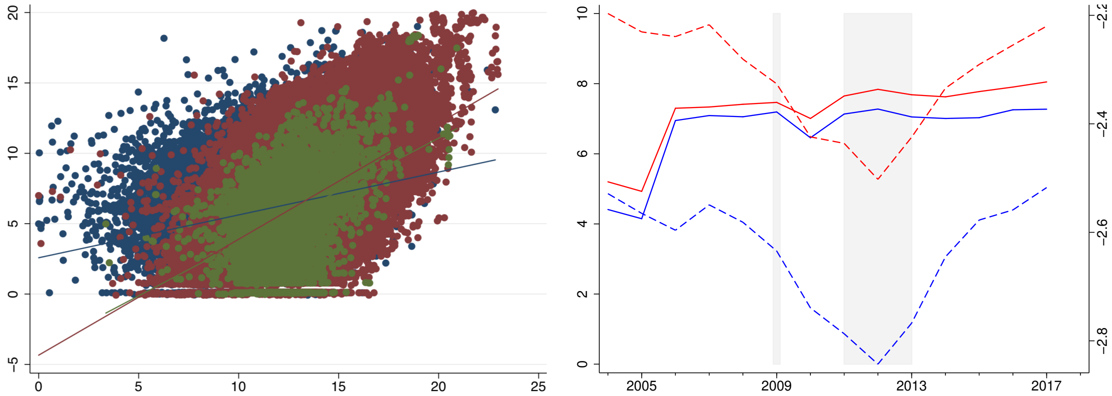
During the Portuguese economic recession of 2008-2013 associated to the financial crisis of 2008, the firms' investment in physical capital was clearly pro-cyclical. Additionally, the financial resources were directed to the non-tradable, further deepening the economic recession (Reis, 2013). That is, capital inflows were directed to unproductive firms in the non-tradable sector, lowering the economy productivity and economic growth.[1] Concerning the firms' investment in R&D, we did not find any empirical evidence about its dynamic or its direction in the literature.

Thus, we looked at the Portuguese firms' level data for the period 2004-2017. We found a positive relationship between the firms' revenues and their R&D investments, which is particularly strong for the financially constrained firms. The investment dynamics in both sectors was similar and procyclical over the business cycle although the non-tradable sector was subject to higher financial constraints. Regarding the direction of R&D investment, the R&D investment carried out by the tradable sector was greater than that made by the non-tradable sector, as well as its the long-run growth rate. Since 2006, the R&D investment in the non-tradable sector has diverged slightly from the R&D investment in the tradable sector.[2] In sum, in a first analysis when we look at the R&D investment by sector, we cannot state that, in terms of the R&D investments, the non-tradable sector took financial resources

[1] In an empirical research for the Portuguese economy, Reis (2013) investigates the behaviour of relative prices, exchange rate, sectors' productivity and other economic indicators for the tradable and the non-tradable sector during the period 2000-2007. Modelling the investment in physical capital as a function of a collateral credit constraint for the tradable and the non-tradable sector, his model replicates the behaviour of the indicators previously analyzed, concluding that capital inflows were directed to unproductive firms in the non-tradable sector. It is worth noting that Reis (2013) models investments in physical capital and considers the manufacturing sector as the tradable sector and the remaining sectors as the non-tradable sectors.

[2] This evidence related to the level of the R&D investment in the tradable and non-tradable was also found by Afonso and Magalhães (2018) using OECD data for the Portuguese economy.

Figure 1: R&D dynamics, firms' total revenue, and financial constraints



Notes: Figure (a): The firm's R&D expenditure (y-axis) and the firm's total revenue (x-axis) are presented in logs. The blue dots and line represent the highly financially constrained firms, the red dots and line represent the financially constrained firms, and the green dots and line represent the non-financially constrained firms. Firms belonging to the education, the public sector, and the health sector were excluded as well as firms with one or less workers. Figure (b): The (average) firm's R&D expenditure (y-axis and solid line) and the (average) firm's financial constraint level (secondary y-axis and dash line) are presented in logs for the tradable (red line) and the non-tradable sector (blue line). The shaded areas represent the periods in which the Portuguese economy had negative growth rates.

away from the tradable sector during the period 2004-2017 (Figure 1). However, a deeper analysis is need and it should be investigated the R&D investment, not only by sector, but also by the firm financial strength.

Thus, two questions arise and require a deep analysis. First, how did the financial constraints affect the Portuguese firms' R&D investment dynamics? That is, is the cyclicality of the investments in R&D of the Portuguese firms dependent on the firms' financial constraints level? Second, did the financial constraints cause a bias in the direction of R&D investment to the non-tradable sector, in particular, during the economic recession? To the best of our knowledge, no micro-economic evidence and explanation for these questions have been provided so far.

The goal of this paper is then to investigate how financial constraints affected the firms' R&D investments dynamics, and consequently, firms' innovation and productivity, in the tradable and non-tradable sectors in the Portuguese economy, in particular during the economic recession. To do that, we extend the firm's dynamic R&D decisions model of Aw et al. (2011) and Peters et al. (2018) by considering incomplete financial markets and the coexistence of production of tradable and non-tradable goods. R&D investments and innovation costs are linked through productivity. Innovating has an effect on the current firms' productivity and future productivity via productivity persistence. Thus, to invest in R&D, firms compare the expected long-run benefit of investing in R&D with the cost of innovating. When financial markets are incomplete, firms face financial constraints and the access to financial funds is constrained, thereby limiting the R&D investments and as a consequence the productivity growth. Simultaneously, financial constraints may influence the allocation of financial funds to less productive firms and bias the R&D direction from tradable to non-tradable sectors.

The model is estimated for the whole population of Portuguese firms from 2004-2017. The data used in this study were collected from the Enterprise Integrated Accounts System (EIAS) of Portugal and the Community Innovation Survey (CIS). Our empirical results show that, in general, previous R&D investments raise the innovating probabilities, which are slightly higher for the tradable sector. The tradable sector needs higher amounts of R&D investments relative to the non-tradable to innovate. The tradable sector's productivity essentially rises with the product innovations while the non-tradable productivity rises with the process innovations. Both sectors have, on average, higher startup costs of innovation than maintenance costs. The results also show a complementary relationship between the R&D benefits and the firm's financial strength, the existence of diminishing marginal returns to capital on innovation benefits, and high heterogeneity of the innovation costs across industries. Finally, this investigation demonstrates a bias of the R&D investment for the non-tradable sector. When the firms' financial strength is taken into account, as well as the trade-off between the tradable and the non-tradable goods, the R&D benefits in the non-tradable sector do not compensate the R&D investment cost in this sector. So the investment carried out in this sector illustrate a misallocation of financial resources.

The paper is organized as follows. Section 2 presents the model. Section 3 presents the data and variables used and their definitions. Section 4 presents the model estimates and main results. Section 5 concludes.

2 Model

This section describes a theoretical model of a firm's dynamic R&D decisions, in which financial markets are incomplete and the production of tradable and non-tradable goods coexist. The model abstracts from the enter and exit decision in production, as in Aw et al. (2011) and Peters et al. (2018), focusing on the R&D decision and the productivity evolution process. Firms are heterogeneous in the sense that both productivity and demand for goods are firm specific. Two extensions are considered to the Aw et al. (2011) and Peters et al. (2018) models. First, firms face credit constraints, as in Bianchi (2011). Second, two sectors coexist in this economy – tradable and non-tradable – and there is imperfect substitutability in production of tradable and non-tradable goods, as in Benigno et al. (2013).

Non-tradable goods are not exposed to international competition and the rise of non-tradable goods has been one of the main drivers of poor economies and external imbalances. Understanding how credit constraints and the imperfect substitutability between these two sectors affect the firm's decision of investing in R&D, the firm's future productivity, and bias the direction of technology change is crucial to improve economic growth and external balance.

2.1 Technology, production and profits

In this economy, and in line with Acemoglu (2009) and Acemoglu et al. (2012), the aggregate final good in period t (Y) is produced competitively under a Constant Elasticity of Substitution (CES) production function using as inputs tradable (T) and non-tradable (NT) goods[3]:

$$Y = \left(\varsigma_{\mathrm{NT}} Y_{\mathrm{NT}}^{\frac{\epsilon}{\epsilon-1}} + \varsigma_{\mathrm{T}} Y_{\mathrm{T}}^{\frac{\epsilon}{\epsilon-1}} \right)^{\frac{\epsilon-1}{\epsilon}}, \tag{1}$$

where Y_{T}, Y_{NT} are tradable and the non-tradable output in period t, ς_{T} and ς_{NT} are the distribution or intensity parameters illustrating the productivity or efficiency of tradable and non-tradable goods, respectively; and ϵ is the elasticity of substitution between the two goods with $\epsilon \in (0, +\infty)$. Thus, if $\epsilon > 1$ the two goods are gross substitutes, otherwise they are complements. By minimizing the production cost, we obtain the optimal demand function for T and NT goods:

$$Y_{\mathrm{T}} = \varsigma_{\mathrm{T}}^{\epsilon} \left(\frac{P_{\mathrm{T}}}{P} \right)^{-\epsilon} Y \quad \text{and} \quad Y_{\mathrm{NT}} = \varsigma_{\mathrm{NT}}^{\epsilon} \left(\frac{P_{\mathrm{NT}}}{P} \right)^{-\epsilon} Y, \tag{2}$$

where P is the price of the final good in period t and it is given by

$$P = \left(\varsigma_{\mathrm{NT}}^{\epsilon} P_{\mathrm{NT}}^{1-\epsilon} + \varsigma_{\mathrm{T}}^{\epsilon} P_{\mathrm{T}}^{1-\epsilon} \right)^{\frac{1}{1-\epsilon}}, \tag{3}$$

and P_{NT} and P_{T} are the prices of non-tradable and tradable goods in period t, respectively.

As illustrated by equation (2), the demand for tradable, T, and non-tradable goods, NT , are interdependent given that, due to the imperfect substitutability between them, they depend on the economy size, Y, and the aggregate price, P, which are a weighted average of the respective outputs and prices of tradable and non-tradable goods.

Tradable and non-tradable goods are produced by a continuum of monopolistic competitive firms. Following Dixit and Stiglitz (1977), the composite tradable and non-tradable good consists of a bundle of i varieties produced by each firm i as follows:

$$Y_{\mathrm{T}} = \left(\int_0^1 X_{\mathrm{T}}(i)^{\frac{\sigma_{\mathrm{T}}-1}{\sigma_{\mathrm{T}}}} di \right)^{\frac{\sigma_{\mathrm{T}}}{\sigma_{\mathrm{T}}-1}} \quad \text{and} \quad Y_{\mathrm{NT}} = \left(\int_0^1 X_{\mathrm{NT}}(i)^{\frac{\sigma_{\mathrm{NT}}-1}{\sigma_{\mathrm{NT}}}} di \right)^{\frac{\sigma_{\mathrm{NT}}}{\sigma_{\mathrm{NT}}-1}}, \tag{4}$$

where $X_{\mathrm{T}}(i)$ and $X_{\mathrm{NT}}(i)$ denote the i-variety of the tradable and non-tradable good in period t, respectively, and $\sigma_j > 0$ with $j = \mathrm{T}, \mathrm{NT}$ denotes the elasticity of substitution between the i-tradable or i-non-tradable variety, that is, the tradable and non-tradable within elasticity. Thus, the higher is σ_j, the higher is the substitutability between

[3] For simplification of the notation, variables that depend on time are not indexed unless it is strictly necessary.

the respective varieties.

The producer of the aggregate tradable and non-tradable good maximizes his profits solving the problem $Max_{X_j(i)} = P_jY_j - \left(\int p_j(i)X_j(i)di\right)$ subject to $Y_j = \left(\int_0^1 X_j(i)^{\frac{\sigma_j - 1}{\sigma_j}} di\right)^{\frac{\sigma_j}{\sigma_j - 1}}$, $j = \text{T}, \text{NT}$, where $p_j(i)$ is the price of the i-variety of tradable or non-tradable good. From the first-order conditions of this problem, we obtain the respective demand for the i-tradable and non-tradable variety:

$$X_{\text{T}}(i) = \left(\frac{p_{\text{T}}(i)}{P_{\text{T}}}\right)^{-\sigma_{\text{T}}} Y_{\text{T}} \quad \text{and} \quad X_{\text{NT}}(i) = \left(\frac{p_{\text{NT}}(i)}{P_{\text{NT}}}\right)^{-\sigma_{\text{NT}}} Y_{\text{NT}}, \tag{5}$$

and the respective prices by the application of the zero-profit condition:

$$P_{\text{T}} = \left(\int_0^1 p_{\text{T}}(i)^{1-\sigma_{\text{T}}} di\right)^{\frac{1}{1-\sigma_{\text{T}}}} \quad \text{and} \quad P_{\text{NT}} = \left(\int_0^1 p_{\text{NT}}(i)^{1-\sigma_{\text{NT}}}\right)^{\frac{1}{1-\sigma_{\text{NT}}}}, \tag{6}$$

where $p_j(i)$ with $j = \text{T}, \text{NT}$ is the price of the $X_j(i)$ variety.

By plugging equation (2) into equation (5) we obtain the demand for tradable and non-tradable i-variety in terms of the economy and sector's aggregate variables:

$$X_{\text{T}}(i) = \varsigma_{\text{T}}^{\epsilon}\left(\frac{P_{\text{T}}}{P}\right)^{-\epsilon}\left(\frac{p_{\text{T}}(i)}{P_{\text{T}}}\right)^{-\sigma_{\text{T}}} Y \quad \text{and} \quad X_{\text{NT}}(i) = \varsigma_{\text{NT}}^{\epsilon}\left(\frac{P_{\text{NT}}}{P}\right)^{-\epsilon}\left(\frac{p_{\text{NT}}(i)}{P_{\text{NT}}}\right)^{-\sigma_{\text{NT}}} Y. \tag{7}$$

Therefore, the i-firm's demand for $X_j(i)$ with $j = \text{NT}, \text{T}$ depends on: (i) the aggregate sector (tradable or non-tradable) price by P_j; (ii) the sector productivity or efficiency by ς_j; (iii) the economy aggregate price and output by P and Y, (iv) the substitutability between tradable and non-tradable goods by ϵ; (v) the i-variety price by $p_j(i)$, and (vi) the substitutability between the i varieties by σ_j. It is worth noting that by defining P and Y by equations (1) and (3), respectively, there is interdependence among firms belonging to the two different sectors.

To produce the $X_j(i)$-variety, firms use capital and labor, and their short-run (log) marginal production cost function is given by:

$$\ln mc(i) = \ln\, c\,(k(i), l(i)) - \omega(i) = \beta_0 + \beta_k \ln k(i) + \beta_l \ln l(i) + \beta_w \ln w - \omega(i), \tag{8}$$

where $k(i)$ and $l(i)$ are the amount of capital and labor used by firm i in period t, $w(i)$ is a vector of variable input prices common to all firms, and $\omega(i)$ is its productivity level.[4] The capital stock is treated as a fixed factor in the short run. Notice that each firm produces a single i-variety of the tradable or non-tradable good and, as illustrated by equation (8), the marginal cost of each i-variety is identical regardless of the sector to which it belongs. In this

[4]Other cost specifications could be considered. In this version we follow the Aw et al. (2011) and Peters et al. (2018) specifications.

context, the firms' cost heterogeneity arises from: (i) the firms' capital and labor stocks observed in the data; and (ii) the firms' productivity observed to firms but not in the data.

Assuming that firms of both tradable and non-tradable i-varieties operate in a monopolistically competitive market, they maximize their short-run profit taken as given $Y, P, P_j,\ j = \text{NT}, \text{T}$.[5] As a consequence, they set the price of their output in each market – tradable and non-tradable – equal to a mark-up over the marginal cost as follows:

$$\max_{p_j(i)} \pi_j(i) = \left(p_j(i) - mc_j(i)\right) X_j(i), \quad j = \text{NT}, \text{T}, \tag{9}$$

where $mc_j(i)$ is the marginal cost in period t defined in (8), and $p_j(i)$ is the optimal price of the i-variety in period t and defined as:

$$p_j(i) = \frac{\sigma_j}{\sigma_j - 1} mc_j(i), \quad j = \text{NT}, \text{T}. \tag{10}$$

By normalizing $P = 1$ and using the equations (2), (7), (10) we obtain the (logarithm) firms' optimal revenue in each market $j = \text{NT}, \text{T}$:

$$\begin{aligned} \ln r_j(i) = \left(1 - \sigma_j\right) \ln\left(\frac{\sigma_j}{\sigma_j - 1}\right) + \sigma_j \ln \varsigma_j + \frac{\epsilon - \sigma_j}{\epsilon} \ln Y_j + \frac{\sigma_j}{\epsilon} \ln Y + \\ \left(1 - \sigma_j\right)(\beta_0 + \beta_k \ln k(i) + \beta_l \ln l(i) + \beta_w \ln w - \omega(i)), \quad j = \text{NT}, \text{T}. \end{aligned} \tag{11}$$

The firms' total revenue depends on the industry aggregates by Y_j, ς_j, the firm-specific variables by $k(i), l(i)$, the input factor prices by $\omega(i)$, and the economy aggregates by Y. Comparing the firms' revenue heterogeneity to the firms' cost heterogeneity, the sector aggregate output, Y_j, introduces a sector heterogeneity in the total firms' revenue. In this way, firms' heterogeneity is driven by the firm and sector specific differences. It is worth mentioning that as Y is a CES aggregation of tradable and non-tradable goods, a firm's revenue depends on its own market conditions (T or NT) but also the other market conditions (NT or T). In particular, the higher is the substitutability among the i-varieties within each market relative to substitutability between tradable and non-tradable ($\frac{\sigma_j}{\epsilon}$), the higher is the economy size effect in the firm's revenue. It is also worth mentioning that the greater is the within substitutability relative to the between substitutability, the greater is the economy size effect and the smaller is the sector size effect on the firm's revenue. In sum, in case of a relative high substitutability across the i-varieties ($\frac{\sigma_j}{\epsilon} > 1$), the sector size has a negative-direct effect on firms' revenue, which is counterbalanced by a more than proportional economy size effect, probably due to the economy multipler effects. Yet, in case of a relative low substitutability across the i-varieties ($\frac{\sigma_j}{\epsilon} < 1$), although the direct sector size effect is positive, the sum of both economy and sector size effects on firms' revenue tends to be smaller than in the previous case.

Given the firms' demand and marginal cost functions, the firms' short-run profit in each period t is linked to firms'

[5] As in Aw et al. (2011); Peters et al. (2018), we abstract from enter or exit decisions and focus on investment decisions and the evolution of the productivity process.

revenue and given by:

$$\pi_j(i) = \frac{1}{\sigma_j} r_j(i)(Y, Y_j, k(i), l(i), \omega(i)). \tag{12}$$

The per-period firms' profit depends on firm specific features such as firms' productivity, capital, and labor stocks and it also depends on the economy and sector features, such as size and substitutability.

2.2 Productivity and R&D investments

Firms' productivity evolution is endogenously affected (and so profits) by the firms' choice of taking or not R&D investments. The link between R&D investment decisions and productivity, and as a consequence profits, is modeled in two steps. First step: the firm makes a discrete decision of investing in R&D in period t, that is, $rd_t(i) \in \{0,1\}$, and this affects the firm's probability of realizing a product or process innovation in period $t+1$, denoted by $z_{t+1}(i)$ and $d_{t+1}(i)$, respectively. Thus, if a product and/or process innovation occurs in the firm i in period $t+1$, $z_{t+1}(i)$ and/or $d_{t+1}(i)$ are equal to 1 and 0 otherwise. The linkage between R&D and innovation can therefore be represented by the cumulative joint distribution of product and process innovations conditioned on: (ii) whether or not the firm invested in R&D; and (ii) the sector the firm is in, that is, $F(z_{t+1}(i), d_{t+1}(i)|rd_t(i), I(f(i)))$, where $I(f(i))$ is a discrete variable equal to 1 if the firm i produces tradable goods and 0 otherwise. Thus, we expect that the higher is the investment in R&D carried out by firm i, the higher is its likelihood to innovate and this likelihood may differ between sectors.

Following Peters et al. (2018), we assume that R&D is a dynamic and discrete choice. In our data we also observe that the probability of a product and process innovation differs between firms that invest in R&D and firms that do not invest (see Table 5) and that fluctuations on the R&D expenditures have little effect on these probabilities. This evidence suggests the existence of two innovation regimes, firms that invest in R&D and firms that do not invest.. Additionally, measurement errors in the R&D level are greater than in the discrete R&D variable.[6] For these reasons, a discrete R&D variable is a robust indicator of firms' investment decisions and allows us to distinguish between firms that invest in R&D and firms that do not.

Second step: having defined the innovation probabilities by F-cdf, we model the link between R&D investments and productivity by $G(\omega_{t+1}(i)|\omega_t(i), z_{t+1}(i), d_{t+1}(i))$ cdf. We assume that firms' productivity is a stochastic variable that depends on the past productivity and current innovations. This formulation for firms' productivity is standard in the literature. It captures, on the one hand, the uncertainty underlying the effect of R&D investments on innovations and, on the other hand, the uncertainty underlying the contribution of an innovation on future productivity and profits. Process and product innovations may t have different impacts on future productivities because they flow through different channels on demand and cost sides. Additionally, product and process innovation probabilities may also differ. It is also allowed that firms' productivity vary according to the market in which

[6]See Mairesse et al. (2005) for discussion and evidence.

the firm operates. In this way, the evolution productivity process is defined by:

$$\omega_{t+1}(i) = \alpha_{j0} + \alpha_{j1}\omega_t(i) + \alpha_{j2}\omega_t^2(i) + alpha_{j3}\omega_t^3(i) + \alpha_{j4}z_{t+1}(i) + \alpha_{j5}d_{t+1}(i) + \alpha_{j6}z_{t+1}(i)d_{t+1}(i) + \varepsilon_{jt+1}(i), \tag{13}$$

where the parameters $\alpha_{jo},...,\alpha_{j5}$ differ with, j=NT,T.

The parameters α_{j1} and α_{j2} capture the productivity persistence over time, while the parameters α_{j3}–α_{j5} capture the effect of the different types of innovation on firms' productivity. The effect of these innovations on productivity, and therefore the productivity evolution process, can differ in the two markets, j = NT, T. The parameter ε_{jt+1} captures the stochastic nature of the productivity process and is treated as an $i.i.d.$ shock with mean zero and variance σ_j^2. Firms' investments in R&D face two sources of uncertainty. First, investments in R&D may or may not lead to innovations, and they are not a necessary condition to innovate. Second, the economic value of investments in R&D is uncertain. In sum, the impact of innovations on productivity and profits is unknown, stochastic, and it may differ between product and process innovations, and between sectors.

2.3 Dynamic R&D investment decisions

This section describes the firm's dynamic decision on whether or not to invest in R&D. Investments in R&D can increase firms' productivity and profits over time, but it is costly. The cost of innovating, and therefore, the cost of increasing the firm's productivity is firm specific. It depends on many factors, as for example, the type of project or projects, the firm's expertise in innovation, the firm's experience in R&D, the firm's capacity to access financial resources, the differences in technological opportunities, and so on (Peters et al., 2018). We assume that the innovation cost is an exponential distribution and its mean depends on firm's size, measured by the capital stock, k_{t-1}, and the previous R&D experience defined by variable rd_{t-1} equal to 1 if the firm invested in R&D in $t-1$ and 0 otherwise. The firm' innovation cost in period t, $C_t(i)$, is:

$$C_t(i) \sim \exp\left(\gamma^m rd_{t-1}(i)K_{t-1}(i) + \gamma^s\left(1 - rd_{t-1}(i)\right)K_{t-1}(i)\right) \leq \theta\pi_t(i), \tag{14}$$

where γ^m and γ^s reflects the maintenance cost and startup cost per unit of capital driving the mean distribution of the innovation cost. A firm with previous R&D experience has to pay the maintenance cost represented by a distribution with mean $\gamma^m K_{t-1}(i)$, while a firm with no previous R&D experience has to pay the startup cost represented by a distribution with mean $\gamma^s K_{t-1}(i)$. The innovation cost is observed by the firm before it makes its R&D investment decision. Due to financial constraints the innovation cost must be less than the θ proportion of its current profits. The parameter $\theta \in (0, 1)$ denotes the quality of the country's financial system. The lower θ is, the more financially constrained is the firm and its investments in R&D.

At the beginning of period t, the firm observes its current productivity level, $\omega_t(i)$, its short-run profit level,

$\pi_t(i)$, and the evolution process of innovation, F, and productivity, G, respectively. Then, at period t, the firm makes its decision about investing in R&D or not, $rd_t(i) \in \{0,1\}$, conditioned on the endogenous state variable $s_t(i) = \{rd_{t-1}(i), \omega_t(i)\}$. The firm maximizes the sum of future discounted expected profits, and its value function can be written as:[7]

$$\begin{aligned} V_j(s_t(i)) = \pi_j(\omega_t(i)) + & \\ & \int_{C_t(i)} \max_{rd\in\{0,1\}} \Big(\beta E_t V_j\left(s_{t+1}(i)|\omega_t(i), rd_t(i)=1\right) - C_t(i);\ \beta E_t V_j\left(s_{t+1}(i)|\omega_t(i), rd_t(i)=0\right)\Big) dC, \\ & j = \text{NT}, \text{T}. \end{aligned} \tag{15}$$

where β denotes the firm's discount factor and $E_t V_j$ denotes the expected future firm's value, which is defined over the future values of productivity and innovation:

$$\begin{aligned} E_t V_j(s_{t+1}(i)|\omega_t(i), rd_t(i)) = & \sum_{d,z} \int_{\omega} V_j(s_{t+1}(i)) dG(\omega_{t+1}(i)|\omega_t(i), d_{t+1}(i), z_{t+1}(i)) dF(d_{t+1}(i), z_{t+1}(i)|rd_t(i)), \\ & j = \text{NT}, \text{T}. \end{aligned} \tag{16}$$

According to equation (15), the firm compares the discounted expected value of future profits from investing, $\beta E_t V_j(s_{t+1}(i)|\omega_t(i), rd_t(i) = 1)$, net of the maintenance or startup cost with the discounted expected value of future profits from not investing, $\beta E_t V_j(s_{t+1}(i)|\omega_t(i), rd_t(i) = 0)$. That is,

$$\begin{aligned} \Delta EV_j(\omega_t(i)) \equiv & \beta E_t V_j\left(s_{t+1}(i)|\omega_t(i), rd_t(i) = 1\right) - \beta E_t V_j\left(s_{jt+1}(i)|\omega_{jt}(i), rd_t(i) = 0\right), \\ & j = \text{NT}, \text{T}. \end{aligned} \tag{17}$$

If the marginal benefit of investing in R&D, $\Delta E_t V_j(\omega_t(i))$, which give us the effect of R&D on the firm's future productivity, is greater than the innovation cost – maintenance or startup – and the innovation cost is lower than the firm's financial constraint, firm will decide to invest in R&D. Mathematically, this can be expressed as:

$$\Delta EV_j(\omega_t(i)) \geq C_t(i) \quad \& \quad C_t(i) \leq \theta\pi_t(i),\ j = \text{NT}, \text{T}. \tag{18}$$

This is the R&D investment condition used in the empirical model to explain the firm's R&D choice, and in particular, how the financial constraints determine the firm's R&D choice and bias the R&D investments direction from the tradable to the non-tradable sector.

[7] To simplify the notation, we omit the exogenous firm characteristics: capital stock, labor amount, factor prices, economy and sector sizes that also enter in the profit function and/or innovation cost. These variables also explain the dynamic R&D decisions but we have expressed this decision only in terms of the endogenous variables. In the empirical section we treat all of these variables as exogenous.

3 Data

3.1 Data, variables, and descriptive statistics

Two databases are used in this research. The firm's data are collected from the Enterprise Integrated Accounts System (EIAS). The EIAS is an annual census of Portuguese firms collected by the Portuguese National Statistical Institute since 2004, covering the entire population of firms – companies, sole proprietors, and independent workers – that carry out production activities of goods and/or services. It is based on information from firms' balance sheets and financial statements. It contains a large set of variables including production, sales, wage bill, total employment, capital stock, value added, investment, data of constitution, industry code, and location.

In this study we exclude independent workers, who clearly have different firm's characteristics, in particular in terms of funding production activities. Our sample covers the period 2004-2017 with firms of 38 different industries at the two-digit level as detailed in Table 11 in the Appendix. To classify industries into tradable and non-tradable we follow the recent methodology that looks at trade openness ratio (trade as percentage of output) as discussed in Zeugner (2013); Mano and Marola (2015). Gouveia et al. (2016) calculated the trade-to-output ratio (TOR) for each sector of the Portuguese economy during the period 2010-2013 and classified as tradable those sectors with a TOR greater than 10% and non-tradable otherwise. In this study, we follow the Gouveia's classification and classify as non-tradable: Water, sewerage, waste management and remediation activities; Construction; Wholesale and retail trade, repair of motor vehicles and motorcycles; Real estate activities; Social work activities; Arts, entertainment and recreation; and Other services activities. The sectors: Education, Public Sector, and Human health services were excluded of our sample. The remaining sectors are classified as tradable.[8]

From the EIAS database and for the empirical analysis we use the following firm-level variables: firm revenue, capital stock, labor, materials, R&D expenditure, innovation expenditures, and Earnings before interests, taxes, depreciations and amortizations (EBITDA). Firm revenue is measured as the total production. Capital stock is measured as the total assets.[9] Labor is measured as the number of workers/employees. Materials are defined as the cost of materials and services purchased, and the external supplies and services, which includes energy. The R&D expenditure is measured as the investment in intangible assets. Innovation expenditures are measured as the sum of the variables investments in intangible assets, investments in software programs, and investments in goodwill and industrial properties such as licenses, patents, and property rights.

As the EIAS database does not provide data on process and product innovations, we use a second database, the Community Innovation Survey (CIS). This survey is carried out every two years. In this study we use the surveys of 2004, 2006, 2008, 2010, 2012, 2014, and 2016. The surveys follow the OECD and Eurostat (2018), which provides the definition, the classification, and the measurement of innovation. The survey is distributed to a

[8]For additional details, see Table 11 in Appendix A.

[9]To eliminate outliers, we winsorize the capital stock at constant prices at the top and bottom 1% of its distribution within each year.

sample of firms which every year complete the questionnaire and return it by email. The sample is updated every two years in order to account for the entrance or exist of firms. The participation is voluntary and around 3500 Portuguese firms across all sectors have answered this questionnaire every year.[10]

The CIS database provides both input and output innovation measures such as the firm's expenditure on activities related to R&D (input) and data on the introduction of new products and processess (output). For the empirical analysis, we collect the output innovation measures. In particular, we collect two variables, one of which is related to the product innovations and the other to the process innovations. These variables are: INPDGD (firm has introduced a new product or product improvements) and INPSPD (firm has introduced a new production process or improvements). The first variable refers to product innovations while the second variable refers to process innovations. Both variables are binary and take the value 1 when there is a new product/process or improvement and 0 otherwise.

The GDP per economic activity was collected from the Portuguese INE (Statistics Portugal) at two-digit level and for the 38 economic activities (see table Table 11 in Appendix A). As direct information on financial constraints is not available, we follow the literature and use EBITDA as a proxy for the firm's financial constraint level (Crnigoj and Verbic, 2014; Helwege, 1999; Carreira et al.). Indeed, to account for differences in the firm' size, we compute the ratio EBITDA to liabilities. The lower this ratio is, the harder is the access to financial funds by firms, and the higher is the financial constraint.

All nominal variables are expressed in 2011 euros. To do that, we use different price indices. For the variables: capital stock, investment in intangible assets, investments in intangible assets, investments in software programs, and investments in goodwill and industrial properties we use the annual GDP deflator. For the variables: firms' total revenue and materials we use the annual producer price index (PPI) by economic activity at two-digit level. As there are no database with the PPI for all economic activities considered in our sample, we collected these data from different databases. We collected the PPI from: i) the FAO database for the agriculture, forestry and fishing sector; ii) the OECD database for the sector mining and quarrying sector; iii) the Eurostat database for the electricity, gas, steam and air-conditioning supply, and the water, sewerage, waste management and remediation activities sectors; iv) the Portuguese INE for manufacturing, construction, and most service sectors except for transportation, publishing, audiovisual and broadcasting activities, social work activities; arts, entertainment and recreation, and other services activities. For these sectors we used the respective consumer price index (CPI) collected from Pordata and OECD databases.

Table 1 and 2 provide summary statistics for our main variables, firms' total revenue, capital stock, number of workers, R&D expenditure, and product and process innovation rate by the financial constraint level for the tradable and the non-tradable sector, respectively. The statistics are also provided for different level of the financial constraint ratio (FC). We group firms into three categories, highly financially constrained firms if $FC \leq 0$, finan-

[10]In odd years only a short questionnaire with few questions are sent by firms. This limits the availability of the full CIS data at every two years.

cially constrained firms if $0 < FC < 0.5$, and non financially constrained firms if $FC > 0.5$. This firm' classification allows us to better understand how the financial constraints are affecting the different groups of firms within the tradable and the non-tradable sector. Also, it will be easier to understand whether the non-tradable sector is taking resources away from the tradable sector or not.

Table 1 shows that the highly financially constrained firms have the lowest total revenue and R&D expenditure of the tradable sector. However, in terms of labor and capital intensity, and product and process innovation rates, these firms have higher labor and capital intensive, and innovation rates than financially constrained firms, although lower than non financially constrained firms. It is also worth noting that the financially constrained firms have, on average, the highest total revenue, R&D expenditure, capital and labor intensity, and innovation rates. The non financially constrained firms tend to be small in terms of labor and capital intensity, having the lowest innovation rates despite presenting a moderate effort in terms of R&D expenditures. Regarding the effects of financial constraint on R&D investments, we should particularly care about the financially constrained and highly financially constrained firms. Note that the former have the highest innovation' rates of the tradable sector while the latter the highest innovation' rates per dollar invested in R&D of the tradable sector.

Table 1: Descriptive statistics for tradable sectors by financial constraints level, average 2004-2017

FC	**Statistics**	**Total revenue**	**Capital stock**	**Number of workers**	**R&D expenditure**	**Product Innovation**	**Process Innovation**
$FC \leq 0$	Obs.	431868	443236	443236	443236	4545	4545
	Mean	442.769	2804.687	8.519	8.343	0.210	0.211
	SD	20971.890	1.27e+05	53.377	578.490	0.407	0.408
$0 < FC < 0.5$	Obs.	1032420	1032563	1032563	1032563	28686	28686
	Mean	1732.318	2913.800	17.673	25.341	0.301	0.318
	SD	36561.208	78845.444	125.205	1845.432	0.459	0.466
$FC \geq 0$	Obs.	45763	46766	46766	46766	1969	1969
	Mean	741.333	420.849	6.995	13.904	0.181	0.209
	SD	13418.921	8937.959	34.829	973.904	0.385	0.407
Total	Obs.	1510051	1522565	1522565	1522565	35200	35200
	Mean	1333.480	2805.465	14.680	20.041	0.282	0.298
	SD	32334.262	94277.958	107.317	1560.837	0.450	0.457

Notes: Market revenue, capital stock, and R&D expenditures are measured in thousand euros.

Table 2 shows that the highly financially constrained firms have, on average, the lowest total revenue of the non-tradable sector, but in terms of R&D expenditure, labor and capital intensity, and product and process innovation rates they have a moderate position, occupying the second position within the non-tradable sector. Yet, the non financially constrained, despite doubling the total revenue of the highly financially constrained firms, tend to be the smallest in terms of capital and labor intensity, presenting the lowest R&D effort and innovation rates. On the contrary, the financially constrained firms have the highest total revenue, labor and capital intensity, R&D investment and innovation rates of the non-tradable sector. Regarding the effects of financial constraint on R&D investments, we should particularly care about the financially constrained and highly financially constrained firms.

Nevertheless, note that within the non-tradable sector, the non financially constrained firms have the highest innovation rate per euro invested in R&D. Thus, it is also relevant to investigate why highly financially constrained and financially constrained firms have relatively high levels of R&D.

Table 2: Descriptive statistics for non-tradable sectors by financial constraints level, average 2004-2017

FC	**Statistics**	**Total revenue**	**Capital stock**	**Number of workers**	**R&D expenditure**	**Product Innovation**	**Process Innovation**
$FC \leq 0$	Obs.	385927	401423	401423	401423	835	835
	Mean	215.184	1090.943	5.767	3.221	0.164	0.101
	SD	2758.505	11293.226	22.775	400.117	0.371	0.301
$0 < FC < 0.5$	Obs.	963875	963904	963904	963904	6575	6575
	Mean	766.576	1898.949	11.060	11.155	0.238	0.173
	SD	10808.256	23628.816	120.070	952.493	0.426	0.378
$FC \geq 0.5$	Obs.	26496	28048	28048	28048	68	68
	Mean	467.389	247.945	5.632	0.529	0.103	0.118
	SD	9659.839	4224.936	14.803	25.626	0.306	0.325
Total	Obs.	1376298	1393375	1393375	1393375	7478	7478
	Mean	606.201	1632.933	9.426	8.655	0.228	0.164
	SD	9263.033	20579.291	100.663	820.828	0.420	0.370

Notes: Market revenue, capital stock, and R&D expenditures are measured in thousand euros.

Thus, when we consider the firms' financial constraint level, the evidence suggests that the misallocation of funds may be a reality. On one hand, the tradable sector needs higher amounts of R&D to innovate, which may lead the financial resources to the non-tradable sector. On the other hand, within the non-tradable sector, the highly financially and financially constrained firms have relatively high levels of R&D when weighted by innovation rate per euro, suggesting that those firms are taking resources away from firms of the tradable sector.

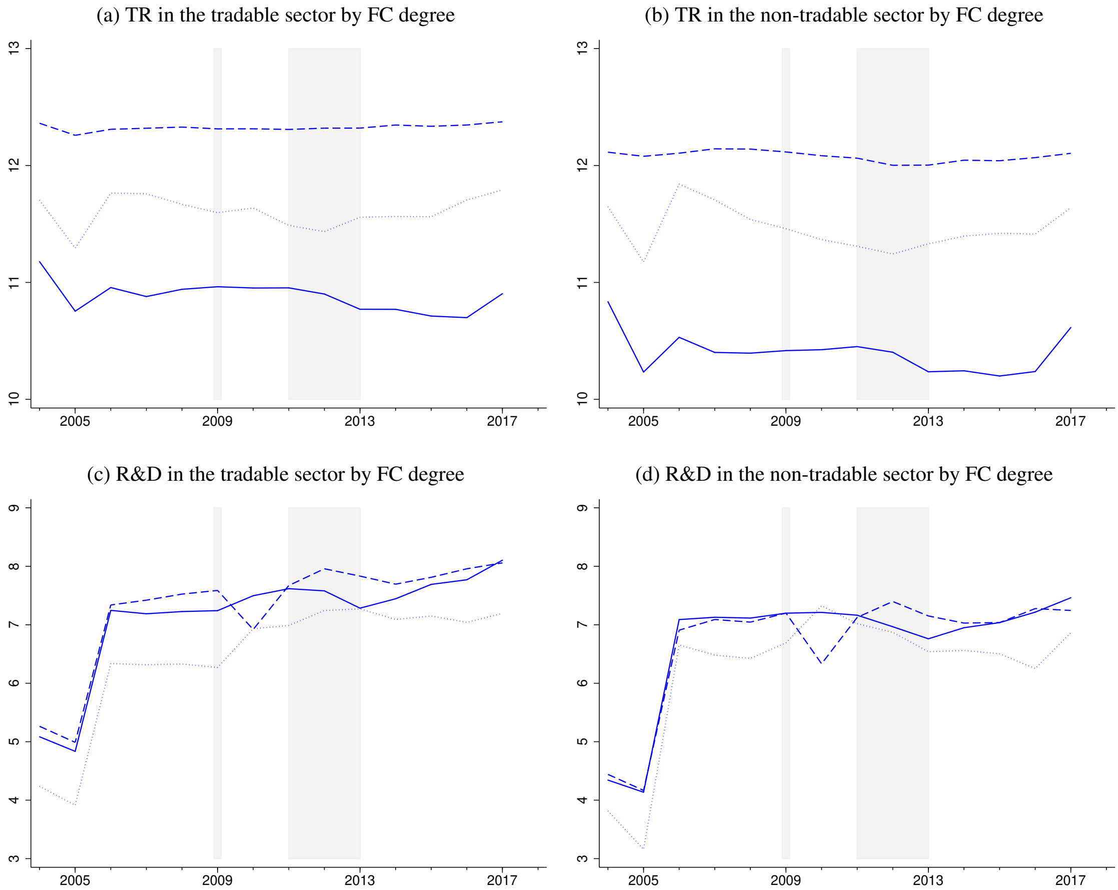
The dynamics of the firms' total revenue and the R&D investment during the period 2004-2017 also reinforce the same conclusion. The total revenue decline is greater in the non-tradable sector than in the tradable one (see Figure 2). Indeed, in the tradable sector, the financially constrained firms kept their total revenue constant even during the economic recession. Yet the dynamics of the R&D investment are identical in both sectors, except for the non financially constrained firms. The non financially constrained firms presented a better behaviour in the tradable than in the non-tradable sector, in particular, during the economic recession of 2010-2013 with a countercyclical dynamic.[11] The financially constrained firms presented a mixed behaviour in both sectors. That is, the dynamics of the R&D investment is countercyclical up to half of the economic recession and, afterward, pro-cyclical. As the total revenue of the financially constrained firms in the tradable sector kept constant over the economic recession, the R&D investment decline in the middle of the economic recession suggests scarcity and bias of the financial resources to non-tradable sector.

Within the non-tradable sector, there is also evidence of a resources bias in favor of highly financially constrained firms. For example, from 2005-2010, highly financially constrained firms had greater levels of R&D than the

[11]This evidence was also found by Aghion et al. (2012) for French firms.

financially constrained firms. Note that in the tradable sector we observe the opposite, suggesting that the highly financially constrained firms in the non-tradable sector are taking financial resources away from other firms within the sector or from firms of the other sector.

Figure 2: Total revenue (TR) and R&D dynamics for tradable and non-tradable sectors by financial constraint level (FC)



Notes: Solid line denotes highly financially constrained firms, dashed line denotes financially constrained firms, and dotted line denotes non financially constrained firms. Total revenue (TR) and R&D are presented in logs. Shaded areas represent the periods in which the Portuguese economy had negative growth rate.

4 Empirical model and estimation

4.1 Innovation and productivity evolution estimates

In this section we explain how we use the EIAS data to estimate the relationship among the firms' revenue, the innovation probability, and between innovation-productivity. The model detailed in Section 2 is estimated using firm-level panel data on tradable and non-tradable market revenue, capital stocks, labor, variable costs, discrete R&D decisions, and innovation probabilities.[12] To better understand the differences in the relationships between the relationship among the firms' revenue, the innovation probability, and between innovation-productivity for

[12]Please note that in the model we assume that firms produce tradable or non-tradable goods but not both goods simultaneously.

tradable and non-tradable sector, we should look at the diversity within each sector.

Table 3: Total Revenue by industry

Economic Activity	Abreviation	r_{ti} share			r_{ti} growth rate		
		2004	2008	2016	2004-08	2008-12	2012-16
Tradable							
01-03	Agriculture	0.011	0.012	0.019	0.064	0.014	0.067
05-09	Mining	0.003	0.005	0.004	0.177	-0.044	-0.032
10-12	Food	0.041	0.059	0.066	0.125	-0.008	0.003
13-15	Textile	0.052	0.034	0.045	-0.077	-0.012	0.053
16-18	Wood	0.027	0.030	0.035	0.055	-0.007	0.015
19	Coke	0.003	0.049	0.045	1.078	0.016	-0.071
20	Chemical	0.015	0.003	0.004	-0.299	0.017	0.014
21	Pharmaceutical	0.010	0.004	0.005	-0.172	0.022	-0.014
22-23	Rubber	0.070	0.033	0.034	-0.146	-0.045	0.018
24-25	Metals	0.027	0.038	0.037	0.115	-0.051	0.015
26	Computers	0.009	0.010	0.009	0.059	-0.134	0.067
27	Electrical	0.011	0.012	0.012	0.058	-0.010	-0.014
28	Machinery	0.013	0.010	0.011	-0.035	-0.053	0.049
29-30	Transports	0.016	0.027	0.037	0.162	-0.002	0.047
31-33	Furniture	0.026	0.016	0.018	-0.092	-0.047	0.041
35	Electricity	0.008	0.059	0.053	0.670	-0.019	-0.041
49-53	Transportation	0.066	0.076	0.083	0.063	-0.012	0.000
55-56	Accommodation	0.028	0.031	0.043	0.055	-0.044	0.092
58-60	Publishing	0.019	0.042	0.010	0.251	-0.280	-0.052
61	Telecommunication	0.009	0.001	0.025	-0.348	0.968	-0.003
62-63	Programming	0.028	0.012	0.017	-0.161	0.010	0.038
64-66	Finance	0.032	0.001	0.000	-0.589	-0.081	-1.000
69-71	Consultancy	0.022	0.030	0.033	0.110	-0.008	0.003
72	Scientific R&D	0.005	0.001	0.001	-0.372	-0.011	0.100
73-75	Advertising	0.028	0.012	0.011	-0.159	-0.091	0.029
77-82	Administrative	0.026	0.040	0.044	0.147	-0.044	0.033
90-93	Arts	0.007	0.007	0.009	0.037	-0.044	0.076
94-96	Other Serv.	0.004	0.004	0.005	-0.005	-0.037	0.051
Sum/mean		0.632	0.658	0.717	0.037	-0.023	0.010
Non-tradable							
36-39	Water	0.008	0.010	0.014	0.106	0.025	0.011
41-43	Construction	0.121	0.145	0.073	0.074	-0.133	-0.061
45-47	Wholesale	0.150	0.137	0.144	0.004	-0.049	0.028
68	Real State	0.024	0.026	0.020	0.047	-0.155	0.069
87-88	Social	0.004	0.001	0.002	-0.290	0.066	0.062
Sum/mean		0.338	0.319	0.252	0.013	-0.089	-0.001

Table 3 presents some statistics for the firms' market revenue within each sector (tradable and non-tradable) and its evolution. Columns 2-4 show the total revenue share by economic activity in total revenue in 2004, 2008, and 2016, respectively. Columns 5-7 show the average growth rate of the market revenue by sector for the periods 2004-08, 2008-12, and 2012-2016, respectively. The firms' market revenue shows a weak or even negative growth over the period in analysis. In particular, during the period 2008-2012 in which the firms' market revenue fell by 2.3% in the tradable sector and 8.9% in the non-tradable sector. From 2012 to 2016, the tradable sector showed a recovery process growing, on average, at 1.% per year pulled up by the strong growth in some sectors, such as Scientific R&D, accommodation, and computers. The non-tradable sector continued a downward trend during this period. This sector's dynamics led to a loss of importance of the non-tradable sector in the Portuguese economy, representing in 2016 just 25.2% of the Portuguese firms' market revenue.

With respect to the probabilities of innovation, we collect the output innovation variables of the CIS database as explained in Section 3. The CIS database covers a sample of firms, and not all firms as the EIAS database. To obtain the innovation rates for the all firms population we follow Baumann and Kritikos (2016); Hall et al. (2009) and estimate what is termed in the literature as the CDM model, i.e., the extended knowledge production function. The CDM model estimates the relationship between the innovation inputs, the innovation outputs, and the productivity in three steps. As we are interested in the relationship between the innovation inputs and outputs, and as we use the EIAS database to find the firms' R&D intensity (innovation input), we focus on the second step of the CDM models.[13] In this context, we assume that the product, z_i and process, d_i, innovation rates can be defined in the following way:

$$\begin{cases} z_i & = \gamma_1 ie_i + \gamma_2 Z_i' + u_{1i} \\ d_i & = \gamma_1 ie_i + \gamma_2 Z_i' + \gamma_3 ii_i + u_{2i}, \end{cases} \tag{19}$$

where ie_i is the i-firm's R&D intensity, Z_i' is the vector with i-firm's knowledge explained variables, ii_i is the i-firm's investment intensity, and u_{1i} and u_{2i} are the error terms.

The R&D intensity, ie_i, is proxied by intensity of innovation expenditures relative to firm's total investment, which according to the OECD and Eurostat (2018) can be understood as a measure of success of innovative activities. Still according the OECD and Eurostat (2018), the total innovation expenditures includes the internal and external R&D spending, purchases of machinery, and software for innovation projects, purchases of other external knowledge such as patents, licenses, and similar intellectual property rights activities related to new product introduction, as well as costs for training employees related to innovation projects. The intensity of innovation expenditures available in our database are: (i) investments in intangible assets; (ii) investments in software programs; and (iii) investments in goodwill and industrial properties such as licenses, patents, and property rights. The firm's total investments in our data includes besides the innovation expenditures, the investments in tangible assets.

The knowledge explained variables, Z_i', is proxied by the number of workers assuming a positive relationship between both of them as in Baumann and Kritikos (2016).[14] Finally, the investment intensity, ii_i, is proxied by the sum of investments in tangible and intangible assets relative to the total assets.

Then, we estimate an augmented CDM model through the bivariate Probit model to account for the interdependence between the probability of product and process innovations. Additionally, we added the discrete variable $r\&d_{it-1}$ to control for the effect of the previous R&D in the innovation probabilities. This discrete variable $r\&d_{it-1}$ takes the value 1 if the firm's R&D expenditure was positive in $t-1$ and 0 otherwise. The estimate results are in Table 4. Column 2 presents the estimate results for product innovations, and column 3 presents the estimate results for process innovation. First, all variables are statistically significant and show a positive relationship between them and the product and process innovation probabilities, even when controlling for sector

[13]See Baumann and Kritikos (2016); Hall (2011) for additional details on CDM models.
[14]Ideally, worker's skills or age should also be considered, but the EIAS does not include that information.

and time effects. Second, and most important, the relationship between the innovation probability and the R&D intensity, the firm's knowledge, and the firm's investment intensity is nonlinear. That is, the innovation probability increases with the R&D intensity, the firm's knowledge, and the firm's investment intensity, but at decreasing growth rates.

Table 4: Bivariate Probit estimations for the product and process innovation probabilities

	z_i	d_i
ie_i	1.423***	0.849***
	(10.77)	(6.22)
Z'_i	0.000395***	0.000537***
	(10.68)	(13.55)
ii_i		2.339***
		(3.68)
ie_i^2	-1.422***	-1.070***
	(-9.41)	(-6.70)
Z'^2_i	-0.000***	-0.000***
	(-7.77)	(-10.73)
ii_i^2		-2.804***
		(-2.24)
$r\&d_{it-1}$	0.248***	0.225***
	(14.08)	(12.57)
Sector-effects	✓	✓
Time-effects	✓	✓
ρ		0.828***
		(68.95)
P values for Wald-test		0.000
Sample-Size		31648

Notes: Robust standard errors in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

By using the estimate results shown in Table 4, we predict the product and process innovation probabilities for the firms' population at each period t conditional on the firm's prior-period R&D investment, that is, $F(z_{t+1}(i), d_{t+1}(i)|rd_t(i), I(f(i)))$ for each firm i.

The (conditional) innovation probabilities for the 38 economic activities considered in this study are reported in Table 5. Columns 2 and 3 report the probability of not innovating or innovating if the firm does not invest in R&D in the previous period, while columns 4 and 5 report identical probabilities if the firm invests in R&D in the previous period.

On average, tradable firms have a probability of not innovating that varies between 33.6% and 86.6% when they have no previous R&D experience, and a probability that varies between 23.6% and 83.4% when they have previous R&D experience. For the non-tradable sectors these probabilities vary between 34% and 85.5% and between 25.2% and 79.1%, respectively. Differences in the innovation rates between tradable and non-tradable sectors suggest the difficulty to innovate in the non-tradable sector.

As concluded previously, innovation is easier for tradable firms. Regarding the previous R&D experience, it seems that the previous R&D effort pays off, in particular, for the simultaneous product and process innovations and the tradable sector. Among the three possible innovation combinations, the most common is when $z = 1$ and $d = 1$ with higher innovating probabilities in the tradable activities, suggesting easiness for simultaneous innovations, which we associate to better efficiency of the financial resources invested in R&D expenditures.

Table 5: Predicted Innovation probability conditioned on past R&D: $F(z_{t+1}(i), d_{t+1}(i)|rd_t(i), I(f(i)))$

		rd_t=0				rd_t=1			
		z=1	z=1	z=0	z=0	z=1	z=1	z=0	z=0
NACE codes	Abbreviation	d=1	d=0	d=1	d=0	d=1	d=0	d=1	d=0
Tradable									
01-03	Agriculture*	0.397	0.135	0.126	0.343	0.497	0.133	0.115	0.254
05-09	Mining	0.400	0.135	0.125	0.340	0.504	0.134	0.113	0.249
10-12	Food	0.185	0.109	0.116	0.591	0.266	0.127	0.123	0.484
13-15	Textile	0.133	0.068	0.137	0.662	0.202	0.085	0.153	0.559
16-18	Wood	0.161	0.066	0.163	0.611	0.233	0.078	0.178	0.511
19	Coke	0.265	0.182	0.081	0.472	0.375	0.196	0.079	0.350
20	Chemical	0.133	0.076	0.124	0.667	0.205	0.096	0.140	0.559
21	Pharmaceutical	0.268	0.158	0.098	0.476	0.387	0.175	0.092	0.345
22-23	Rubber	0.228	0.124	0.117	0.531	0.323	0.139	0.120	0.419
24-25	Metals	0.184	0.081	0.150	0.584	0.265	0.095	0.160	0.479
26	Computers	0.325	0.144	0.115	0.416	0.445	0.151	0.107	0.298
27	Electrical	0.348	0.154	0.108	0.390	0.470	0.157	0.098	0.275
28	Machinery	0.270	0.162	0.095	0.473	0.373	0.177	0.092	0.358
29-30	Transports	0.281	0.096	0.163	0.460	0.407	0.101	0.159	0.333
31-33	Furniture	0.206	0.137	0.099	0.558	0.290	0.156	0.102	0.451
35	Electricity	0.044	0.023	0.111	0.822	0.095	0.038	0.149	0.718
49-53	Transportation	0.041	0.062	0.042	0.855	0.072	0.087	0.056	0.786
55-56	Accommodation	0.010	0.003	0.101	0.886	0.019	0.005	0.141	0.834
58-60	Publishing	0.104	0.116	0.064	0.716	0.173	0.153	0.075	0.599
61	Telecommunications	0.113	0.097	0.085	0.706	0.238	0.125	0.101	0.536
62-63	Programming	0.175	0.121	0.099	0.605	0.266	0.144	0.108	0.482
64-66	Finance	0.060	0.063	0.067	0.810	0.144	0.089	0.086	0.681
69-71	Consultancy	0.063	0.041	0.104	0.792	0.105	0.058	0.128	0.710
72	Scientific R&D	0.216	0.100	0.139	0.545	0.342	0.119	0.142	0.398
73-75	Advertising	0.077	0.048	0.111	0.764	0.126	0.066	0.135	0.674
77-82	Administrative*	0.405	0.134	0.125	0.336	0.516	0.132	0.111	0.242
90-93	Arts*	0.399	0.135	0.125	0.341	0.508	0.133	0.113	0.246
94-96	Other Serv.*	0.398	0.135	0.125	0.342	0.519	0.136	0.108	0.236
Average		0.203	0.100	0.107	0.589	0.299	0.117	0.117	0.467
Non-tradable									
36-39	Water	0.080	0.035	0.146	0.739	0.135	0.050	0.175	0.640
41-43	Construction	0.040	0.033	0.077	0.850	0.065	0.045	0.098	0.791
45-47	Wholesale	0.067	0.127	0.035	0.771	0.108	0.167	0.042	0.683
68	Real State*	0.398	0.135	0.125	0.341	0.499	0.135	0.113	0.252
87-88	Social*	0.399	0.135	0.125	0.340	0.501	0.133	0.115	0.252
Average		0.197	0.093	0.102	0.608	0.262	0.106	0.109	0.524

Notes: The estimates for the "" sectors are based on a smaller number of observations and, essentially, predicted by the firm's explanatory variables for innovation. As it was difficult to compare the predictions with real data, we should be careful with their interpretation, which does not occur with the remaining sectors.*

In Section 2, we define the firm's incentive to invest in R&D and show that it depends on ΔEV, equation (17). It must be greater than the innovation cost and, in the presence of credit constraints, this cost can not be greater than a share θ of the firm's profits (equation (18)). Focusing on the first condition of firm's incentive to invest in R&D, i.e., on the difference of innovation rates when firms invest or not in R&D, $(F(z_{t+1}(i), d_{t+1}(i) = 1|rd_t(i) = 1, I(f(i))) - F(z_{t+1}(i), d_{t+1}(i) = 1|rd_t(i) = 0, I(f(i))))$, the probability of a product and/or process innovation increases, on average, by 12.2 and 8.4 percent points for tradable and non-tradable firms, respectively. There is a benefit of carrying out R&D, slightly higher for tradable firms, although it may be weaker than expected when compared to other countries, as, for example, Germany Peters et al. (2017). This may suggest that there are other channels affecting the innovation probabilities for thePortuguese economy besides the R&D investments.[15]

Next, we investigate the relationship between innovation and productivity. To do that, we first estimate the firm's productivity, in contrast to the firm's sales, costs, or capital stocks, firm's productivity is not directly observed from the data. To estimate the productivity we follow Olley and Pakes (1996); Aw et al. (2011) and rewrite it in terms of observed variables that are correlated with it.

As the firm's demand for inputs depends on productivity level, we can write the productivity level conditional on the capital stock and labor as a function of the variable inputs levels $\omega(k_{it}, l_{it}, m_{it}, n_{it})$, where m_{it} and n_{it} denote materials and electricity, respectively. Thus, we use the expenditure on materials and electricity borne by firms to control for the productivity in equation (11). By rewriting equation (11) we obtain:

$$\ln r_j(i) = \left(1-\sigma_j\right)\ln\left(\frac{\sigma_j}{\sigma_j-1}\right) + \sigma_j \ln \varsigma_j + \frac{\epsilon-\sigma_j}{\epsilon}\ln Y_j + \frac{\sigma_j}{\epsilon}\ln Y + \sum_{t=1}^{T}\gamma_t D_t$$
$$\left(1-\sigma_j\right)\beta_0 + h(k_{it}, l_{it}, m_{it}, n_{it}) + u_{it}, \quad j = \textsc{nt}, \textsc{t}, \tag{20}$$

where the function $h(k_{it}, l_{it}, m_{it}, n_{it}) = \left(1-\sigma_j\right)(\beta_k \ln k_{it} + \beta_l \ln l_{it} - \omega_{it})$ captures the combined effect of capital, labor, and productivity in the total revenue. As in Aw et al. (2011) the market-level factor prices are captured by a set of time dummies D_t. As the firm's productivity in unobserved, we approximate $h(\cdot)$ with a cubic function of its arguments and cross-products. On the other hand, as the coefficient of the variables of Y_j with $j = \textsc{nt}, \textsc{t}$ and Y are related, to avoid multicolineariety problems and ensure that the sum of the respective coefficients is one, as predicted by the model, we transform the estimated equation without changing the coefficients we are interested in:

$$\ln \frac{r_j}{Y_j}(i) = \left(1-\sigma_j\right)\ln\left(\frac{\sigma_j}{\sigma_j-1}\right) + \sigma_j \ln \varsigma_j + \frac{\sigma_j}{\epsilon}\ln\frac{Y}{Y_j} + \sum_{t=1}^{T}\gamma_t D_t$$
$$\left(1-\sigma_j\right)\beta_0 + h(k_{it}, l_{it}, m_{it}, n_{it}) + u_{it}, \quad j = \textsc{nt}, \textsc{t}. \tag{21}$$

We estimate equation (21) with ordinary least squares and obtain the estimate of $h(\cdot)$ denoted by $\hat{\phi}$, which is an estimate of $\left(1-\sigma_j\right)(\beta_k \ln k_{it} + \beta_l \ln l_{it} - \omega_{it})$.

The estimate results from equation 21 are presented in Table 6. The first observation is that the model explains more than 62% of the market revenue variation for both tradable and non-tradable sectores. The second observa-

[15]The New Econometric Model of Evaluation by Sectoral Interdependency and Supply (NEMESIS) used by European Commission considers other channels, such as Information and Communication Technologies (ICT), investments in Other Intangibles (OI), knowledge spillovers, human capital knowledge externalities for R&D, network externalities of ICT and OI (Dosso et al., 2015).

tion is that all variables are statistically significant and that the estimate coefficient for $\frac{Y}{Y_j}$ has a positive sign in all presentations as predicted by the model (see equation 20), except in the tradable sector with sector-effects, i.e., industry effects.[16] This result illustrates that, for the tradable sector, the world economy's dynamic is relatively more important than the size and dynamic of the national economy due to international competition.

By looking at the last two columns in more detail, we observe that the greater is the economy relative to the size of the sector, the greater is the non-tradable firm's revenue. As this positive effect is greater than one, there is a greater facility of substitution within the non-tradable goods than between the tradable and non-tradable goods. For the tradable sector, the relative size of the economy is not statistically significant.[17]

Regarding the input factors estimates, labor, capital, and materials have a positive and statistically significant effect in both sectors. All factor's contribution to the firms' revenue is greater in the non-tradable sector, being labor the input factor with the highest contribution.

Once we have obtained the estimate of $\hat{\phi}$ from equation (21), we can generate the productivity series for each firm.[18] That is, we first substitute ω_{it} as $\omega_{it} = -\frac{\hat{\phi}_{it}}{1-\sigma_j} + \beta_k \ln k_{it} + \beta_l \ln l_{it}$ into equation (13) and rewrite the productivity process equation as a function of $\hat{\phi}, k_{it,it}, l_{it}, d_{it}, z_{it}$ and σ_j as follows:

$$\begin{aligned}\hat{\phi}_{it} =& \left(1-\sigma_j\right)(\beta_k \ln k_{it} + \beta_l \ln l_{it}) - \left(1-\sigma_j\right)\alpha_o + \alpha_1\left(\phi_{it-1} - \left(1-\sigma_j\right)\beta_k \ln k_{it-1} - \left(1-\sigma_j\right)\beta_l \ln l_{it-1}\right) \\ &- \left(1-\sigma_j\right)\alpha_2\left(\frac{\hat{\phi}_{it-1}}{1-\sigma_j} - \beta_k \ln k_{it-1} - \beta_l \ln l_{it-1}\right)^2 \\ &+ \left(1-\sigma_j\right)\alpha_3\left(\frac{\hat{\phi}_{it-1}}{1-\sigma_j} - \beta_k \ln k_{it-1} - \beta_l \ln l_{it-1}\right)^3 \\ &- \left(1-\sigma_j\right)(\alpha_4 z_{it} + \alpha_5 d_{it} + \alpha_6 z_{it} d_{it}) - \left(1-\sigma_j\right)\varepsilon_{it} + v_{it}. \end{aligned} \tag{22}$$

Next, we estimate the equation (22) with nonlinear least squares method. Given the estimate of $\hat{\sigma_j}$ we obtain the estimates for α, β. and ε. Afterwards, we construct the estimate of productivity for each observation ω_{it} as follows:

$$\hat{\omega}_{it} = -\frac{\hat{\phi}_{it}}{1-\hat{\sigma_j}} + \hat{\beta}_k \ln k_{it} + \hat{\beta}_l \ln l_{it}. \tag{23}$$

Notice that the estimate of $\hat{\sigma_j}$ is obtained from the estimate coefficient of $\ln \frac{Y_j}{Y}$ in equation (20) once we know the elasticity of substitution between tradable and non-tradable, ϵ. To estimate the elasticity of substitution between

[16]Recall that both within and between elasticities, σ_j and ϵ, are by definition greater than zero.

[17]For the next steps, and following Aw et al. (2011), we will consider the estimates with time and sector effects, but without (firms) fixed effects. In this way, the fixed effects are not removed from the firm's productivity that is what we are trying to explain.

[18]Please note that $\ln \frac{r_j}{Y_j}(it) = \beta_0 + \beta_1 \ln \frac{Y_j}{Y}(it) + \sum_{t=1}^{T} \gamma_t D_t + h(k_{it}, l_{it}, m_{it}, n_{it}) + u_{it}$ and therefore $\hat{\phi} = \ln \frac{r_j}{Y_j} - \beta_0 - \beta_1 \ln \frac{Y_j}{Y} - \sum_{t=1}^{T} \gamma_t D_t - u_{it}$.

Table 6: Market revenue estimates for tradable, T and non-tradable, NT, sectors

	T	NT	T	NT	T	NT
$\ln \frac{Y}{Y_j}$	21.901***	4.358***	19.405***	3.958***	-0.657	1.132***
	(1.41)	(0.20)	(1.36)	(0.19)	(0.94)	(0.16)
$\ln l_i$	1.175***	2.121***	1.362***	1.555***	0.702***	1.020***
	(0.05)	(0.07)	(0.05)	(0.07)	(0.02)	(0.05)
$\ln l_i^2$	0.065***	-0.247***	0.001	-0.095***	-0.018***	-0.052***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)
$\ln l_i^3$	0.008***	0.015***	0.007***	0.024***	0.002***	0.010***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\ln m_i$	1.003***	1.514***	0.955***	1.215***	-0.156***	-0.049***
	(0.05)	(0.07)	(0.06)	(0.06)	(0.01)	(0.02)
$\ln m_i^2$	0.031***	0.070***	0.048***	0.083***	0.085***	0.100***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\ln m_i^3$	-0.003***	-0.008***	-0.004***	-0.008***	-0.003***	-0.004***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\ln k_i$	0.588***	1.810***	0.676***	1.342***	0.034***	0.395***
	(0.04)	(0.07)	(0.04)	(0.07)	(0.01)	(0.02)
$\ln k_i^2$	0.044***	-0.043***	0.033***	-0.003	0.032***	0.011***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\ln k_i^3$	-0.003***	-0.002***	-0.003***	-0.003***	-0.001***	-0.001***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\ln k_i \ln m_i$	-0.151***	-0.287***	-0.152***	-0.249***	-0.028***	-0.078***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)
$\ln k_i \ln m_i^2$	0.005***	0.010***	0.006***	0.009***	0.001***	0.002***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\ln k_i^2 \ln m_i$	0.004***	0.009***	0.003***	0.007***	0.000**	0.003***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\ln k_i \ln l_i$	-0.088***	-0.001	-0.100***	-0.050***	-0.053***	-0.059***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)
$\ln k_i \ln l_i^2$	-0.009***	0.014***	-0.004***	-0.005***	0.000	-0.002*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\ln k_i^2 \ln l_i$	0.003***	-0.008***	0.003***	-0.000	0.002***	0.001***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Const.	-56.873***	-29.745***	-52.699***	-26.186***	-6.374***	-11.912***
	(2.82)	(0.71)	(2.71)	(0.65)	(1.88)	(0.41)
Sample-Size	1508508	1377835	1508508	1377835	1508508	1377835
$Adj-R^2$	0.787	0.621	0.802	0.651	0.919	0.836
Time-effects	✓	✓	✓	✓	✓	✓
Sector-effects			✓	✓	✓	✓
Fixed-effects					✓	✓

Notes: Material and electricity expenditures are measured together due to availability restrictions in our database. Robust standard errors are in parenthesis. Please note that time-effects are the γ_t coefficients, which are omitted because of space reasons. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

tradable and non-tradable goods, we use the demand for tradable and non-tradable goods, equation (2), and estimate the following equation:

$$\ln \frac{Y_{NT,t}}{Y_{T,t}} = \rho_o + \rho_1 \ln \left(\frac{P_{NT,t}}{P_{T,t}} \right) + \mu_t, \tag{24}$$

where $\rho_0 = \epsilon \ln \frac{\varsigma_T}{\varsigma_{NT}}$ and $\rho_1 = -\epsilon$. This is the methodology followed by the traditional literature and regresses the relative expenditure share of non-tradable goods on the relative price of non-tradable goods. We use a single equation regression model as in Kravis and Lipsey (1988); Stockman and Tesar (1995). The particularity in our study is that we consider the real expenditure rather than the nominal expenditure because our time period is from 2004-2017 rather than a unique time period, as in the above-mentioned studies. Moreover, we estimate equation 24 considering the existence of an income effect in the demand function as in Kravis and Lipsey (1988); Stockman and Tesar (1995). Thus, we added the explanatory variable $\ln Y_{pc}$ to our equation 24, where Y_{pc} denotes the log of the real GDP per capita. The estimated coefficients are statistically significant at the usual significance levels, and the long-run elasticity of substitution between tradable and non-tradable is about 0.45, which is closer to the estimate obtained by Stockman and Tesar (1995) (0.44) than to the estimate of 0.74 obtained by Mendoza (1995).[19]

The estimates for the productivity evolution described in equation (22) are reported in Table 7 for tradable and non-tradable sectors for the full sample and according to the firm's financial condition. Given the conditional product and process probabilities described in Table 5, we consider $z_i t = 1$ when the product innovation probability is greater than 0.5 and $z_{it} = 0$ otherwise. The same interpretation is done for the process innovation, d_{it}.

The estimate of α_4 and α_5 measure the product and process innovations' effect on firms' productivity gain compared to those firms that have not innovated. For the tradable sector, a new product innovation increases, on average, 2.27% the productivity, and a new process innovation increases, on average, 0.9% the productivity level[20]. One possible explanation for the smaller impact of process innovations on productivity may be the nature of the tradable sector, that is, it is a sector that essentially produces goods. Another explanation is that traditionally the tradable sector innovations are more complex and demanding in terms of R&D expenditures than those in the non-tradable sector. The positive productivity effect of innovations increases with the firm's financial constraint. The higher is the firm's financial constraint, the higher is the innovation effect on productivity.

For the non-tradable sector, the results are different. New product innovations have, on average, a not statistically significant effect on the productivity level. The exception are the non financially constrained firms for which the product innovation increases, on average, the productivity 47.2%. Note that for the financially constrained firms, the productivity decreases, on average, 5.19% at a significance level of 10%. A negative effect between innovation and productivity is not new in the literature. For example, in developing countries the evidence is

[19]Results available upon request. The evidence of unit roots was also checked.
[20]Although Portugal presents probabilities of innovation greater than Germany, the innovation effects on productivity, although similar, are slightly smaller than those found by Peters et al. (2018).

Table 7: Estimated model results

	Tradable				Non-tradable			
	Full sample	$FC \leq 0$	$0 < FC < 0.5$	$FC > 0.5$	Full sample	$FC \leq 0$	$0 < FC < 0.5$	$FC > 0.5$
α_0	-0.121***	-0.171***	-0.0646***	-0.745***	-0.681***	-0.822***	-0.616***	-6.837***
	(-44.52)	(-48.85)	(-17.33)	(-4.97)	(-72.05)	(-52.36)	(-38.53)	(-11.51)
β_k	0.283***	0.253***	0.341***	0.140***	1.020***	0.869***	1.147***	0.479***
	(89.96)	(68.19)	(110.82)	(22.64)	(105.18)	(74.55)	(127.21)	(21.12)
β_l	0.444***	0.502***	0.410***	0.466***	1.322***	1.429***	1.248***	1.528***
	(246.98)	(133.64)	(217.96)	(45.98)	(226.00)	(110.59)	(209.89)	(34.50)
α_1	0.913***	0.924***	0.870***	0.697***	0.918***	0.947***	0.839***	0.0430
	(522.61)	(416.45)	(329.37)	(7.59)	(555.81)	(478.05)	(218.72)	(0.40)
α_2	0.0107***	0.0129***	0.00341**	-0.0103	0.00461***	0.00445***	-0.00630***	-0.0348***
	(19.90)	(16.84)	(2.23)	(-0.70)	(30.88)	(20.69)	(-6.89)	(-6.91)
α_3	0.000***	-0.000***	0.000***	0.000***	-0.0000***	-0.000***	-0.000***	-0.000***
	(14.14)	(-14.82)	(15.27)	(5.93)	(-62.79)	(-41.61)	(-51.42)	(-5.60)
α_4	0.0227***	0.0285***	0.0245***	0.223***	-0.0258	0.0694	-0.0519*	0.472***
	(7.58)	(3.79)	(7.87)	(5.54)	(-0.97)	(1.38)	(-1.70)	(3.24)
α_5	0.00923***	0.0116***	0.00745***	0.00103	0.116**	0.129	0.130***	0.0915
	(6.80)	(3.14)	(5.50)	(0.06)	(2.32)	(1.29)	(2.61)	(0.42)
α_6	-0.00846***	-0.00978**	-0.00660***	0.00269	-0.101*	-0.0671	-0.148***	0.0214
	(-5.75)	(-2.48)	(-4.48)	(0.14)	(-1.93)	(-0.64)	(-2.77)	(0.09)
Sample-Size	810196	166433	625365	18398	686279	133781	543691	8807
$Adj-R^2$	0.962	0.944	0.966	0.916	0.947	0.937	0.950	0.860
Prob	0.962	0.944	0.966	0.916	0.947	0.937	0.950	0.860

Notes: The variables z_{it}, d_{it}, and $z_{it}d_{it}$ associated to the coefficients α_4, α_5, α_6 take the value 1 if there is an innovation in t or $t-1$.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

mixed. Innovative firms have higher productivity than non-innovative firms in fewer than half of the countries.[21] A new process innovation increases, on average, a 11.6% the productivity level at a significance level of 10%. This effect also varies with the firm' financial constraint level. Indeed, this positive effect is only observed for the financial constrained firms while for the others level of financial constraint no statistically and significant effect is observed.

In this context, the tradable sector should focus on product innovations, in particular, the highly financially and financially constrained firms. The non-tradable sector should focus on process innovations, but only the financially constrained firms.

Regarding the effect of the past productivity on future productivity, we observe the coefficients of $\phi_{it-1}, \phi^2_{it-1}, \phi^3_{it-1}$ and $\alpha_1 - \alpha_3$. The first result is that productivity is highly persistent and there is a nonlinear statistically significant relationship between the lagged and the current productivity in both sectors. This means that there is a long-run effect payoff of R&D investments because the persistence shows a low depreciation effect on productivity and profits from innovations.

The remaining coefficients, β_k and β_l, are an estimate of the capital and labor elasticity in the marginal cost function. For tradable goods $\beta_k = 0.283$, which means that the total variable cost is higher for plants with higher capital stock. For non-tradable goods as $\beta_k = 1.02$, the variable cost is greater for plants with higher capital stock. Identical interpretation is done for β_l. It is worth mentioning that, for example, in Germany a negative relationship was found between firms' variable costs and capital and labor stocks. For the Portuguese and tradable

[21]The use of innovation dummies, although common in the literature, might not fully capture the overall effect of innovative activities.

sector plants, this result suggests that there are no scale effects. Additionally, labor and capital are costly for the non-tradable sector.

4.2 Cost innovation estimates

The R&D firm's decision is based on comparison of the long-rung expected benefit of taking R&D, $\delta EV(\omega_{it})$ with the maintenance or startup cost of innovation, C_{it}, which given the financial constraints cannot be greater than $\theta\pi_{it}$. Thus, the probability that the firms choose to carry out R&D is:

$$\begin{aligned} Pr(rd_{it}=1|s_{it}) &= Pr(\delta EV(\omega_{it})) \geq C_{it}(rd_{it-1}) \\ &= 1-exp\left(\delta EV\left(\omega_{it}|\gamma^m * rd^*_{it-1}k_{it}+\gamma^s*(1-rd_{it-1})^* k_{it}\right)\right), \end{aligned}$$

and $C_{it} < \theta\pi_{it}$. To construct the value functions we apply the fixed-point algorithm to estimate the dynamic discrete R&D choice. We discretize the state space, $s_{it} = (\omega_{it}, rd_{it})$ into 100 grid points for productivity and two values for previous R&D choice. The firm's value also varies across firms due to differences on capital sock, labor, and relative sector-size. The benefit of investing in R&D is calculated for each data point by using a cubic spline to interpolate across the state space grid points.

Assuming s_{it} independent of the cost draws and that costs are $i.i.d.$, we estimate cost innovation parameters by using the likelihood function:

$$L(\gamma^s,\gamma^m|rd,s) = \prod_i\prod_t Pr(rd_{it}|s_{it},\gamma^s,\gamma m), \tag{25}$$

where rd and s are the firm's R&D choices and state variables, respectively, for each t. The parameters γ_s, γ_m are the start-up and maintenance costs.

Firms must pay a cost to generate a product or process innovation and raise their productivity. The estimates for these costs are provided in Tables 8-10 according to the cost specification described in (14). In these estimations, the mean of the cost distribution differs with the firms' financial constraint level, the firms' size, and the industry that a firm belongs to. The firms' size is defined by the firm's capital stock. For all these specifications, we estimate the startup, γ^s, and maintenance costs, γ^m.

Analyzing the results presented in Tables 8-10, we find the following results. First, in general, the startup cost is higher than the maintenance cost. Thus, for two firms with the same productivity, capital stock, labor amount, and belonging to the same industry, it is more expensive to innovate for the firm with no previous R&D experience. This result is in accordance with the results shown in Table 5, the innovation probability is lower for firms with no previous R&D experience, and hence to innovate, firms face a higher cost.

Second, the startup and maintenance costs, in general, increase with the strength of the firms' financial situation. The stronger is the firms' financial situation, the higher are the expected benefits of R&D. So, the highly financially constrained firms may have difficulties in financing all necessary resources for their R&D projects, as well as in fully benefiting from their product and process innovations. Despite having a higher R&D investment, innovation rate, and innovation effects on productivity, the highly financially constrained firms have reduced expected benefits due to their financial situation. In other words, there is a complementary relationship between the R&D benefits and the firm's financial strength.

Third, the startup and maintenance costs tend to decrease with the firms' size. That is, small firms have higher expected benefits of innovations relatively to large firms, and therefore, are willing to incur higher R&D costs to obtain the expected productivity rise from R&D investments. This result illustrates the presence of diminishing marginal returns to capital on innovation benefits.

Fourth, the startup and maintenance costs present a high heterogeneity across industries. For example, agriculture, coke, rubber, electricity, telecommunications, advertising are industries with expected benefits of R&D higher than the average benefits of large firms. The same is observed for medium and small firms. Indeed, for medium firms, besides the industries enumerated we should also include the textile and accommodation industries. For the small firms, should include the wood, metals, publishing, machinery, administrative, and arts industries. It is also worth mentioning that, as the expected benefits of R&D increase with the strength of the firms' financial situation, non financially constrained firms may have huge expected benefits independently of their size.

Finally, for the non-tradable sector our estimate results show that the expected benefits of innovating are very small and firms should not carry out R&D, hence no cost should be faced by these firms.

Table 8: Dynamic cost estimates for large firms by financial constraint level

Sector	$FC \leq 0$		$0 < FC < 0.50$		$FC \geq 0$	
	γ^s	γ^m	γ^s	γ^m	γ^s	γ^m
Agriculture	11.635	1.058	43.382	9.211	16.016	1999.779
Mining	1.741	0.475	6.553	1.346	7.183	3.312
Food	3.577	0.775	35.158	6.128	2999.145	47.783
Textile	1.750	0.211	11.226	2.177	2732.204	1999.763
Wood	1.446	0.328	25.720	3.158	a)	a)
Coke	23.700	17.853	344.483	8.417	a)	a)
Chemical	8.808	1.087	26.465	4.318	5.681	1.475
Pharmaceutical	1.205	0.303	5.827	0.584	19.522	5.746
Rubber	199.417	0.679	13.342	2.624	3.453	10.542
Metals	6.496	1.302	15.125	3.353	a)	a)
Computers	0.797	0.158	20.641	1.553	a)	a)
Electrical	10.248	1.224	11.078	1.503	a)	a)
Machinery	3.637	0.533	5.480	2.247	2.816	8.687
Transports	3.154	0.676	29.129	3.992	9.498	0.134
Furniture	4.658	0.689	40.395	8.175	4999.962	0.035
Electricity	127.643	26.503	139.558	18.955	4999.999	66.441
Transportation	9.325	1.068	37.135	4.665	132.282	9.039
Accommodation	1.446	0.200	13.450	1.972	4343.687	0.118
Publishing	1.988	0.180	26.333	4.267	24.616	0.062
Telecommunications	23.370	0.704	73.375	3.562	1842.232	0.960
Programming	2.167	0.495	25.992	3.476	11.926	0.235
Consultancy	4.056	0.610	40.762	6.067	607.218	24.295
Scientific R&D	1.508	0.293	10.753	1.378	a)	a)
Advertising	71.857	8.858	81.574	13.990	15.088	5.241
Administrative	13.309	1.776	45.897	40.420	39.018	7.689
Arts	4.342	0.851	19.694	2.557	a)	a)
Other Serv.	4.614	0.358	18.127	2.743	0.331	0.167

Notes: a) insufficient number of observations.

Table 9: Dynamic cost estimates for medium firms by financial constraint level

Sector	$FC \leq 0$		$0 < FC < 0.50$		$FC \geq 0$	
	γ^s	γ^m	γ^s	γ^m	γ^s	γ^m
Agriculture	35.442	3.812	145.883	13.538	5000.000	223.713
Mining	14.932	2.142	47.606	6.505	102.050	16.261
Food	14.696	26.365	118.198	16.673	870.063	162.360
Textile	138.111	2.068	100.523	13.348	1500.420	242.100
Wood	37.822	88.374	8281.470	103.490	524.698	94.044
Coke	16.713	2.867	143.363	a)	a)	a)
Chemical	27.753	2.674	41.432	6.579	15.342	18.951
Pharmaceutical	2.288	0.954	20.783	5.601	a)	
Rubber	25.472	2.997	80.253	10.265	1430.946	47.671
Metals	13.980	6.030	59.713	7.482	1749.315	288.327
Computers	8.768	1.774	48.108	6.705	a)	a)
Electrical	22.568	1.010	640.890	5.461	489.599	90.324
Machinery	18.378	2.035	48.890	7.200	645.581	87.535
Transports	29.992	3.358	103.391	15.987	795.582	46.224
Furniture	3.923	1.234	998.174	7.138	667.132	95.572
Electricity	136.072	15.675	188.603	24.896	78.343	25.117
Transportation	70.182	54.065	200.688	18.458	1393.476	216.934
Accommodation	102.476	1.010	39.290	4.960	91.697	15.745
Publishing	32.398	14.772	173.621	20.960	1522.705	96.411
Telecommunications	74.824	18.016	117.247	22.720	a)	a)
Programming	19.141	2.943	70.972	10.726	369.478	86.604
Consultancy	22.333	3.145	86.587	13.140	534.827	80.447
Scientific R&D	5.402	1.140	32.251	4.228	38.446	2.926
Advertising	53.438	6.615	91.790	17.150	321.138	49.664
Administrative	77.706	9.760	224.613	32.422	828.363	68.355
Arts	38.628	4.879	211.227	30.266	1511.158	241.216
Other Serv.	16.626	1.021	78.267	5.504	309.445	23.088

Notes: a) insufficient number of observations.

Table 10: Dynamic cost estimates for small firms by financial constraint level

Sector	$FC \leq 0$		$0 < FC < 0.50$		$FC \geq 0$	
	γ^s	γ^m	γ^s	γ^m	γ^s	γ^m
Agriculture	195.384	10.464	457.901	0.660	2072.998	88.036
Mining	88.724	6.560	114.488	15.842	483.081	1.031
Food	23.224	4.424	179.565	25.645	1821.562	179.270
Textile	27.655	9.073	291.941	23.809	4375.480	253.122
Wood	128.293	9.774	233.461	16.759	1483.092	87.433
Coke	100.128	4.898	396.904	26.125	a)	a)
Chemical	44.516	7.312	b)	b)	a)	a)
Pharmaceutical	31.004	0.168	457.012	39.957	a)	a)
Rubber	97.229	6.072	368.977	14.847	1173.020	103.368
Metals	180.903	24.544	10.000	10.000	2261.470	174.835
Computers	47.359	7.393	248.516	20.195	a)	a)
Electrical	163.308	19.356	10.000	16.125	444.164	14.259
Machinery	139.716	12.012	183.933	16.931	824.647	234.646
Transports	78.952	6.379	113.534	16.343	1120.710	130.720
Furniture	99.396	94.119	1178.170	18.221	1587.680	126.992
Electricity	49.534	13.740	245.898	30.250	a)	a)
Transportation	80.493	8.449	259.815	14.049	2645.290	47.851
Accommodation	213.602	10.651	103.515	9.751	1711.680	54.778
Publishing	109.613	13.956	335.038	29.878	4877.600	418.184
Telecommunications	459.713	103.251	367.242	116.375	1101.670	5999.999
Programming	71.433	11.548	258.365	30.726	2118.580	145.963
Consultancy	83.357	30.157	170.827	21.600	970.961	113.431
Scientific R&D	52.128	5.944	220.640	23.976	481.323	1.134
Advertising	49.524	5.030	260.258	38.329	1207.160	226.949
Administrative	782.063	26.846	705.458	84.434	1234.270	377.542
Arts	192.059	13.707	452.629	118.132	2539.790	400.028
Other Serv.	17.181	3.699	1608.320	21.102	604.302	48.753

Notes: a) insufficient number of observations; b) firms do not invest in R&D.

5 Conclusion

In this paper, we extend the firms dynamic R&D decisions model of Aw et al. (2011) and Peters et al. (2018), by considering incomplete financial markets and the coexistence of production of tradable and non-tradable goods. Firms' R&D investment raises the probability of innovating and increases their future productivity and profits. R&D investment's benefits are obtained in the future and depend on firms' previous R&D experience, innovation probabilities, and financial strength.

We estimate the model by using micro data collected from the CIS and the EIAS databases for the Portuguese economy from 2004-2017. The EIAS database includes firms panel data on firm revenue, capital stock, labor, materials, R&D expenditure, innovation expenditures, and EBITDA for the firms' population. The CIS database includes firms panel on product and process innovations. With this set of variables, we construct, first, the innovation probabilities for the Portuguese firms' population, and then, construct their productivity and short-run profits, and estimate the firm's R&D choice and the costs they must incur to generate an innovation. The construction of these variables was done for 34 industries (29 tradable industries and 4 non-tradable industries). The firm's financial constraint can affect its R&D choice, and as a consequence, its productivity evolution. Thus, the estimates of the firm's R&D investment decision, productivity, and innovation costs are conditioned by the firm's financial constraint level measured through the ratio EBITDA to liabilities.

Our empirical results show a positive relationship between the R&D dynamics and the firms' financial situation; an R&D bias in favor of the non-tradable sector and the highly financially constrained within the non-tradable sector, when the firms' financial situation is taken into consideration; a counter-cyclical R&D dynamics for the non-financially constrained firms in the tradable sector; an increment in the innovation probabilities when firms have previous R&D experience, which is slightly higher for the tradable sector; a predominance for high startup costs of innovation relative to maintenance costs; a relationship of complementary between the R&D benefits and the firm's financial strength; diminishing marginal returns to capital on innovation benefits; a high heterogeneity of the innovation costs, and consequently, of the expected benefits of R&D across industries, which can be huge for the non financially constrained and the small firms in the tradable sector; and finally, a bias of the R&D investment for the non-tradable sector given that the R&D benefits do not cover the R&D investment costs in this sector when the financial constraints exist and the trade-off between the tradable and the non-tradable goods is taken in consideration. So that, the R&D investment carried out in this sector illustrate a misallocation of the financial resources.

Appendix

A Industry classification

Table 11: National Accounts Classification by Industry - Base 2011

NACE Rev.2	Abreviation	Description
01-03	Agriculture	Agriculture, forestry and fishing
05-09	Mining	Mining and quarrying
10-12	Food	Manufacture of food products, beverages and tobacco products
13-15	Textile	Manufacture of textiles, wearing apparel and leather products
16-18	Wood	Manufacture of wood and paper products, and printing
19	Coke	Manufacture of coke, and refined petroleum products
20	Chemical	Manufacture of chemicals and chemical products
21	Pharmaceutical	Manufacture of basic pharmaceutical products and pharmaceutical preparations
22-23	Rubber	Manufacture of rubber and plastics products, and other non-metallic mineral products
24-25	Metals	Manufacture of basic and fabricated metal products, except machinery and equipment
26	Computers	Manufacture of computer, electronic and optical products
27	Electrical	Manufacture of electrical equipment
28	Machinery	Manufacture of machinery and equipment n.e.c.
29-30	Transports	Manufacture of transport equipment
31-33	Furniture	Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment
35	Electricity	Electricity, gas, steam and air-conditioning supply
36-39	Water	Water, sewerage, waste management and remediation activities
41-43	Construction	Construction
45-47	Wholesale	Wholesale and retail trade, repair of motor vehicles and motorcycles
49-53	Transportation	Transportation and storage
55-56	Accommodation	Accommodation and food service activities
58-60	Publishing	Publishing, audiovisual and broadcasting activities
61	Telecommunications	Telecommunications
62-63	Programming	Computer programming, consultancy and related activities; information service activities
64-66	Finance	Financial and insurance activities
68	Real estate	Real estate activities
69-71	Consultancy	Legal, accounting and head offices activities; management consultancy activities; architecture & engineering activities; technical testing and analysis
72	Scientific R&D	Scientific research and development
73-75	Advertising	Advertising and market research; other professional, scientific and technical activities; veterinary activities
77-82	Administrative	Administrative and support service activities
84	Public Serv.	Public administration and defence; compulsory social security
85	Education	Education
86	Health	Human health services
87-88	Social	Social work activities
90-93	Arts	Arts, entertainment and recreation
94-96	Other Serv.	Other services activities
97-98	Households	Activities of households as employers of domestic personnel and undifferentiated goods and services production of households for own use
99	Extra-territorial	Activities of extra-territorial organizations and bodies

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