The effects of the functional and geographical breadth of collaborations on radical innovation performance: the moderating role of firm size

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Abstract

Purpose – Due to the constantly increasing competitiveness along with the complexity of knowledge, firms perceive collaboration as a key strategy that preserves firms' radical innovation performance. In this context, this paper aims to examine how firms' partners' diversity in open innovation activities influences the development of radical innovations, critical for social development. In particular, this study analyzes how the functional and geographical breadth of the firm's collaboration portfolio affects its radical innovation performance. Furthermore, it also explores the role of firm size as a moderator in the relationships proposed.

Design/methodology/approach – This research employs panel data analysis, using a sample of 4,677 Spanish firms, with data sourced from the PITEC database.

Findings – The results of this study show that there is an inverted U-shaped relationship between the functional and the geographical breadth of collaborations and the firms' radical innovation performance. Moreover, this study finds partial support for the moderating role of firm size, in the sense that small and medium-sized enterprises (SMEs) and large firms vary in their optimal number of diversity of partners.

Originality/value – This research provides a better understanding on how partners' functional and geographical diversity, along with organizational characteristics such as firm size, affect how firms benefit from collaboration for innovation. This study shows that both SMEs and large firms experience diminishing returns when their collaboration networks become overly diverse in pursuit of radical innovation, due to increased costs. However, in SMEs, the turning point occurs at a later stage, consistent with the idea that small firms need broader functional networks to access complementary and novel resources they usually lack.

Keywords Radical innovation, Open innovation, Collaboration portfolio, Functional breadth of collaborations, Geographical scope, Firm size

Paper type Research paper

1. Introduction

In the context of rapid technological change, globalization and highly competitive markets, external knowledge has become critical for companies looking to develop and introduce new products (Torres de Oliveira *et al.*, 2022). In this sense, the importance of using external knowledge to increase innovation performance has long been noted by many researchers in the field of open innovation (Cheng and Huizingh, 2014; Kang and Kang, 2009; Parida *et al.*, 2012; Zhao *et al.*, 2016). Open innovation refers to the use of the required external knowledge to improve innovation performance as well as identifying new market opportunities for external exploitation (Chesbrough and Bogers, 2014).

Frequently, firms do not have all the knowledge inputs required to develop disruptive innovative outcomes (Haus-Reve *et al.*, 2019), which boosts their engagement in collaborations (Zhang *et al.*, 2023). From the knowledge-based view (KBV), collaboration diversity triggers various knowledge flow mechanisms (Hagedoorn *et al.*, 2018). Thus, innovative firms have been trying to diversify their collaboration portfolio to respond to fast-changing environments and introduce new knowledge and products to the market; this is why a crucial aspect in collaboration is the selection of relevant partners (Lee *et al.*, 2022; Nieto and Santamaría, 2010; van Beers and Zand, 2014). As the diversity in a firm's collaboration portfolio is determined by the proximities and differences among network partners (Delgado-Márquez *et al.*, 2018), the existing literature reveals that partners' variety and their characteristics play crucial roles in innovative success (Capaldo and Petruzzelli, 2014; Elia *et al.*, 2019). Consequently, to identify and select the most suitable collaboration partners, multiple studies pay close attention to the role of proximity to partners (Ardito *et al.*,

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2019; Capaldo and Petruzzelli, 2014; Delgado-Márquez *et al.*, 2018). Existing studies suggest that proximity between different collaboration partners, in terms of geographic (Capaldo and Petruzzelli, 2014), cultural (Elia *et al.*, 2019) and technological or organizational aspects, among others, facilitates coordination, repeated interactions, knowledge spillovers and reduces uncertainty and conceptual ambiguity between them (Felzensztein *et al.*, 2014b; Geldes *et al.*, 2015). Nevertheless, distant partners can also provide less redundant knowledge sources, which in turn could lead to enhanced innovation outputs (Bolívar–Ramos, 2019).

In line with previous arguments, a diverse collaboration portfolio reflects the degree of variance in partners, functional purposes, location and managerial strategies (Jiang *et al.*, 2010), which facilitate improvements in knowledge flows and the enriching of information sources, but can also generate management problems. In this context, and more concretely, scholars have long noted the need to distinctly analyze the importance of functional diversity, i.e. the number of different partner types including suppliers, competitors, customers and universities, with whom a firm collaborates (Hagedoorn *et al.*, 2018), and the geographical diversity of the collaboration portfolio – from the standpoint of different geographic areas in which partners act – to address how they affect firms' innovation performance (Capaldo and Petruzzelli, 2014; Trąpczyński *et al.*, 2018; van Beers and Zand, 2014). Notably, diverse functional partners provide a dissimilar and complementary knowledge base, while geographically diverse partners induce a greater openness to new ideas (Bernal *et al.*, 2022; Sarpong and Teirlinck, 2018). Despite this, it is vital to mention that overly distinct partners from different knowledge areas and locations can lead to situations of conflict that may negatively affect the introduction of radically new products (Cheng *et al.*, 2016), due to potential opportunistic behaviors (Pillai *et al.*, 2023).

Despite acknowledging the crucial role of richer knowledge sources for innovation, empirical studies on the diversity in collaboration portfolios still offer contradictory arguments, specifically in terms of how the functional and geographical diversity of collaborations affect firms' radical innovation performance. This aspect is critical to elucidate how partners' diversity in collaboration portfolios affects a firm's ability to develop radical innovations. These innovations are key to addressing societal problems in fundamentally novel ways and to driving technological and economic progress. While some studies claim that greater partners' diversity leads to greater innovation for the firm (Sarpong and Teirlinck, 2018), other scholars claim that too diverse collaboration portfolios, involving different types of partners and geographies, may result in diminishing returns in innovation activities due to higher coordination and management costs (Carree *et al.*, 2019; Delgado-Márquez *et al.*, 2018). As inconclusive results persist, the heterogeneity and diversity in collaboration portfolios and its effect on firms' radical innovation performance requires further attention.

Furthermore, our study also explores how firm size, which is one of the most important and debated firm-level contingencies affecting innovation activities (Messeni Petruzzelli *et al.*, 2018), influences the relationships between the functional and geographical breadth of the collaboration portfolio and firms' radical innovation performance. To the best of our knowledge, scant research has tackled this topic (Carree *et al.*, 2019), and a deeper understanding in terms of how these relations may vary in small and medium-sized enterprises (SMEs) and large firms is required, as they differ in their organizational characteristics, resource base, innovation behavior and level of experience (Carree *et al.*, 2019; Jang *et al.*, 2017; Popa *et al.*, 2017; Shinkle and Kriauciunas, 2010; Veer *et al.*, 2016). On the one hand, large firms may be involved in more diverse collaboration portfolios, thanks to their resource base and experience, which ensures relevant networks (Jang *et al.*, 2017). However, SMEs are more flexible and can rapidly adapt their processes to adopt radical innovations (O'Connor and DeMartino, 2006). Thus, this paper tries to shed some light on how firm size affects the relationships between diverse collaboration portfolios (i.e. functional and geographical) and firms' radical innovation performance.

Based on the previous research gaps, the main research questions this study addresses are the following:

RQ1. How does the functional breadth of the collaboration portfolio affect firms' radical innovation performance?

RQ2. How does the geographical scope of the collaboration portfolio affect firms' radical innovation performance?

RQ3. How does firm size moderate the aforementioned relationships?

To answer these research questions, we conducted an empirical analysis using a sample of 4,677 Spanish manufacturing and service firms over the years 2012–2016. The results of the analysis indicate that there is an inverted U-shaped relation between the functional breadth of the collaboration portfolio and firms' radical innovation. Furthermore, the geographical scope of the collaboration network and firms' radical innovation performance also present an inverted U-shaped relationship. Moreover, firm size moderates the relationship between the functional diversity of collaborations and radical innovation performance, from the perspective that SMEs have a higher optimal number of functional partners compared to large firms, which may be explained due to the need to acquire knowledge and complementary resources and competencies from diverse sources (Zeng *et al.*, 2010).

This paper contributes to the literature on partner selection by discussing the role of the breadth of collaborations, and partner characteristics, to consider potential complementarities and synergistic effects in innovative activities (Capaldo and Petruzzelli, 2014) while also accounting for the costs involved. In addition, our study provides a deeper understanding of the differences in the behavior of SMEs and large firms in terms of the distinctness of their engagement in collaboration and ability to implement radical innovation (Carree *et al.*, 2019; O'Connor and DeMartino, 2006; Shinkle and Kriauciunas, 2010; Verhees *et al.*, 2010). We demonstrate that SMEs can benefit more from engaging in more varied functional R&D collaboration, although after a certain point the benefits tend to reduce with increasing diversity in the collaboration network.

This paper is structured as follows. Section 2 presents the theoretical background and the research hypotheses. Section 3 explains the methodology and empirical strategy. Section 4 describes the models and main results. Finally, Section 5 presents the conclusions, the limitations of the study and suggests future research directions.

2. Theoretical background

2.1 Radical innovation and open innovation

Schumpeter argued that radical innovation favors the generation of important changes in markets and organizations through a process of creative destruction (Pino *et al.*, 2016). Open innovation has become an effective driver to produce radical innovations, that create wholly new technological frontiers. Opened boundaries to external knowledge allow firms to facilitate the acquisition of new and valuable information or knowledge and then strengthen the ability to reveal progressive technologies to stimulate radical innovation development (Cheng *et al.*, 2016). Radical innovation encompasses significantly advanced technologies and knowledge. It includes the highest order innovations and knowledge that fosters the creation of new products, markets or even industries; promoting the achievement of competitive advantages as competitors need time to create technologies that are able to compete with existing ones (Torres de Oliveira *et al.*, 2022). New innovative products allow firms to achieve market differentiation and improve their current performance (Ritala *et al.*, 2018). In addition, as Bers *et al.* (2009) pointed out, radical innovations induce technological progress and determine some of the most important advances in society in fields such as medicine, transportation, power or information technology, among others. Overall, these breakthrough innovations contribute to scientific development, economic growth and improvements in the quality of human life. To illustrate, in the context of the COVID-19 pandemic, it has been possible to develop and launch a novel vaccine, based on mRNA, thanks to the collaboration between companies such as Pfizer and BioNTech that have provided complementary resources and technologies. Thus, studying the mechanisms (e.g. external collaborations) that may help firms succeed in this process is crucial, given its benefits not only for companies but also for society as a whole. Unfortunately, this long-term, risky and unpredictable process does not always bear fruit, to society's detriment (Bers *et al.*, 2009). Radical innovations can have unclear technical or market outcomes, along with uncertainty between actions and results (Shaikh and O'Connor, 2020). Moreover, achieving radical innovation entails higher risks and requires more tacit knowledge (Forés & Camisón, 2016) and a significant transformation of existing organizational structures, processes and foremost resources (Colombo *et al.*, 2017). Overall, given its implications for firms and society, and due to the mixed evidence on how to obtain successful results, some scholars have recently emphasized that research on the effects on open innovation and firms' radical innovation performance require special attention at present (Delgado-Márquez *et al.*, 2018; Ismail *et al.*, 2024).

2.2 Collaborations and knowledge (knowledge-based view)

From the stance of firms' KBV, the obtaining, assimilation and implementation of relevant knowledge is critical to gain competitive advantages and, in turn, improve firms' innovative performance (Grant, 1996). This includes not only knowledge generated internally but also knowledge sourced from external partners through collaborations. Along these lines, the open innovation literature (Bouncken *et al.*, 2018; Chesbrough, 2004; Zhu *et al.*, 2019) has emphasized that external knowledge sourcing has become a critical process for firms to develop and profit from innovations (Berchicci, 2013; Lin and Lekhawipat, 2023). Hence, interorganizational collaborations become a powerful tool to enhance the development of new products (Bouncken *et al.*, 2018). In other words, collaborations help firms scan the competitive markets, develop new knowledge and ideas and consequently pursue radical innovations (Ritala *et al.*, 2018). In this realm, integration within different innovation networks allows firms to effectively structure their search for new knowledge and gain access to different technologies that can help them improve their innovative performance and competitiveness.

Different scholars highlight that collaborations with a diverse set of partners makes the firm more productive in innovation processes by increasing the learning of innovation skills (van Beers and Zand, 2014) and the acquisition of new knowledge (Hagedoorn *et al.*, 2018). Extant research suggests that different innovation collaboration portfolios (i.e. in terms of partners and location diversity) can have different effects on firms' innovation performance (Sarpong and Teirlinck, 2018; Trąpczyński *et al.*, 2018; van Beers and Zand, 2014), as these portfolios provide varied and distinct knowledge sources (Bolívar-Ramos, 2017). In other words, in terms of the KBV, relevant partner diversity facilitates various knowledge-sharing mechanisms that may be associated with firm innovation performance (Hagedoorn *et al.*, 2018). Diversity can be related to the breadth of various types of partners (i.e. functional diversity) or the geographic areas in which partners are active (geographical diversity). These aspects, and their effects on innovation activities, will be discussed next.

2.3 Breadth of collaborations (functional/geographical) and innovation

Innovation stems from the linkages and synergies among firms, universities, public institutions and other stakeholders (Geldes *et al.*, 2015). Functional partners typically include clients, suppliers, competitors, universities and private or public research centers (Sarpong and Teirlinck, 2018). The functional breadth of collaboration allows firms to obtain access to richer information and knowledge combinations from partners, thereby accelerating the propensity to innovate (Haus-Reve *et al.*, 2019). For instance, collaboration with suppliers and customers provides relevant information on technologies, markets and customer needs (Geldes *et al.*, 2017b), while collaboration with competitors is used to share risks and information about regulation (Badillo and Moreno, 2016; D'Agostino and Moreno, 2018). Regarding collaboration with universities and research centers, firms may access specialized infrastructures and equipment (Giannopoulou *et al.*, 2019). Hence, firms with more specialized knowledge obtained from different partners have a greater chance of introducing brand new innovations.

In addition to the functional diversity, accessing foreign knowledge through the geographical scope of collaboration helps firms to adapt to local needs and regulations, procure highly skilled employees and gain external knowledge (Duysters and Lokshin, 2011), all of which are needed to facilitate radical innovation. For example, clusters that share physical geography – from a single city/state to a country or group of neighboring countries – allow partners to be interconnected and collaborate by virtue of "complementarities and commonalities" (Felzensztein *et al.*, 2014a). In this context, the geographical breadth of collaboration relates to the regional scope of the collaboration network, where firms collaborate with partners across different geographic locations (Shi and Weber, 2018). As certain scholars have highlighted, collaboration networks that involve partners from diverse geographical locations are key to increasing knowledge diversity and the recombination of heterogeneous valuable inputs that firms need to produce the latest technological developments (Patel *et al.*, 2014), while also avoiding "lock-in" effects due to too much proximity (Geldes *et al.*, 2017b; Xu *et al.*, 2023). Nevertheless, and although currently information and communication technologies also facilitate cross-border knowledge management and innovative activities (Bolívar-Ramos, 2019; Geldes *et al.*, 2015), it is certain that too much diversity among the partners in the collaboration portfolio can be detrimental to the development of radical innovation outputs. This is because the greater the geographical distance among partners, the greater the difficulties to coordinate, acquire tacit knowledge, interact repeatedly and establish effective interactions due to cultural barriers (Ardito *et al.*, 2019; Xu *et al.*, 2023), which may hinder knowledge transfer, integration and exploitation into radically new products.

In line with previous arguments, past research highlights that increasing diversity among partners in the collaboration portfolio may perform yield positive outcomes up to a certain point. After this, the marginal costs of diversity tend to be superior to the expected advantages due to the increased complexity (Duysters and Lokshin, 2011). This view is also shared by Laursen and Salter (2006), who point out that although the breadth and depth of information sources improves innovation, there is a tipping point after which "over-search" in the breadth of open innovation may hinder innovation performance. Starting from this premise, and being more concrete in terms of the diversity of partners, current research has tried to clarify how the functional and geographical breadth of collaboration portfolios affect firms' radical innovation performance. In this sense, Carree *et al.* (2019), after analyzing a panel database of 3,536 Dutch manufacturing firms, provided evidence of the existence of an inverted U-shaped relationship between the breadth of R&D collaboration and firms' radical innovation performance. Moreover, they explored how firm size and the level of internal R&D intensity moderate this relationship. The authors concluded that small and low R&D-intensive firms usually benefit more from R&D collaborations than their larger counterparts, despite these benefits also tending to decrease more rapidly when the number of types of collaboration partners increases. Despite the valuable insights of this study, the research did not explore the separate effects of the functional breadth of collaborations and the geographical scope of the collaboration portfolio. This extreme was considered by Sarpong and Teirlinck (2018), who investigated the differential effects of geographical, functional and hierarchical collaboration portfolios on firms' innovative output, although their study proposed linear relations between collaboration diversity and innovation output. In particular, they found that the diversity in the type and geographical spread of partners is positively associated with the introduction of innovations that are new-to-the-market. Also shedding some light on this topic, Delgado-Márquez *et al.* (2018) analyzed the effects of the functional and geographical breadth of networks on firms' radical innovation performance, proposing inverted U-shaped relationships. While they focused their attention on multinational and subsidiary interorganizational networks, their study did not account for the differences between SMEs and large firms. Recently, other studies also supported the idea that the relationship between collaboration breadth and innovation performance follows an inverted U shape (Ismail *et al.*, 2024; Temel *et al.*, 2023), but do not clarify the distinct effects of the functional and geographical breadth of collaborations and do not consider the role firm size may play. Overall, scholars usually agree that the returns from collaboration breadth depend on the geographical location of partners and other internal factors (e.g. investments in digital technologies) (Belitski *et al.*, 2024). Table 1 presents the conclusions of empirical research on this topic and existing research gaps.

To summarize, past research on the effects of R&D collaboration has often found a curvilinear relationship (inverted U shape) between the functional breadth of the collaboration portfolio and firms' radical innovation performance (Bayona-Saez *et al.*, 2017; Carree *et al.*, 2019; Delgado-Márquez *et al.*, 2018). However, inconclusive results persist, as explained. In addition, assessing how firm size may affect these relationships, as a contingency that clearly affects innovation activities, including knowledge search and its recombination (Messeni Petruzzelli *et al.*, 2018), has been scarcely explored. As suggested by past research, SMEs and large firms differ in their engagement in collaboration and ability to introduce new knowledge and innovations (Carree *et al.*, 2019; Shinkle and Kriauciunas, 2010; Verhees *et al.*, 2010). Often, the difference between large firms and SMEs relates to their strengths; it follows that smaller firms typically have behavioral advantages, whereas large firms possess resource advantages (Nieto and Santamaría, 2010). SMEs have advantages in their organizational flexibility in communication and a faster market reaction. However, they may lack sufficient financial resources, qualified employees and possess less experience in collaboration than large firms (Geldes *et al.*, 2017b). Thus, tackling their differences becomes a critical aspect. Based on the arguments discussed in this section, Figure 1 summarizes the model proposed.

3. Hypotheses development

3.1 Functional breadth of the collaboration network and radical innovation performance

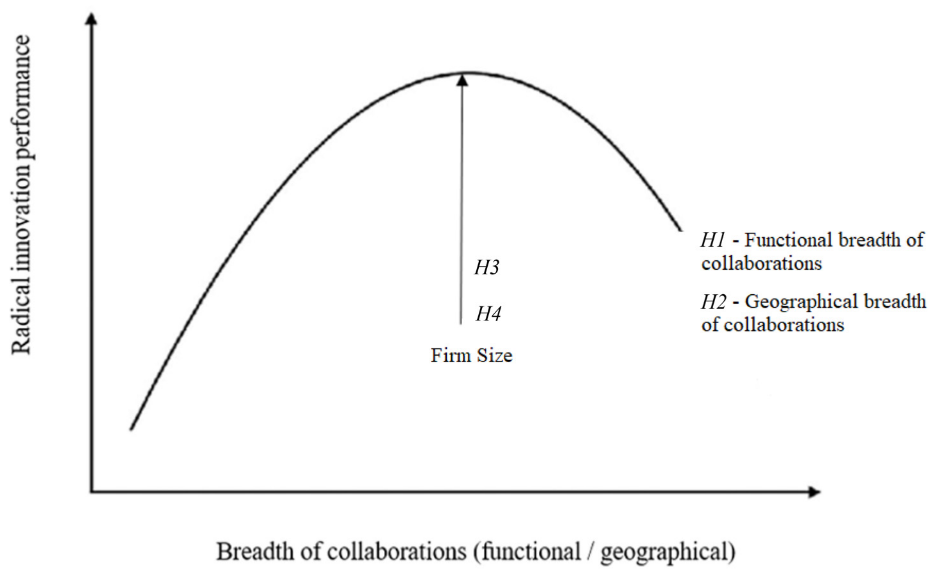
Past literature highlights that the open innovation process that provides knowledge from different partners and sources is a topic that has received increasing attention in the field of innovation management over the past decade (Popa *et al.*, 2017). Functional collaborations foster the acquisition of information and knowledge that are not available within the firm concerning different functional areas, such as customer demand and needs, market requirements or technological information about a product (Kobarg *et al.*, 2019). Engaging in functional collaboration with different partners allows firms to gain access to knowledge that is more specialized and

Table 1 Breadth of collaborations and innovation: recent research and research gaps

Previous empirical research	Research gap
Belitski *et al.* (2024): The breadth of collaboration with national, regional and international partners affects product and process innovation. Yet, this relationship is conditioned by the geographical location of the partner, the type of partner and the firm's absorptive capacity	The role of firm size (this study analyzes the role of investments in digital technologies). Also, the effects on radical innovation
Ismail *et al.* (2024): Collaboration breadth has a curvilinear (inverted U-shaped) relationship with innovation performance. The optimal breadth is lower for incremental innovation than for radical innovation performance	Distinct effects of functional and geographical breadth of collaborations. The role of firm size
Temel *et al.* (2023): The relationship between the breadth of collaboration and a firm's innovation performance follows an inverted U shape. This study separates the breadth of innovation objectives and breadth of collaboration	The separate effects of the functional and the geographical breadth of the collaboration portfolio. The role of firm size
Carree *et al.* (2019): Inverted U-shaped relationship between the breadth of R&D collaborations and a firm's radical innovation performance. The moderating role of size	The separate effects of the functional and geographical scope of the collaboration portfolio
Sarpong and Teirlinck (2018): Differential effects of the geographical, functional and hierarchical collaboration portfolios on the firm's innovative output	Linear relationships between collaboration diversity and innovation output (not curvilinear)
Delgado-Márquez *et al.* (2018): Inverted U-shaped relationships between the functional and geographical breadth of collaborations and the firm's innovation performance	Differences between SMEs and large firms, in terms of the role of size

Source: Authors' own elaboration

Figure 1 Conceptual model



Source: Author's own work

exceptional (Hagedoorn *et al.*, 2018), thus increasing their chance to introduce brand new innovation, thanks to the recombination of this knowledge.

Moreover, functional partner diversity is important at different stages of the innovation process (Veer *et al.*, 2016). For instance, at earlier stages, functional collaboration increases access to alternative concepts from competitors and valuable feedback from customers that might help firms in improving their existing strategy and processes. Furthermore, collaboration with universities, laboratories and research institutions can provide firms with new scientific and technological knowledge (Zeng *et al.*, 2010). At later stages, firms might need the necessary financial and managerial resources to adapt to radical technological change (Rothaermel, 2001). Thus, collaboration diversity with various partners can facilitate the process of adopting new knowledge inputs. At all stages, it may lead to increasing radical innovation performance.

Nevertheless, the functional diversity in the collaboration portfolio may also bring negative effects after a certain point. A rising number of collaboration partner types generate growing managerial information demands and, consequently, transaction costs (Rothaermel, 2001), which may lead to a negative effect. In other words, firms incur in coordination and organizational costs when handling R&D collaborations with multiple functional partners. Furthermore, broadening the collaboration portfolio increases the risk of unintentional knowledge sharing and spillovers (Hottenrott and Lopes-Bento, 2016; Ismail *et al.*, 2024). Consequently, there may be a point at which these costs may outweigh the gains, diminishing radical innovation performance and creating an inverted U-shaped relationship between the functional breadth of collaboration and innovation performance. Finally, as Veer *et al.* (2016) suggested, firms may also find it challenging to concentrate their efforts evenly among different partners. This could lead to a longer feedback cycle and a slower reaction to changes.

Based on these ideas, we propose the first hypothesis:

H1. There is an inverted U-shaped relationship between the functional breadth of the collaboration portfolio and firms' radical innovation performance.

3.2 Geographical diversity of the collaboration network and radical innovation performance

Past studies suggest that both geographical openness and the establishing of networks outside their area of activity affect firms' productivity and allow them to enhance their innovation performance (Belderbos *et al.*, 2013; Jespersen *et al.*, 2018; Sarpong and Teirlinck, 2018). In a geographic context, to choose the most appropriate partner, firms can rely on the physical, institutional or cultural distance between actors to evaluate this decision (Ardito *et al.*, 2019; Capaldo and Petruzzelli, 2014). As Jespersen *et al.* (2018) mentioned, the smaller the distance between the partners, the more efficient the informal interactions that lead to facilitating knowledge sharing and open innovation. In fact, geographical clustering can be a potential source of competitive advantage for interconnected firms, because local firms can gain access to important networks and resources of colocated firms (Felzensztein *et al.*, 2018). However, on the contrary, local networks may create undesired spillovers and knowledge lock-in effects that hinder radical innovation (Capaldo and Petruzzelli, 2014).

In recent years, due to improvements in telecommunications as a result of technological progress, firms have been able to obtain more diverse specialized knowledge inputs from various appropriate networks, even though partners may be located across the globe. The utilization of dynamic capabilities of partners and advanced technologies like Zoom or Skype has enhanced international collaboration. This collaboration has the potential to drive innovation by enabling firms to acquire richer knowledge sources. Companies are actively participating in international collaboration to not only catch up with the technological frontier but also surpass it (Fu *et al.*, 2022; Fu and Li, 2016). Thus, it can be expected that the more diversified the range of geographical areas, the more likely innovative firms will acquire the necessary information and knowledge required. This can subsequently lead to more fruitful combinations of complementary knowledge and improvements in firms' radical innovation performance (van Beers and Zand, 2014). In other words, a diverse geographical portfolio of R&D partners allows firms to gain access to a wider range of new knowledge, ideas and technologies, as well as market information that the firm needs. Moreover, the openness to new ideas and technologies from different locations might provide more flexibility to carry out innovation. Thanks to collaborating with partners in different locations, firms can access markets that are entirely new, thereby extending their production process (Dittrich and Duysters, 2007) and possibly facilitating radical innovation. In addition, through geographical diversity in collaborations, firms can adapt faster to local market needs, getting access to highly skilled staff and obtain valuable knowledge about regulations in this location (Duysters and Lokshin, 2011).

However, firms' ability to obtain, absorb and adopt the new knowledge required to solve different problems is also crucial (Zahra and George, 2002) at all stages of collaboration. It can be argued that a collaboration portfolio in which there are broad cultural differences across partners may be a key barrier to technology transfer (Elia *et al.*, 2019). Furthermore, geographical distance decreases face-to-face contact, repeated interactions and greater opportunities to strengthen social relationships (Felzensztein *et al.*, 2018; Geldes *et al.*, 2017b; Xu *et al.*, 2023), which may reduce the benefits of geographic network diversity to foster the development of novel products (Bolívar–Ramos, 2019; Capaldo and Petruzzelli, 2014). Thus, a high geographical diversity may negatively affect ideas and knowledge spread, as it may cause a situation in which technologies and other inputs become too diverse (Beretta, 2019), creating exploitation problems. Furthermore, there is a chance that employees collaborating in different locations may have different levels of experiences and cultural values (Zhang *et al.*, 2020). This also increases coordination costs between partners from different locations, which negatively affects the process of adopting new knowledge and radical innovation performance.

Based on these findings, we expect there to be a curvilinear relationship between the geographical scope of the collaboration network and a firm's radical innovation performance, in such a way that the geographical diversity in the portfolio brings gains to firms, but after a certain point in which diversity is too high, it has a negative effect. Thus:

H2. There is an inverted U-shaped relationship between the geographical scope of the collaboration portfolio and firms' radical innovation performance.

3.3 The moderating role of firm size on the relation between the functional/geographical diversity of collaborations and firms' radical innovation performance

Previous studies have shown that firm size is a factor that plays a crucial role in innovation activities (Messeni Petruzzelli *et al.*, 2018; Nieto and Santamaría, 2010; Spithoven *et al.*, 2013). Engaging in collaborations to obtain information and knowledge in SMEs may differ from that of large firms (Chiambaretto *et al.*, 2020; Verhees *et al.*, 2010). According to Popa *et al.* (2017), more severe resource constraints in SMEs may be a strong barrier to the adoption of open innovation practices, including collaboration with different partners. On

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the contrary, as SMEs may have a greater gap in human, financial and other resources, this fact may increase their enrollment in the diverse types and locations of collaboration. It is also plausible that large firms can take greater advantage of a more solid reputation and experience in collaboration networks with different partners (Shinkle and Kriauciunas, 2010). This, in turn, allows them to obtain specialized skills and knowledge through various collaboration portfolios to a greater extent than smaller firms. In addition, SMEs are likely to have higher marginal costs when operating in external collaborations, compared to larger firms (Carree *et al.*, 2019). This links with the idea that larger firms already have established processes and may have sufficient financial resources to bear coordination costs.

Regarding functional collaboration, Jang *et al.* (2017) pointed out that SMEs tend to select partners related to development stages, whereas large firms prefer to collaborate with partners related to explorative stages and partners focused on the search for new technologies. Commonly, in their open innovation practices, due to their lower flexibility, larger firms may face greater challenges to keep pace with market changes during their establishment of networks with additional suppliers and competitors (Messeni Petruzzelli *et al.*, 2018). However, on the contrary, large firms' past collaboration experiences and higher absorptive capacity can help to explain their ability to introduce radical innovations. In other words, larger firms may have a higher likelihood of implementing and exploiting diverse functional resources and benefiting from them due to their strong resource base and bargaining power, which ensures relevant networks (Jang *et al.*, 2017). Despite this, it could still be plausible that SMEs have a higher propensity to collaborate with more diverse partners to overcome the liability of newness and the financial and knowledge constraints required to innovate (Bolívar–Ramos, 2019). Furthermore, SMEs are usually more flexible and can rapidly change processes to adopt radical innovations (O'Connor and DeMartino, 2006). Moreover, SMEs may benefit from broader collaboration networks aiming to achieve economies of scope and scale (Jespersen *et al.*, 2018). Although small firms may lack sufficient financial resources and possess less experience in collaboration than large firms (Jang *et al.*, 2017), SMEs' greater freedom from bureaucracy, smoother communications between managers and employees and increased entrepreneurial orientation promoting innovative ideas creates a favorable environment in which to take advantage of more novel knowledge to facilitate valuable innovations (Messeni Petruzzelli *et al.*, 2018), thus supporting radical innovations.

Despite the benefits of functional diversity in SME and large firm collaborations, an overly diverse collaboration portfolio may bring negative effects due to unwanted knowledge leakage, difficulties with control and communications and costs related to imitation issues (Veer *et al.*, 2016). In this context, even though SMEs may be in a weaker position in terms of their existing experience in collaboration and developed resource bases, compared to large firms they may have a stronger motivation to engage in more diverse functional collaboration portfolios to overcome their newness and lack of resources, therefore, requiring a more diverse network to achieve their best level of radical innovation performance. We contend that for SMEs it may be easier to benefit from heterogeneous functional partners providing innovative competences because of their flexibility and adaptability to the new environment. However, SMEs may also suffer more when the functional breadth of collaboration becomes too diverse due to the absence of the necessary resources to adopt new information flows. Thus:

H3. The relationship between the functional breadth of the collaboration network and firms' radical innovation performance is moderated by firm size, in a way that SMEs have a higher optimal number of functional partners than large firms.

In terms of the geographical scope of the collaborations, large firms have financial and resource advantages that afford them the ability to cooperate with partners from different locations. As they may also possess more highly skilled employees, including scientists and engineers (Carree *et al.*, 2019), larger firms are more likely to better understand the collaboration process, recognize the value of unexploited knowledge (Messeni Petruzzelli *et al.*, 2018) and facilitate the knowledge absorption from different locations to implement radical innovation. However, large firms' established routines and their bureaucratic structure is a factor that usually hampers their chances of benefiting from valuable novel knowledge for radical innovations (Messeni Petruzzelli *et al.*, 2018). Thus, despite large firms may be better positioned to gain access to broader geographical networks, the resource constraints can motivate SMEs to engage with more diverse geographical partners to compete in different international markets (Dooley *et al.*, 2016). Moreover, SMEs may have a higher propensity to diversify the geographical scope of collaborations for overcoming local constraints. In this way, SMEs can relocate activities into low-cost locations (Lejpras, 2015) and enter new markets. In addition, despite new markets potentially presenting different culture specifics, SMEs may possess more flexibility and ability to adapt to the new environment. Furthermore, despite distance being a factor that can negatively affect SMEs' innovation activities (Capaldo and Petruzzelli, 2014), the actors (e.g. scientists) involved in partnerships for developing radical outcomes can easily collaborate beyond national frontiers thanks to their use of new technologies and standard and common codes (e.g. publications) (Bolívar–Ramos, 2019).

To summarize, when the geographical scope of the collaboration network is too broad, the knowledge inputs become too diverse and business relations tend to be even more complex due to greater geographic and cultural differences (Capaldo and Petruzzelli, 2015; Elia *et al.*, 2019). In this sense, SMEs may face a larger challenge due to coordination costs when managing different partners (Zhang *et al.*, 2020). Nevertheless, in the case of large firms, it may be more difficult to adapt to any additional geographical network due to their organizational rigidities, in comparison to SMEs. Building on these diverse ideas, we expect that due to their higher needs of heterogeneous resources to favor knowledge recombinations, greater flexibility and ability to adapt to new environments and develop nascent technologies, SMEs may rely on higher geographical diversity in collaboration networks to foster radical innovations compared with large firms. Nevertheless,

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this will occur up to a certain point at which increased communication with partners of dissimilar cultures, along with different backgrounds, is likely to negatively interfere in SMEs' management of the innovation process:

H4. The relationship between the geographical scope of the collaboration network and firms' radical innovation performance is moderated by firm size, in such a way that SMEs have a higher optimal number of geographic areas in the portfolio than large firms.

4. Methodology

4.1 Data

For our empirical analysis, we use the PITEC (*Panel de Innovación Tecnológica*) database, a panel of firms annually surveyed by the Spanish National Statistics Institute (*INE*) up to 2016, consistently with the Community Innovation Survey (Mendi *et al.*, 2020). Spain is an appropriate setting for our study as it is a member of the European Union and represents a suitable environment for the research and study of technological and innovation activities (Coad *et al.*, 2021; Delgado-Márquez *et al.*, 2018). Regarding the use of PITEC, it is a database that follows the methodology of the OECD countries, provides information on more than 12,000 firms concerning their strategies and innovation activities and has been widely used by researchers to address the relation between collaboration and innovation (Delgado-Márquez *et al.*, 2018). More generally, PITEC is designed to analyze the economic development and technological activities of Spanish manufacturing and services firms (Mavroudi *et al.*, 2020). Notably, the database allows the analysis of the dynamics of innovation as it has a panel structure (Coad *et al.*, 2021), that permits controlling for firm-specific, unobserved factors that may jointly affect the outcome and the independent variables (Mendi *et al.*, 2020).

As discussed, in this research we test the inverted U-shaped models and moderator effects using PITEC, focusing on the period 2012–2016. PITEC provides comprehensive information concerning firms' technological and innovation activities (Cruz-Castro *et al.*, 2018), including the functional types of collaboration and firms' regional characteristics. One of the main advantages of using this database is that it allows for partial control over potential endogeneity issues by introducing lags between independent and dependent variables (Badillo and Moreno, 2016). Another advantage of using this database is the possibility of distinguishing between innovating and noninnovating firms (Carree *et al.*, 2019), based on whether the firm has introduced (or not) new or developed innovations. Moreover, PITEC includes information about internal and external R&D activities, product outcomes and different obstacles to innovation, as well as other variables that are required to test the hypotheses proposed. Finally, the analysis is restricted to the sample of firms that present innovation expenditures over the period 2012–2016 (Tamayo and Huergo, 2017), 4,677 firms. This period was chosen for analysis as it directly followed the economic and financial crisis of 2008–2011, which was characterized by market instability and recession (Martin-Rios and Pasamar, 2018).

4.2 Variables and measures

4.2.1 Dependent variable

Radical innovation performance reflects the ability of the firm to produce radical innovations and shows how well a firm succeeded in introducing a new product to the market. Radical innovation represents completely new products and services to meet customer needs (Shi and Zhang, 2018). It is measured as the ratio of sales from products that are new to the market over total sales; a similar approach was used in previous studies (Delgado-Márquez *et al.*, 2018; Carree *et al.*, 2019). Moreover, to avoid simultaneity problems, the dependent variable is introduced with a $t + 1$ *year* lag (Cinyabuguma *et al.*, 2005).

4.2.2 Independent and moderator variables

Functional breadth of collaborations. The combination of diverse partners in collaboration networks generates synergies and facilitates research productivity, thereby increasing the likelihood of introducing new knowledge that may be hard for rivals to replicate (Sarpong and Teirlinck, 2018). The functional breadth of collaborations was measured as the breadth of different partners with whom a firm collaborates (Delgado-Márquez *et al.*, 2018). The functional breadth of collaboration includes suppliers, clients from the private sector, clients from the public sector, competitors, suppliers of software, laboratories, universities, public research institutions and private research institutes. Hence, this variable takes values ranging from 0 if a firm did not collaborate with external partners up to 9, when a firm collaborated with all categories of functional partners.

Geographical scope of collaborations. This variable considers information about different geographical regions, where firms intensively collaborate in the development of innovation activities. The geographical scope of collaborations was measured as the breadth of different geographical regions in which firms collaborate (Delgado-Márquez *et al.*, 2018). The Spanish innovation survey includes five different regions: Spain, Europe, the USA, China and India and all countries mentioned. Thus, the geographical scope of collaborations is a variable with values ranging from 0 to 5 depending on the number of different geographical locations included in firms' network. A value of 0 reflects that a firm did not collaborate with any partners, and a value of 5 indicates that the firm collaborated with partners from each of the five aforementioned different locations.

Size. Consistent with past research, this variable is measured as the logarithm of firms' total number of employees (Tamayo and Huergo, 2017). In this study, firm size is the moderator variable, in line with arguments that suggest that large firms and SMEs have different abilities to access key resources and undertake radical innovation (Cheng *et al.*, 2016).

4.2.3 Control variables

Product innovation. This variable has traditionally been associated with positive effects on company success and competitiveness (Naranjo-Valencia *et al.*, 2017). In this study, it is measured as a dummy variable equal to 1 if the firm introduced a product innovation at least once during the period analyzed (and 0 otherwise).

Process innovation. In this study, this was measured as a dummy variable equal to 1 if the firm introduced a process

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innovation at least once during the period analyzed (and 0 otherwise).

Knowledge, market and financial constraints. Firms may face different challenges, constraints and uncertainty about future market opportunities. These may induce firms to reduce their investments in innovation (D'Agostino and Moreno, 2018), including radical innovations. Constraints can include lack of knowledge and information on technologies, financial constraints and high barriers to market entry (Pellegrino, 2018). This study included knowledge, market and financial constraints as three binary variables, where 1 reflects that a firm faced each particular constraint, and 0 otherwise.

Public support. Firms may need the external help of institutions and governments to overcome the scarcity of financial resources and foster open innovation. The public support variable is computed as the breadth of funding sources (Chapman *et al.*, 2018) to assess the support the firm receives from European Union offices, local or regional administrations and the national government.

Internal R&D. Benefits from technological collaboration and further innovation performance depends on the absorptive capacity of the firm (Lopez, 2008). This is captured by the logarithm of internal R&D expenditures of the firm.

Number of patents. The patents variable is measured by the logarithm of a firm's total number of patents, as in previous research (Mendi *et al.*, 2020). Even though patents can be costly, firms that produce new knowledge may increase their chances of developing patentable inventions to secure new knowledge as a result of imitations, which can also condition their innovativeness.

Technology park. This binary variable indicates whether a firm is located in a Science or Technology Park, which can have an effect on firms' innovation performance due to location advantages.

Tech sectors. As in Cruz-Castro *et al.* (2018), this variable is presented by dummies that represent all the economic activities in the manufacturing sector, according to CNAE2009 (the Spanish acronym for Spain's National Classification of Economic Activities).

Year. This variable represents the current year in which firms operate, and its inclusion helps to control for changing macroeconomic conditions over time (Nieto and Rodríguez, 2011).

4.3 Empirical strategy

Table 2 reflects the correlation matrix and the summary statistics for the research variables. As can be observed, the correlation is low between the main independent variables and radical innovation, and the results are statistically significant.

To rule out multicollinearity problems, we computed variance inflation factors (VIFs). Hair *et al.* (2012) indicated that, as a rule of thumb, VIFs higher than 5 reflect a sign of severe multicollinearity. The results displayed in Table 3 show that the study's VIFs are below the acceptable threshold. Hence, multicollinearity is not a problem in the research.

The methodology used in this study is conditioned by the nature of the dependent variable, radical innovation performance *RI* (measured in the period $t+1$). In line with the study and the research hypotheses, we introduce four different models:

(1) Equation for Model 1 (*H1*)

$$RI_{t+1} = \alpha + \beta_1 FC_{it} + \beta_2 (FC_{it})^2 + \beta_3 FirmSize_{it} + \gamma X_{it} + \nu_{it}$$

(2) Equation for Model 2 (*H2*)

$$RI_{t+1} = \alpha + \beta_4 GC_{it} + \beta_5 (GC_{it})^2 + \beta_6 FirmSize_{it} + \gamma X_{it} + \nu_{it}$$

(3) Equation for Model 3 (*H3*)

$$RI_{t+1} = \alpha + \beta_7 FC_{it} + \beta_8 (FC_{it})^2 + \beta_9 FirmSize_{it} + \beta_{10}(FC_{it} \times FirmSize_{it}) + \beta_{11}\left((FC_{it})^2 \times FirmSize_{it}\right) + \gamma X_{it} + \nu_{it}$$

(4) Equation for Model 4 (*H4*)

$$RI_{t+1} = \alpha + \beta_{12} GC_{it} + \beta_{13} (GC_{it})^2 + \beta_{14} FirmSize_{it} + \beta_{15}(GC_{it} \times FirmSize_{it}) + \beta_{16}\left((GC_{it})^2 \times FirmSize_{it}\right) + \gamma X_{it} + \nu_{it}$$

In all models, i and t represent the identity of firms and the period considered (from 2012 to 2016), respectively. $FC_{i,t}$ represents the functional breadth of collaborations, which ranges from 0 to 9, as explained previously. GC_{it} considers the geographical scope of the collaboration network, which ranges from 0 to 5. Furthermore, $FirmSize_{it}$ is the moderator, measured by the logarithm of the number of employees employed by the firm. Furthermore, the study includes a vector of control variables X_{it}; this accounts for product and process innovation variables, obstacles to innovation, patents number, internal R&D, public support and sectoral and yearly dummies. In addition, $\nu_{i,t}$, contains industry and time fixed effects. Finally, in Models 3 and 4, the interaction terms of firm size and the functional and geographical diversity in their collaboration portfolios were represented. $FC_{it} \times FirmSize_{it}$ represents an interaction term calculated by multiplying the functional breadth of collaborations and firm size, whereas $GC_{it} \times FirmSize_{it}$ represents the interaction term created by multiplying the geographical scope of collaborations and firm size.

In the next step, the Hausman test was applied to select between the fixed and random effects estimators. We ran the Hausman test for the proposed models. The rejection of the null hypothesis *H0* assumes that there is a difference in fixed and random effects, therefore, the fixed effect should be selected over the random effect (Frondel and Vance 2010), as in this case.

5. Results

Table 4 illustrates the results for the four different models. Models 1 and 2 contain the results of the base models and help to test *H1–H2*. The rest of the models include different interaction terms to explore the moderating role of firm size, therefore analyzing *H3–H4*.

Considering the estimated parameters, in Model 1, the coefficients $\beta_1 = 0.398$ ($p < 0.05$) and $\beta_2 = -0.0689$ ($p < 0.05$)

Table 2 Descriptive statistics and correlation matrix

Variables	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Radical innovation performance (1)	5.743186	7.210499	1.0000												
Product innovation (2)	0.5867409	0.4924328	0.3170*	1.0000											
Process innovation (3)	0.2681399	0.4430037	0.2392*	0.0427*	1.0000										
Knowledge factors (4)	0.2025405	0.4019045	0.0064	0.0191*	0.0097	1.0000									
Cost factors (5)	0.5167914	0.4997325	−0.0092	−0.0417*	0.0532*	0.1884*	1.0000								
Market factors (6)	0.3216171	0.4671105	0.0169*	0.0574*	0.0275*	0.2660*	0.2178*	1.0000							
Public support (7)	0.7880633	0.9099726	0.1433*	0.0250*	0.1719*	0.0414*	0.0837*	0.0445*	1.0000						
Internal R&D (log) (8)	12.55593	1.59886	0.2539*	0.1315*	0.1876*	−0.0269*	−0.0655*	−0.0262*	0.3990*	1.0000					
Number of patents (log) (9)	0.2323149	0.6112017	0.1720*	0.1282*	0.0744*	0.0023	−0.0093	−0.0017	0.2468*	0.3489*	1.0000				
Technology park (10)	0.0834058	0.2765027	0.0409*	−0.0293*	0.1096*	0.0087	0.0491*	0.0299*	0.2289*	0.1661*	0.1168*	1.0000			
Functional breadth of collaborations (11)	0.5879009	1.352385	0.2183*	0.1246*	0.2275*	0.0083	0.0269*	0.0232*	0.3770*	0.4215*	0.2956*	0.1386*	1.0000		
Geographical scope of collaborations (12)	0.8551708	1.073445	0.2278*	0.1466*	0.2218*	0.0299*	0.0234*	0.0384*	0.4049*	0.4271*	0.2787*	0.1273*	0.7599*	1.0000	
Size (log) (13)	4.370006	1.520066	0.1634*	0.0900*	0.1162*	−0.0750*	−0.1659*	−0.0904*	0.1133*	0.5336*	0.1951*	−0.0384*	0.2442*	0.2536*	1.0000

Note: $^{*}p < 0.05$
Source: Authors' own work

Table 3 Multicollinearity check

Variables	VIF	1/VIF
Process innovation	1.15	0.866520
Product innovation	1.14	0.877712
Knowledge factors	1.10	0.909526
Cost factors	1.11	0.898331
Market factors	1.12	0.889338
Public support	1.39	0.720483
Internal R&D	1.91	0.523360
Number of patents	1.20	0.832776
Tech park	1.10	0.912040
Functional breadth of collaborations	2.51	0.398493
Geographical scope of collaborations	2.57	0.389195
Size	1.52	0.656948
Mean VIF	*1.43*	

Source: Authors' own work

have the expected signs to support the curvilinear effect proposed, thus suggesting the existence of an inverted U-shaped relationship between the functional breadth of the collaboration network and firms' radical innovation, which provides empirical support for hypothesis 1. These results also confirm the idea that engaging in different types of functional collaboration increases firms' radical innovation performance, although it also brings negative effects after a certain point.

The next research hypothesis links the geographical scope of collaborations and firms' radical innovation performance. The results show that the coefficients $\beta_4 = 0.577$ ($p < 0.01$) and $\beta_5 = -0.155$ ($p < 0.01$), along with their significance levels, reveal the existence of an inverted U-shaped relationship. Thus, *H2* is supported, reinforcing the idea that engaging in geographically diverse collaboration networks enhances firms' radical innovation performance. Nevertheless, this only occurs up to a certain point at which innovation performance decreases, likely due to the increased complexity of managing diverse knowledge sources from different locations.

In Model 3, the estimated coefficients of $\beta_{10} = 0.216$ ($p < 0.05$) and $\beta_{11} = -0.0397$ ($p < 0.05$) confirm the moderating effect of firm size in the inverted U-shaped relation between the functional breadth of collaborations and firms' radical innovation.

To calculate the tipping point after which the diversity in the breadth of collaborations has a decreasing effect on radical innovation, we followed the method used by Carree *et al.* (2019). First, we divided small and large firms depending on the number of employees working in the firm. A common approach in the literature is to define SMEs as those firms that have fewer than 250 employees, whereas large firms are those that possess more than 250 employees (Badillo *et al.*, 2017). As size was computed as the logarithm of the total number of employees, we estimated the tipping point as a value of firm size. Second, the tipping point is calculated by using the formulas:

Table 4 Fixed-effects (FE) models

Variables	Model 1	Model 2	Model 3	Model 4
Control variables				
Product innovation	0.679*** (0.184)	0.661*** (0.185)	0.682*** (0.184)	0.661*** (0.185)
Process innovation	0.649*** (0.215)	0.635** (0.214)	0.637** (0.215)	0.63** (0.214)
Knowledge factors	0.063 (0.233)	0.068 (0.233)	0.055 (0.233)	0.066 (0.233)
Cost factors	−0.266 (0.188)	−0.269 (0.187)	−0.257 (0.188)	−0.27 (0.187)
Market factors	−0.018 (0.194)	−0.019 (0.194)	−0.019 (0.194)	−0.018 (0.194)
Public support	0.173 (0.125)	0.163 (0.125)	0.179 (0.125)	0.164 (0.125)
Internal R&D (log)	0.181+ (0.105)	0.173+ (0.105)	0.176+ (0.105)	0.172+ (0.105)
Number of patents (log)	0.283+ (0.166)	0.309+ (0.166)	0.282+ (0.166)	0.308+ (0.166)
Technology park	1.979* (0.806)	1.924* (0.806)	1.972* (0.802)	1.919* (0.807)
Tech sectors	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Main variables				
Functional breadth of collaborations	0.398* (0.182)		−0.702 (0.561)	
Functional breadth of collaborations squared	−0.0689* (0.036)		0.142 (0.117)	
Geographical scope of collaborations		0.577*** (0.195)		0.205 (0.6)
Geographical scope of collaborations squared		−0.155** (0.057)		−0.118 (0.163)
Size (log)	0.439 (0.356)	0.435 (0.356)	0.43 (0.36)	0.386 (0.357)
Interactions				
Functional breadth of collaborations x size			0.216* (0.115)	
Functional breadth of collaborations squared x size			−0.0397* (0.023)	
Geographical scope of collaborations x size				0.0819 (0.13)
Geographical scope of collaborations squared x size				−0.00895 (0.033)
Observations	15,209	15,209	15,209	15,209
R-squared	0.108	0.107	0.107	0.107
F-stat	7.559***	7.945***	6.751***	6.978***

Notes: Dependent variable: radical innovation. $p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***p <0.001; Standard errors are in parentheses
Source: Authors' own work

(5) Tipping point for the functional breadth of collaborations:

$$-0.5 \times \frac{\beta_7 + \beta_{10} \times \log(size)}{\beta_8 + \beta_{11} \times \log(size)}$$

Thus, the optimal number of functional collaborators for large firms with 500 employees is 3.04, whereas with 250 employees it is 3.18. In addition, the optimal functional breadth of collaborations for SMEs with 100 employees is 3.59 and 5.39 for SMEs with 50 employees. These ideas support *H3*, in the sense that the smaller the firms are, the higher their optimal number of functional R&D partnerships for radical innovation. Figure 2 depicts these results.

Regarding Model 4, there is not empirical support for the moderating role of firm size on the relation between the geographical scope of collaborations and firms' radical innovation performance ($p > 0.1$ for coefficients β_{15} and β_{16}). Thus, the results are not significant and *H4* is not supported.

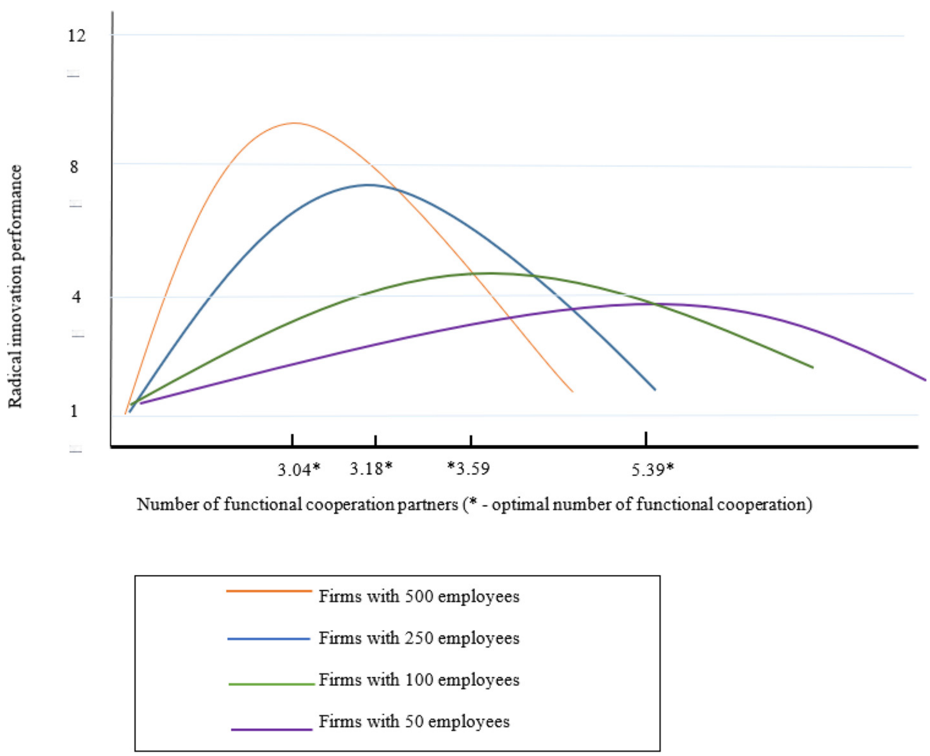
Finally, before settling on the aforementioned results, additional robustness tests for the proposed models for alternative periods (available upon request) were conducted. The estimations show that the results largely remain the same for the key variables of the research.

6. Discussion and conclusions

Innovation is a critical factor for business growth, competitiveness and firm survival (Pino *et al.*, 2016). The importance of using external knowledge, including collaboration, to increase innovation performance has been analyzed by numerous researchers in the field of open innovation (Cheng and Huizingh, 2014; Kang and Kang, 2009; Parida *et al.*, 2012; Popa *et al.*, 2017; Zhao *et al.*, 2016). In turn, open innovation has become an effective driver to introduce new products. Thanks to opened boundaries to external knowledge flows, firms can facilitate the acquisition of valuable knowledge and technologies to enhance radical innovation (Cheng *et al.*, 2016).

Constantly advancing technologies, economic globalization and increasing competitiveness justify the importance of diversifying the collaboration portfolio as a key external search strategy to responding to fast-changing environments and introducing new knowledge and products to the market (Geldes *et al.*, 2017b; Nieto and Santamaría, 2010; van Beers and Zand, 2014). Along this line, past research shows that different innovation collaboration portfolios affect firms' innovation performance differently (Sarpong and Teirlinck, 2018; Trąpczyński *et al.*, 2018; van Beers and Zand, 2014). Nevertheless, previous studies have not paid significant attention or provided sufficient theoretical and empirical evidence regarding the different impacts of the functional breadth of collaboration and the geographical scope of collaborations on firms' radical innovation performance. Thus, this study has examined this research gap by analyzing how the functional and geographical breadth of the collaboration portfolio affect firms' radical innovation performance. This investigation reveals that engaging in diversified functional and geographical collaboration enhances firms' radical innovation performance, although innovation returns decrease after a certain point at which the diversity of partners is too high.

Figure 2 Optimal number of functional collaboration partners for SMEs and large firms



Source: Author's own work

These results confirm the "too much of a good thing" effect, as an excessive diversity leads to higher coordination costs and misappropriation risks (Hottenrott and Lopes-Bento, 2016). Furthermore, as a key contribution, this study underscores the differences in the behavior of SMEs and large firms, by analyzing the moderating role of firm size (Carree *et al.*, 2019). Overall, this research helps us understand how firms can promote radical innovations. Radical innovation matters for firms because it enables them to stay competitive with revolutionary new approaches, adapt to changing market conditions and create new revenue streams (Pino *et al.*, 2016). By promoting radical innovation, firms can position themselves for long-term success and growth in their respective industries (O'Connor and Ayers, 2005).

6.1 Theoretical, managerial and policy implications

Under the framework of the KBV (Grant, 1996), this study emphasizes the significance of acquiring, assimilating and implementing relevant knowledge to enhance firms' competitive advantage and innovative performance. This research contributes to the literature on open innovation (Chesbrough and Bogers, 2014), and relevant partner selection, by explaining how the diversity in the collaboration portfolio, in functional (e.g. customers and suppliers) and geographical terms (e.g. national and international), affects the radical innovation performance of firms. Our study shows that despite the rich and diverse knowledge inputs they both provide, that produce valuable complementarities that positively impact the development of breakthrough innovations, excessive diversity generates additional costs, thus diminishing the likelihood of radical innovation (resulting in an inverted U-shaped relationships). While this finding aligns with past research (Ismail *et al.*, 2024; Temel *et al.*, 2023), this study goes a step further by separately analyzing the effects of the functional and geographical breadth of collaborations. Thus, we contribute to current research on the topic that highlights that collaboration with other firms and/or organizations is key to improve internal innovation, but this result is affected by the actor's heterogeneity, the geographical context and the different dimensions of networks (Delgado-Márquez *et al.*, 2018; Geldes *et al.*, 2017b). Furthermore, as a key contribution, this paper underscores the differences in the behavior of SMEs and large firms, by analyzing the moderating role of firm size (Carree *et al.*, 2019), as a critical factor affecting these relationships. Specifically, the study reveals that SMEs collaborate with a greater number of distinct functional partners than their larger counterparts do, which can be explained by their need of complementing existing resources and their flexibility in innovative activities. This resolves some divergent views on this topic in the literature, as some scholars pointed that larger firms may have more diverse functional collaboration networks due to their significant resource base in comparison with smaller firms (Jang *et al.*, 2017). Our research also shows that both SMEs and large firms experience diminishing returns from too diverse functional collaborations for radical innovation, due to increased costs. However, in large firms, the decline occurs at an earlier stage compared with SMEs, consistent with the idea that small firms need broader networks (in terms of functional partners) to access complementary and novel resources they usually lack.

From a managerial point of view, this research highlights that paying more attention to proper partner selection allows firms to establish more effective partnership relationships and benefit from its diversity. In other words, firms should seek partners that complement their functional characteristics and involve a certain degree of internationalization (but not excessively so) to generate the knowledge that would allow them to produce radical innovative outcomes. To be more precise, this study guides managers trying to balance diversity in firms' collaboration portfolios, as even though increasing the functional breadth of the collaborations and their geographical scope may benefit firms' radical innovation performance at the beginning, this can be a disadvantage after a certain point. The reason is that SMEs have greater opportunities to learn and acquire social capital, for instance through repeated interactions, when diversity is not too high, as it favors interconnectedness and fosters complementarities (Felzensztein *et al.*, 2014a). To illustrate, this occurs in clusters (Xu *et al.*, 2023). Hence, managers should take into account all the risks and costs incurred to avoid engaging in overly diverse functional/geographical collaboration networks. Furthermore, when partners are not in geographical proximity, managers should foster the use of platforms – e.g. Facebook or LinkedIn – and other forms of communication technologies to create global virtual teams that enrich the firm's social capital for innovative purpose (Felzensztein *et al.*, 2014b). In addition, managers should consider the fact that SMEs and large firms behave differently, given their respective levels of resources, experience and flexibility. For instance, to introduce radical innovation, SMEs may have a greater need to diversify their functional collaboration portfolios to gain access to alternative concepts from competitors and receive valuable feedback from customers, which might help firms in improving their existing strategies and processes. Therefore, SMEs can benefit more from the functional diversity of collaboration portfolios. However, SMEs also have to pay greater managerial attention to balancing these types of networks, as they usually have fewer assets with which to adopt new information flows.

Finally, in terms of policy implications, public policies should establish programs to foster innovation networks that include SMEs as well as research and development institutions that help these firms generate radical innovations through diverse collaboration networks (Geldes *et al.*, 2017a). Second, policies that promote regional development can help firms from different geographic locations collaborate and benefit from each other's expertise and resources. This may be possible through initiatives that encourage the development of innovation clusters, technology parks and other regional networks that foster collaboration and knowledge exchange (Cruz-Castro *et al.*, 2018). In addition, firms and public institutions would benefit from programs of innovation management that foster collaboration across industries, a culture of innovation and enterprise networks (Geldes *et al.*, 2017a).

6.2 Limitations and future research

Despite all the implications and contributions mentioned, this paper is not exempt from limitations that open new opportunities for further research. First, in this analysis, we only considered Spanish firms. Future studies could compare the relations between the diversity in open innovation networks and its effects on firms' radical innovation in Spain versus other countries, to analyze whether the results are consistent in different geographical contexts. Second, the study does not analyze a number of other potential moderators that could also affect the relations between radical innovation and the functional and geographical scope of collaborations. To illustrate, given that the absorptive capacity defines firms' ability to identify, absorb and exploit external knowledge (Zahra and George, 2002), exploring this variable as a moderator may enhance our understanding of how firms benefit from diverse collaboration networks for innovating, according to their internal capacity. Finally, for theoretical reasons (i.e. radical innovations are new to the market) the study fails to tackle the distinction between radical and incremental innovations. However, diversity in collaboration portfolios may also have different effects on firms' ability to introduce incremental innovations; a topic that future research may address.

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