European Commission

JRC TECHNICAL REPORT

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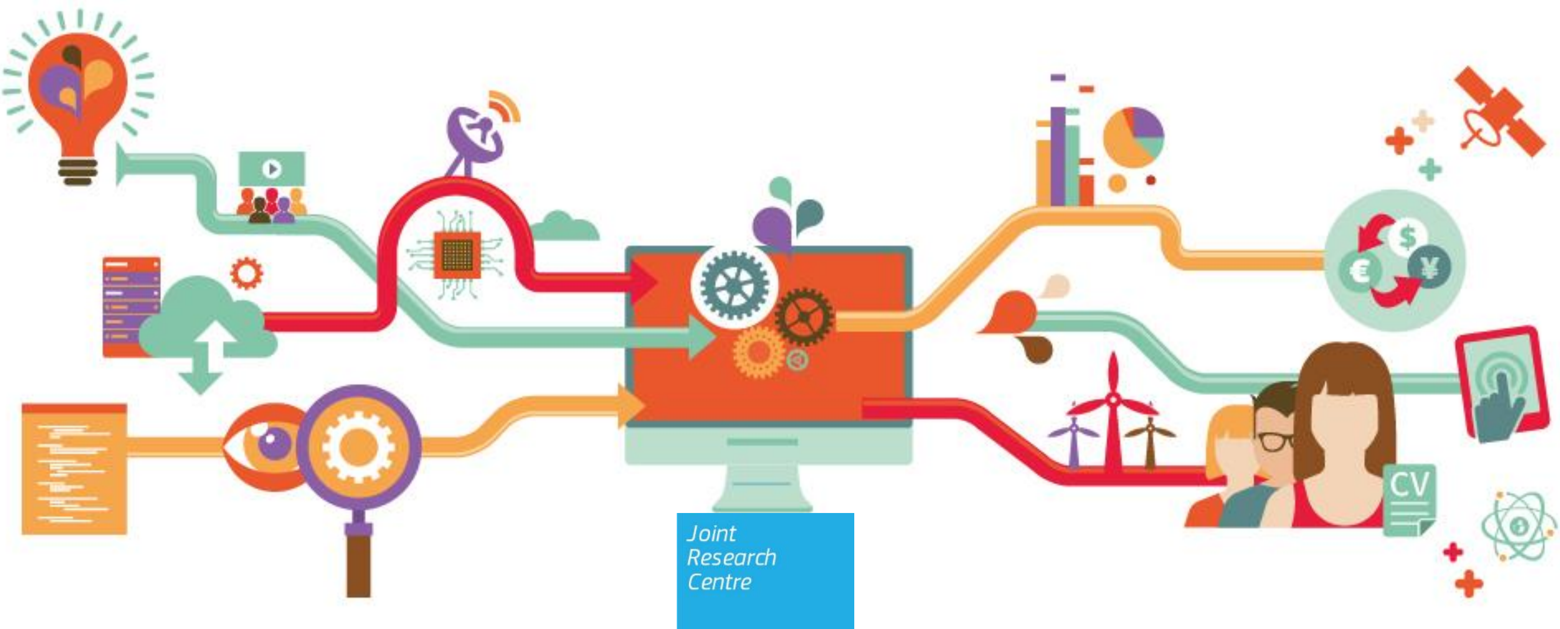
JRC Working Papers on Corporate R&D and Innovation No 05/2020

Amoroso, S. and Audretsch B. D.

2020



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This document has been produced within the context of the Global Industrial Research & Innovation Analyses (GLORIA) activities that are jointly carried out by the European Commission's Joint Research Centre –Directorate Innovation and Growth and the Directorate General for Research and Innovation-Directorate F, Prosperity. GLORIA has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 811163.

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EU Science Hub
https://ec.europa.eu/jrc

JRC122287

Seville: European Commission, 2020

How to cite this report: Amoroso, S., Audretsch, B. D. (2020), *The role of gender in linking external sources of knowledge and R&D intensity*, JRC Working Papers on Corporate R&D and Innovation No 05/2020, European Commission, 2020, JRC122287

The role of gender in linking external sources of knowledge and R&D intensity*

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Abstract

Scholars examining the effect of knowledge spillovers on R&D and innovation all agree on one thing—there is a strong relationship between the firm's R&D effort and knowledge spillover. The sign of this relationship depends, however, on many things, such as the type of spillovers (horizontal, vertical, or from other sources), the level of appropriability , the type of firm (e.g., age and sector), and the measurement of the spillover itself.

A missing piece of evidence to this literature is the role of gender in the founding team of the firm. Our contribution is to fill this gap by explicitly analyzing the role played by gender in the founding team. Given that the relationship between a firm's R&D intensity and external knowledge spillovers is ultimately context-specific, we analyse the differences between

*The authors wish to thank Mercedes Teruel, Michele Pezzoni, Enrico Santarelli, Al Link, and an anonymous referee for their valuable comments on a previous version of this paper. Any remaining errors are ours alone. The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

male-owned and female-owned young entrepreneurial firms with respect to the influence that knowledge spillovers have on their R&D intensity.

Keywords Women entrepreneurs, absorptive capacity, knowledge intensive enterprise, spillovers, Europe

1 Introduction

Despite the rising number of successful female entrepreneurs (Fackelmann and De Concini, 2020),[1] women still face many constraints limiting their ability to grow their businesses. Female owned entrepreneurial firms are not only smaller, less experienced, younger, less profitable, and more risk averse than male ones (Link and Strong, 2016), but research suggests that they are also less growth and profit oriented (Liao et al., 2003; Carter, 2007).

As R&D plays a central role in long-term productivity, both at the firm- (Coad and Rao, 2010) and aggregate-levels (Stokey, 1995), scholars have started to look at the role of R&D and innovation as one of the factors contributing to the gender gap in the performance of startups (Gottschalk and Niefert, 2013; Marvel et al., 2015; Link and van Hasselt, 2020; Quiroz-Rojas and Teruel, 2020). Female-owned firms invest less in R&D and innovate less than male-owned firms. This is in part due to the fact that female firms are concentrated in less innovative sectors (Fontana et al., 2016), but also because women have a lower propensity to patent relative to men (Cook and Kongcharoen, 2010). However, recent evidence shows that when comparing the patenting rates of both male and female firms in the same high-tech sectors, firms owned by males seem to lag behind (Demiralp et al., 2018).

The role of R&D spillovers and external sources of knowledge has long been

[1] US Chamber of Commerce Foundation

studied since mid-1980s (Levin and Reiss, 1984; Spence, 1984; Cohen and Levinthal, 1989; Cohen and Levin, 1989), as they can create both positive and negative incentives to invest in R&D.[2] External sources of knowledge are especially important for the survival of young entrepreneurial companies (Caloghirou et al., 2014; Protogerou et al., 2017; Amoroso et al., 2018). However, it is unclear how firms adjust their internal R&D activities when dealing with external knowledge, in particular when different types of sources or partners are involved. Indeed, absorbing and integrating information from a university, which primarily focuses on basic research, may require larger investment in R&D to be able to level up and put that information to use, compared to the information coming from a competitor or a value-chain partner, who may have similar and/or complementary knowledge and capabilities.

Only a few recent studies have looked at the interplay between internal R&D and external knowledge sources (Chen et al., 2016; Doloreux et al., 2018; Basit and Medase, 2019; Audretsch and Link, 2019), however none of them have specifically taken into account the role of gender. Theoretically, female-led firms could have an advantage in accessing external source of knowledge. In fact, some studies suggest that women seem to have certain advantages in managerial functions related to people. These advantages are due to the fact that women invest more time in networking and conducting market research (for an overview of the economics of women's entrepreneurship Galindo and Ribeiro, 2011, see). Social networks constitute key channels for information and resources exchange that can enhance the success of a new venture (Coleman, 1988).

So far, the analysis of the role of gender in the relationship between external

[2] Bloom et al. (2013) explains that "R&D generates at least two distinct types of "spillover" effects. The first is technology (or knowledge) spillovers, which may increase the productivity of other firms that operate in similar technology areas. The second type of spillover is the product market rivalry effect of R&D. Whereas technology spillovers are beneficial to other firms, R&D by product market rivals has a negative effect on a firm's value due to business stealing."[p. 1347]

sources of knowledge and R&D investment has been largely neglected. This paper constitutes the first attempt at analysing the theoretical and empirical differences between male-owned and female-owned entrepreneurial firms with respect to their ability to exploit external knowledge spillovers, thereby increasing or reducing their R&D intensity.

In the next section, we review the literature on the relationship between R&D investment and knowledge spillovers, focusing on studies that concern female entrepreneurship. Section 3 describes the data and the empirical methodology, while Section 4 presents the results. We discuss and draw our conclusions in Section 5.

2 Knowledge spillovers and firm-level R&D investment

The essence of knowledge spillovers traces back to Nelson (1959) and Arrow (1962), who were among the first scholars to recognise the peculiar economic characteristics of information as a commodity that can be reproduced infinitely at virtually no cost. Access to free information may reduce the incentive to invest in R&D, as the involuntary spillovers from the R&D of one firm may allow other firms to achieve results with less research effort (Jaffe, 1986). Spence (1984) suggested that research collaborations are a way of internalising the knowledge spillovers. Following Spence's work, many studies focused on the effects of R&D cooperation on R&D incentives and welfare and found that internalising the knowledge spillovers by cooperating leads to higher R&D and welfare only when the R&D spillovers rates are high (Katz, 1986; D'Aspremont and Jacquemin, 1988; Kamien et al., 1992). Cohen and Levinthal (1989) stressed the importance of investing in R&D to increase the possibility to absorb others' knowledge and to ultimately increase the return to incoming spillovers.

The importance of external knowledge has been further emphasised in the seminal work of Chesbrough (2003), introducing the open innovation paradigm, where internal R&D is seen again as a tool to identify, understand, absorb, complement, and integrate external knowledge (see West and Bogers, 2014, for a thorough review on open innovation studies). Moilanen et al. (2014) study the relationship between external knowledge, absorptive capacity and innovative performance for SMEs and find that absorptive capacity is an important mediator for transforming external knowledge inflows into higher innovative performance, especially for R&D intensive SMEs.Gesing et al. (2015) find that firms' ability to capture value from collaboration and internal R&D depends on the its governance mechanisms. In particular, internal R&D increases the return from collaborations only if the relationship between collaboration partners is informal and not contract-based. A recent study from Audretsch and Belitski (2020) investigates the relationship between investments in R&D, knowledge spillovers, innovation, and their impact on productivity, and finds that the availability of knowledge spillovers increases the intensity of investing in internal R&D.

The industrial organization (IO) literature looked at the relationship between incoming and outgoing spillovers[3] and how firms usually attempt to manage spillovers by minimizing outgoing spillovers while at the same time maximizing incoming ones (Amir, 2000; Cassiman et al., 2002; Martin, 2002; Amir et al., 2008; Hagedoorn and Wang, 2012). While classical IO research on R&D spillovers has typically considered only horizontal spillovers (i.e. spillovers from firms competing in the same industry), empirical IO and innovation management studies looked at difference sources of knowledge as reported in firms' surveys (Belderbos et al., 2004; Cantù et al., 2015; Audretsch and Link, 2019). Some studies focused on the

[3]The incoming spillovers are measures of the importance of external information flows for the firm's innovation process. The outgoing spillovers derive from knowledge leaking out of the company or organization.

importance of various sources of knowledge for innovation, R&D cooperation, and firm performance (Nieto and Santamaría, 2007; Cappelli et al., 2014; Basit and Medase, 2019), while others analysed the relationship between sources of knowledge and the characteristics of young entrepreneurial firms' founders (Caloghirou et al., 2014; Fontana et al., 2016; Amoroso et al., 2018; Hodges and Link, 2018).

The empirical findings of these studies suggests heterogeneity in the role of spillovers, with some studies reporting negative or no effect of knowledge sources from the customers on innovation output (Lööf and Heshmati, 2002; Monjon and Waelbroeck, 2003), while others find evidence of positive effect of sourcing from value chain partners and horizontal connections, but we do not find support for complementarity between firm's R&D effort and collaborations with universities and research labs (Chen et al., 2016). More recently, Basit and Medase (2019) using firm-level data from the German Community Innovation Survey (CIS) examine and finds positive effects of horizontal and vertical spillovers on firm innovation.

2.1 The role of appropriability regimes

Many scholars have argued that sectoral appropriability conditions of sectors are an important environmental factor that influences a firm's resource-seeking behaviours such as searching for similar or complementary external sources of knowledge (Cohen and Walsh, 2000; Cassiman and Veugelers, 2002; Zobel et al., 2017; Seo et al., 2017).

Therefore, in this study we explore the effect of knowledge spillovers on firm R&D efforts depending on the level of appropriability conditions, i.e. the degree to which different appropriability mechanisms or strategies increase the R&D rents.

2.2 Female entrepreneurship and R&D investment

Because female entrepreneurship is steadily growing all over the world, the number of studies analysing female-owned enterprises grows accordingly. Despite the academic findings related to gender and the economic performance of entrepreneurial firms being mixed, the general picture suggests that female entrepreneurial firms are generally smaller, younger, more risk averse, and less profitable than male ones (see Link and Strong, 2016, for a thorough review).

Another empirical regularity is that female-owned firms invest less in R&D and innovate less. One reason for this is that female entrepreneurs are typically concentrated in less innovative sectors such as service and low-tech manufacturing (Amoroso and Link, 2018, 2019). By contrast, male-owned firms are more R&D intensive and tend to be more innovative than female-owned ones. Due to the high risk associated with R&D investment and the reported high risk aversion of women, research has started to look at the relationship between gender and firm innovation. Cook and Kongcharoen (2010) show that in the US women are less likely to patent than men, while Demiralp et al. (2018) go further with US data to show that men-owned businesses in STEM fields are less likely to generate IP (including patents, trademarks, and copyrights) than female-owned firms.

In this paper, we investigate the relationship between R&D investment and the gender of firms' founders.

2.3 Female entrepreneurship and sources of knowledge

Innovation management scholars have posited that women are restricted in their access to networks and are not able to use their networks for resource acquisition or growth (Carter, 2007; Nissan et al., 2012; Achtenhagen et al., 2013; Ozkazanc-Pan and Muntean, 2018).

Atherton (2003) and Fuentes-Fuentes et al. (2015) suggest that, especially for start-ups and small businesses, the relationship with customers, suppliers, competitors, support organisms and services should be considered when investigating knowledge acquisition through business and entrepreneurial networks. In particular, Fuentes-Fuentes et al. (2015) using a survey on Spanish women entrepreneurs, show that information gathered from customers and other business-related contacts, relative to market trends and technical and market know-how, has a positive influence on entrepreneurial orientation, which in turn has a positive effect on firm performance. Given that the key components of entrepreneurial orientation[4] deal with firm engagement in R&D and risky activities, it follows that female entrepreneurs with a high entrepreneurial orientation are more involved in R&D. Even though the authors do not use R&D investment or intensity to proxy the entrepreneurial orientation, we think that one interpretation of their study is that the acquisition of external source of knowledge for female entrepreneurs is positively associated with their engagement in R&D activities. Unfortunately, the study considers only knowledge acquisition from business ties, such as customers and collaborators (suppliers, financial institutions, business associations and government entities) and it does differentiate among different sources of knowledge used.

Nonetheless, in this paper we advance and test the hypothesis that the acquisition of external source of knowledge for female entrepreneurs is positively

[4]The entrepreneurial orientation is defined as a set of strategic actions taken by managers and entrepreneurs which are driven by perceptions of opportunity, and oriented towards the exploitation of these opportunities (Wiklund and Shepherd, 2003). According to Lumpkin and Dess (1996), the three main components of entrepreneurial orientation are innovativeness, risk-taking propensity, and proactiveness. Innovativeness is the firm's engagement in experimentation and R&D activities that may result in new products or technological processes. Proactiveness refers to the firm's forward-looking perspective to anticipate future needs by seeking new opportunities. It may play a significant role for the R&D investment. Risk-taking propensity involves the willingness to commit significant resources to exploit opportunities or engage in business strategies with a highly uncertain outcome.

associated with their R&D investment. In addition, we empirically explore the heterogeneity among the different sources of external knowledge.

3 Data and methodology

To analyse the relationship between R&D intensity, gender, and various sources of knowledge used by young entrepreneurial firms, we use data from the AEGIS (Advancing Knowledge-Intensive Entrepreneurship and Innovation for Economic Growth and Social Well-being in Europe) project, funded by the European Commission's 7th Framework Programme (FP7), under Theme 8 "Socio-Economic Sciences and Humanities". The focus of the AEGIS project was on small knowledge intensive entrepreneurial firms. As part of the AEGIS project, a broad-based survey of 4,004 firms established between 2001 and 2007 across 10 European countries was conducted from late 2010 into 2011. The countries included in the survey were (alphabetically): Croatia, Czech Republic, Denmark, France, Germany, Greece, Italy, Portugal, Sweden, and the United Kingdom. Both high-tech and low-tech manufacturing sectors, and knowledge-intensive business services sector are represented in the database.

Similar to the Eurostat's Community Innovation Surveys, the AEGIS survey collected companies' assessment of the importance of certain information sources. The survey question is:

Please evaluate the importance of the following sources of knowledge for exploring new business opportunities on a 5-point scale, were 1 is not important and 5 is extremely important.

1. Clients or customers

2. Suppliers

3. Competitors
4. Public research institutes
5. Universities
6. External commercial labs/R&D firms/technical institutes
7. In-house (know-how, R&D laboratories in your firm)
8. Trade fairs, conferences and exhibitions
9. Scientific journals and other trade or technical publications
10. Participation in nationally funded research programmes
11. Participation in EU funded research programmes (Framework Programmes)

Given that we relate external sources of knowledge to firm R&D intensity, we exclude the category n. 7 "In-house (know-how, R&D laboratories in your firm)". Additionally, the literature on knowledge spillovers considers a narrower categorisation of sources of knowledge, as the average importance of knowledge sources is similar among homogeneous sources (Amoroso et al., 2018; Hodges and Link, 2018). Thus, following this literature, and the clustering of homogenous sources, we created 5 categories from the above 10: Vertical sources, Horizontal sources, Research Institutes, Research Programmes, and Publications & Conferences (see Table 1). Moreover, we transformed these responses into dichotomous variable where 1 is important (a survey response of 4 or 5) and 0 is not important (a survey response of 1, 2, or 3).[5]

<Table 1 about here>

[5] We categorise 3 as not important since firms scoring 3 on a Likert 1-5 scale are not actually rating the source of knowledge as important.

To relate the R&D intensity to different sources of knowledge, we estimate the following Tobit model:

$$\begin{aligned} RDint_i^* &= f_i(Spill^k, Female\ leader, X) + \epsilon_i \\ RDint_i &= RDint_i^* \quad \text{if} \quad RDint_i > 0 \end{aligned}$$

where the R&D intensity of firm i is regressed on k types of external knowledge sources, $Spill$, namely horizontal, vertical, research institutes, research programmes, and publications&conferences ($k = Ver, Hor, Rinst, Rprog, PubConf$), a gender variable indicating if the first-listed founder is a woman, $Female\ leader$ (we also use the share of female founders in the founding team, $\%\ Women$), and a set of control variables X. As control variables, we include the firm size (log of employees), the average experience of founders, the average age and education categories, product or process innovation, the perceived market concentration, country and sector (FE, pseudo 2-digit NACE rev.1.1) dummies, $X = (log(empl), exp, age, edu, inno, compet, FE)$. Table 2 reports summary statistics and a description of the variables; Table 3 displays the pairwise correlation coefficients between variables.

<Tables 2 and 3 about here>

Table 4 reports 2-sample t-tests of differences in the importance of external knowledge spillovers by gender of the first-listed founder. Vertical knowledge spillovers (i.e. knowledge acquired from clients and suppliers) and spillovers from publications and conferences are the most important sources of external knowledge for both female and male founded firms (roughly 90% and 50% of firms classified these two sources of knowledge as important for entrepreneurial activities). Knowledge from competitors (horizontal) and research institutes is also important for 43% and 25% of firms, however these sources of knowledge are statistically significantly more important for female founded firms than for male founded ones. Finally, the knowledge acquired via the participation to public research programmes is important for only less than 20% of the firms.

<Table 4 about here>

To analyse the relationship between R&D intensity and knowledge spillovers from a gender perspective, we include interaction effects between spillovers and the gender variable. Moreover, following Cohen and Walsh (2000), we explore the relationship between knowledge spillovers and firm R&D efforts under different levels of appropriability conditions. To measure the appropriability conditions, similar to Seo et al. (2017), we use an industry-level measure of the use of intellectual property mechanisms (IPPMs). In the AEGIS survey, firms are asked to report whether they used any IPPMs in the last three years (2007–2009) such as patents, trademarks, copyrights, confidentiality agreements, secrecy, lead-time advantages, and design complexity. We take the average number of IPPMs used by firms in each sector, and split the sample in two groups – sectors with an average number of IPPMs above the median (16 sectors and 1,950 firms) and sectors below the median (10 sectors and 2,054 firms). Table 5 reports the number of firms per sector, categorised as either 'low' appropriability conditions, or 'high' appropriability. The share of firms with a female first-listed founder is similar between the two samples (7.7% and 7.5% in the low and high appropriability samples, respectively; see Table 6).

<Tables 5 and 6 about here>

In the next section, we present and discuss the results from the Tobit regression model for the whole sample and for the two samples of firms in sectors with low or high appropriability conditions.

4 Results and discussion

Table 7 reports the marginal effects of the five sources of external knowledge on the R&D intensity of small entrepreneurial firms in Europe. The first column (1) displays the results of the simplest specification where R&D intensity depends only on spillovers, the gender dummy, and country-sector dummies. Column (2) includes all other control variables. Between the two specifications the regression coefficients do not vary much. In general, vertical and horizontal sources of knowledge are not related to the R&D intensity, while research institutes, participation to research programmes, and access to publications and conference increase the R&D spending of 7.3, 3.8, and 3.2 percentage points (ppt), respectively (column (2)).

The dummy for female-founded firms is negatively related to the R&D intensity, confirming that women-led firms have a lower R&D intensity, probably due to their risk aversion to the uncertain nature of R&D investment. In particular, the average R&D intensity is 2.8 percentage points lower in female founded firms than in male founded ones. When looking at the share of women in the founding team (column (4)), we obtain a similar result – an increase of 10 percentage points (e.g. going from 0% to 10%) in the share of female founders corresponds to a lower R&D intensity (0.36 percentage points lower).

The regression coefficients of the control variables are in line with what other studies find. The larger and more innovative firms invest more in R&D; younger, more educated, and more experienced founding teams are also more R&D intensive (Protogerou et al., 2017; Amoroso and Link, 2018). Finally, firms have a higher R&D intensity when the market concentration is high (few competitors).

The main variables of interest are the interactions between knowledge sources and the gender dummy. Columns (3) and (5) report the results for an econometric specification that takes into account such interactions. In column (3), there is some evidence that female-founded firms have an advantage compared to male-founded ones in reaping the benefits of knowledge acquired from research institutes. Similarly, knowledge spillovers from research institutes correspond to higher R&D intensity for larger share of women in the founding team.[6] Figure 1 reports the average marginal effects of knowledge from value chain business ties (vertical) and research institutes, by share of female founders. The effect of the increase in the number of women among the founders is more accentuated for vertical spillovers. It seems that once the team has more than 40% of female founders, vertical spillovers become more associated with R&D investment. The effect for research institutes spillovers is not as strong. In fact, once reached a minimum of 30-40% of women, the effect flattens out.

<Table 7 about here>

Our results are in line with Fuentes-Fuentes et al. (2015) who find that the acquisition of external knowledge has a positive effect on the engagement in R&D and risky activities of women entrepreneurs. Moreover, we add a deeper layer of understanding to their findings, in that we are able to distinguish between sources of knowledge. Not only do we confirm that firms' clients are a critical source of knowledge that leads to innovative activities (Argote, 2013), but we also show that other sources of knowledge are important for the R&D activities of female founded firms, such as research institutes. Overall, our findings suggest that, compared to men, female collaborative orientation (Sorenson et al., 2008) pays off in terms of complementing internal R&D capabilities with the acquisition of valuable external knowledge resources.

[6]In the interaction terms between spillovers and the share of women, we normalised the share of women founders to have a zero population mean, so that we can interpret the average effect of spillovers as β_k. For example, the average increase in R&D due to knowledge spillovers from research programmes is 3.774 ppt.

Table 8 reports the results for specifications including the role of appropriability. Columns (1) and (2) include the dummy *appropriability* which is equal to one if the firm in in one of the sectors characterised by high appropriability (see Table 5) and the interaction between such dummy and the spillovers variables. The results do not differ from those of Table 7 and no direct statistically significant effect is found for the appropriability variable nor for the interaction terms. However, separate estimations for the two samples of sectors (columns (High) and (Low)) offer two very different pictures. The participation in public research programmes is only associated with higher R&D efforts in sectors with a low appropriability level. Knowledge from research institutes corresponds to higher R&D intensity for firms in high appropriability sectors (the average R&D intensity is 3.4 ppt higher then in the low appropriability ones). Finally, there is a gender difference in the R&D intensity only in the high appropriability, more innovative sectors, where female-led firms report a lower average R&D intensity.

<Table 8 about here>

The interaction effects reveal a more nuanced story for the role of gender entrepreneurship in the relationship between external knowledge and R&D investment. In sectors with high levels of appropriability, information from customers and suppliers still remain more valuable for female founded firms than for male founded ones. These sources of information may be more relevant to obtain access to external knowledge resources in sectors with high appropriability, because suppliers and customers are not direct competitors. Indeed, in low appropriability sectors, the R&D intensity of firms with female first-listed founders is positively associated with spillovers from competitors (horizontal) and research institutes.

Overall, our findings indicate that both female and male founded firms complement their internal R&D strategies with the acquisition of external source of knowledge such as research institutes, publications and conferences, and the participation to research programmes (in sectors with low appropriability conditions). However, only female-led firms are able to also benefit from what are thought to be most important sources of knowledge, i.e., competitors and customers (Liao et al., 2003)

These results could be due not only to the fact that women have more collaborative and cooperative approaches to leading and organising (Sorenson et al., 2008), but also because women tend to value stakeholders more highly than men do (Posner and Munson, 1981). Moreover, as firms develop and grow, the professional relationships become increasingly significant to the entrepreneur's networks. This has been shown to be particularly relevant for women entrepreneurs in two Scandinavian countries Achtenhagen et al. (2013). Also, the stronger relationship of spillovers from research institutes and R&D intensity of female founded firms could stem from the fact that public research institutes and universities may follow more inclusive social norms that emphasise gender equality (Fang et al., 2019).

5 Conclusions

There is no consensus regarding the relationship between internal R&D activities and other sources of knowledge, primarily because this relationship varies with the type of knowledge source, and with appropriability conditions (Laursen and Salter, 2014). Following the footsteps of Cohen and Levinthal (1989), many studies have analyzed the impact of R&D collaboration with different partners, externally sourced R&D, and R&D spillovers on innovation and productivity. However, very few studies have attempted to directly link the two faces of R&D à la Cohen and Levinthal (1989), namely the innovation-generating R&D and the assimilate-and-exploit-existing-information R&D, distinguishing by sources of information. Most importantly, there is no empirical evidence on the role gender of firms' founders and the difference in their ability to exploit external sources of information. By exploiting the unique features of a data sample of knowledge-intensive entrepreneurial firms, we are able to analyse the relationship between different sources of knowledge and firms' R&D intensity, accounting for the gender of first-listed founders.

Differently from previous studies which claimed and found that the most important areas of knowledge emanate from competitors and customers (Liao et al., 2003; Fuentes-Fuentes et al., 2015; Chen et al., 2016), our estimates show that value-chain (i.e., vertical) or horizontal knowledge spillovers have no effect on R&D intensity of the average firm. The knowledge sources that are mostly associated with internal R&D capabilities are research institutes, public research programmes, and publications and conferences. These results indicate that when the sources of knowledge are less directly related to firms' core business activities, firms' own R&D could be a critical resource:

> "When outside knowledge is less targeted to the firm's particular needs and concerns, a firm's own R&D becomes more important in permitting it to recognise, assimilate and exploit valuable knowledge. Sources that produce less targeted knowledge include, for example, university laboratories involved in basic research, while more targeted knowledge may be generated by contract research laboratories or input supplier" (Cohen and Levinthal, 1989, p.572)

Another important finding is related to the appropriability conditions. According to Teece (1986), high-tech and innovation intensive industries are characterised by high appropriability conditions. By estimating separate regressions for two groups of firms—firms in high and a low appropriability sectors—we observe that the effect on R&D spending of sources of knowledge differs between the two groups. In sectors with high appropriability conditions, knowledge spillovers from research institutes and publications and conferences lead to higher R&D intensity than in low appropriability sectors. The knowledge acquired via the participation in public research programmes has no effect on R&D spending of firms in high appropriability sectors. A potential explanation is that while a firm can extract useful information and knowledge by participating in research programmes, it may also involuntarily spill over some of its tacit know-how (Amoroso and Vannuccini, 2019). The possibility of giving away useful knowledge to other firms (competitors, value-chain partners, or firms in a research consortium) does not create the incentive to invest more in R&D. This type of knowledge is, however, the most valuable in sectors with low appropriability conditions.

The main contribution of this paper is however the analysis of the role of female founders. While most studies focus on the economic or innovative performance of women entrepreneurs, we look instead at the knowledge absorptive capability from a gender perspective. More specifically, we examine how female first-listed founded firms differ from male ones in translating the knowledge from external sources into R&D efforts. Our findings suggest that female-led firms have an advantage compared to male-led ones in reaping the benefits of knowledge acquired from research institutes and value-chain partners. Moreover, in sectors with low appropriability conditions, female founded firms are able to complement their internal R&D with information from competitors as well. These results align with the theoretical underpinnings of management and organisational studies which suggest that women have a preference and tendency to organise and manage their activities as collaborative networks, where they use their relational skills to create and develop connections with both professional and personal contacts (Sorenson et al., 2008; Achtenhagen et al., 2013). This feminine approach to managing and organising in collaborative networks is associated with higher R&D intensity, which is seen as a key component of the entrepreneurial orientation (Wiklund and Shepherd, 2003).

From a policy perspective, these results are especially relevant. Indeed, our results suggest that encouraging the natural tendency of women entrepreneurs to rely on formal and informal collaborative networks and supporting social structures may offset and even reverse their aversion to risky investment such as R&D.

In spite of its contributions, the present study has its limitations. Methodologically, the choice of censored regression (Tobit model) takes into account the truncation of the error term due to the fact that we observe the R&D intensity only for a part of the sample. However, this approach may introduce a specification error as we restrict the way in which the explanatory variables simultaneously determine the probability of performing R&D and the intensity of R&D spending. Indeed, the knowledge spillover variables may not affect the probability of engaging in R&D, but only affect R&D performance. A second estimation problem stems from the endogeneity of market concentration and innovation which are endogenous variables and must be seen as simultaneously determined within a system. Moreover, our analysis is based on a cross-sectional survey and cannot be used to understand the evolution and the dynamic relationship between internal R&D and different sources of external knowledge. Lastly, we do not take into account cooperations as an additional way in which firms may access pools of knowledge. For example, consulting with a research institute or a university to solve a technical problem, or collaborating with universities to develop a new technology, may correspond to different levels of internal R&D.

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Tables and Figures

Table 1: Categorisation of external sources of knowledge

AEGIS 10 original categories	5 new categories
Clients or customers	Vertical
Suppliers	Vertical
Competitors	Horizontal
Public research institutes	Research Institutes
Universities	Research Institutes
External commercial labs/R&D firms/technical institutes	Research Institutes
Trade fairs, conferences, and exhibitions	Publications&Conferences
Scientific journal and other trade or technical publications	Publications&Conferences
Participation in nationally funded research programmes	Research Programmes
Participation in EU funded research programmes	Research Programmes

Table 2: Summary statistcs

Variable	Mean	SD	Min	Max
RDint (% of sales)	12.46	19.35	0	100
Vertical	0.90	0.30	0	1
Horizontal	0.43	0.50	0	1
Research Institutes	0.25	0.43	0	1
Research Programmes	0.18	0.38	0	1
Publications&Conferences	0.49	0.50	0	1
Female leader	0.15	0.36	0	1
% Women	18.34	30.92	0	100
log(empl)	1.69	1.17	-0.69	7.3
Exp	12.23	9.23	0	55
Age	2.99	0.79	1	4
Edu	2.76	1.10	0	5
Inno	0.64	0.48	0	1
Compet	1.48	0.62	1	3

Note: The importance of external sources of knowledge has been re-codified. Originally, they range from 1 (not important) to 5 (extremely important). The values 1–3 have been codified as 0 and the values 4–5 as 1.

A *female-owned* firm is a firm where the first listed founder is a woman. % Wmn founders is the share of founders. The maximum number of founders is 4 and the average number of founders is 2.

Experience, *Age* and *Edu* are the average experience (in years), age groups (1–4) and education level (1–5) of all founders of a firm.

Compet takes value 1 when the firm's market is not very concentrated (many competitors) and 3 when is very concentrated (oligopolistic).

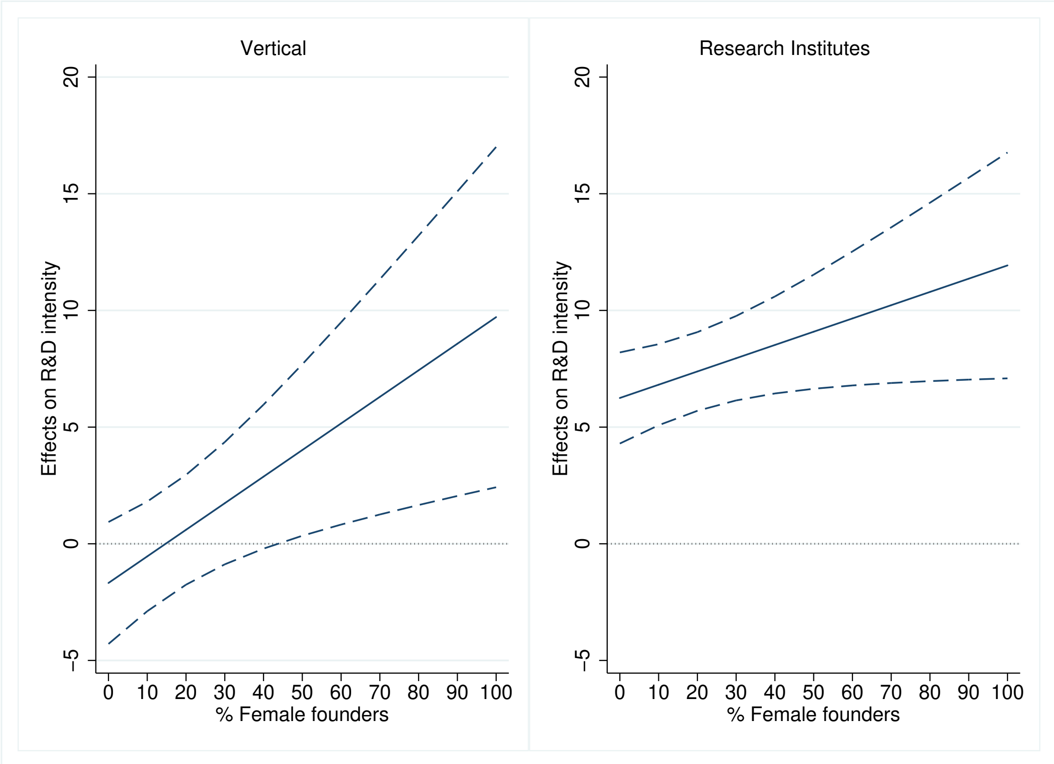

Figure 1: Average marginal effects of vertical (value chain) and research institutes sources of knowledge by share of female founders (90% CIs)

Table 3: Pairwise correlation coefficients

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) RDint	1											
(2) Vertical	0	1										
(3) Horizontal	0.04*	0.13*	1									
(4) Research Institutes	0.18*	0.05*	0.17*	1								
(5) Research Programmes	0.18*	0.06*	0.13*	0.40*	1							
(6) Publications&Conferences	0.14*	0.10*	0.14*	0.25*	0.24*	1						
(7) Female leader	-0.05*	0.01	0.02	0.02	0.01	0.02	1					
(8) log(empl)	0.03	0.03	0.07*	0.03	0.11*	0.01	-0.11*	1				
(9) Exp	0	0.01	-0.03	0.04*	0	0	-0.11*	-0.01	1			
(10) Age	-0.04*	0	-0.03	0.03	0.01	0	-0.06*	0	0.47*	1		
(11) Edu	0.15*	-0.03*	-0.04*	0.02	0.04*	0.06*	0	-0.06*	-0.04*	0.01	1	
(12) Inno	0.21*	0.03	0.05*	0.11*	0.12*	0.12*	-0.02	0.16*	-0.04*	-0.04*	0.05*	1
(13) Compet	0.17*	0	-0.06*	0.03	0.08*	0.02	-0.04*	0.01	0	0.06*	0.03*	0.08*

Note:* shows significance at the .05 level

Table 4: The importance of sources of external knowledge by gender

	Vertical	Horizontal	Research Institutes	Research Programmes	Publications Conferences	N. firms
male leader	0.90	0.43	0.25	0.18	0.49	3,395
female leader	0.91	0.46	0.27	0.19	0.52	609
2-sample t-test	-0.94	-1.34*	-1.48*	-0.52	-1.24	

Note: The table reports the average importance (0 = not important, 1 = important) of the five sources of external knowledge.
Significance code '***' p<0.001, '**' p<0.01, '*' p<0.1

Table 5: Number of firms, by sector and by appropriability conditions

NACE code	Description	Appropriability Low	High
15	Manufacture of food products and beverages	297	
17	Manufacture of textiles	91	
18	Manufacture of wearing apparel; dressing&dyeing of fur		84
19	Leather, manufacture of leather products		34
20	Manufacture of wood&wood products, except furniture	122	
21	Manufacture of pulp, paper and paper products		46
22	Publishing, printing and reproduction of recorded media		572
24	Manufacture of coke, refined petroleum products&nuclear fuel		51
27	Manufacture of basic metals	31	
28	Manufacture of fabricated metal products, except machinery&equipment	214	
29	Manufacture of machinery and equipment n.e.c.		201
30	Manufacture of office machinery and computers		20
31	Manufacture of electrical machinery and apparatus n.e.c.		45
32	Manufacture of radio, television and communication equipment and apparatus		35
33	Manufacture of medical, precision and optical instruments, watches and clocks		67
35.3	Manufacture of aircraft and spacecraft		1
36.1	Manufacture of furniture	111	
64.2	Telecommunications		24
72	Computer and related activities		518
73	Research and development		71
74.1	Legal, accounting, book-keeping and auditing activities; tax consultancy; market research and public opinion polling; business and management consultancy; holdings	767	
74.2	Architectural and engineering activities and related technical consultancy	317	
74.3	Technical testing and analysis	60	
74.4	Advertising		116
74.5	Labour recruitment and provision of personnel	44	
74.8	Miscellaneous business activities n.e.c.		65
Total		2,054	1,950

Table 6: Distribution of firms by gender of the first-listed founder and appropriability conditions, absolute numbers and (percentages)

	Appropriability		
	Low	High	row total
male leader	1,745 (43.6)	1,650 (41.2)	3,395 (84.8)
female leader	309 (7.7)	300 (7.5)	609 (15.2)
column total	2,054 (51.3)	1,950 (48.7)	4,004 (100)

Table 7: Estimation results from Tobit regression model

Dep. var: $RDint \mid RDint > 0$	(1)	(2)	(3)	(4)	(5)
Vertical	0.307	0.087	-0.769	0.108	0.411
	(1.390)	(1.405)	(1.502)	(1.405)	(1.417)
Horizontal	0.588	0.608	0.514	0.624	0.635
	(0.857)	(0.847)	(0.916)	(0.847)	(0.847)
Research Institutes	7.882***	7.310***	6.552***	7.296***	7.290***
	(1.035)	(1.023)	(1.106)	(1.023)	(1.022)
Research Programmes	6.266***	3.768***	3.947***	3.779***	3.774***
	(1.157)	(1.152)	(1.248)	(1.152)	(1.151)
Publications&Conferences	4.397***	3.157***	3.119***	3.151***	3.129***
	(0.868)	(0.860)	(0.924)	(0.860)	(0.861)
Female leader	-3.884***	-2.853**	-10.591**		
	(1.186)	(1.192)	(4.292)		
% Women				-0.036**	-0.138***
				(0.014)	(0.049)
Ver×Female [% Wmn]			6.673		[0.114]**
			(4.289)		(0.049)
Hor×Female [% Wmn]			0.686		[0.001]
			(2.371)		(0.028)
RInst×Female [% Wmn]			4.764*		[0.057]*
			(2.861)		(0.034)
RProg×Female [% Wmn]			-1.263		[-0.010]
			(3.176)		(0.038)
PubConf×Female [% Wmn]			0.217		[-0.030]
			(2.464)		(0.029)
ln(empl)		0.741*	0.756**	0.756**	0.761**
		(0.384)	(0.384)	(0.384)	(0.384)
exp		0.107**	0.108**	0.108**	0.109**
		(0.051)	(0.051)	(0.051)	(0.051)
age		-2.078***	-2.097***	-2.097***	-2.095***
		(0.601)	(0.601)	(0.601)	(0.600)
edu		2.240***	2.244***	2.244***	2.223***
		(0.402)	(0.403)	(0.403)	(0.403)
inno		10.776***	10.774***	10.774***	10.752***
		(0.898)	(0.899)	(0.899)	(0.898)
compet		5.627***	5.666***	5.666***	5.602***
		(0.667)	(0.667)	(0.667)	(0.667)
var(e.RDint)	581.012***	517.487***	516.907***	516.907***	514.844***
	(16.791)	(15.445)	(15.427)	(15.427)	(15.364)
N	3947	3602	3602	3602	3602

Note: The table reports the marginal effects of the five sources of external knowledge on R&D intensity. The coefficients can be interpreted as the average R&D intensity being β percentage points higher for knowledge sources that are considered important (equal to 1)
Country and 2-digit sector dummies included but not reported
Significance code '***' p<0.001, '**' p<0.01, '*' p<0.1

Table 8: Estimation results from Tobit regression model (by appropriability conditions)

Dep. var: $RDint \mid RDint > 0$	(1)	(2)	(High)	(Low)
Vertical	-0.769	0.273	-1.732	0.657
	(1.502)	(2.071)	(2.239)	(1.983)
Horizontal	0.514	0.014	2.034	-1.150
	(0.916)	(1.244)	(1.372)	(1.200)
Research Institutes	6.552***	6.059***	8.356***	5.019***
	(1.106)	(1.465)	(1.702)	(1.413)
Research Programmes	3.947***	5.099***	1.752	6.019***
	(1.248)	(1.693)	(1.862)	(1.643)
Publications&Conferences	3.119***	2.655**	3.444**	2.791**
	(0.924)	(1.263)	(1.375)	(1.219)
Female leader	-10.591**	-10.643**	-12.916**	-8.290
	(4.292)	(4.299)	(6.342)	(5.732)
Ver×Female	6.673	6.594	10.832*	2.689
	(4.289)	(4.296)	(6.377)	(5.689)
Hor×Female	0.686	0.785	-5.818	7.033**
	(2.371)	(2.372)	(3.654)	(3.063)
Rinst×Female	4.764*	4.817*	-0.878	9.719***
	(2.861)	(2.860)	(4.470)	(3.620)
Rprog×Female	-1.263	-1.377	4.460	-5.826
	(3.176)	(3.176)	(4.910)	(4.054)
PubConf×Female	0.217	0.318	0.276	-0.381
	(2.464)	(2.464)	(3.784)	(3.191)
appropriability	2.457	3.525		
	(3.592)	(4.507)		
Ver×appro		-1.935		
		(2.812)		
Hor×appro		0.973		
		(1.686)		
Rinst×appro		1.045		
		(2.035)		
Rprog×appro		-2.312		
		(2.270)		
PubConf×appro		0.901		
		(1.705)		
log(empl)	0.756**	0.757**	1.009*	0.554
	(0.384)	(0.384)	(0.592)	(0.490)
exp	0.108**	0.108**	0.096	0.107*
	(0.051)	(0.051)	(0.082)	(0.064)
age	-2.097***	-2.091***	-2.329**	-1.844**
	(0.601)	(0.601)	(0.913)	(0.780)
edu	2.244***	2.248***	3.108***	1.407***
	(0.403)	(0.403)	(0.598)	(0.534)
inno	10.774***	10.790***	12.221***	9.746***
	(0.899)	(0.900)	(1.408)	(1.133)
compet	5.666***	5.649***	6.721***	4.466***
	(0.667)	(0.667)	(1.006)	(0.870)
var(e.RDint)	516.907***	516.441***	574.052***	442.836***
	(15.427)	(15.414)	(23.895)	(18.971)
N	3602	3602	1729	1873

Note: The table reports the marginal effects of the five sources of external knowledge on R&D intensity. The coefficients can be interpreted as the average R&D intensity being β percentage points higher for knowledge sources that are considered important (equal to 1)
Country and 2-digit sector dummies included but not reported
Significance code '***' p<0.001, '**' p<0.01, '*' p<0.1

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