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Competition and innovation: Evidence from worldwide corporate R&D spenders*

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Abstract

This paper aims at assessing the effect of competition on firm-level innovation. The sample is composed of the world top corporate R&D spenders listed in the EU 2017 industrial R&D Scoreboard, and the analysis covers the years spanning 2007 to 2016. We use an industry-year indicator, the inverse of the Lerner Index, to measure the competition level. R&D expenditures are used as a proxy for innovation. Model is estimated using two-stage least squares, to control for potential endogeneity of the competition indicator. Results confirm the existence of an inverted-U relationship between competition and innovation. Further analysis is undertaken splitting the overall firm sample into services and manufacturing sectors according to technology and knowledge intensities. We validate the inverted-U shaped relationship between competition and innovation for the firms in medium-high-tech and high-tech manufacturing sectors whereas we do not observe this impact for the firms in medium-low and low-tech manufacturing sectors nor services sectors.

Keywords: Competition, Innovation, Manufacturing, Services.

JEL classification: L10, O31, O32.

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1 Introduction

Governments believe that competition enhances economic efficiency and social welfare (Svizzero and Tisdell, 2001). More competitive markets offer consumers lower prices, higher variety, and better quality of goods and services (OECD, 2012). However, since firms may distort fair competition (e.g., abuse of a dominant position, mergers, horizontal and vertical agreements), there is a need to control such practices through public policies.

Motta (2004:30) defines competition policy as "the set of policies and laws which ensure that competition in the marketplace is not restricted in a way that is detrimental to society." According to Motta (2004), the aim of competition policy is vast, covering several areas such as improving consumer welfare, protecting smaller firms, promoting market integration and economic freedom, fighting against inflation, and enhancing fairness and equity in business operations.

The importance of competition for society has attracted many scholars that assessed its impact on innovation over the last decades. Another reason for the interest of such type of analysis is that the findings in the literature are still highly divergent in terms of the impact of competition on innovation.[1] Some authors point out a positive effect (e.g., Arrow, 1962; Correa and Ornaghi, 2014), whereas others find a negative (e.g., Schumpeter, 1943; Crépon et al., 1998) or a non-monotonic effect (e.g., Boone, 2001; Aghion et al., 2005).

The present paper aims to contribute to the literature by assessing the effect of competition on firms' innovation using a sample of firms composed of the world top corporate R&D spenders. Firms are ranked in the EU industrial R&D Scoreboard 2017, and the analysis covers the years from 2007 to 2016. We use an industry-year indicator, the inverse of the Lerner Index, as a measure of competition. Firm-level R&D expenditures are used as a proxy for innovation. Model is estimated using two-stage least squares, to control for potential endogeneity of competition levels.

The originality of the present study comes firstly from its geographical coverage. While most of the existing studies in the literature assess the impact of competition on innovation focusing on samples of firms located in a country,[2] the present study uses a sample composed of worldwide firms. The non-consensus about the effect of competition could be, indeed, due to macroeconomic factors that are external to firms and that can influence the sign of the impact. Through our study, we seek to provide empirical evidence overcoming this limitation.

The second main contribution of the study is distinguishing manufacturing and services sectors, and their technological and knowledge intensities in the analysis. In the course of structural transformation towards knowledge based economies, advanced economies depend highly on technological and knowledge intense industries and services in their economic development, and their business and public sectors rely strongly on knowledge, information and high skill levels (OECD, 2005). Manufacturing and services sectors differ in their innovation characteristics.[3] Highly technological manufacturing and knowledge intense services sectors rely more on R&D than other manufacturing

[1] For a survey of literature see e.g., Symeonidis (1996), Gilbert (2006) or Holmes and Smitz (2010).

[2] Some exceptions are founded for authors using survey data, where competition indicators are not estimated using firm financial information coming from income statements but are based on the entrepreneur self-perception about competition pressure (see e.g., Carlin et al., 2004, Cincera and Waelbroeck, 2005) or the number of competitors in the market (see e.g. Friesenbichler and Peneder, 2016; Crowley and Jordan, 2017).

[3] See for instance Coombs and Miles (2000) and Hipp and Grupp (2005) for the discussion on the differences in innovation in services and manufacturing sectors

and services firms and their innovation decision facing competition shall be distinguished from the firms operating in other manufacturing and services sector.[4] In that respect, we seek to provide more comprehensive analysis by investigating the differences firstly for the manufacturing and services firm samples and subsequently, we show our results for the technology intense manufacturing and knowledge intense services firm samples.

The present paper is divided into five sections. After the introduction, section 2 summarizes the main findings of the literature about the effect of competition on innovation. The description of the database and the methodological framework are described in Section 3. Section 4 presents and discusses the results of the study. Section 5 concludes and highlights some policy recommendations.

2 Related literature

Most studies investigating the impact of competition on innovation depart from the theoretical framework of Joseph Schumpeter (1943). Defending that a firm in monopoly position has an incentive to innovate in order to maintain its dominant status; the theory of Schumpeter on the impact of competition on innovation is based on the hypothesis that R&D activities decrease in markets characterized by high levels of competition. Schumpeter (1943) explains the negative impact of competition on innovation activities claiming that restrictions and market power alleviate the challenges of the process of creative destruction for a firm.

On the other side, Arrow (1962) defends the idea that incentives to innovate may exist even under perfectly competitive markets. According to Arrow (1962), one of the main objectives of firms to innovate comes from the reduction of production costs (process-oriented R&D), and a firm faces higher incentives to innovate under competition pressure than under a monopoly. Arrow (1962) shows that the royalties arising from an invention raise the profits of the innovative firm without affecting the nature of competition, and these returns could even be equivalent to the monopoly profit.

The main limitations of Schumpeter (1943) and Arrow (1962) theories is that competition is considered as exogenous, which implies a unidirectional relationship between innovation and competition. In such frameworks, firms are assumed to be symmetrical in the market, i.e., all firms have the same level of efficiency.

Contradicting results in literature show that there is more than one factor at play determining the impact of competition on innovation. The results vary depending on the market and firm characteristics. Market characteristics such as the degree of neck-and-neck competition versus unlevelled competition, the possibility of price discrimination with the novel product, barriers to entry for the new firms, anti-trust regulations and, the strength of intellectual property rights and appropriability conditions are underlined as the determinant factors on the sign of the impact. The sign of the impact is also influenced by the firm characteristics in the market, such as its cost efficiency and distance from the technological frontier of the market.

According to Dasgupta and Stiglitz (1980), the degree of concentration in an industry as well as the nature of innovation depend on several factors such as the technological area, demand conditions, the capital market (the costs of transaction and access to finance) and the legal system (e.g.

[4] Tether and Hipp (2002) provide evidence from German services firms where they distinguish knowledge intense services among the other services sectors in their innovative efforts especially in terms of R&D spending.

investor protection, strength of the Intellectual Property Right System). Dasgupta and Stiglitz (1980) formulate a model where the social benefit for a given good is the result of a convex function of cost production, associated with R&D cost reduction. The paper shows that, after controlling for endogeneity, the (non-) concavity of the relationship is influenced by factors, such as the degree of concentration, the size of the market and barriers to entry in the market. Consecutively, Boone (2001) proposes a theoretical model where firms are different in term of efficiency, and the number of firms in a market is endogenous. Differentiating firms at their cost levels and allowing for strategic interactions between them, the paper highlights a non-monotonic relationship between competition and innovation. For the low levels of competition, more competition gives incentives to innovate to the follower firms that are less efficient and leads to a decrease in innovative value. With higher intensity of competition, more competition gives incentives to innovate to the leading firms that are more efficient and, hence, leads to an increase in innovative value.

Some empirical studies support a non-linear impact of competition on innovation well before the theoretical evidence. Scherer (1967), for instance, reports a non-linear impact of competition on innovation using data from US manufacturing industry under certain restrictions. A non-linear relationship between R&D and competition is only observed when the proxy chosen to test this relationship is the intensity of technical employment.[5]

The question of a non-linear impact received further attention of research after the evidence brought by Aghion et al. (2005) of an inverted-U shaped relationship using a sample composed of firms listed on the London Stock Exchange. The paper predicts that both technology leaders and followers in an industry can innovate, and innovation incentives depend on the difference between the rents of a firm before and after innovation. Firm-level and market-level characteristics are the factors that determine the difference between the pre-innovation and post-innovation rents. Using patent citations as the measure of innovation and the inverse of price-cost margin as the measure of competition, the study reports an inverted-U shaped relationship between competition and innovation.[6] Aghion et al. (2005) argue that competition decreases the rents before innovation and, thus, gives incentives to innovate and to lead the market when firms are neck-and-neck in the sector ("escape-competition effect"). On the other hand, competition harms innovation for the laggard firms, i.e., firms far away from the technological frontier and this discourages them from innovating since it decreases their rents after innovation and motivation to catch-up with the leaders ("Schumpeterian effect").

Since the pioneering contribution of Aghion et al. (2005), several research scholars have investigated the hypothesis of an inverted-U shaped relationship. Findings in the literature, however, reveal that the link between both variables is complex and could be influenced by the characteristics of the sample, by the macroeconomic environment and by the indicators used for measuring competition. For instance, Tingvall and Poldahl (2006) support the theory of Aghion et al. (2005) only when using market share as a proxy for competition rather than market power.[7] Using market power as the proxy for competition, the study suggests a direct impact of competition on inno-

[5] Scherer (1967) used as indicators for innovation the number of technical engineers and natural scientists employed in the industry, and private R&D employment (proportion of scientists and engineers engaged in R&D activities funded by the private sector). These variables were estimated in level and as a percentage of total employment.

[6] Nevertheless, when R&D expenditure was used as an alternative measure for innovation, the competition variable in square becomes non-significant.

[7] The detailed description of different competition indicators used in the literature is given in the methodology section.

vation in Swedish manufacturing industry (Schumpeterian effect). Subsequently, Askenazy et al. (2008) provide evidence from a sample composed of French firms, and the non-monotonic impact of competition on R&D expenditure depends on firm size and the cost of innovation. The study confirms the presence of an inverted-U shaped relationship only for large firms and finds that the impact disappears if the costs of innovation are high.

On the other hand, Correa and Ornaghi (2014) confirm a direct and positive impact of competition on innovation. Using US manufacturing firms' data, the paper measures the competition by the inverse of the price-cost margin and uses patents as the measure of innovation. For Correa and Ornaghi (2014) the absence of an inverted U-shaped relationship can be explained by the presence of a well-defined intellectual property rights (IPR) system in the market. Indeed, the nature and intensity of competition, as well as the intensity of the innovative process depend on the country and sector characteristics, such as technological opportunity and appropriability conditions, the nature and the diffusion of knowledge (Edquist, 1997), and the characteristic of demand (Symeonidis, 1996). If the knowledge created as a result of R&D activities is not well protected and not well diffused among competitors, more competition will not necessarily enhance innovation.

Spence (1984) defends the idea that R&D spillovers and appropriability conditions are the two key elements in a market to stimulate innovation. Appropriability refers to firm protection from copycat behaviors which permits to achieve returns from R&D investments without enduring the initial costs necessary to produce the new knowledge while R&D spillovers represent the knowledge transfers when inventors are unable to entirely and exclusively appropriate all the benefits associated with the new knowledge created. For example, a firm develops a new product and obtains intellectual property rights through a patent. Once the product is in the market, competitors will gain an advantage of the knowledge generated that is not protected (e.g., the benefit for society and the identification of a new consumer need) and develop a substitute to the original discovery. In this case, both R&D spillovers and inventor protection stimulate innovation. According to Gilbert and Newbery (1982), the IPR system may, under some conditions, create opportunities for firms with monopoly power to maintain their position in the market. These authors explain that firms with monopoly power can have incentives to patent new technologies for pre-empting purposes, i.e., in order to prevent the entry of competitors in the market and to maintain their monopoly power. In this case, the (so-called sleeping) patented innovation is not commercially valorized but is used instead to block the market entry of other firms.

Santos et al. (2018) suggest that the sign of the impact of competition on innovation as well as the existence of a non-monotonic relationship between these two variables may vary across sectors. Based on a representative sample of Portuguese firms, Santos et al. (2018) provide evidence of the presence of an inverted U-shaped relationship between competition and patents but only for the model including all the sectors of activity. The results obtained when the sample is restricted to firms operating in manufacturing sectors reveal only a linear and positive effect (escape competition effect).

Although there has been substantial amount of empirical studies looking at the impact of competition on innovation in the manufacturing sector, limited empirical evidence has been provided on its impact in services sector. Miles (2005) provide evidence for the knowledge intense services in Europe sourced from Eurostat data for the services sectors for the years 1998-2002. The knowledge intense sectors are distinguished with higher growth rates and internationalisation from other

Table 1: The summary of main findings about the impact on competition on innovation: the direction of the effect, output variable, the name(s) of the author(s) and scope

Impact	Output	Author	Geographical scope
Negative	R&D expenditure	Schumpeter (1943)	Theoretical model
	R&D expenditure	Crépon et al. (1998)	France
	R&D expenditure	Tingvall and Poldahl (2006)	Sweden
	R&D expenditure	Castellacci (2011)	Norway
Positive	R&D expenditure	Arrow (1962)	Theoretical model
	R&D and scientific employment	Scherer (1967)	US
	Patent	Correa and Ornaghi (2014)	US
Non - monotonic	R&D expenditure	Dasgupta and Stiglitz (1980)	Theoretical model
	R&D expenditure	Boone (2001)	Theoretical model
	Innovation	Carlin et al. (2004)	Transition economies
	Patent	Aghion et al. (2005)	Worldwide (London Stock Exchange)
	R&D expenditure	Tingvall and Poldahl (2006)	Sweden
	R&D expenditure	Askenazy et al. (2008)	France
	R&D expenditure	Friesenbichler and Peneder (2016)	Eastern Europe and Central Asia
	Innovation	Crowley and Jordan (2017)	Central and East Europe and East Asia
	Patent	Dhanora et al. (2017)	India
	Patent	Santos et al. (2018)	Portugal

Source: Authors' own elaboration based on Schumpeter (1934); Arrow (1962); Scherer (1967); Dasgupta and Stiglitz (1980); Crepon et al. (1998); Boone (2001); Carlin et al. (2004); Aghion et al. (2005); Tingvall and Poldahl (2006); Askenazy et al. (2008); Castellacci (2011); Correa and Ornaghi (2014), Dhanora et al. (2017) and Santos et al. (2018).

Note: The studies of Carlin et al. (2004), Friesenbichler and Peneder (2016) and Crowley and Jordan (2017) refer to survey data analysis where competition indicators are estimated taking into entrepreneur's self-perception about competitors and market pressure, and all the empirical analysis are based on firm financial information coming from income statement.

services sectors. When it comes to market competition, it is observed that knowledge intense services sectors are composed of small firms while experiencing increasing concentration. Tingvall and Karpaty (2009) investigate the inverted-U shaped relationship between competition and innovation in Swedish service sector firms. The study uses the Boone profit elasticity measure as well as the Herfhindal market concentration index to measure market competition and the results suggest an inverted-U shaped relationship between competition and R&D spending for the exporting Swedish firms in services sector.

The present paper seeks to provide further empirical evidence for both strands of the literature and for which there is still not a clear-cut consensus about the impact of competition. Most of the empirical evidence in the literature originates from samples of firms located in a single country where the National Innovation System (NIS) is able to influence the direction of the impact.[8] We discuss the lack of consensus about the impact of competition on innovation by considering that variations in findings might be due to macroeconomic factors that are external to a firm. To that end, we use a representative sample composed of multinational enterprises (MNEs), and we use their consolidated financial information to look at their activities worldwide. Another essential feature of our firm sample is its high representativeness in terms of business expenditures on R&D in the world that constitute our indicator of innovation. Our sample is particularly representative for the firms operating in technology intense manufacturing and knowledge intense services sectors.

[8]Exceptions are some survey data analysis (see e.g., Carlin et al., 2004; Friesenbichler and Peneder, 2016; Crowley and Jordan, 2017) and the study of Aghion et al. (2005) which covered worldwide firms publicly traded in London Stock Exchange.

This allows us to assess the impact of competition on the firm-level innovation for the firms operating in these sectors where firms innovate more intensely with respect to the firms operating in other manufacturing and services sectors. The next section presents in detail the database constructed for this study as well as the empirical framework.

3 Data and Empirical framework

3.1 Data

The sample of firms used in the present study comes from the EU 2017 Industrial R&D Investment Scoreboard (the Scoreboard), published annually by the European Commission since 2004. Firms included in the Scoreboard are headquartered in 43 countries[9] and account for nearly 90% of the world's business R&D spending (EC, 2017).

The Scoreboard provides financial data for the top 2,500 corporate R&D investors from the EU and from abroad. It is based on firm-level data extracted directly from the annual reports of companies.[10]

The variables available in the Scoreboard are the following: number of employees, net sales, capital expenditure, R&D expenditure, operating profit, main sector of activity, and country where the parent company is located. Table 2 provides a detailed description of each variable.

All monetary variables are expressed in million euros and at constant prices (base 100=2016).

Table 2: Information available in the Scoreboard

Variables	**Description**
Number of employees	Total consolidated average employees or year-end employees if average not stated
Net sales	Firm' total sales, excluding sales taxes and shares of sales of joint ventures & associates
Capital expenditure	Expenditure used by a company to acquire or upgrade physical assets such as equipment, property, industrial buildings. In accounts capital expenditure is added to an asset account (i.e., capitalized), thus increasing the asset's base. It is disclosed in accounts as additions to tangible fixed assets
R&D Expenditure	Cash investment in Research or/and Development funded by the companies themselves. It excludes R&D undertaken under contract for customers such as governments or other companies. It also excludes the companies' share of any associated company or joint venture R&D investment
Operating profit	Profit (or loss) before taxation, plus net interest cost (or minus net interest income) minus government grants, fewer gains (or plus losses) arising from the sale/disposal of businesses or fixed assets
Sector	Industry Classification Benchmark (ICB) at 3-digits.
Country	Country where the parent company is located

Source: Authors' elaboration based on EC (2017).

Information about deflator was extracted from the IMF. 4-digit NACE sector codes of each company were provided by the European Commission.

[9] For a geographical distribution of the firm in the Scoreboard see Table 7. in Appendix.

[10] For more information, see the official website: http://iri.jrc.ec.europa.eu/scoreboard.html

3.2 Competition measure

In the empirical literature, competition pressure is usually measured by the Lerner Index (LI) proposed by Lerner (1934). The LI is estimated by the ratio between the difference of price (P) and marginal cost (MC), and P. P refers to the unitary price and MC refers to the cost of producing one additional unit of product or service. Equation (1) defines LI:

$$LernerIndex(LI) = (P - MC)/P; whereMC = \frac{\partial Cost}{\partial Quantity} \tag{1}$$

As LI refers to the firm's market power or its ability to control its price compared to a situation of perfect competition where $P = MC$, the inverse of the market power indicator is generally used in the in the literature to measure the level of competition (Aghion et al., 2005; Okada, 2005; Correa and Ornaghi, 2014). The competition measure based on LI ($c_{j,t}$) reported in equation (2) is an industry-year indicator, where i indexes the firm and j indexes the industry. The $c_{j,t}$ considers the total number of firms (N) in industry j in year t, to estimate the average LI across all firms within an industry j in a given year t. Values close to 1 indicate higher levels of competition, and those close to 0 indicate lower levels of competition (or higher levels of market power).

$$c_{j,t} = 1 - 1/N_{j,t} \sum_{i \in j} LI_{i,t} \tag{2}$$

In the present study, we calculate LI as the ratio between operating profit and net sales, following the work of Aghion et al. (2005) and Correa and Ornaghi (2014). When information about price and marginal cost are not available, the so-called price cost margin or profitability index is used. Aghion et al. (2005) calculate this indicator using the difference between operating profits and financial costs divided by sales.[11] We use the operating profit variable reported in the Scoreboard, which is the profit or loss before taxation. This means that the amortization is already removed from the operating profit, and consequently, there is no need to estimate the financial cost. In order to calculate our industry-year indicator, we use the weighted mean of the profitability of each firm where the weight ($w_{i,t}$) corresponds to the firm's share in total sales of industry j for a given year. Our competition indicator is expressed in equation (3):

$$c_{j,t} = 1 - \sum_{i \in j} w_{i,t}(operatingprofit_{i,t}/sales_{i,t}) \tag{3}$$

3.3 Relevant market

When assessing market power, an important issue is the determination of the relevant market in order to identify among which product or service categories and in which markets the competition between firms takes place. The concept is based on the characteristics of the product or the service (i.e., their degree of substitutability vs. to other similar products or services) as well as the geographical area of influence (or spatial reach) of firms.

Concerning product characteristics, all empirical studies using firms' financial data, listed in Table 1, use the classification of firm's sector of activity, such as the Industry Classification Benchmark (ICB) or the Statistical Classification of Economic Activities in the European Community (NACE).

[11] Financial costs are used as a proxy of amortization and are subtracted from operating profits.

As it can be seen in Table 3, using the ICB classification at 3-digits level leads to a highly aggregated sector classification in 19 sectors.

Table 3: The number of sectors by ICB and NACE code classification in the sample

Sector Classification		Number of sectors
ICB	3-digits	19
NACE	4-digits	198
	3-digits	131
	2-digits	56

Source: Authors' elaboration.
Note: Classifications of NACE 3-digits and 2-digits are obtained using NACE 4-digits.

We also have information for NACE classifications at 2-, 3- and 4-digits aggregation levels that give more disaggregated sector classifications. Amador and Soares (2013) suggest the use of the highest level of disaggregation to avoid biases and to identify products as close as possible to their substitutes. Due to the small number of firms by sector and the similar results obtained when using NACE 2-digits and NACE 4-digits, we choose the NACE 3-digits aggregation level.[12]

Concerning the geographical area of influence, we choose to limit our sample to firms that are operating in markets where products and services are traded worldwide (see Table 8 in Appendix). The main reasons for this choice are twofold: (1) Our sample is representative at the worldwide level, and (2) we use the consolidated financial information of the firm sample rather than country-specific financial information. This means that we do not include individual firms in our analysis that are operating more at a local scale in sectors limited in a given region or country, such as electricity, public water or telecommunication services.

3.4 R&D function

Equation (4) represents the R&D function. Together with the competition indicators ($comp_{i,t}$ and $comp_{i,t}^2$), other factors that influence R&D activities are added in the equation. In line with the literature (see e.g., Crépon et al., 2000), we consider, among these factors, the firm size ($lemp_{i,t}$), measured by the number of employees, and firms' growth ($\Delta lsales_{i,t}$), measured by the growth of sales. Both variables are one-year lagged in order to ensure that current R&D activities do not influence them. They are expressed in the logarithmic form. We include year dummies to control for potential exogenous shocks or economic trends.

$$lrd_{i,t} = \beta_0 + \beta_1 lemp_{i,t-1} + \beta_2 \Delta lsales_{i,t-1} + \beta_3 comp_{i,t} + \beta_4 comp_{i,t}^2 + \tau_t + u_{i,t} \quad (4)$$

We estimate Equation (4) using two-stage least squares (2SLS) for panel-data models, with fixed effects (FE) and random effects (RE) estimators and controlling for the endogeneity of competi-

[12]The results of ICB 3-digits, NACE 2, and 4-digits are reported as robustness tests in Table 13 in Appendix.

tion. The main instruments used are the lagged variables of the endogenous variables, namely, competition.

4 Results and discussion

4.1 Descriptive statistics

After selecting only firms included in sectors where competition is at worldwide level (see selected sectors in Table 8 in the Appendix), and data is available for all the variables included in both models, the final sample is composed of 1,974 firms over the period 2007 – 2016. However, since we use some variables lagged or in first differences, we lose two years of our sample. The descriptive statistics of the sample are reported in Table 4.

Table 4: Mean, standard deviation, minimum and maximum

Variables	Obs.	Mean	Std. Dev.	Min	Max
Competition NACE 2-digits (*)	13,234	0.882	0.054	0.591	1
Competition NACE 3-digits (*)	13,234	0.88	0.059	0.537	1
Competition NACE 4-digits (*)	13,234	0.88	0.061	0.537	1
Competition ICB 3-digits (*)	13,234	0.883	0.053	0.558	0.979
Net Sales (euro millions, constant price)	13,234	7,284	18,855	6.335	301,451
Number employees	13,234	22,693	46,550	19	626,715
R&D expenditures (euro millions, constant price)	13,234	310	949	2.9	13,672
R&D Stock (euro millions, constant price)	13,234	1,663	5,162	6.6	66,741
Physical capital Stock (euro millions, constant price)	13,234	3,251	11,776	0.195	179,312
Manufacturing sector (Dummy)	13,234	0.78	0.414	0	1
High-tech manufacturing sector (Dummy)	10,324	0.409	0.492	0	1
Medium-high tech manufacturing sector (Dummy)	10,324	0.38	0.485	0	1
Medium-low tech manufacturing sector (Dummy)	10,324	0.114	0.317	0	1
Low tech manufacturing sector (Dummy)	10,324	0.098	0.297	0	1
Services sector (Dummy)	13,234	0.197	0.398	0	1
Knowledge-intensive services - KIS (Dummy)	2,613	0.853	0.354	0	1
Other services (Dummy)	2,613	0.147	0.354	0	1
Other sectors (Dummy)	13,234	0.022	0.148	0	1

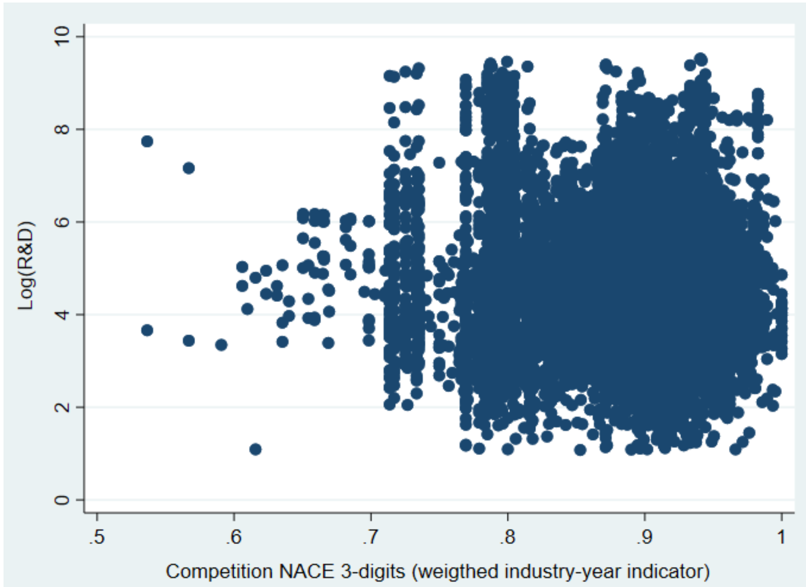
Source: Authors' own elaboration.
Note: Competition indicators are weighted industry-year indicators. Baseline year = 2016.

The Lerner competition index (industry-year indicator) is on average about 0.88 for all the indicators estimated (NACE 4 to 2-digits and ICB 3-digits) and, at least, for one sector in a given year this value is close to one, which means that the average ratio between operating profits and net sales is close to zero in this sector.

The sample is quite heterogeneous and divided into 139 NACE 3-digits sectors (Table 8 in the Appendix), but strongly concentrated in manufacturing sectors which represents nearly 78% of the sample. Services sectors account for about 20% and other sectors[13] near to 2% of the sam-

[13] such as agriculture, forestry and fishing; mining and quarrying; electricity, gas, steam, and air-conditioning supply; water supply, sewerage, waste management, and remediation and construction.

Figure 1: Two-way plot: Log(R&D) and Competition



Source: Authors' own elaboration

ple. High-tech and medium-high tech firms correspond to 79% of the manufacturing sector and knowledge-intensive services (KIS) near 85% of the services sector.

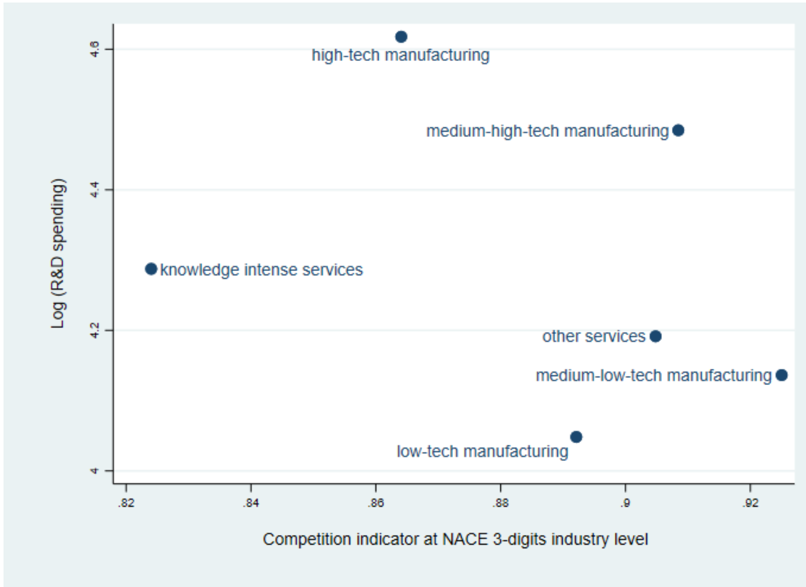
On average the level of competition in the manufacturing sector is higher than in the services ones (Table 9 in Appendix). Manufacturing sector reports a higher level of R&D expenditures than the services sector, but a lower level of R&D intensity (per employee and by net sales). Market power is higher in High & Medium-High tech (Table 10 in Appendix) and Knowledge-Intensive Services (Table11 in Appendix) than in other sectors (respectively, Medium-Low & Low tech and other services sectors). Both groups also display a higher average amount of R&D expenditure and R&D intensity (Table 10 and Table 11 in Appendix). [14]

Concerning the relationship between competition and R&D, Figure 1 shows two-way plots between R&D expenditures expressed in logarithmic form and competition levels. We can see that there is high heterogeneity in the data since wide ranges of R&D expenditures are observed for each degree of industry-year competition.

We further investigate the relationship between R&D expenditures expressed in logarithmic form and competition levels distinguishing manufacturing and services sectors in terms of their technological and knowledge intensities. Figure 2 shows the relationship between competition and innovation for manufacturing sectors grouped according to their technological level as well as the services sectors grouped according to their knowledge intensities. Firms operating in High & Medium-High tech sectors display a higher level of R&D in comparison with firms that are active in Medium-Low & Low tech sectors, Competition levels are on average lower for the firms operating in High & Medium-High tech sectors with respect to the average of firms active in Medium-Low & Low tech sectors. Firms operating in KIS sectors registered a higher level of R&D expenditures facing lower

[14]Except R&D per employee in KIS, which is not statistically different from non-KIS (Table 11 in Appendix).

Figure 2: Competition and R&D spending by technology and knowledge intensities in sectors



Source: Authors' own elaboration

levels of competition than firms active in other services sectors.

4.2 R&D equation

Table 5 presents the results of fixed effects (FE) and random effects (RE) estimators for the R&D function. The results of the Wald test, performed to test the joint significance of the estimated parameters, indicates that the model is correctly specified. We do not detect any problem of multicollinearity based on the results of variance inflation factors (VIF) for the independent variables and correlation matrix (Table 12 in the Appendix). The Hausman test suggests that only FE regression's results are consistent.

The results of the FE estimator in column (1) show an inverted-U shaped relationship between competition and innovation, and this result is in line with the findings of Aghion et al. (2005). However, the relationship between competition and innovation is endogenous, and we test for endogeneity using 2SLS regressions.[15] Our instrumental variables are the first and the second lags of competition variables in level and square, and the Sargan-Hansen test reveals that the set of instruments used is valid.[16] Similar to the previous estimation, the Hausman test rejects the hypothesis that validates the use of RE estimation. The FE estimates shown in column (3) support, once more, an inverted-U shaped relationship. Thus, controlling for endogeneity, our results remain in line with the findings of Aghion et al. (2005).

Our control variables are 1-year lagged firm sales growth expressed in logarithm, and 1-year lagged

[15]Usually, the use of difference GMM of Arellano and Bond (1991) is not appropriate for the small size of samples and in the presence of multicollinearity. Therefore, we used 2-step differences GMM method where applicable considering the endogeneity of our competition indicators and control variables for our estimations (results available in 15 in Appendix).

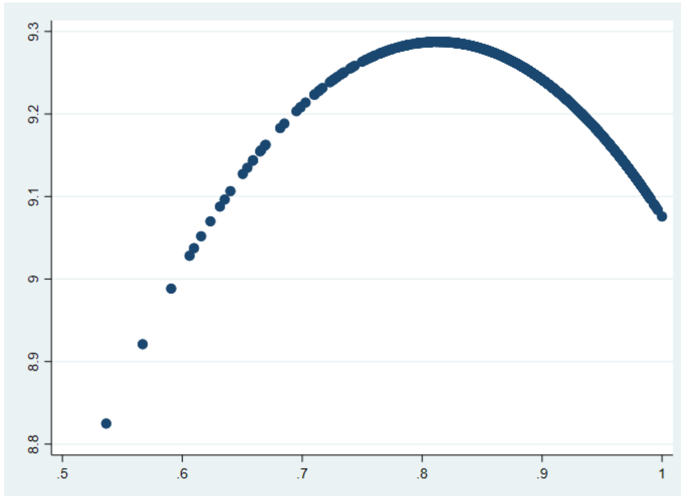
[16]The results with the first lag of competition variables in level and square are available on request.

Table 5: The results of R&D equation

Variables	Y = Log(R&D)			
	FE (1)	RE (2)	IV - FE (3)	IV – RE (4)
Competition (1 - Lerner)	6.096***	6.973***	9.839***	10.65***
	(1.597)	(1.583)	(3.615)	(3.468)
Competition – Squared	-3.624***	-4.424***	-6.051***	-7.095***
	(0.941)	(0.932)	(2.178)	(2.077)
Growth of sales - Log in T-1	0.102***	0.102***	0.100***	0.0989***
	(0.0113)	(0.0113)	(0.0113)	(0.0114)
Number employees - Log in T-1	0.579***	0.558***	0.580***	0.563***
	(0.00974)	(0.00805)	(0.00983)	(0.00819)
Year dummy	YES	YES	YES	YES
Constant	-3.417***	-3.397***	-4.819***	-4.584***
	(0.678)	(0.672)	(1.491)	(1.441)
Observations	13,234	13,234	13,234	13,234
Number of firms	1,974	1,974	1,974	1,974
R-squared	0.4393	0.4384	0.4386	0.4334
Wald test	0	0	0	0
Hausman test	0		0	
Endogenous variables	NO	NO	Competition	
Instruments	-	-	L(1/2).Competition	
Sargan-Hansen test	-	-	0.766	0.0966

Source: Authors' own elaboration.
Note: Robust standard errors in parentheses:*** p<0.01, ** p<0.05, * p<0.1.
Instrumental variables are the first and the second lags of competition variables.

Figure 3: Estimated relationship between competition and innovation



Source: Authors' own elaboration
Notes: Figure based on the results of IV-FE reported in column (3) of Table 5. Y = Log(R&D) and X = Competition (1-Lerner). Innovation is measured by the logarithm of R&D expenditures.

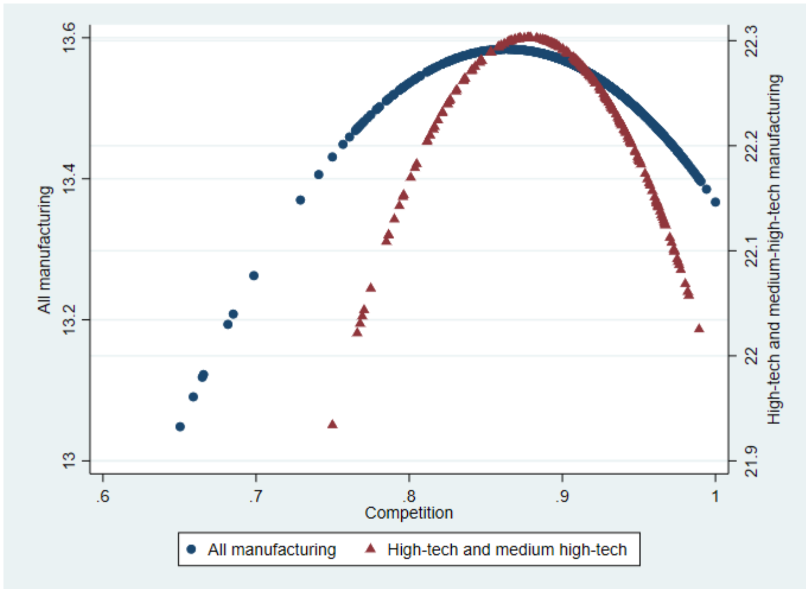
firm size approximated by the number of employees. The results for the control variables are positive and significant. In line with the literature, we find that large firms and firms that experience growth of their sales tend to invest more in R&D.[17]

Figure 3 illustrates the estimated relationship between competition and innovation based on the results of IV-FE estimation reported in column (3) of Table 5.

Subsequently, we split our firm sample into six sub-sample according to firms' sector of activities. Distinguishing manufacturing and services sectors, we look at the impact of competition in the manufacturing and services sectors. The results of the 2SLS FE estimations shown in columns (1) and (4) of Table 6 reveal an inverted-U shaped relationship in line with the findings of Aghion et al. (2005) for manufacturing sectors whereas we do not observe any significant impact of competition on innovation in the services sector. Our sample composes of large firms with high levels of R&D spending worldwide. Due to this bias in our sample, we investigate further in detail the impact of competition in the manufacturing and services sectors by distinguishing manufacturing sectors' firms according to their technological intensities, and services sectors' firms according to their knowledge intensities. The results shown in column (2) of Table 6 prevail that the inverted-U shaped relationship in the manufacturing sector is valid for the firms that are active in high-tech and medium-high-tech manufacturing sectors that represent around the 79% of the overall manufacturing sample. The results shown in column (2) indicate that the coefficients of competition indicators almost double with respect to overall manufacturing sample. Although the signs of the coefficients remain the same, the results for the medium-low-tech and low-tech manufacturing sectors' firms shown in column (3) are not significant. Looking at the firms operating in services sectors in columns (4) – (6), we observe an inverted-U shaped relationship in services sectors when we restrict our sample to the firms active in knowledge-intense services sectors in column (5).

[17] See, for instance, Crépon et al. (2000).

Figure 4: Competition and R&D spending by technology and knowledge intensities in sectors



Source: Authors' own elaboration
Notes: Figure based on the results of IV-FE reported in column (3) of Table 5. Y = Log(R&D) and X = Competition (1-Lerner). Innovation is measured by the logarithm of R&D expenditures.

Figure 4 illustrates and compares the estimated relationship between competition and innovation based on the results of IV-FE estimation reported in the columns (1) and (2) of Table 6. Competition and innovation levels are higher for firms operating in high-tech and medium-high-tech sectors and the inverted-U shaped relationship between competition and innovation is steeper with respect to the overall manufacturing sample.

Table 6: The results of R&D equation by technology and knowledge intensities within the manufacturing and services sectors

	Y = Log(R&D)					
Variables	All Manufacturing	H and MH tech	L and ML tech	All Services	KIS	non-KIS
Competition	20.27***	39.39***	7.629	22.79	32.23*	-1.5
	(6.249)	(9.940)	(7.043)	(16.64)	(17.37)	(30.30)
Competition – Squared	-11.73***	-22.43***	-5.16	-14.98	-21.69*	1.913
	(3.622)	(5.787)	(4.136)	(11.00)	(11.47)	(20.08)
Growth of sales - Log in T-1	0.109***	0.118***	0.0624	0.0506	0.0312	0.165
	(0.0210)	(0.0223)	(0.0568)	(0.0346)	(0.0343)	(0.110)
Firm size: Number employee - Log in T-1	0.523***	0.555***	0.374***	0.751***	0.790***	0.528***
	(0.0234)	(0.0265)	(0.0450)	(0.0372)	(0.0412)	(0.0892)
Year dummy	YES	YES	YES	YES	YES	YES
Observations	10,324	8,144	2,180	2,613	2,230	383
R-squared	0.408	0.448	0.268	0.54	0.548	0.452
Number of firms	1,495	1,182	313	433	374	59
Wald test	0	0	0	0	0	0
Sargan-Hansen test	0.4773	0.0853	0.0602	0.7019	0.93	0.7028
Restrictions: Worldwide competition	YES	YES	YES	YES	YES	YES

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses:*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Instrumental variables are the first and the second lags of competition variables in level and square.

4.3 Robustness checks

We apply several robustness checks to validate our results. First of all, FE estimation results for subsamples available in Table 14 in Appendix confirm the inverted-U shaped relationship between competition and innovation for manufacturing and high-tech manufacturing sectors' firms. The coefficients of competition indicators remain around double for the firms operating in high-tech manufacturing sectors with respect to manufacturing sample. FE regression does not yield significant results for services sectors' firms even when splitting into subsamples and looking at knowledge intense services' firms exclusively. Second, we investigate our findings using 2-step difference GMM method of Arellano and Bond (1991). Considering the endogeneity of our competition indicators and control variables for our estimation, results available in Table 15 in Appendix confirm our previous findings of an inverted-U shaped relationship for manufacturing and high-tech manufacturing firms.

Next, we investigate the relationship between competition and innovation for our subsamples interacting sector dummies with competition indicators. The results of the interaction regressions available in Table 16 in Appendix do not indicate a difference for firms from high-tech and medium-high-tech manufacturing sectors compared to overall manufacturing sample. For low-tech and medium-low-tech sectors' firms, however, we find the opposite behaviour in their R&D spending facing competition (results available in Table 16 in Appendix). We do not find significant results for services sectors' firms and its subsamples.

Finally, we test our results using an alternative classification for sector-level technological intensities proposed for the Scoreboard firms by the European Commission.[18] The methodology classifies the sectors according to the average sector-level R&D intensities identified by aggregated R&D expenditures divided by aggregated net sales per sector. Sectors are identified as High-tech if R&D intensities are above 5%; Medium-high-tech if R&D intensities are between 2% and 5%; Medium-low-tech if R&D intensities are between 1% and 2%, and Low-tech if R&D intensities are below 1%.[19] We test our 2SLS regressions with subsamples as well as with interaction terms using the alternative classification for technological intensities. The results are available in Table 18 and Table 19 in Appendix and confirm our findings for manufacturing, and high-tech and medium-high-tech sectors' firms with the new classification. We do not find significant results for services sectors' firms and its subsamples.

5 Conclusions

The paper assesses the impact of competition on firm-level innovation. We test the relationship between competition and innovation measured by R&D expenditures. The originality of the study comes from the representativeness of its firm-sample at the worldwide in terms of business R&D expenditures, its attempt to better define the competition indicator identifying the relevant markets for the firm-sample and the control for endogeneity of the competition indicator.

Results confirm the inverted-U shaped impact of competition on innovation. This is in line with the recent works of Aghion (2017) and Aghion et al. (2005 and 2009). When we further examine our firm sample distinguishing manufacturing and services sectors according to their technological

[18] The 2014 EU Industrial R&D Investment Scoreboard European Commission, JRC/DG RTD.

[19] Subsamples and their shares in manufacturing and services sectors are listed in Table 17 in Appendix.

and knowledge intensities, the inverted-U shaped relationship is, however, only observed for the firms operating in medium-high-tech and high-tech manufacturing sectors. Our results are robust to different sector aggregations and different methodologies used to determine the knowledge and technology intensities of sectors. These findings can be explained by the theoretical predictions of Aghion et al. (2005). An "escape competition effect" seems to prevail for firms that are operating in high-tech and medium high-tech sectors and competition gives incentives to innovate more. The results with interaction terms indicate the opposite impact of competition on innovation for the firms operating in medium-low-tech and low-tech manufacturing firms ("Schumpeterian effect").

The results of the paper imply that competition policy should be implemented with attention taking into the characteristics of the firms and sector of activities. In addition, policies that foster competition have a positive impact on a firm's innovative efforts in medium-high-tech and high-tech manufacturing sectors only up to a certain level of competition. Too competitive markets are at risk of missing incentives for a firm to innovate.

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6 Appendix

Table 7: The geographical distribution of the firms included in R&D Scoreboard (Number of firms)

Countries	Number of firms
Germany	134
United Kingdom	134
France	71
Netherlands	39
Sweden	36
Denmark	26
Italy	24
Ireland	23
Finland	19
Austria	16
Spain	16
Belgium	15
Luxembourg	6
Greece	3
Portugal	2
Hungary	1
Malta	1
Slovenia	1
Sub-total European Union (EU)	567
US	822
China	376
Japan	365
Taiwan	105
South Korea	70
Switzerland	52
Canada	27
India	25
Israel	22
Australia	15
Norway	12
Rest of the world	42
TOTAL	2,500

Source: Authors' own elaboration.

Table 8: Average level of competition, NUMBER of firms and observations by NACE 3-Digits

Code	Description	Competition	# firms	# obs.
11	Growing of non-perennial crops	0.901	3	23
32	Aquaculture	0.842	2	12
51	Mining of hard coal	0.759	2	8
61	Extraction of crude petroleum	0.877	7	43
71	Mining of iron ores	0.759	3	20
72	Mining of non-ferrous metal ores	0.828	4	32
89	Mining and quarrying n.e.c.	0.888	2	11
91	Support activities for petroleum and natural gas extraction	0.923	15	101
101	Processing and preserving of meat and production of meat products	0.944	3	19
102	Processing and preserving of fish, crustaceans and molluscs	0.979	1	8
103	Processing and preserving of fruit and vegetables	0.89	5	40
104	Manufacture of vegetable and animal oils and fats	0.938	1	8
105	Manufacture of dairy products	0.92	10	72
106	Manufacture of grain mill products, starches and starch products	0.927	3	21
107	Manufacture of bakery and farinaceous products	0.963	2	16
108	Manufacture of other food products	0.872	27	180
109	Manufacture of prepared animal feeds	0.951	2	14
110	Manufacture of beverages	0.829	8	55
120	Manufacture of tobacco products	0.688	4	32
131	Preparation and spinning of textile fibres	0.952	4	26
132	Weaving of textiles	0.913	1	8
133	Finishing of textiles	0.945	1	8
139	Manufacture of other textiles	0.917	5	30
141	Manufacture of wearing apparel, except fur apparel	0.842	7	48
151	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness; dressing and dyeing of fur	0.813	2	10
152	Manufacture of footwear	0.928	6	44
162	Manufacture of products of wood, cork, straw and plaiting materials	0.93	2	10
171	Manufacture of pulp, paper and paperboard	0.956	6	43
172	Manufacture of articles of paper and paperboard	0.901	13	82
181	Printing and service activities related to printing	0.961	3	20
191	Manufacture of coke oven products	0.777	1	8
192	Manufacture of refined petroleum products	0.937	11	74
201	Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	0.887	44	333
202	Manufacture of pesticides and other agrochemical products	0.82	5	37
203	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	0.914	11	80
204	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	0.839	22	166
205	Manufacture of other chemical products	0.928	45	337
206	Manufacture of man-made fibres	0.941	4	29
211	Manufacture of basic pharmaceutical products	0.853	15	108
212	Manufacture of pharmaceutical preparations	0.793	156	964
221	Manufacture of rubber products	0.912	17	116
222	Manufacture of plastics products	0.915	15	98
231	Manufacture of glass and glass products	0.933	9	63
232	Manufacture of refractory products	0.929	1	8
234	Manufacture of other porcelain and ceramic products	0.917	4	29

Continued on next page

Table 8 – *Continued from previous page*

Code	Description	Competition	# firms	# obs
235	Manufacture of cement, lime and plaster	0.908	9	66
236	Manufacture of articles of concrete, cement and plaster	0.912	1	5
239	Manufacture of abrasive products and non-metallic mineral products n.e.c.	0.796	4	32
241	Manufacture of basic iron and steel and of ferro-alloys	0.961	11	83
242	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel	0.907	3	23
243	Manufacture of other products of first processing of steel	0.946	19	134
244	Manufacture of basic precious and other non-ferrous metals	0.939	13	96
245	Casting of metals	0.958	11	68
251	Manufacture of structural metal products	0.935	8	56
252	Manufacture of tanks, reservoirs and containers of metal	0.927	5	36
254	Manufacture of weapons and ammunition	0.908	2	11
255	Forging, pressing, stamping and roll-forming of metal; powder metallurgy	0.915	3	17
257	Manufacture of cutlery, tools and general hardware	0.879	2	16
259	Manufacture of other fabricated metal products	0.911	15	105
261	Manufacture of electronic components and boards	0.886	189	1276
262	Manufacture of computers and peripheral equipment	0.909	62	340
263	Manufacture of communication equipment	0.888	66	466
264	Manufacture of consumer electronics	0.973	11	71
265	Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks	0.868	75	552
266	Manufacture of irradiation, electromedical and electrotherapeutic equipment	0.793	14	108
267	Manufacture of optical instruments and photographic equipment	0.901	18	127
271	Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	0.916	27	184
272	Manufacture of batteries and accumulators	0.935	8	52
273	Manufacture of wiring and wiring devices	0.967	2	13
274	Manufacture of electric lighting equipment	0.922	7	43
275	Manufacture of domestic appliances	0.948	18	114
279	Manufacture of other electrical equipment	0.939	9	60
281	Manufacture of general — purpose machinery	0.902	41	298
282	Manufacture of other general-purpose machinery	0.918	41	300
283	Manufacture of agricultural and forestry machinery	0.901	11	83
284	Manufacture of metal forming machinery and machine tools	0.863	10	70
289	Manufacture of other special-purpose machinery	0.917	71	522
291	Manufacture of motor vehicles	0.945	41	288
292	Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers	0.97	6	41
293	Manufacture of parts and accessories for motor vehicles	0.933	60	422
301	Building of ships and boats	0.959	4	30
302	Manufacture of railway locomotives and rolling stock	0.935	5	38
303	Manufacture of air and spacecraft and related machinery	0.908	28	211
309	Manufacture of transport equipment n.e.c.	0.942	10	67
310	Manufacture of furniture	0.917	8	60
321	Manufacture of jewellery, bijouterie and related articles	0.797	1	8
322	Manufacture of musical instruments	0.948	1	8
323	Manufacture of sports goods	0.91	5	40
324	Manufacture of games and toys	0.886	11	77
325	Manufacture of medical and dental instruments and supplies	0.835	48	333
329	Manufacturing n.e.c.	0.844	3	20

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Table 8 – *Continued from previous page*

Code	Description	Competition	# firms	# obs
331	Repair of fabricated metal products, machinery and equipment	0.857	1	6
332	Installation of industrial machinery and equipment	0.907	1	4
451	Sale of motor vehicles	0.939	3	20
452	Maintenance and repair of motor vehicles	0.918	1	8
453	Sale of motor vehicle parts and accessories	0.75	1	8
461	Wholesale on a fee or contract basis	0.895	1	4
464	Wholesale of household goods	0.981	4	24
465	Wholesale of information and communication equipment	0.898	6	37
467	Other specialised wholesale	0.829	4	22
469	Non-specialised wholesale trade	0.875	4	28
471	Retail sale in non-specialised stores	0.964	7	49
475	Retail sale of other household equipment in specialised stores	0.897	2	11
477	Retail sale of other goods in specialised stores	0.923	4	26
479	Retail trade not in stores, stalls or markets	0.923	9	60
511	Passenger air transport	0.953	2	13
522	Support activities for transportation	0.919	6	41
581	Publishing of books, periodicals and other publishing activities	0.901	6	41
582	Software publishing	0.755	91	561
601	Radio broadcasting	0.767	1	8
602	Television programming and broadcasting activities	0.904	4	31
619	Other telecommunications activities	0.862	34	234
620	Computer programming, consultancy and related activities	0.799	108	652
631	Data processing, hosting and related activities; web portals	0.839	18	120
642	Activities of holding companies	0.883	18	66
643	Trusts, funds and similar financial entities	1	2	5
649	Other financial service activities, except insurance and pension funding	0.643	3	18
661	Activities auxiliary to financial services, except insurance and pension funding	0.856	8	52
701	Activities of head offices	0.95	26	101
702	Management consultancy activities	0.893	3	21
711	Architectural and engineering activities and related technical consultancy	0.921	9	59
721	Research and experimental development on natural sciences and engineering	0.889	12	54
731	Advertising	0.936	3	13
732	Market research and public opinion polling	0.935	1	8
742	Photographic activities	0.962	1	8
743	Translation and interpretation activities	0.905	1	8
749	Other professional, scientific and technical activities n.e.c.	0.865	20	134
772	Renting and leasing of personal and household goods	0.926	1	8
791	Travel agency and tour operator activities	0.766	2	16
801	Private security activities	0.862	1	8
802	Security systems service activities	0.894	2	15
829	Business support service activities n.e.c.	0.831	4	21
851	Pre-primary education	0.963	1	8
855	Other education	1	1	4
869	Other human health activities	0.988	1	8
920	Gambling and betting activities	0.87	2	14
931	Sports activities	0.91	1	3

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Table 8 – *Continued from previous page*

Code	Description	Competition	# firms	# obs
932	Amusement and recreation activities	0.808	1	8
960	Other personal service activities	0.6	1	2
	TOTAL		1,974	13,234

Source: Authors' own elaboration.

Table 9: Results of two-sample t-test for the equality of means: manufacturing versus services

Variables	Manufacturing		Services		Diff (Manufacturing - Services)		
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	p-value
Competition NACE 3-digits	0.891	0	0.836	0.001	0.055	0.001	0
R&D expenditures (1)	328.4	9.6	248.4	17.4	80.1	21	0
R&D expenditures per employee (2)	24.45	0.45	35.06	1.49	-10.61	1.16	0
R&D intensity (R&D/Sales)	0.072	0.001	0.124	0.002	-0.052	0.002	0

Source: Authors' own elaboration.
Note: (1) Expressed in euro millions, constant price; (2) Expressed in euro thousands, constant prices.
Baseline year=2016. Number of observations= 12,937: Manufacturing=10,324 and Services= 2,613.

Table 10: Results of two-sample t-test for the equality of means: H+ MH tech versus ML + L tech

Variables	H + MH Tech		ML + L Tech		Diff (H+MH - ML+L)		
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	p-value
Competition NACE 3-digits	0.885	0.001	0.91	0.001	-0.024	0.001	0
R\&D expenditures (1)	383.7	12	122	4.7	261.7	23.4	0
R\&D expenditures per employee (2)	29	0.6	7.5	0.3	21.5	1.1	0
R\&D intensity (R\&D/Sales)	0.085	0.001	0.025	0.001	0.059	0.002	0

Source: Authors' own elaboration.
Note: (1) Expressed in euro millions, constant price; (2) Expressed in euro thousands, constant prices.
Baseline year=2016. Number of observations=10,324: H+MH=8,144 and ML+L=2,180.

Table 11: Results of two-sample t-test for the equality of means: KIS versus non-KIS

Variables	KIS		Non-KIS		Diff (KIS - non-KIS)		
	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	p-value
Competition NACE 3-digits	0.824	0.001	0.905	0.003	-0.081	0.004	0
R\&D expenditures (1)	263.7	20.2	159.3	16.1	104.3	49.3	0.034
R\&D expenditures per employee (2)	35.4	1	32.8	8.5	2.6	4.2	0.537
R\&D intensity (R\&D/Sales)	0.136	0.003	0.054	0.004	0.082	0.006	0

Source: Authors' own elaboration.
Note: (1) Expressed in euro millions, constant price; (2) Expressed in euro thousands, constant prices. Baseline year=2016. Number of observations=2,613: KIS=2,230 and Non-KIS=383.

Table 12: Collinearity diagnostics and correlation

			Correlation matrix		
	Variables	VIF	1	2	3
1	Competition	1.07	1		
2	L.ΔLog(Sales)	1.04	-0.125	1	
3	L.Log(Employee)	1.09	0.243	-0.191	1
	Mean VIF	1.07			

Source: Authors' own elaboration.
Note: Number of observations = 13,234. Δ is first difference operator. L means that variable is lagged one period. VIF corresponds to the variance inflation factor and values higher than 10 reveal evidence of collinearity (Baum, 2006). Once the results on Table above show that the maximum VIF is less than 2, no evidence of collinearity is found.

Table 13: Robustness test: The results of innovation equation (2SLS), by the different levels of sector aggregation

	Y = Log(R&D)		
Variables	NACE 4-digits	NACE 2-digits	ICB 3-digits
Competition (1 - Lerner)	8.512*	11.46**	13.30*
	(5.046)	(5.800)	(7.221)
Competition - Squared	-5.047*	-7.023**	-7.913*
	(2.971)	(3.425)	(4.141)
Growth of sales - Log in T-1	0.101***	0.0998***	0.100***
	(0.0189)	(0.0189)	(0.0189)
Number of employees - Log in T-1	0.580***	0.580***	0.580***
	(0.0211)	(0.0209)	(0.0209)
Year dummy	YES	YES	YES
Observations	13,234	13,234	13,234
Number of firms	1,974	1,974	1,974
R-squared	0.439	0.439	0.439
Wald test	0	0	0
Sargan-Hansen test	0.7746	0.4889	0.0763

Source: Authors' own elaboration.
Note: Robust standard errors in parentheses:*** p<0.01, ** p<0.05, * p<0.1. Instrumental variables are the first and the second lags of competition variables in level and square.

Table 14: Robustness test: The Fixed-Effects results for manufacturing and services subsamples

Variables	Y = Log(R&D)					
	All Manufacturing	H + MH Tech	ML + L Tech	All Services	KIS	non-KIS
Competition	9.756**	17.27***	2.914	1.973	2.6	0.727
	(3.991)	(5.896)	(4.986)	(6.024)	(6.621)	(11.86)
Competition - Squared	-5.853**	-10.06***	-2.273	-1.378	-1.921	0.313
	(2.276)	(3.355)	(2.892)	(3.575)	(3.969)	(6.605)
Growth of sales - Log in T-1	0.109***	0.117***	0.0653	0.05	0.0294	0.166
	(0.0221)	(0.0239)	(0.0552)	(0.0412)	(0.0407)	(0.124)
Number of employees - Log in T-1	0.525***	0.560***	0.375***	0.747***	0.783***	0.533***
	(0.0393)	(0.0465)	(0.0645)	(0.0539)	(0.0593)	(0.126)
Year dummy	YES	YES	YES	YES	YES	YES
Constant	-4.430**	-7.899***	-0.387	-2.838	-3.129	-1.979
	(1.732)	(2.544)	(2.145)	(2.575)	(2.786)	(5.662)
Observations	10,324	8,144	2,180	2,613	2,230	383
R-squared	0.409	0.45	0.269	0.553	0.577	0.453
Number of firms	1,495	1,182	313	433	374	59
Restrictions: Worldwide competition	YES	YES	YES	YES	YES	YES

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses:*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 15: Robustness test: The 2-step difference GMM results of R&D equation

Variables	Y = Log(R&D)					
	All Manufacturing	H + MH Tech	ML + L Tech	All Services	KIS	non-KIS
Competition	20.15***	40.55***	8.36	23.03	31.73*	8.445
	(6.248)	(9.926)	(6.932)	(16.540)	(17.320)	(27.870)
Competition - Squared	-11.64***	-23.06***	-5.494	-15.27	-21.43*	-4.761
	(3.621)	(5.779)	(4.080)	(10.940)	(11.450)	(18.420)
Growth of sales - Log in T-1	0.109***	0.120***	0.0734	0.0505	0.0319	0.177
	(0.0208)	(0.0222)	(0.0545)	(0.0346)	(0.0343)	(0.109)
Number of employees - Log in T-1	0.522***	0.554***	0.380***	0.752***	0.789***	0.533***
	(0.0234)	(0.0265)	(0.0447)	(0.037)	(0.0409)	(0.089)
Year dummy	YES	YES	YES	YES	YES	YES
Observations	10,324	8,144	2,180	2,613	2,230	383
R-squared	0.408	0.448	0.268	0.54	0.548	0.452
Number of firms	1,495	1,182	313	433	374	59
Wald test	0	0	0	0	0	0
Sargan-Hansen test	0.4773	0.0853	0.0602	0.7019	0.93	0.7028
Restrictions: Worldwide competition	YES	YES	YES	YES	YES	YES

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses:*** $p<0.01$, ** $p<0.05$, * $p<0.1$. In GMM estimation, Sargan Hansen test statistics report Hansen J test statistics for over identification.

Table 16: Robustness test: The 2SLS results for manufacturing and services subsamples with interaction terms

Variables	Y = Log(R&D)			
	H + MH Tech	ML + L Tech	KIS	non-KIS
Competition	24.02**	40.13***	40.03	30.69
	(10.44)	(12.35)	(58.47)	(21.43)
Competition - Squared	-13.83**	-22.95***	-24.9	-20.56
	(5.921)	(7.182)	(38.42)	(14.15)
High * Competition	-7.09			
	(11.37)			
High * Competition - Squared	3.995			
	(6.408)			
Low * Competition		-37.96***		
		(13.04)		
Low * Competition - Squared		21.08***		
		(7.527)		
KIS * Competition			-38.1	
			(59.83)	
KIS * Competition - Squared			23.32	
			(39.20)	
Non-KIS * Competition				-28.66
				(22.35)
Non-KIS * Competition - Squared				19.89
				(14.49)
LD.lns	0.109***	0.110***	0.0505	0.0507
	(0.0209)	(0.0210)	(0.0349)	(0.0346)
L.lemp	0.523***	0.520***	0.747***	0.753***
	(0.0234)	(0.0235)	(0.0366)	(0.0372)
Year dummy	YES	YES	YES	YES
Observations	10,324	10,324	2,613	2,613
R-squared	0.407	0.407	0.546	0.534
Number of firms	1,495	1,495	433	433
Wald test	0	0	0	0
Sargan-Hansen test	0.5557	0.1527	0.3752	0.903
Restrictions: Worldwide competition	YES	YES	YES	YES

Source: Authors' own elaboration.

Note: Robust standard errors in parentheses:*** p<0.01, ** p<0.05, * p<0.1. Instrumental variables are the first and the second lags of competition variables in level and square.

Table 17: Robustness test: Sector-level technological intensities with IPTS' formulation

Variables	Obs.	Mean	Std. Dev.	Min	Max
Manufacturing sector (Dummy)	13,234	0.78	0.414	0	1
High-tech manufacturing sector (Dummy)	10,324	0.409	0.492	0	1
Medium-high tech manufacturing sector (Dummy)	10,324	0.38	0.485	0	1
Medium-low tech manufacturing sector (Dummy)	10,324	0.114	0.317	0	1
Low tech manufacturing sector (Dummy)	10,324	0.098	0.297	0	1
Services sector (Dummy)	13,234	0.197	0.398	0	1
High-tech services sector (Dummy)	2,613	0.409	0.492	0	1
Medium-high tech services sector (Dummy)	2,613	0.38	0.485	0	1
Medium-low tech services sector (Dummy)	2,613	0.114	0.317	0	1
Low tech services sector (Dummy)	2,613	0.098	0.297	0	1

Source: Authors' own elaboration.

Table 18: Robustness test: 2SLS regression results for manufacturing and services subsamples using IPTS' formulation

Variables	Y = Log(R&D)			
	H + MH Tech	ML + L Tech	KIS	non-KIS
Competition	35.39***	6.742	17.2	38.33
	(9.059)	(10.28)	(14.81)	(34.45)
Competition - Squared	-20.16***	-4.84	-11.76	-22.87
	(5.207)	(6.507)	(9.767)	(21.47)
Growth of sales - Log in T-1	0.110***	0.114	0.0464	0.449
	(0.0216)	(0.0764)	(0.0347)	(0.414)
Firm size: Number of employees - Log in T-1	0.519***	0.547***	0.761***	0.18
	(0.0242)	(0.0923)	(0.0373)	(0.274)
Year dummy	YES	YES	YES	YES
Observations	9,372	952	2,441	172
R-squared	0.423	0.242	0.572	0.198
Number of firms	1,360	135	407	26
Wald test	0	0	0	0
Sargan-Hansen test	0.275	0.157	0.7606	0.6657
Restrictions: Worldwide competition	YES	YES	YES	YES

Source: Authors' own elaboration.
Note: Robust standard errors in parentheses:*** p<0.01, ** p<0.05, * p<0.1. Instrumental variables are the first and the second lags of competition variables in level and square.

Table 19: Robustness test: The 2SLS results for manufacturing and services subsamples with interaction terms using IPTS' formulation

Variables	Y = Log(R&D)			
	H + MH Tech	ML + L Tech	KIS	non-KIS
Competition	32.32**	37.82***	65.68	23.61
	(15.70)	(10.21)	(53.09)	(18.57)
Competition - Squared	-19.11*	-21.55***	-41.56	-15.73
	(10.07)	(5.868)	(34.90)	(12.31)
High * Competition	-20.09		-66.66	
	(15.86)		(52.88)	
High * Competition - Squared	11.97		41.83	
	(10.07)		(34.74)	
Low * Competition		-33.95***		-6.699
		(11.65)		(30.35)
Low * Competition – Squared		18.38***		7.274
		(6.686)		(18.55)
LD.lns	0.109***	0.111***	0.0501	0.0479
	(0.0209)	(0.0209)	(0.0351)	(0.0345)
L.lemp	0.523***	0.521***	0.748***	0.752***
	(0.0235)	(0.0235)	(0.0360)	(0.0370)
Year dummy	YES	YES	YES	YES
Observations	10,324	10,324	2,613	2,613
R-squared	0.407	0.407	0.549	0.539
Number of firms	1,495	1,495	433	433
Wald test	0	0	0	0
Sargan-Hansen test	0.6689	0.1589	0.4724	0.6303
Restrictions: Worldwide competition	YES	YES	YES	YES

Source: Authors' own elaboration.
Note: Robust standard errors in parentheses:*** p<0.01, ** p<0.05, * p<0.1. Instrumental variables are the first and the second lags of competition variables in level and square.