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EXTERNAL R&D ACQUISITION AND PRODUCT INNOVATION

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External R&D Acquisition and Product Innovation

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Abstract

The outsourcing of R&D activities is considered an important way to acquire external technological information that can be integrated into a firm's own knowledge endowment. Given the complex relationship between R&D partnerships and innovation performance, it becomes of paramount importance for scholars, managers and policy-makers to understand whether and how outsourcing benefits the firm. This paper tries to assess the impact that external sources of R&D may have on product innovation, differentiating between R&D supplied by universities and other companies. The empirical analysis is based on a large and representative sample of European manufacturing companies. The analysis considers R&D an endogenous decision in investigating its effect on product innovation. An instrumental variable two-step estimation method is employed to deal with this issue. The results suggest that R&D intensity, or the share of R&D acquired from external sources, has a positive and significant effect on product innovation. Furthermore, we find evidence of an inverse U-shaped relationship between R&D outsourcing and innovation, meaning that on average, costs start to outweigh benefits as the R&D collaboration projects increase. We also estimate high returns from R&D acquired from universities on the probability to achieve product innovations, while having firms in the same group as research partners has the largest effect on innovative product sales. The results have straightforward implications for the practice of R&D managers. In order to gain advantages from partnership in research, innovation managers need to jointly exploit these different types of collaboration activities and their potential synergies. Given that the innovative firms in the sample desire additional credit which actually they do not obtain, R&D managers should also be concerned with the financing sources firms have access to. Finally, the analysis suggests that managers ought to identify the appropriate level of external acquisition in order to fully benefit on innovation.

Keywords: External R&D, research partners, innovation performance, IV model.
Jel classification: O31, O32, L60, C36.

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1. Introduction

Innovation is commonly viewed as a crucial leverage of competitive advantage for business, and it has become one driving paradigm in management and research. Several papers have analysed the relationship between R&D and innovation, often within the area of study which relates firms' innovative activities to productivity and competitiveness (Carayannis and Grigoroudis, 2014; Medda and Piga, 2014), confirming the central role played by R&D in the innovation process inside the firm.

Firms' decision to carry out innovative activities is driven by internal characteristics such as size, age of firm, financial structure, along with external factors: the set of technological opportunities given by the system the firm is part of. Opportunities may take the form of spillovers (Jaffe, 1986), in which case the firm takes advantage of freely available technology developed by external agents (other companies, universities, public or private research centres) depending on the proximity to the source of the externalities and the degree of appropriability of knowledge. Other external sources of technology are represented by frequent and heterogeneous knowledge exchanges which have been a substantial driving force for the growing number of domestic and international technological collaborations in recent decades. The rationale of R&D outsourcing is that it may allow firms ~~to~~ access to resources that are not available internally (Faems, van Looy, and Debackere, 2005). Resources can range from the organizational knowledge, physical assets, human capital, and other tangible and intangible factors (Cassiman and Veugelers, 2002; Atzeni and Carboni, 2004; Aristei, Vecchi, and Venturini, 2016).

Partnership with other firms in R&D can allow access to external resources and stimulate knowledge transfer, resource exchange, and organizational learning (Becker and Dietz, 2004). Firms also use R&D alliance to access information and build R&D networks. In addition to finding externally financial, material and human resources that complement the internal ones, this form allows the sharing of the risk associated with innovative activities and having access, at least partially, to external knowledge (Cassiman and Veugelers, 2002). The basic idea is that a higher level of collaborative R&D generates positive externalities and promotes the generation and introduction of new processes or products. Several empirical studies have investigated the effect of R&D cooperation on a firm's innovative performance and find that joint research activities have positive effects on the success of product innovations (Brouwer and Kleinknecht, 1999, for the Netherlands; Branstetter and Sakakibara, 2002, for Japanese firms; Czarnitzki, Ebersberger, and Fier, 2007, for Germany; Medda, 2018, for European manufacturing companies).

Recent academic work has studied the configuration of an alliance portfolio, in particular with respect to its diversity, as a critical strategic issue (Faems, van Looy, and Debackere, 2005; Grimpe and Kaiser, 2010; Carboni, 2012; Lee, Kirkpatrick-Husk, and Madhavan, 2017). Increasing the variety of partner types is likely to produce benefits for innovation performance as it provides broader knowledge access. Different types of partners often own distinctive resources, skills and experiences. For instance, in R&D partnerships between industry and public research centres and universities firms look at public agents as an important source of high quality scientists and innovation competencies in a context of non-competitive R&D collaboration (Bozeman, Fay, and Slade, 2013).

However, a recent strand of the management of R&D collaborations literature has pointed out that beneficial effects from R&D collaborations may be held back when firms find it difficult to appropriate the benefits from joint research efforts, or when competition among partners lead to opportunistic behaviour, such as selecting projects with a low probability of success (Un, Cuervo-Cazurra, and Asakawa, 2010; Berchicci, 2013). Furthermore, as external R&D intensity and complexity increase, firms face higher costs of coordination, steering and control. These considerations have led scholars to investigate a possible U-inverted shape relationship between external R&D and innovation success; Grimpe and Kaiser (2010) and Hottenrott and Lopes-Bento (2016) have found evidence that the returns to increasing R&D outsourcing intensity for German firms start to decline over a certain threshold.

1.1. Objectives of the paper

In the attempt to shed some more light on these arguments, in this paper we investigate the impact that external sources of R&D have on product innovation performance, differentiating between R&D supplied by other firms inside the same group, universities and research centres, and other companies. We employ two measures of firm innovation performance: a variable indicating whether a firm did carry out any product innovation, and a variable expressing the average percentage of turnover from innovative products sales.

More specifically, we investigate the relationship between R&D and product innovation, studying the effects of the intensity of R&D acquired from external partners and of the firms' collaboration breadth. Differently from previous studies, we exploit a large international dataset of 13,621manufacturing firms (EU-EFIGE/Bruegel), based on a survey carried out by leading academic institutions and coordinated by Bruegel in five European Countries: France, Germany, Italy, Spain, and the UK. The survey collects information over the period 2007 – 2009 on a large span of firms' characteristics, including R&D activities and innovation performance (see Altomonte and Aquilante, 2012, for an in-depth description of the dataset).

Also, differently from other existing research, the analysis considers R&D as an endogenous variable. We first study the determinants of firms' propensity to carry out R&D with special attention to the role played by regional technological opportunities and public support of companies' R&D activities. Subsequently, we estimate the impact of different forms of external R&D sources on product innovation. We use instrumental variable estimation technique to estimate the marginal effect of external R&D variables on (1) the probability to undertake product innovations, and (2) the market success on product innovations measured by the share on total turnover of innovative products sales, after controlling for firms' internal factors, countries and manufacturing sectors' fixed effects and regional technological opportunities.

Given the growing number of actors involved in a more distributed innovation process (Faems et al., 2010; Lee, Kirkpatrick-Husk, and Madhavan, 2017), we focus on partner type diversity as an important type of alliance portfolio diversity (Carboni, 2013). Finally, following the recent literature on this topic, we also try to assess if “over-outsourcing” may represent a threat to firm's innovation performance. Therefore, we check if there is an inverse U-shaped relationship between the degree of R&D outsourcing and innovation engagement.

Despite the cross section nature of dataset, which prevents us from studying possible time lags between R&D and innovation outcomes, the analysis provides some interesting results. ***First***, external sources of R&D ameliorate innovation outcomes, in terms of both the probability to carry out product innovations and sales from innovative products. However, beyond a certain threshold, firms show negative marginal effects on innovation performance. ***Second***, R&D acquisition from universities or other research centres particularly influence the probability to obtain product innovations. ***Third***, collaborating with firms within the group a company belongs to has the larger marginal effect on market success of product innovations measured by the share of total turnover from innovative products, compared to collaborating with universities or other firms.

1.2. Policy management indications

As the R&D partnerships become more common practice, the question arises whether such external knowledge acquisition is always beneficial for innovation performance and what ought to be the management attitude. Hence, R&D outsourcing requires a considerable amount of management attention to establish external relationships with R&D contractors. These latter need to be selected, continuously monitored and assessed. Management attention is required for allocating internal and external knowledge resources in order to appropriately exploit all the potentialities deriving from technological information flows.

In the light of these general statements, the analysis supplies some interesting indications which may be of value for R&D managers' strategy decisions. First, innovation managers ought to be particularly concerned with firm's R&D partnership involvement, as this strongly impacts innovation. In order to gain advantages from an innovation, innovation managers need to jointly exploit these different types of innovation activities and their potential synergies (Carboni and Russu, 2018). Furthermore, R&D managers should especially consider the financing sources firms have access to. The analysis reveals, in fact, that innovative firms, whatever the type of collaboration, desire additional credit which they do not receive. Since this constrains the firm's technological growth, R&D managers should also be concerned with the financing sources firms have access to.

The article is structured as follows. Section 2 describes the theoretical background and outlays the hypothesis we have built upon it. Section 3 describes the variables used and dataset. Section 4 outlines the empirical model specification and the estimation results. Section 5 concludes.

2. Theoretical background and hypothesis

Innovation is a manifold process, comprising new products, new production methods, new markets, new sources of supply, and new forms of organization. The concept of a knowledge production function (Griliches, 1979), allows one to study the process behind the transformation of inputs of the technological innovation activities such as R&D and human capital into new economically useful knowledge. Results of the innovation process can be roughly classified into product innovations or cost-reducing process innovations.

Product innovations, in particular, are the result of searching for technological competitiveness, and are market-oriented innovations. Firms renew their existing products, in order to improve the quality and variety of items they are able to supply to customers. While there is general consensus about innovation being a crucial source of firms' competitiveness and there are a number of papers that investigate the determinants of innovation, less is known about the possible relationships between innovation and the different types of research partnership that a firm commonly faces. The growing role of R&D collaboration in firms' innovative activities (Hagedoorn, 2002; Weigelt, 2009) has been extensively explored from different fields, such as managerial literature, transaction cost approaches and industrial organization.

Theoretical contributions in the management literature typically study R&D alliance in the light of minimizing transaction costs and exploiting complementary know-how between partner firms, and are particularly concerned with the voluntary nature of knowledge exchange in R&D partnerships. From this perspective collaboration may diminish costs through a better control on technology transfer and exploiting potential complementarities. In markets where collaboration and competition coexist, coordination, risk sharing, resources, and the acquisition of new competencies are the means through which firms gain from alliances in R&D (Faems et al., 2005; Grimpe and Kaiser, 2010; Un, Cuervo-Cazurra, and Asakawa, 2010). The management literature also supplies helpful insights about motivations and problems for R&D cooperation with different types of partners, with customer cooperation more focused on bringing products to market, supplier alliances mostly aimed at cost reduction and university collaboration focused on new generic technologies.

2.1. Collaboration types

The type of partnership may affect the ability and the incentives to patent, i.e. patent quality and quantity, differently (Hottenrott and Lopes-Bento, 2016). According to Cassiman and Veugelers (2002) partner selection depends on the intensity of spillovers. Firms are more willing to cooperate with universities and other public research centres when they detect high potential technology spillovers (Bozeman, Fay, and Slade, 2013; Siegel and Wessner, 2012). Higher appropriability of innovative results increase the probability to collaborate with other companies. Aristei, Vecchi, and Venturini (2016) supply empirical evidence on the determinants that affect European manufacturing firms' choice among different types of potential R&D partners.

The cooperative technology policy framework (Bozeman, Fay, and Slade, 2013) considers university-industry partnerships at the core of government policies aimed at the transfer of applied research and technology to industry, on the basis that the market fails to realize the optimal investment in innovative activities. Hall, Link, and Scott (2003) have emphasized the growing patterns of industry-university relationships in highlighting the access to complementary research and to key university personnel as the main factors promoting it. Particularly for basic, long-term research projects, university-industry collaborations are likely to have a significant impact on firms' development of innovations and of performance in a broader sense (Siegel and Wessner, 2012). Research collaborations with universities are found to have a positive impact on product innovations in Un, Cuervo-Cazurra, and Asakawa (2010) for Spanish firms, Kang and Kang (2010) for Korean firms, Huang and Yu (2012) for Taiwan, Kobarg, Stumpf-Wollersheim, and Welpe (2018) for Germany, and Medda (2018) in a cross section of European companies.

R&D collaborations with other companies allow firms to share the risk inherent in the innovation process, combine resources and skills exploiting complementarities, becoming a source of competitive advantage (Cassiman and Veugelers, 2002; Becker and Dietz, 2004). Nevertheless, the impact of collaborations with other firms on innovation performance is controversial, depending on the horizontal or vertical position in the supply chain. For both types of relationships between companies, collaborations may lead to a poor outcome in terms of innovations achieved: the search for self-interest instead of a common goal, especially when tasks between the parties are not strictly assigned, can make a joint research project fail. Furthermore, competitive and free riding behaviour may arise: a company may try to absorb the maximum knowledge of the other while hiding its own technological capabilities. Furthermore, in some cases firms perceive that cooperation may reduce their ability to fully appropriate the benefits of the research, opting to both exert the minimum effort possible and select projects whose objectives have a low probability of success (Berchicci, 2013; Un, Cuervo-Cazurra, and Asakawa, 2010).

Considering vertical relationship between firms, external R&D significantly enhances product innovation when it is carried out with suppliers and competitors (Nieto and Santamaría, 2007). Un, Cuervo-Cazurra, and Asakawa (2010) confirm a positive relationship between collaboration with suppliers and product innovations in Spanish manufacturing, although a non-significant coefficient for partnerships with customers. These authors analysed horizontal collaboration too, and they found a negative coefficient for cooperation with competitors; and Aschhoff and Schmidt (2008) suggest that neither vertical nor horizontal collaborations have a significant impact on product innovations. Similar results are found by Belderbos et al. (2015), although they found strong positive correlations when cooperation with suppliers, customers and competitors last for two consecutive years.

Other studies also reveal different pictures concerning the implication of R&D collaboration types for firm innovation performance. R&D outsourcing might be unfavourable to innovation because excessive external knowledge acquisition may hurt the firm's integrative skills needed to effectively build upon it (among others Weigelt, 2009; Broedner, Kinkel, and Lay, 2009; Cui and O'Connor, 2012). Berchicci (2013) argues that decreasing returns to external R&D is particularly relevant for high-tech companies, while Hottenrott and Lopes-Bento (2016) find that small and young firms do not seem to have any negative effect from collaboration.

Finally, in some studies no significant effect of R&D outsourcing between firms is found (Bengtsson, 2008; Medda, 2018). However, Lahiri (2016) concludes that outsourcing can result in positive, negative, mixed or no impact on the firm, depending on how outsourcing and performance are measured.

Some authors have argued that the effect of external R&D on innovation performance depends on the intensity of external engagement, typically measured by the share of R&D acquired from external sources over total R&D spending (Grimpe and Kaiser, 2010) or the share of R&D projects carried out with external partners (Hottenrott and Lopes-Bento, 2016). Gains from collaborating with external partners cease beyond a certain level of external R&D intensity; unfavourable effects such as complexity increase, involving higher cost of coordination, steering and control, which predominate over beneficial effects, and the relationship between external R&D and innovation turns negative. In other words, an inverted U-shaped relation is hypothesized, and recent studies have found empirical support (Grimpeand Kaiser, 2010; Berchicci, 2013; Hottenrott and Lopes-Bento, 2016).

A parallel line of analysis concerns diversification in firms' external sources of technological knowledge as a factor empowering the effectiveness of innovative activities. Different types of partners provide different resources and innovating firms try to collect diversified knowledge and technical competencies. Research has shown that firms with a wide breadth of R&D partners are more likely to benefit from external knowledge in terms of innovation output (Nieto and Santamaría, 2007), although recent literature results suggest that "too much" diversification hampers the managing and success of innovative activities, hypothesising an U-inverted relationship between the breadth of external R&D partners' type and the innovation performance by the firm (Grimpe and Kaiser, 2010; De Leeuw, Lokshin, and Duysters, 2014; Hagedoorn, Lokshin, and Zobel, 2017).

2.2. Conceptual framework

The above arguments suggest that external R&D collaborations are an important channel of technological transfer between organizations. Firms find externally financial and human resources that complement the internal ones. Particularly, firms acquire from external sources knowledge, technologies, production methods, prototypes and services, which would be costly to develop internally. However, beyond certain limits, the use to external sources can lead to decreasing returns in terms of innovations gained. The tipping point from which additional R&D outsourcing has negative effects on innovation performance can vary across types of external partners. On these grounds, we have built several hypotheses which are tested in the empirical analysis.

First, as discussed above, several studies have analysed empirically the effects of R&D collaborations and outsourcing on firms' innovation performance. The early studies have generally found positive effects of collaborations and partnerships on companies' measures of innovation. For instance, Brouwer and Kleinknecht (1999), for the Netherlands, find a higher propensity to patent among collaborating companies in comparison to non-collaborating firms. Similar results are found for Japan by Branstetter and Sakakibara (2002) and for Germany by Czarnitzki, Ebersberger, and Fier (2007).

However, barriers to R&D collaborations may arise when firms find it difficult to appropriate the benefits from joint research efforts, leading to both exert minima efforts and to opportunistic behaviour, such as selecting projects with a low probability of success (Un, Cuervo-Cazurra, and Asakawa, 2010). Furthermore, as external R&D intensity and complexity increase, firms face higher cost of coordination, steering and control. Among those who have investigated the possible non-linear relationship between external R&D and innovation success, Grimpe and Kaiser (2010) and Hottenrott and Lopes-Bento (2016) have found evidence that the returns to increasing R&D outsourcing intensity for German firms start to decline over a certain threshold. On these grounds, we formulate the following:

> ***Hypothesis 1****: R&D outsourcing has an inverse U-shaped relationship with both the probability to undertake product innovations and the intensity of innovative products sales for each kind of external partner.*

Recent studies have put emphasis on the firms' choice of the type of partners in order to carry out collaborative R&D activities and to acquire external R&D (Aristei, Vecchi, and Venturini, 2016; Medda, 2018). Also, the heterogeneity of partners has been found to exert an influence on innovation success: on one side, companies with a large number of R&D agreements are more capable to absorb external knowledge; on the other side, reducing the number or type of external sources alleviates the cost of coordination, steering and management of inward knowledge flows. Grimpe and Kaiser (2010) found an inverse U-shaped relationship between the breadth of R&D collaborations and innovation performance. Similar results were estimated for the Netherlands by Hagedoorn, Lokshin, and Zobel (2017); these authors also find an inverse U-shaped relationship between firms' external research acquisition and innovation performance.

In the empirical section, we analyse the effect on innovation outcomes of both external partners breadth and relevance, by the use of a homogeneity index which simultaneously takes into account the number of external partners types (firms within the group, universities, firms outside of the group) and the share of external R&D acquired from each type of partner. We expect that, departing from a situation of equally distributed external R&D among the three types of partners, concentrating external R&D acquisitions has positive effects on the innovation success but, beyond a certain threshold, decreasing positive effects arise. Thus, we formulate the following hypothesis:

> ***Hypothesis 2****: Concentrating external R&D acquisitions on a narrow set of partner types enhances outcome from product innovations, although with an U-inverted shape relationship.*

The selection of external R&D partners depends largely on the possible incoming technology transfer a firm can incorporate to foster its own innovative capacity. Firms which search for external R&D sources often need complementary knowledge which cannot be developed internally; at the same time, firms try to guarantee themselves a large degree of appropriability of results. University and other research centres have a large potential to transfer applied research to industry, and this activity is put at the core of public policies intended to promote technological progress (Bozeman, Fay, and Slade, 2013).

Recent studies have generally found empirical support for the positive impact of University industry R&D-collaboration on firms' product innovations (Un, Cuervo-Cazurra, and Asakawa, 2010, and Belderbos et al. 2015 for Spain; Kobarg, Stumpf-Wollersheim, and Welpe, 2018 for Germany; Lööf and Broström, 2008 for Sweden, among others). Medda (2018) has estimated a larger impact on the probability to carry out product innovations of university-industry partnerships compared with external collaboration with other firms for a large cross section of European firms. These arguments and empirical literature evidence, combined with Hypothesis 1, lead us to the formulation of the following:

> ***Hypothesis 3****: Acquiring external R&D from University and other research centres has a larger positive impact on the probability to undertake product innovations than R&D supplied by other firms, independent of the amount of external R&D acquired.*

Although firms may find complementary knowledge and key research personnel in Universities, collaborating with other companies allows them to direct the research efforts towards a market-oriented point of view, sharing the risk inherent in the innovation process, and combining resources and skills required for the implementation of R&D and the commercialization of new products generated by R&D (Cassiman and Veugelers, 2002).

Focusing on the share of innovative products sales over total turnover as a measure of firms' innovation outcome, we argue that collaborating with other firms is more advantageous in terms of market success than with Universities. We expect that if partnership with Universities enhance a firm's probability to carry out product innovations, commercial success of these innovations need a more market-oriented approach that Universities don't have. However, recent studies have found little support for external R&D conducted with other firms presumably due to barriers to collaborations, as discussed above. Only when collaborations are persistent in time (Belderbos et al., 2015) or are performed with suppliers, rather than with competitors or customers (Nieto and Santamaría, 2007; Un, Cuervo-Cazurra, and Asakawa, 2010), R&D carried out with other firms is found to have beneficial impacts on innovation outcomes. We argue that acquiring external R&D from other firms within the same group may alleviate competitive behaviour by the firm. Also in this case, an inverse U-shaped relationship is hypothesized between R&D carried out with firms within the same group and innovative sales.

> ***Hypothesis 4***: *Acquiring external R&D from other firms within the same group has a larger positive impact on the intensity of innovative products sales compared with R&D supplied by other firms or Universities. Also, the tipping point from which additional R&D outsourcing has negative effects on innovation is reached at smaller values of external R&D acquired from Universities.*

3. Data and empirical methods

To accomplish the objectives of this research, we use data from the EU-EFIGE/Bruegel Survey carried out by leading academic institutions and coordinated by Bruegel[1] (Altomonte and Aquilante, 2012), with the purpose to collect information about the structure and the behaviour of 14,911 manufacturing firms across seven European countries: about 3,000 firms are from France, Germany, Italy and Spain, 2,000 from the UK, and 500 from Austria and Hungary. We have dropped observations from Austria and Hungary due to missing data which prevented us from building important variables, as will be discussed below. The dataset contains 150 qualitative and quantitative variables following the EFIGE questionnaire structure and is divided in six thematic sections, one of which concerns technological innovation and R&D, and it is the one we will focus on.

The companies included in the data set have been selected using a sampling project that stratifies companies by sectors (11 industry NACE classification), regions (NUTS-1 level of aggregation), and size classes (10-19; 20-49; 50-250; more than 250 employees). The reference population consists of companies with more than 10 employees. All the questions were about 2008, with some questions asking for information on 2009 and others asking for averages over the years 2007-2009. A number of papers, as surveyed in Carboni and Medda (2018, 2019), have recently exploited the EFIGE dataset.

3.1. Innovation variables

Our dependent variables attempt to capture the output of the innovation process in terms of product innovations. We have built a dummy variable equal to one if in the questionnaire the firm answers "yes" to the question "on average in the last three years

[1] EFIGE is the acronym of "European Firms in a Global Economy": a project for internal policies and external competitiveness supported by the Directorate General Research of the European Commission through its 7th Framework Programme and coordinated by Bruegel.

(2007-2009), did the firm carry out any product innovation?", otherwise it equals zero. We use this variable to estimate how the external R&D collaborations affect the propensity to carry out product innovations. We also measure innovation performance by the ratio of sales from innovative products, with values ranging from zero to one hundred per cent. The innovative products sales variable is an often used indicator of innovation success as it provides a direct measure of commercialization of a firm's innovations (Hottenrott& Lopes-Bento, 2016; Hagedoorn, Lokshin, and Zobel, 2017).

3.2. R&D variables

Further on, firms answer several "yes" or "no" questions regarding their research activity in the years 2007 - 2009 that allow us to build dummy variables equal to one if (1) the firm has invested in R&D, and equal to zero otherwise, (2) if the firm has undertaken R&D acquired from other firms within the same group, (3) from other firms/consultants, or (4) supplied by Universities and R&D centres. We have also built a dummy variable indicating whether the firm has acquired R&D from any form of external sources (at least one of the (2)-(4) dummies equals one).

Firms also provide information about the intensity of their R&D efforts. The percentage of investment in R&D over total turnover on average in the years 2007 – 2009 is the base for our R&D intensity variable. The intensities of R&D provided by external sources are expressed as shares of overall R&D intensity, on a per cent scale. A variable measuring the percentage of R&D intensity acquired from other firms within the group has been built. Analogously we have built two variables indicating, respectively, the share of R&D acquired from other firms/consultants outside the group, and that supplied by Universities and research centres. The sum of those three variables is used as an indicator for the overall external R&D over total R&D intensity. For each variable indicating the shares of R&D acquired from external sources we have computed squared terms, to test the hypothesis of an inverted U relationship between external R&D and innovation.

Since one of the hypotheses presented in the previous section is related to the relationship between the breadth of external partners, we have built an *R&D external partners homogeneity index* as the sum of squared terms of shares over external R&D of three types of external R&D. The homogeneity index ranges from *0*, in the case of no external R&D, *1/3* if external R&D is equally distributed between the three partners' types, to *1* if total R&D is supplied by only one type of external partner. This measure of variety of external partners in R&D activities is different from the *partner type variety* measures used by Laursen and Salter (2006), Hagedoorn, Lokshin, and Zobel (2017), and Grimpe and Kaiser (2010) which use a simple count of partner types. It is also different from Hagedoorn, Lokshin, and Zobel's (2017) measure of partner type relevance which makes use of judgements by firms' managers on the relevance of each partner type. Instead we use actual values of R&D acquired from each partner type to construct our homogeneity index.

3.3. Determinants of R&D

A key concern in the literature on the effects of firms' R&D on innovation and productivity is that performance measures may be affected by unobservable facts that also affect firms' R&D. This puts forth a problem of endogeneity. In the econometric application we deal with this issue, by controlling for exogenous factors which affect firms' R&D but are not directly connected with the innovation output. We identify regional technological environment as an important factor that has an influence on firms' decision to carry out R&D and on their R&D intensity. The regional technological environment is proxied by two variables: the average regional government sector R&D spending over GDP and the average regional business sector R&D spending over GDP. These two variables are built using Eurostat data referring to year 2007 and matched to the EFIGE dataset on a regional basis[2]. Other studies have already used regional-based variables in micro data analysis with the intent to capture regional opportunities and spillovers for the firms which are located in a particular region (Altomonte et al. 2016; Medda 2018).

3.4. Control variables

Companies show a considerable heterogeneity in relation to R&D activities and innovation performance. In the empirical analysis, such heterogeneity is taken into account by means of several control variables such as the (log of) number of employees, which we use as a proxy for firm's size, and the (log of) age of firm, measured in years since their establishment. Size is commonly recognized as an important factor for understanding the differences in the innovative activities of firms, in relation to the correlation with organizational capacity, economies of scale and scope, access to markets and acquirement of resource. Firm's size is found to be positively correlated with product innovation outcomes in Spain (Un, Cuervo-Cazurra, and Asakawa, 2010) and the Netherlands (Hagedoorn, Lokshin, and Zobel, 2017), while medium-sized firms are found to be more innovative in Germany (Hottenrott and Lopes-Bento, 2016). Also, firm's size may be a crucial factor in determining whether to conduct innovative activities and the amount of resources firms put on it (Cohen and Levinthal, 1990). The age of the firm is aimed at capturing the behaviour of younger, new entrant firms which are prone to carry out riskier innovative activities, in comparison to post-entry and older firms, although the evidence is mixed (García-Quevedo, Pellegrino, and Vivarelli, 2014).

A dummy variable indicating whether the firm has exported before 2008 is also included among the controls. Participating in international markets is often considered an important source of technological knowledge. Exporting firms are generally found to have their own distinct characteristics, in terms of capability to absorb new technology and of competitiveness, since they are required to push efficiency up to international standards (Cassiman and Golokvo, 2011). Two variables which are equal to one if the firm belongs to a group and if the firm is head of the group are also included. The rationale is that belonging to a group may alleviate financial constraints. Firms in a group can also internalize externalities from innovative activities (Guzzini and Iacobucci, 2014). As pointed out by Hall et al. (2016) financial constraints are, in general, good at explaining under-investment in technology and in R&D expenditure. For this reason, we include a variable equal to 1 in case a firm considers the lack of appropriate financing as the main factor hampering innovation, equal to 0.5 if the lack of appropriate financing is ranked as the second factor hampering innovation, and zero otherwise.

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[2] Unfortunately, firms' information about the region where they are located is not available for Hungary and Austria, thus the decision to exclude these countries from the present analysis.

Finally, the analysis accounts for unobserved country and industry effects (manufacturing sectors, defined by two digit NACE Rev. 1 codes) to check for potential sectoral systematic differences in innovative activities.

3.5. Sample description and descriptive statistics

Table 1 reports sample statistics for country and firms' size classes. France, Germany and Italy have each about 3,000 observations, while Spanish firms are represented by almost 2,700 observations and British firms are 2,032. Small firms (those with a number of employees under 50) represent over 73% of the sample (10,006 firms). Large companies (those with more than 250 employees) are 6.8% of the sample.

In 2007 - 2009, 48.9% of firms carried out product innovations. British companies show the largest propensity to carry out product innovations with a share of innovating firms (58.1%) well above the average sample share. In France the companies which declare to have carried out product innovations are 44.3%. Large companies are those with the largest propensity to carry out product innovations (64.7%).

Firms which are engaged in R&D activities are 51.5% of the sample. In Italy 55.1% of firms declare to have undertaken R&D activities in the years 2007 – 2009 while Spain shows the smallest percentage of R&D firms (44.8%). Over 75% of large companies carried out R&D, while only 45.5% of small firms did.

Since our purpose is to estimate the effect of external R&D alliances on product innovation, in Table 1 we also report percentages of firms by type of external sources. The percentage of R&D performing firms which have acquired R&D from external sources varies from 11.8% for Spanish firms to 24.8% for Italian companies, with a total sample mean equal to 19.3%. More than 7% of companies which declared research expenditures acquired R&D from other firms within the same group. R&D companies in France show the largest propensity to collaborate with other firms and consultants outside of their group (6.5%). Finally, the use of Universities or other research centres as external sources of R&D is 18.7% for firms in Italy and 8.8% for Spain. Large firms show the largest propensity to acquire R&D externally (26.8%); these use other firms (within the same group or outside of their group) as a supplier for R&D. Medium companies (50-250 employees) show the largest propensity to acquire external R&D from Universities or other research centres.

Descriptive statistics for intensities of innovative sales, R&D, shares of different types of external R&D, and control variables are presented in Table 2. The mean value of innovative products sales over total turnover is 3.94 for firms which did not carry out R&D, and 13.09 for R&D firms. Regardless of having carried out R&D or not, firms which have undertaken product innovations show a mean value equal to 17.70. R&D firms have a mean intensity for R&D expenditures equal to 7.17. On average, firms with product innovations spent more on R&D over sales (5.69) compared to no product innovations firms (1.78).

Firms which have been supplied R&D by external sources, on average, spent 9.10% of their total R&D intensity going outside. On average, 1.69% of total R&D has been supplied by other firms within the same group, 5.57% by other companies or consultants, and 1.79% has been acquired from Universities or other research centres. Note, from Table 2, that the average share of external R&D over total R&D is larger for companies which carried out product innovations, also controlling for each type of external partner.

4. The econometric setting

We test the four hypotheses discussed above using instrumental variables methods with dependent variables indicating, respectively, *a*) whether firms have carried out product innovations, and *b*) the average share of innovative product sales over total turnover, in the three years covered by the survey. R&D indicators are main explanatory variables, along with other control variables and industry and country dummies. In the analysis we treat the decision to undertake R&D as endogenous. In other words, in accordance with literature started by Crepon et al (1998), we consider that unobservable factors which affect product innovation success also affect the R&D yes/no decision. Hence, the sub-sample of firms performing R&D might not be random, and ignoring endogeneity can lead to biased estimates.

To overcome problems of endogeneity we use instrumental variable estimation techniques. The estimation procedure consists of two stages. First, we estimate the reduced form equation, where a binary variable indicating whether the firm has undertaken R&D or not depends on several control variables. Controls capture firms' characteristics such as size, age, having exported in the past, along with industry and country fixed effects. The two instrumental variables, measuring the regional technological opportunities, namely the average regional R&D spending by the public sector and the business sector, both over GDP, are derived from Eurostat's statistics. Although in this paper we do not focus on the determinants of firms' R&D engagement, the reduced form equation analysis allows us to study the impact on firms' R&D propensity of different components of average regional R&D, according to Eurostat (2017) classification (Medda, 2018). Following Angrist and Krueger (2001) the R&D participation equation is regressed linearly.

In the second stage of our model, we estimate the structural equation where external R&D variables are included to test their effect on product innovation outcome. Note that the identification of our models requires that instrumental variables are not correlated with innovation outcome variables and are excluded from the structural equation. In other words, the regional R&D variables influence the R&D behaviour of the firm (whether or not to undertake R&D) and affect innovation success solely through their impact on R&D decisions.

Since the dependent variables in the structural equations are *1*) a dummy variable equal to one if the firm has undertaken any product innovation (zero otherwise), and *2*) a left-censored variable indicating the average share of turnover from innovative products sales, we estimate our models using respectively: *1*) an instrumental variable probit model, and, *2*) an instrumental variable tobit model, to obtain consistent and efficient estimates (Wooldridge, 2010).

Formally, model 1) is described by

$$y_i^* = \beta_0 + \beta_1 \mathit{DUMMY\_R\&D}_i + \beta_2 \mathit{EXT\_R\&D}_i + \beta_3 X_{1i} + u_i \quad (1)$$

$$\mathit{DUMMY\_R\&D}_i = \alpha_0 + \alpha_1 X_{1i} + \alpha_2 X_{2i} + v_i \quad (2)$$

where y_i is an innovation outcome indicator for firm *i, i* = 1 … *N*. We observe $y_i = 1$ if $y_i^* > 0$ and $y_i = 0$ if $y_i^* \leq 0$. $\mathit{DUMMY\_R\&D}_i$ indicates if the firm has carried out

R&D. $EXT\_R\&D_i$ collects shares of R&D acquired from each of three types of external partners in some specifications, and the homogeneity index, as described in the previous section in other specifications. X_{1i} is a vector of exogenous industry and country variables. X_{2i} collects the additional instrumental variables. The R&D equation (2) is in linear reduced form:

$$\binom{u}{v} \sim N\left[\binom{0}{0}, \begin{pmatrix} 1 & \rho \\ & \sigma_v \end{pmatrix}\right] \tag{3}$$

Similarly, model 2) differs only in the structural equation, to account for the fact that the innovation dependent variable, the share of turnover from innovative products sales, is left-censored at zero. In other words, we observe $y_i = y_i^*$ if $y_i^* > 0$ and $y_i = 0$ if $y_i^* \leq 0$. Model 2), as a consequence, is specified as a tobit model with an endogenous explanatory variable (Wooldridge, 2010).

4.1. Results

As mentioned in Section 4, in this paper we consider two outcome variables: the propensity to undertake any product innovation, and the intensity of product innovation success in terms of share of total turnover from innovative product sales. The estimates account for the potential endogeneity of the firms' participation in R&D by the use of instrumental variables techniques. Before presenting the results for the product innovations regressions, and although it is not among the aims of this paper to explore the factors affecting firms' decision to carry out R&D, we briefly describe the main results of the reduced form equation, where we linearly regress the dummy variable indicating whether each firm has positive R&D expenditures or not, on several variables and controls, including regional technological opportunities indicators.

4.1.1. The propensity to carry out R&D (reduced-form equation)

Similarly to Medda (2018), we found a positive and significant impact of the size variable on the decision to carry out R&D expenditures, while a non-significant effect is estimated for the age variable[3]. Positive effects are found for the variables indicating whether firms are head of a group (no significant effects are found for the variable indicating whether a firm belongs to a group *per se*) and if they have exported in the past. A positive correlation is found between the R&D decision and that lack of appropriate finance. This latter is a crucial factor hampering innovation confirming the importance of financial resources for innovative activities (Hall et al., 2016).

Highly significant and positive impacts on R&D propensities are found for indicators of regional technological opportunities and spillovers from both the public sector and the business sector. This is on the same line of studies which stress the geographical dimension as a source of considerable differences in firms' innovation performance (Lychagin et al. 2016) and confirms the importance of public involvement in promoting technological

[3] Estimates of reduced form equations are omitted and are available upon request.

innovation (Bozeman, Fay, and Slade 2013). Average business sector R&D spending shows a (still positive and significant) lower impact on firms' R&D participation, of the magnitude of one fifth with respect to government R&D. Private companies try to protect their innovative activities, thus the spillover effect from firm to firm may be less intense (Caniëls, 2000). Finally, country and industry controls result both significantly different from zero at the 1% level.

4.1.2. External R&D intensity and innovation outcome (structural equation)

In this section, we present estimates of structural equation (1) to assess the role of external R&D intensity on two innovation outcome variables: the probability to undertake any product innovation (*model 1*) and the intensity of sales from innovative products (*model 2*). More in detail, we check for a possible U-inverted relationship between external R&D and innovation (*hypothesis 1*) and between concentration of external R&D among three types of partners, and innovation performance (*hypothesis 2*). In all the specifications we control for endogeneity of the decision about conducting R&D or not, using instrumental variable techniques. For the estimation of *model 1* (columns 1 and 2 in Table 3), we use a binary choice model with the R&D yes/no variable as endogenous regressor, while for *model 2* (columns 3 and 4 in Table 3) we use a left-censored dependent model, again with the R&D yes/no variable as endogenous regressor. [4]

In Table 3, estimates displayed in columns 1 and 3 substantially confirm our *hypothesis #1*. In column 1 the share of external R&D is positive and significant at the 1% level. The negative sign of the coefficient of the squared term indicates that the positive impact of external R&D on the probability to achieve product innovations decreases over higher values of the ratio external R&D over total R&D. The same results, in terms of expected signs and significance levels, are found when we check for the U-inverted relationship of external R&D and the intensity of innovative products sales (column 3). It seems to confirm, thus, the positive impact of acquiring R&D from external sources on innovation performance measures, although over certain limits the positive impact is decreasing. Carrying out in-house R&D generates absorptive capacity which helps a firm to incorporate external technology opportunities. External R&D, in this view, is a complement of internal technological capabilities, although it fails to completely substitute internal R&D.

In the appendix, we present graphics of the estimated relationships between measures of external R&D and predicted innovation performance. In particular, solid lines in Figures 2 and 3 illustrate the U-inverted shape relationships between the share of external R&D and, respectively, the probability to achieve any product innovation, and the share of total turnover from innovative products sales. In Figure 2 the probability to carry out product innovations increases with the share of external R&D over total R&D, until it reaches a tipping point at around 44% of the share of external R&D. Beyond that value, the marginal effect of an increase in external R&D turns out to be negative. This result, although

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[4] Note that, since ivprobit and ivtobit command are inappropriate not appropriate when a dummy endogenous regressor is used, all estimates are conducted using Stata cmp command (conditional mixed process estimator) developed by Rodman (2011), based on maximum simulated likelihood methods (Cappellari and Jenkins, 2003).

confirming the non-linear relationship between external R&D and the probability of product innovations, is 60%, a lower value than what was found by Hottenrott and Lopes-Bento (2016) for German companies. However, these authors use a different measure of external R&D, namely the percentage of innovative projects carried out with external partners.

Figure 3 confirms the U-inverted shape of the relationship also using the share of total turnover coming from innovative products sales as a measure of innovation performance. In this case, the maximum is found at a value of around 42% of the ratio external R&D over total R&D. Beyond this value the marginal impact of increases of external R&D on innovative sales becomes negative, indicating a negative effect from over-outsourcing.

As expected and confirming the main results in the literature, the R&D dummy has a significant and positive influence on both the probability to carry out product innovations and the intensity of innovative products sales. Also, the highly significant estimates of *rho* allow us to reject the hypothesis of no correlation between errors in the reduced form and the structural equation. This corroborates our choice of using an instrumental variable approach to control for endogeneity of R&D.

Hypothesis #2 is tested in columns 3 and 4 in Table 3. Also in this case the hypothesis is confirmed. An U-inverted shape relationship is found between the index measuring the concentration of external R&D among different types of partners, and the innovation outcomes. The results also show a positive and significant coefficient for the homogeneity index and a negative and significant coefficient for its squared term. R&D provided by one or two types of partners has a positive impact on both the probability to carry out product innovations and the share of sales from innovative products until a value of the homogeneity index equal to, respectively, 55% and 60%. As Figure 1 shows, after these values the marginal impact of limiting the partners' breadth on innovation outcomes turns out to be negative. These results confirm the estimates in Grimpe and Kaiser (2010) on German firms where a tipping point is found for R&D partners' heterogeneity.

Results in Table 3 indicate that small firms have higher probability of introducing product innovations and to gain larger share of total turnover from innovative products sales. Young firms are more likely to have larger shares of innovative products sales compared to old ones. A non significant effect of age of firms is found for the propensity to carry out any product innovation. No systematic difference is found between firms belonging to a group and independent companies, and between companies' head of a group and other firms. Small significance is found for the variable indicating whether a firm has been an exporter in the past in column 1. Country and manufacturing sector fixed effects are found, as expected, to be jointly different from zero with high levels of significance.

4.2. Types of R&D partners and innovation

Table 4 and 5 contain the estimates of the hypothesized U-inverted relationship between external R&D and, respectively, *a*) the probability to carry out product innovations and *b*) the share of innovative product sales on total turnover, with a breakdown of external R&D into R&D acquired from other firms within the same group, supplied by Universities and other research centres, and by other firms. Estimates reported in Table 4 supply the test for hypothesis 3, while those in Table 5 are linked to hypothesis 4.

The U-inverted relationship between external R&D and the probability to achieve product innovations for all three types of external providers of R&D (Table 4)is also confirmed. For each type of partner, the share of R&D acquired externally enters positively. The negative sign of the second-order term indicates that the relationship between the intensity of external R&D and the probability to achieve new product innovations decreases for high shares of external R&D over total R&D. Having Universities as supplier has a larger effect on the probability to achieve product innovations compared to other research partnerships. This result confirms the findings in recent studies which have empirically estimated strong impact of University-industry R&D collaboration and firms' product innovations (Belderbos et al. 2015; Un, Cuervo-Cazurra, and Asakawa, 2010; Medda, 2018). In finding facilities and personnel in Universities to complement internal R&D resources, companies enhance their technological performance in terms of innovations achieved. Figure 2 illustrates the results of estimates in Table 4. Note that tipping points for each type of external partner are reached at very close values of the share of external R&D (in the range of 41%-43%).

Estimates reported in Table 5 replicate those in Table 4, with innovative product sales intensity as dependent variable in place of the variable indicating whether a company has carried out any product innovation or not. For each partner type, the concave shape of the relationship between external R&D and innovation is confirmed, which add robustness to our *hypothesis 1*. All the estimated coefficients for external R&D are positive and highly significant, while the squared terms for each type of partner are negative and significant at the 1% level. Moreover, coefficients reported in Table 5 show that acquiring external R&D from other firms in the same group gives to a company larger returns in terms of share of total turnover coming from innovative sales, compared with external R&D acquired from other firms or consultants outside the group or Universities and other research centres. In Figure 3, we show that marginal effects of extending the share of R&D acquired from other firms within the same group. Despite an U-inverted shape, these effects are larger in terms of innovative sales for all possible range of the share of external R&D, compared with R&D purchased from other partners. Also, a significant difference arises between tipping points: the share of R&D acquired from Universities over which marginal effects turn negative is around 34%, while the tipping points for the share of R&D acquired from other firms, within or outside the group, is at about 43%.

The estimates of the effect on innovation outcomes of external R&D purchased by types of partners confirm the results previously found regarding young and small firms, which have larger propensity to carry out product innovations and to obtain returns in terms of sales from innovative products. No difference across companies is found with respect to belonging to a group or being head of a group, as well as having exported before 2008. Systematic differences arise between industries, as the joint test of significance for manufacturing sectors dummies is highly significantly different from zero. Finally, in all the models, the *rho* statistic, which indicates the correlation between first-stage and second-stage equations, is significantly different from zero, suggesting the appropriateness of using instrumental variable techniques to control for endogeneity of the R&D binary variable.

Despite the limitations of the dataset, which is a cross section of companies, thus preventing us to study possible time lags between R&D and innovation outcomes, the econometric analysis allows us to draw some conclusions. First, external sources of R&D are important to enhance innovation outcomes, both in terms of the probability to carry out product innovations and to obtain sales from innovative products. However, over a certain threshold, companies face R&D negative marginal effects on innovation performance(over-outsourcing). Second, acquiring R&D from Universities or other research centres increases the probability to achieve product innovations. The rationale may be that acquiring R&D from Universities allows firms to obtain complementary knowledge. Also, collaborating with Universities rather than with other firms prevents the arising of competitive and perverse behaviours which may hamper the probability to find new products. Third, collaborating with firms within the same group a company belongs to may provide resources in terms of organizational structure and market knowledge, which help to exploit commercially product innovation.

5. Discussion

This work provides empirical evidence to test theoretical considerations suggesting that firms can benefit from external R&D. It is now widely acknowledged that a firm's innovation success depends not only on internal resource endowment, but also on the knowledge it can obtain from outside its boundaries. While much has been written on innovation as being a crucial source of firm's competitiveness, less is known about the possible relationships between innovation and the different types of research channels that a firm may enter.

The outsourcing of R&D is considered an important way to acquire external technological information that can be integrated into a firm's own knowledge endowment. R&D collaboration may help the matching of complementary skills, learning from the partner and, not less important, the sharing of risks and costs. Given the multifaceted relationship between R&D partnerships and innovation performance, it becomes of paramount importance to understand whether and how outsourcing may benefit the firm. Particularly, for the increasing complexity and variability technology, external collaborations are likely to benefit companies in a number of way, such as, access to external resources, knowledge transfer, resource exchange, and organizational learning and building of R&D networks. For such reasons, a growing number of firms no longer use exclusively their internal R&D and have started collaborative relationships with a variety of partners, ranging from suppliers to customers and research organizations. Technological collaboration has become a crucial organizational component of the innovation process particularly in sectors where innovation is growing in complexity, such as biotechnology and information technology.

Most of the literature has analysed the impact of a single type of collaboration on innovation focusing on the particularities of each relationship. However, despite its importance, there has been limited research on how and why the different types of collaborations affect product innovation. Moreover, many companies use several types of partnership at the same time.

The analysis of the impact of different forms of technological alliances is important, since it may supply better information about the appropriateness of undertaking them. Firms choose their partners for innovative activities trying to fully appropriate the results from innovations and, at the same time, seeking the most suitable external knowledge to complement the internal one. The idea is that one form of collaboration might produce more beneficial effects than another for a particular type of innovation. From this perspective, this work complements existing studies discussing how different types of R&D

partnerships influence product innovation (Hagedoorn, Lokshin, and Zobel, 2017; Grimpe and Kaiser, 2010; Hottenrott and Lopes-Bento, 2016; Un, Cuervo-Cazurra, and Asakawa, 2010; Wu, 2012). Moreover, micro-level studies which have tried to estimate directly the effect of alliances with different partners on firms' product and/or process innovation are based on single country analysis, utilizing a cross section or short panel of firms with a limited number of observations.

Therefore, the main contribution of this study is to explicitly assess the relationship between different external sources of R&D and firms' product innovation output. More in detail, three kinds of external R&D partners are distinguished, namely: other firms within the same group a company belongs to, Universities and other research centres, and other companies. Furthermore, we investigate how concentrating external R&D acquisitions on one or two types of partners may affect a company's product innovation success.

Although R&D collaborations are a source of competitive advantage, they may create perverse effects, as firms are aware that alliances with other firms will reduce their ability to fully appropriate the benefits of the research investment. Hence, following the recent literature on this topic, this paper also tries to assess if "over-outsourcing" may represent a threat to firm's innovation performance. We check if there is an U-inverted shape relationship between the share of external R&D over a firm's total R&D and product innovation performance measured by, respectively, the probability to achieve any product innovation, and the share of total turnover from innovative products sales.

The empirical analysis is carried out by employing a large and unique sample of 13621 cross-European firms which collects quantitative and qualitative answers from the EFIGE survey of manufacturing firms from five countries: France, Germany, Italy, Spain, and the UK. This makes our work different from our study of previous research based on single country data.

The econometric application treats R&D as an endogenous decision, and we use instrumental variable estimation technique to estimate the marginal effect of external R&D variables on the probability to undertake product innovations and the share of innovative product sales over total turnover, also checking for firms' internal factors as well as countries and industry fixed effects. Despite the limitations of the cross section dataset, which prevents us from studying possible time lags between R&D and innovation outcomes, the analysis suggests some interesting conclusions.

First, external sources of R&D enhance innovation outcomes, both in terms of the probability to carry out product innovations and sales from innovative products. However, beyond a certain threshold, firms face R&D over-outsourcing and show negative marginal effects on innovation performance.

Second, R&D acquisition from Universities or other research centres give firms larger effects in terms of probability to achieve product innovations. Acquiring R&D from Universities permit firms to obtain complementary knowledge. Also, collaborating with universities rather than with other firms prevents potential competitive and perverse behaviours which hamper the probability to find new products.

Third, collaborating with firms within the group a company belongs to provides resources to commercially exploit product innovation in terms of organizational structure and market knowledge.

Highly significant and positive impacts on R&D propensities are found for indicators of regional technological opportunities and spillovers from both the public sector and the business sector, on the same line of studies which stress the geographical dimension as a source of considerable differences in firms' innovation performance (Lychagin et al. 2016). Confirming the importance of public involvement in promoting technological innovation (Bozeman, Fay, and Slade 2013), an important role is found for government R&D expenditures at the regional level,

5.1. Policy management implications

Although the cross-sectional structure of the data does not allow the long term effects to be estimated, the analysis may be of straightforward value for R&D managers' strategy decisions. The analysis strongly suggests that innovation managers ought also to give special attention to firm's R&D external commitment, as this latter strongly impacts production innovation.

One of the characteristics of innovation is that it is systemic and encompasses many aspects simultaneously (Griliches, 1979; Weigelt, 2009; Faems et al. 2005) and it is derived from complex interactions involving workers, organizations, and the external environment. In order to gain advantages from innovation, it may be important to make changes to other parts of innovation efforts, including the system of production and the organizational structure that supports the innovation. Managers are asked to devote resources and build technological and organizational human skills within the company. Firms which are able to fully exploit their technological activities are able to benefit from complementary expertise in other areas of their business. Understanding such aspects of a firm's innovations may be important and may help R&D managers to better design strategies aimed at improving firms' performance. This allows, in fact, knowledge and resource sharing, strategic decision making, and a more efficient coordination of the complex process of innovation.

Deciding whether or not to engage in a research alliance is a major decision for a firm and so is the decision about how to structure and manage this alliance for maximum innovation benefit and competitive advantage. Since in a competitive environment some firms will survive while others perish, as conditions change, the firm ought to be able to reassess its alliance structure and adjust appropriately. Hence is becomes crucial for R&D managers to identify all the possible solutions to the problem of outsourcing. As a firm considers the value-added chain for its product and its own position along that chain, it has to decide to what extent each activity is best sourced in-house or externally (Cassiman and Veugelers, 2002; Hottenrott and Lopes-Bento, 2016), also in light of the information and appropriability problems which may be typically associated with knowledge processes. The basic idea is that knowledge process outsourcing is an alliance strategy and the decision of where to outsource an important strategic decision.

While it is clear that collaborating with other organizations helps firms in innovation because of the potential technological (though not only) knowledge flows, not all R&D alliances necessarily have the same effect on product innovation. Hence, managers may very likely desire to select those R&D partners that are more likely to facilitate innovation, reduce fixed costs and allow a better control of R&D time and budgets. Cost benefits may be realized by specialization of the contractor or by cost sharing in a joint commissioning of more than one client. These insights highlight the role of R&D managers of continuously supervising alliance activities by balancing benefits and costs, and by adjusting collaboration strategies accordingly (Hottenrott and Lopes-Bento, 2016). Finally, given the non-linear effect of outsourcing on product innovation, meaning that the cost of disclosure can countervail the benefits from R&D alliances, the trial for managers and firms is to determine the best collaboration intensity that is likely to return the most promising results.

5.2. Limitations and future research

The cross section structure of the Efige dataset does not allow us to consider the possible lags between R&D spending and strategies, and innovation outcomes. Depending on types of innovations, industrial sector and other observable and unobservable factors, the gestation period for R&D to show results in terms of innovation, in fact, may require time. Recent empirical evidence show that a large proportion of companies experienced lags from one to two years (see a survey by Hall, Mairesse, and Mohnen, 2010); Dechezleprêtre et al. (2016) find that patent applications are usually submitted quite close to research investments for UK firms. Furthermore, due to high adjustment costs, companies tend to smooth their R&D spending over time, and a high degree of persistence has been found in R&D engagement by the firms (García-Quevedo et al., 2014; Peters, 2009). On these grounds, and considering the limitations of our dataset, we estimate the effect of current R&D spending strategies on product innovation outcome; however, future research could analyse a longitudinal dataset of companies to assess the medium and perhaps the long-term effect of R&D activities on innovation. Also, having panel data available would allow scholars to deepen the study of the long term role of R&D alliances and partnerships on innovation.

Another limitation of this work lies in the lack of information about the nature of collaborations. We have data on R&D provided by other firms, belonging to the same group or outside the group; however, we argue that great interest should put also on industry research collaborations distinguishing between vertical collaborations, those with customers or suppliers, and horizontal partnerships, those with competitors or other companies which operate in different markets.

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Table 1 – Innovative activities – sample description

	Freq.	carry out product innovations	undertake R&D	R&D firms which acquired R&D supplied by external sources	firms within same group	other firms / consultants	Universities / research centres
Country							
France	2,957	44.3%	50.7%	20.8%	5.7%	6.5%	11.8%
Germany	2,929	49.8%	53.9%	14.2%	7.4%	1.8%	10.1%
Italy	3,004	49.2%	55.1%	24.8%	7.7%	3.6%	18.7%
Spain	2,699	45.6%	44.8%	11.8%	6.8%	1.2%	8.8%
UK	2,032	58.1%	52.9%	24.3%	7.9%	4.5%	18.4%
Size class							
Small (< 50 empl.)	10,006	45.0%	45.5%	17.0%	5.5%	1.7%	12.9%
Medium (50 – 249 empl.)	2,694	58.1%	65.8%	22.2%	9.8%	5.0%	15.0%
Large (≥ 250 empl.)	921	64.7%	75.4%	26.8%	10.8%	12.1%	14.3%
Total sample	13,621	48.9%	51.5%	19.3%	7.1%	3.6%	13.5%

Table 2 - Descriptive statistics

Variable	undertake R&D?				carry out product innovations?			
	no		yes		no		yes	
	mean	*s.d.*	*mean*	*s.d.*	*mean*	*s.d.*	*mean*	*s.d.*
average % of turnover from innovative products sales in the last three years	3.94	10.74	13.09	17.81	0	0	17.70	18.20
average % of turnover invested in R&D in the last three years	0	0	7.17	9.48	1.78	5.24	5.69	9.18
average % of R&D acquired from external sources	0	0	9.10	23.23	2.70	14.67	6.77	19.43
average % of R&D supplied by another firm in the group	0	0	1.69	10.90	0.55	6.78	1.21	8.85
average % of R&D supplied by other firms / consultants	0	0	5.57	18.48	1.72	11.72	4.07	15.14
average % of R&D supplied by Universities and R&D centres	0	0	1.79	9.26	0.42	5.21	1.45	7.94
R&D external partners homogeneity index (%)	0	0	5.83	19.66	2.14	13.28	3.91	15.45
Log of number of employees in 2008	3.33	0.85	3.80	1.11	3.42	0.92	3.73	1.10
Log of years from establishment	3.17	0.85	3.26	0.87	3.19	0.84	3.25	0.87
Dummy = 1 if the firm has exported before 2008	0.49	0.5	0.79	0.41	0.53	0.5	0.76	0.43
Dummy = 1 if the firm belongs to a group	0.16	0.37	0.27	0.45	0.19	0.39	0.25	0.44
Dummy = 1 if the firm is head of the group	0.02	0.15	0.05	0.21	0.03	0.16	0.04	0.21
Lack of appropriate financing as factor hampering innovation	0.22	0.38	0.26	0.41	0.23	0.39	0.26	0.41
Average business enterprise sector R&D expenditure over Pil by NUTS 2 regions	0.20	0.16	0.21	0.17	0.20	0.16	0.21	0.16
Average government sector R&D expenditure over Pil by NUTS 2 regions	1.06	0.78	1.15	0.82	1.08	0.78	1.14	0.82

Table 3 – External R&D and innovation performance

	(1)			(2)			(3)			(4)		
Dependent Variable:	**did the firm carry out any product innovation? dummy variable (Yes = 1/No = 0)**						**average share of total turnover from innovative products sales**					
Log of number of employees in 2008	-0.070	***	(0.023)	-0.069	***	(0.023)	-0.029	***	(0.008)	-0.029	***	(0.008)
Log of years from establishment	0.002		(0.013)	0.001		(0.013)	-0.010	***	(0.004)	-0.010	***	(0.004)
Dummy = 1 if the firm has exported before 2008	-0.136	*	(0.078)	-0.132	*	(0.078)	-0.020		(0.026)	-0.020		(0.026)
Dummy = 1 if the firm belongs to a group	-0.041		(0.030)	-0.050	*	(0.030)	-0.013		(0.009)	-0.015	*	(0.009)
Dummy = 1 if the firm is head of the group	0.043		(0.062)	0.059		(0.062)	0.014		(0.017)	0.017		(0.017)
France	-0.215	***	(0.043)	-0.226	***	(0.043)	-0.034	***	(0.011)	-0.037	***	(0.011)
Germany	-0.187	***	(0.042)	-0.189	***	(0.042)	0.017	*	(0.010)	0.017		(0.010)
Italy	-0.223	***	(0.040)	-0.246	***	(0.041)	0.010		(0.010)	0.005		(0.010)
Spain	-0.115	**	(0.048)	-0.117	**	(0.048)	0.037	***	(0.012)	0.036	***	(0.012)
The firm has undertaken R&D activities (Yes/No)	2.176	***	(0.121)	2.171	***	(0.120)	0.594	***	(0.096)	0.596	***	(0.096)
Share of R&D acquired from external sources	1.967	***	(0.284)				0.356	***	(0.048)			
Square of Share of R&D acquired from external sources	-2.245	***	(0.319)				-0.421	***	(0.058)			
R&D external partners homogeneity index				1.637	***	(0.367)				0.213	***	(0.063)
Squared of R&D external partners homogeneity index				-1.477	***	(0.365)				-0.178	***	(0.065)
Constant	-0.478	***	(0.068)	-0.471	***	(0.067)	-0.179	***	(0.022)	-0.179	***	(0.022)
rho_12	-0.650	***		-0.651	***		-0.541	***		-0.544	***	
N	13,621			13,621			13,621			13,621		
Joint significance of Industry fixed effects	450.1	***		450.9	***		478.2	***		478.5	***	

10 manufacturing sector dummies included

Robust standard errors in parentheses

* p<0.10, ** p<0.05, ***p<0.01

Table 4 - External R&D partners and the propensity to carry out product innovations

model	(1)			(2)			(3)		
Dependent Variable:	did the firm carry out any product innovation? dummy variable (Yes = 1/No = 0)								
Log of number of employees in 2008	-0.069	***	(0.022)	-0.066	***	(0.023)	-0.070	***	(0.023)
Log of years from establishment	0.001		(0.013)	0.000		(0.013)	0.002		(0.013)
Dummy = 1 if the firm has exported before 2008	-0.141	*	(0.077)	-0.132	*	(0.079)	-0.139	*	(0.078)
Dummy = 1 if the firm belongs to a group	-0.042		(0.030)	-0.041		(0.030)	-0.035		(0.030)
Dummy = 1 if the firm is head of the group	0.045		(0.062)	0.051		(0.062)	0.041		(0.062)
France	-0.223	***	(0.043)	-0.227	***	(0.043)	-0.217	***	(0.043)
Germany	-0.191	***	(0.042)	-0.198	***	(0.043)	-0.186	***	(0.042)
Italy	-0.236	***	(0.040)	-0.242	***	(0.040)	-0.224	***	(0.040)
Spain	-0.119	**	(0.047)	-0.127	***	(0.048)	-0.112	**	(0.047)
The firm has undertaken R&D activities (Yes/No)	2.219	***	(0.110)	2.192	***	(0.119)	2.195	***	(0.115)
Share of R&D acquired from another firm in the group	1.512	***	(0.501)						
Square of Share of R&D acquired from another firm in the group	-1.826	***	(0.553)						
Share of R&D acquired from Universities and R&D centres				2.117	***	(0.447)			
Square of Share of R&D acquired from Universities and R&D centres				-2.448	***	(0.536)			
Share of R&D acquired from other firms / consultants							1.969	***	(0.321)
Square of Share of R&D acquired from other firms / consultants							-2.296	***	(0.363)
constant	-0.479	***	(0.067)	-0.476	***	(0.067)	-0.486	***	(0.068)
rho_12	-0.663	***		-0.650	***		-0.658	***	
N	13,621			13,621			13,621		
Joint significance of Industry fixed effects	448.6	***		451.6	***		449.9	***	

10 manufacturing sector dummies included

Robust standard errors in parentheses

* p<0.10, ** p<0.05, ***p<0.01

Table 5 – External R&D partners and the intensity of product innovation performance

model	(1)			(2)			(3)		
Dependent Variable:	average share of total turnover from innovative products sales								
Log of number of employees in 2008	-0.029	***	(0.008)	-0.028	***	(0.008)	-0.029	***	(0.008)
Log of years from establishment	-0.011	***	(0.004)	-0.010	***	(0.004)	-0.010	***	(0.004)
Dummy = 1 if the firm has exported before 2008	-0.022		(0.026)	-0.020		(0.026)	-0.022		(0.026)
Dummy = 1 if the firm belongs to a group	-0.015	*	(0.009)	-0.013		(0.009)	-0.011		(0.009)
Dummy = 1 if the firm is head of the group	0.016		(0.017)	0.016		(0.017)	0.014		(0.017)
France	-0.037	***	(0.011)	-0.037	***	(0.011)	-0.036	***	(0.011)
Germany	0.015		(0.010)	0.015		(0.010)	0.017		(0.010)
Italy	0.006		(0.010)	0.006		(0.010)	0.009		(0.011)
Spain	0.035	***	(0.012)	0.034	***	(0.012)	0.037	***	(0.012)
The firm has undertaken R&D activities (Yes/No)	0.610	***	(0.097)	0.601	***	(0.096)	0.606	***	(0.097)
Share of R&D acquired from another firm in the group	0.441	***	(0.109)						
Square of Share of R&D acquired from another firm in the group	-0.512	***	(0.126)						
Share of R&D acquired from Universities and R&D centres				0.366	***	(0.083)			
Square of Share of R&D acquired from Universities and R&D centres				-0.533	***	(0.117)			
Share of R&D acquired from other firms / consultants							0.315	***	(0.061)
Square of Share of R&D acquired from other firms / consultants							-0.369	***	(0.075)
constant	-0.180	***	(0.022)	-0.181	***	(0.022)	-0.183	***	(0.022)
rho_12	-0.552	***		-0.544	***		-0.551	***	
N	13,621			13,621			13,621		
Joint significance of Industry fixed effects	478.6	***		479.1	***		479.1	***	

10 manufacturing sector dummies included

Robust standard errors in parentheses

* p<0.10, ** p<0.05, ***p<0.01

Figure 1 – External partners breadth and product innovation outcomes

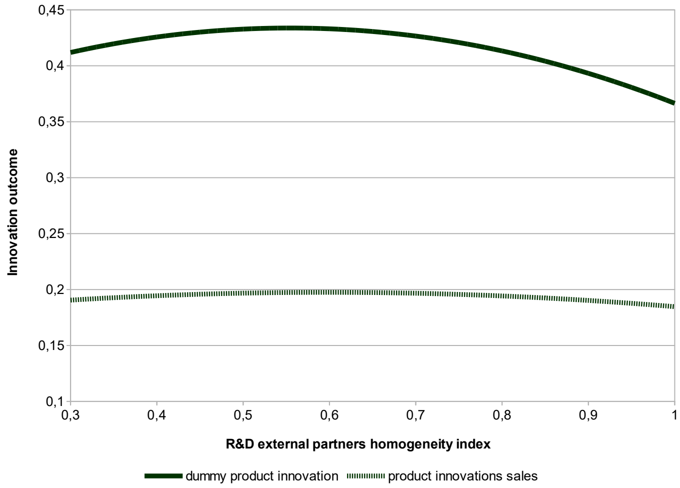


Figure 2 – External R&D and the propensity to carry out product innovations

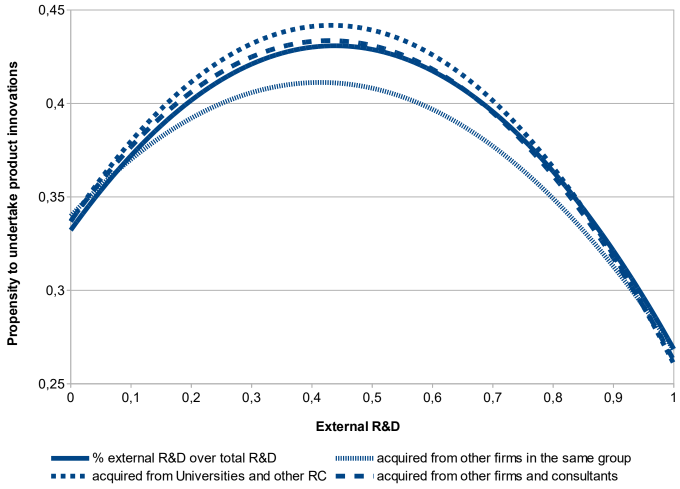
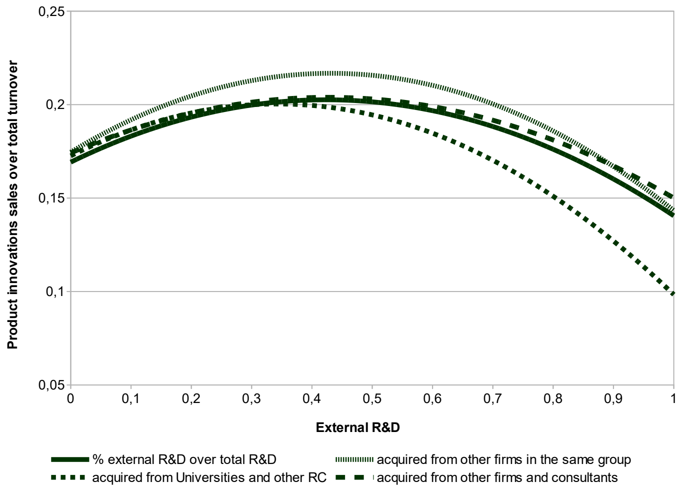


Figure 3 – External R&D and the share of innovative products sales



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