A multilevel analysis of the technological impact of University-SME joint innovations

Abstract

The present research analyses the determinants of the technological impact of the innovations developed by R&D collaborations between universities and Small and Medium Enterprises (SMEs). Specifically, by adopting a multi-level approach, this study reveals the significant role played by SME's absorptive capacity, as well as by social and geographical proximity between the partnering organizations. In addition, this paper shows the positive impact of the regional knowledge spillovers that are close to the technological fields of the innovations developed. The findings provide a better understanding of interactive learning in R&D collaborations between universities and SMEs, explaining how it may be further nurtured by knowledge spillovers available in SME's Regional Innovation Systems (RIS). The paper may also support SME managers in the definition of these collaborations, university managers in the orientation of their technology transfer effort, as well as policy-makers interested in the development of a more effective RIS.

***Keywords*:** SME; University-Industry collaboration; Absorptive capacity; Proximity; Regional Innovation System

1 Introduction

In the last years, many scholars have thoroughly analysed how Small and Medium Enterprises (SMEs) can trigger and improve their innovation process (Edwards et al., 2005; Terziovski, 2010). The attention of the literature on this topic, first of all, is due to the large prevalence of SMEs in many countries, especially in the European Union, where they represent the 99.8 per cent of firms operating in non-financial business sectors (Muller et al., 2017). Second, this attention is motivated by the different innovation process adopted by SMEs and large companies (Çakar & Ertürk, 2010; Ketchen et al., 2007). Indeed, SMEs have usually at disposal fewer tangible and intangible resources, which may strongly affect their absorptive capacity (Dornbusch & Neuhäusler, 2015; Teirlinck & Spithoven, 2013), thus influencing their ability to scan the environment and absorb relevant external knowledge.

This problem can be, at least partially, solved through the development of collaborations with external organizations, which can support the absorption of external knowledge through interactive learning processes (Lane & Lubatkin, 1998). SMEs may have a better ability to leverage their relational capacity, thanks to their higher flexibility, compared to large firms (Thorpe et al., 2005). Specifically, collaborations with universities have been proven to play a critical role for sustaining SMEs' competitiveness, since they may favour the integration of scientific knowledge into the SMEs' innovation processes (Usman et al., 2018), also reducing potential appropriation issues (Tidd & Trewhella, 1997). R&D collaborations between university and SME support each organization in the interpretation and absorption of the partner's knowledge, thus enhancing more effective interactive learning processes and the opportunity to develop collaborative innovations with a relevant technological impact (Savino et al., 2017).

The participation of an SME in the development of high impact innovations may grant access to tacit knowledge that can be reused for developing successive related innovations (Kim & Song, 2007). Besides, it may enhance the SME's reputation as an innovative firm (Goldberg et al., 2003), thus increasing its ability to attract potential partnering organizations (Sampson, 2004). Nevertheless, only a few studies (Bstieler et al., 2015; Dornbusch & Neuhäusler, 2015; Kodama, 2008) have analysed some possible determinants of the technological impact of innovations resulting from R&D collaborations between university and SME. These studies provide a limited view of the impact of the SME's absorptive capacity, which should guarantee a correct interpretation of the scientific knowledge provided by the university (Muscio, 2007; Teirlinck & Spithoven, 2013).

Similarly, these studies have only partially analysed the determinants of the interactive learning processes that characterize its R&D collaborations with a university. Following the relative absorptive capacity framework (Lane & Lubatkin, 1998), interactive learning can be favoured by a common basic knowledge base between university and SME, which allows them to understand the assumptions and the importance of the knowledge provided by the partnering organization. Nevertheless, in accordance with the same framework, university and SME should be characterized by different specialized knowledge base, which increases the opportunities for interactive learning between the partnering organizations (Clauss & Kesting, 2017). Hence, interactive learning processes in R&D collaborations between university and SME may be affected by their cognitive proximity (Johnston & Huggins, 2018). Besides, these processes may be also supported by other forms of proximities, such as social proximity (Steinmo & Rasmussen, 2016), which enhances interactive learning thanks to shared language and trust developed in previous collaborations, and geographical proximity (Messeni Petruzzelli & Murgia, 2019), which instead reduces the cost of interactive learning thanks to easier face-to-face meetings.

Finally, previous studies do not consider the influence of the regional context in which the organizations operate. The importance of the regional context on the innovativeness of local firms represents a key topic in the literature on economic geography, which, in line with Marshall (1920), emphasizes how local firms tend to absorb knowledge spillovers mainly from their Regional Innovation System (RIS) (Maurseth & Verspagen, 2002; Munari et al., 2012). Nevertheless, the literature on the RIS' effect on the innovation strategies developed by local firms often treats these firms only as passive recipients of local knowledge spillovers, overlooking their active role in their search and absorption (Feldman, 2003), and neglecting the heterogeneity among local firms (Beugelsdijk, 2007). Crescenzi and Gagliardi (2018) partially fill this research gap, by showing how the RIS' effect on the innovation strategies developed by local firms is influenced by their absorptive capacity. Conversely, as far as the authors know, there are no studies that exactly analyse this relationship in SMEs, even if, compared to large firms, they may be considered as the main beneficiaries of RIS, because of their lower ability in attracting labour force and partnering organizations, other than in absorbing spillovers, from distant regions (Rodríguez-Pose & Refolo, 2003).

To fill these research gaps, the present study analyses R&D collaborations between university and SME offering an answer to the following research question: *How is the technological impact of an R&D collaboration between university and SME affected by their ability to absorb relevant external knowledge and by the amount of knowledge available at the regional level?* Precisely, by using a multilevel approach (Gupta et al., 2007; Hitt et al., 2007; Crossan & Apaydin, 2010), the present paper investigates how the impact of an R&D collaboration between university and SME is affected by SME's technological capital (Kodama, 2008; Messeni Petruzzelli & Murgia, 2019), by cognitive, social and geographical proximity between them (De Jong & Freel, 2010; Dornbusch & Neuhäusler, 2015), and by the level of regional knowledge spillovers (Acosta et al., 2012).

To test the effect of these determinants, the authors collect several data on 630 joint patents applied by a certain dyad of European SME and German or Italian university. To evaluate the effect of some potential determinants of the technological impact of these joint patents, the study uses a Poisson Multilevel model, based on two hierarchically nested levels, that is the focal joint patent, and the university partner. This analysis shows that the technological impact of these joint patents may be significantly affected by SME's absorptive capacity, as well as by the various forms of proximities that may influence the relative absorptive capacity of the collaboration between SME and university. In particular, both social and geographical proximity show a significant and positive effect, while the effect of cognitive proximity is less evident. Finally, the regional knowledge spillovers available in the SME's RIS show a significant and positive effect on the technological impact of the joint patent.

The results of this paper provide a more complete view of the impact of absorptive capacity on successful collaborations between university and SME. Indeed, they show how the ability of these collaborations to assimilate and exploit external knowledge depends not only on the absorptive capacity of the partnering organizations and the different forms of proximity that may affect their interactive learning processes, but also on the RIS where the partnering organizations operate. The location in a more innovative region may enhance the search and assimilation of knowledge spillovers, by lowering the cost of these activities and making them feasible even for SMEs, which would instead be prevented by their limited resources. These results contribute to explain the role of regional embeddedness on SMEs' innovation capabilities, thus enhancing the cross-fertilization between economic geography and strategic management proposed by Crescenzi and Gagliardi (2018). Besides, the present study provides further insights into the effect of several forms of proximity on the relative absorptive capacity (Lane & Lubatkin, 1998) of a collaboration between university and SME. In particular, this study shows how the mutual understanding between the partnering organizations may be strengthened by higher social and geographical proximity.

This paper provides also several practical contributions to SME and university managers, other than to policymakers. In line with some recent papers (Johnston & Huggins, 2018), the results of the present study shed new light on some possible criteria useful for the selection of university partner. Besides, these findings suggest to address university technology transfer towards technological domains that are closer to the specialization of potential collaborators, especially local SMEs (Messeni Petruzzelli and Murgia, 2019). Finally, these results may support the redefinition of the policies aiming at increasing the collaborations between university and SME, with a stronger emphasis on the potential benefits from the knowledge spillovers available at the regional level, as suggested by the "Smart Specialisation" approach (Crescenzi & Gagliardi, 2018).

The paper is structured into five sections. Section 2 describes the theoretical framework. Section 3 illustrates data, variables and method. Section 4 illustrates the main results of the paper. Section 5 presents the theoretical and practical contribution of the paper, its limitations, and some possible future developments.

2 Theoretical framework

The best practices for innovation management developed by large companies cannot be easily applied to SMEs, since their limited financial, human, and managerial resources (Bougrain & Haudeville, 2002; North & Varvakis, 2016). To overcome these limitations, SMEs may improve their innovation process by adopting an open innovation approach (Usman et al., 2018; Wynarczyk et al., 2013). In this way, SMEs may access specialized resources and knowledge, thus reducing risk, cost, and time necessary for innovation development (Parida et al., 2012). Previous studies have revealed the tendency of SMEs to interact especially with customers and suppliers (Cooke et al., 2000), since customers may expose SMEs to novel requirements that challenge their existing routines, while suppliers may provide the embedded knowledge necessary to resolve these challenges (Simmie, 2002). Nevertheless, SMEs are often reluctant to adopt open innovation because of the fear of losing some sources of their competitive advantage (Enkel et al., 2005; Verbano et al., 2015).

To overcome this issue, many SMEs prefer to collaborate with universities, which are less interested in exploiting their partners' knowledge (Teirlinck & Spithoven, 2013; Tidd & Trewhella, 1997). Moreover, collaborations with universities may favour the search and absorption of scientific knowledge that SMEs cannot easily develop by using only their own resources and capabilities (Usman et al., 2018; Wynarczyk et al., 2013). Through the collaborations with universities, SMEs can enhance their long run innovation capabilities, mainly their absorptive capacity (Bishop et al., 2011). Not surprisingly, the European Union, as well as national and regional authorities, has promoted specific policies aiming at stimulating the relationships between SME and university (Wynarczyk et al., 2013).

Nevertheless, a collaboration with a university may also provide some short run advantages to an SME, even in the development of a single innovation. Specifically, innovations developed by a collaboration between university and SME may benefit from the complementarities between the SMEs' exploitative, short run approach to innovation, and the universities' explorative, long run orientation (Hadjimanolis, 2006). Thanks to these complementarities, innovations developed in collaboration with a university may be characterized by a higher technological impact, since they may be reused in the development of a larger number of successive innovations (Briggs, 2015; Briggs & Wade, 2014). An SME, having participated in the development of high impact innovations, may avail of the tacit knowledge necessary to develop successive related innovations (Kim & Song, 2007), other than of the enhancement of a reputation as an innovative firm (Goldberg et al., 2003). These factors may increase not only the SME's innovation performance (O'Cass & Sok, 2014), but also its ability to attract potential partnering organizations (Sampson, 2004). Besides, the technological impact of the innovations developed by a collaboration between a university and an SME may be considered as an evidence of the effectiveness of this collaboration (Sampson, 2007), which may be consequently maintained, modified or interrupted by the same SME (Natalicchio et al., 2017). For this reason, a better comprehension of the determinants of the technological impact of these innovations may support SMEs in the choice of their partnering universities, thus reducing the effect of the costs and risks of these collaborations (Bruneel et al., 2010; Goduscheit & Knudsen, 2015).

This paper analyses the possible determinants of the technological impact of innovations developed by a collaboration between SME and university by adopting a multilevel interactionist approach (Beugelsdijk, 2007). This approach states that the innovativeness of a firm depends on the interaction between some characteristics of the specific organization and of the regional context where the organization operates (Crescenzi & Gagliardi, 2018). In the present study, since the organizations under analysis are collaborations between SMEs and universities, the authors first discuss the potential effect of some determinants related to the single SME and its relationship with the partnering university. Second, they analyse also the potential effect of the Regional Innovation Systems where the SME operates. This paper is based on five different hypotheses summarized in Figure 1 and described in detail in the next subsections.

FIGURE 1

2.1 The effect of absorptive capacity on collaborations between university and SME

The ability of a firm to develop innovations with a high technological impact is strongly affected by its absorptive capacity, which allows scanning the environment, identifying some relevant external knowledge, and exploiting the possible complementarities with the internal resources (Cohen & Levinthal, 1990). Nevertheless, absorptive capacity may be critical especially for SMEs, since they are often characterized by limited previous R&D investments and human capital (Freel & Robson, 2017; van de Vrande et al., 2009).

To overcome this limitation, the development of innovations by an SME can be supported through the collaboration with an external organization, which can more effectively implement knowledge exploration, thus absorbing some relevant new knowledge from the environment (Fernández-Esquinas et al., 2016). Hence, this knowledge can be transferred to the SME, which can assimilate it on the base of the amount of its absorptive capacity (Roper & Hewitt-Dundas, 2012). Indeed, without a certain degree of absorptive capacity, an SME cannot trigger any interactive learning process with the partnering organization, thus reducing the exploitation of the possible complementarities between the partners' knowledge base.

This line of reasoning is especially true in the case of collaborations with universities. From one perspective, their scientific knowledge can strongly improve the effectiveness and efficiency of knowledge exploration, by better prioritizing the potential search avenues (Fabrizio, 2009). By contrast, collaboration with a university requires large previous R&D investments by the SME (Fernández-Esquinas et al., 2016; Fontana et al., 2006). Thanks to these investments, an SME can overcome the cognitive problems associated with the interpretation and assimilation of the scientific knowledge shared by universities (Kealey & Ricketts, 2014; Zahringer et al., 2017). These cognitive difficulties are strengthened by the peculiar language and methods adopted in the development and communication of scientific knowledge, which is related to its specific nature. Indeed, scientific knowledge aims at providing an understanding of the underlying fundamental laws generating an observed phenomenon, differently from other forms of knowledge that are more interested in the simple description of the same phenomenon (Fleming & Sorenson, 2004). The peculiarity of the scientific knowledge provided by a university increases the importance of SME's absorptive capacity for its assimilation and exploitation through the development of high impact innovations. Thereby, this paper argues that:

H1. SME's absorptive capacity has a positive effect on the technological impact of innovations developed by an R&D collaboration between university and SME.

2.2 The effect of proximity on collaborations between university and SME

A certain degree of SME's absorptive capacity, per se, may not be sufficient to reduce the cost for the interpretation and the absorption of the scientific knowledge shared by universities. Indeed, because of the heavy differences among technological fields, absorptive capacity is not a general purpose ability, but rather specific on the technological fields on which an organization has cumulated its prior R&D investments and knowledge (Cohen & Levinthal, 1990). This requires that a university and an SME have developed their prior R&D investments in the same technological fields so to have a certain level of cognitive proximity (Boschma, 2005), with similar basic knowledge, language (Villani et al., 2017), and technological expertise (Johnston & Huggins, 2018). As suggested by Lane and Lubatkin (1998) in their relative absorptive capacity framework, interactive learning processes in an R&D collaboration are possible only in presence of a shared understanding of the assumptions and the importance of the knowledge provided by the partnering organizations. Thus, a certain level of cognitive proximity may favour the sharing of the partners' knowledge base and the development of innovations based on reasonable combinations of this knowledge, which may be more easily reused in successive innovations, even by other organizations.

Nevertheless, too high level of cognitive proximity may cause technological lock-in and hinder creativity in the collaboration, hence reducing the level of novelty of the innovations resulting from the combinations of this knowledge (Nooteboom et al., 2007). No wonder, even if affected by strong uncertainty, thoroughly novel innovations have a higher probability to be characterized by a breakthrough technological impact (Verhoeven et al., 2016). In this sense, a collaboration between an SME, with a more market-oriented knowledge, and a university, with a more research-oriented knowledge, can usefully combine their different specialized knowledge (Dornbusch & Neuhäusler, 2015), thus supporting the development of novel and valuable innovations (Teece, 1986). Indeed, in an R&D collaboration between university and SME, the university may enhance the search for radically new scientific knowledge (Fleming & Sorenson, 2004), while SME may trigger and address this search towards industrially applicable solutions (Dornbusch & Neuhäusler, 2015).

The above arguments suggest that cognitive proximity between university and SME may have a non-monotonic effect on their innovation output and the technological impact of their innovation, as previously shown by Lin et al. (2012) and Messeni Petruzzelli (2011). Thereby, this paper argues that:

H2. Cognitive proximity between university and SME has a curvilinear effect (inverted U-shaped) on the technological impact of innovations developed by their R&D collaboration.

The development of high impact innovations resulting from an R&D collaboration between university and SME may be hindered not only by the cost for the interpretation of the knowledge provided by each partner or absorbed by the external environment. In fact, it may be affected also by the willingness of the partners to reciprocally disclose their knowledge base.

In this sense, the effectiveness of the interactive learning processes in an R&D collaboration between university and SME may be enhanced by a high level of social proximity between these organizations (Cassi & Plunket, 2014; Steinmo & Rasmussen, 2016). This is the degree of social embeddedness of their relationship, measured on the base of their kinship, friendship, or experience

(Boschma, 2005), which may be strengthened when the same university and SME have reiterated over time their R&D collaborations. Indeed, the reiteration of these collaborations may have a self-reinforcing effect on their social proximity, because it may increase the degree of social embeddedness of their relationship (Balland et al., 2015). Thus, it may favour the development of R&D collaborations based on mutual trust between the partnering organizations, which may be more encouraged to openly share their, even tacit, knowledge (Garcia-Perez-de-Lema et al., 2017; Masiello et al., 2015). For this reason, social proximity may reduce the cost for the monitoring of the possible opportunistic behaviours of the partnering organizations, and improve their commitment and coordination in the collaboration (Letaifa & Rabeau, 2013; Presutti et al., 2011). All these potential benefits from social proximity are confirmed by several studies in the literature, which show its positive effect on R&D collaborations between university and company, in terms of overall innovation output (Kim & Song, 2007) and impact of their innovations (Hewitt-Dundas et al., 2019; Messeni Petruzzelli, 2011). Thus, this paper assumes the subsequent hypothesis:

H3. Social proximity between university and SME has a positive effect on the technological impact of innovations developed by their R&D collaboration.

As previously shown by Hohberger (2014) and Messeni Petruzzelli and Murgia (2019), the technological impact of innovations jointly developed by a university and an SME may be positively affected also by their geographical proximity. Indeed, geographical proximity may reduce the cost of an R&D collaboration between a university and an SME, thus increasing their ability in the joint development of high impact innovations.

In particular, a university and an SME located at a limited distance may incur in a lower cost to establish an R&D collaboration, and, once taken off, to develop it with higher flexibility (De Jong & Freel, 2010). In this sense, spatially proximate university and SME may benefit from more frequent face-to-face meetings that allow an easier transmission and assimilation of tacit knowledge

(Villani et al., 2017), hence enriching the results of their interactive learning processes. Frequent face to face meetings may also support an easier resolution of coordination problems (Cassi & Plunket, 2014), thus enhancing the effort provided by the partners in innovation development.

The arguments discussed above lead us to argue that:

H4. Geographical proximity between university and SME has a positive effect on the technological impact of innovations developed by their R&D collaboration.

2.3 The effect of Regional Innovation System on collaborations between university and SME

In line with economic geography, the technological impact of innovations developed by R&D collaborations between university and SME may be influenced not only by their spatial proximity, but even by their location in a specific RIS. In fact, in many countries, regional authorities are in charge of innovation policies and funding, so that they can establish specific incentives aiming at supporting the development of effective R&D collaborations between university and SME (Caloffi & Mariani, 2018; Cooke et al., 2000). Besides, the innovation capabilities of each partnering organization may be influenced by the regional level of agglomeration of a skilled labour force, potential partnering organizations, and, more in general, knowledge spillovers (Marshall, 1920). No wonder, firms tend to mainly absorb knowledge spillovers from their local innovation system (Maurseth & Verspagen, 2002; Munari et al., 2012), since the presence of a dense network of relationships among local actors may favour the access and assimilation of local spillovers, even those associated with tacit knowledge.

Compared to SMEs, universities and large firms may be less constrained by the use of local spillovers, thanks to their resources and their national or global orientation (Beugelsdijk, 2007; Capasso & Morrison, 2013). Indeed, SMEs, because of their limited resources and absorptive capacity, are less able to scan distant regions so to attract labour force and partnering organizations, and absorb knowledge spillovers[1] (Kapetaniou & Lee, 2019; Koschatzky & Sternberg, 2000; Rodríguez-Pose & Refolo, 2003).

For this reason, an SME can more easily improve the development of its innovations by adopting a search of knowledge spillovers among those reachable through the interaction with external actors operating in the same RIS[2] (Asheim & Isaksen, 2003; Beise & Stahl, 1999). Frequent and direct interactions with local customers, suppliers, competitors, research organizations, and technology transfer organizations can constantly transmit missing external, even tacit, knowledge spillovers to an SME (Bathelt et al, 2004; Romijn & Albaladejo, 2002). No wonder, SME's innovation capabilities may be significantly affected by the embeddedness in its RIS, as demonstrated by the different search strategies adopted by SMEs located in core and non-core regions (Grillitsch & Nilsson, 2015; Martynovich, 2017).

Specifically, the present paper surmises that an SME may especially benefit from some of these local knowledge spillovers that are those in the same technological fields of the innovation under development. These technologically-close spillovers can be more easily recognized, interpreted and reused by an SME interested in developing related innovations (Wang & Li, 2008). Conversely, the acquisition of technologically-distant knowledge spillovers may provoke confusion, information overcharge, and diseconomies of scope (Ahuja & Morris Lampert, 2001), because these spillovers may be neither coherent nor complementary with the innovation under development. For this reason, this study assumes that the effect of RIS on the innovations developed by local SMEs may depend, rather than on the total knowledge spillovers available at the local level (Rodríguez-Gulías et al., 2018), on the level of these technologically-close knowledge spillovers. This assumption seems to be supported by the studies of Beaudry and Breschi (2003) and Mitze and Makkonen

[1] In particular, the lack of specialized human resources, characterized by cutting-edge knowledge and ability to interact in international networks, may reduce SMEs' capacity to search and absorb international knowledge spillovers (Buse et al., 2010). This does not imply that all SMEs have difficulty in absorbing international spillovers, given that this capacity varies according to the characteristics of the individual firm (Ebersberger & Herstad, 2013) and the sector (Fransman, 2006).

[2] RIS may affect the development not only of a single innovation developed by a local SME, but also of its own absorptive capacity (Lau & Lo, 2015; Zahra & George, 2002), which can be nurtured, other than by the specific regional innovation policies, by the long run exposure to local sources of relevant knowledge.

(2019), which show that a RIS characterized by a high level of intra-sector spillovers may enhance the innovation output and productivity of local SMEs. Thereby, this paper argues that:

H5. The level of technologically-close knowledge spillovers in the SME region has a positive effect on the technological impact of innovations developed by an R&D collaboration between university and SME.

3 Data and methods

3.1 Data and sample

The sample includes a large number of innovations jointly filed by SME and university. Specifically, the authors selected innovations developed by universities from Germany and Italy. Even if they are the largest manufacturers and exporters in the European Union, these two countries are characterized by a specific industrial specialization, other than by a different role of SMEs. Indeed, even if in both countries SMEs represent more than 99 per cent of the enterprises, their contribution, in terms of value added and persons employed, is far larger in the Italian than in the German economy. Other differences between these two countries are related to their peculiar higher education system and the role of regional authorities in the regulation of innovation issues. Despite German and Italian university systems are both mainly public, the relationships with industry present many differences. First, while all the Italian universities are characterized by a uniform mission, German “universities of applied sciences” (Fachhochschule) have a more practical orientation that favours their relationship with companies, especially SMEs. Second, in the last years, Germany and Italy have approved opposite regulations of university patenting (Geuna & Rossi, 2011). In Germany, after the approval of a law in 2002, the Intellectual Property Rights

(IPRs) on the inventions made by academics are assigned to the universities. In Italy, a law ratified in 2001 allocated these IPRs to the academic inventors, in accordance with the professor's privilege. The sample is limited to inventions filed from 2003 to 2016 so to lessen the effect of these legislative changes. The differences between Germany and Italy are less noticeable concerning the role of regional authorities in the promotion of innovation policies. Indeed, while German states contribute to the regulation of these issues in accordance with the Constitution approved in 1949 (Cooke et al., 2000), several competencies related to innovation policy were handed over to Italian regions by the constitutional reform approved in 2001 (Caloffi & Mariani, 2018).

Data collection was based on the lists of universities collected in the ETER project[3]. For each German and Italian university, the authors collected all the patents filed to the patent offices included in PATSTAT. Subsequently, they selected all the dyadic joint patents applied by only a university and an SME. In order to detect SMEs, they strictly applied the European definition, collecting data from ORBIS database related to the balance sheet total, the turnover, the number of employees, as well as the links to a group. The authors gathered 630 joint patents applied by 115 different universities located in different German states or Italian regions. These joint patents were co-filed by 465 different SMEs; only 14 SMEs co-filed a patent with more than one university. In order to compute the variables described in the next subsection, they collected patent data from PATSTAT, SMEs' data from ORBIS and Google, and universities' data from the ETER project and Google, while regional data were collected from EUROSTAT.

3.2 Variables

Dependent variable. The technological impact of each joint patent under analysis was measured by counting the number of forward citations obtained up to 2017, excluding assignees' self-citations (*JointPatImp*) (Jaffe et al., 1993; Messeni Petruzzelli & Rotolo, 2015). Indeed, subsequent patents

[3] https://www.eter-project.com/

tend to include the citation to patents whose technological knowledge was used for their development (Acosta et al., 2012).

Independent variables. The authors considered different independent variables associated with the main phenomena that may affect the impact of the joint patents filed by an SME and a university: SME's absorptive capacity, cognitive, social and geographical proximity between SME and university, and the level of technologically-close knowledge spillovers in the RIS where the SME is located.

SME's absorptive capacity. The authors measured the level of the SME's absorptive capacity by computing its technological capital (*SMETechCap*), which was measured as the number of patents applied by the SME in the five years before the filing of the focal joint patent (Phene et al., 2006). Technological capital may provide an adequate proxy of absorptive capacity[4], since it shows the SME's ability to combine and transform previous knowledge into technological innovations (Zahra & George, 2002).

Cognitive proximity. In order to measure cognitive proximity between university and SME, the authors considered their technological proximity, which is more strictly related to innovation development than other dimensions of cognitive proximity, which may instead affect functional areas, such as production and marketing (Gilsing et al., 2008). In line with Messeni Petruzzelli (2011), the authors measured technological proximity by computing the level of the technological relatedness between the partnering organizations. Technological relatedness evaluates the similarity of their technological experiences, which may favour a similar knowledge base. Following Sampson (2007), technological relatedness (*TechRel*) was measured by analysing the degree to which the university and the SME had patented in the same technology classes (3-digit International Patent Classification codes). Exactly, the authors adopted the following index:

[4] To be precise, technological capital may be considered as a proxy for the firm's realized absorptive capacity that is its observed capacity to exploit external knowledge (Zahra and George 2002). Conversely, technological capital cannot measure potential absorptive capacity, which is the capability to acquire external knowledge, but not to exploit it. This latter dimension of absorptive capacity can be measured by using data, like R&D investments, not available in the present dataset.

$$TechRel_{i,j} = \frac{f_i f_j'}{\sqrt{(f_i f_i')(f_j f_j')}}$$

where the vectors f_i and f_j (apex designates the transposed vector) count all the patents filed, respectively, by the university (i) and the SME (j) in the previous 5 years up to the filing date of the focal joint patent and associated with the patent class n (n=1, …, 129). *TechRel* varies from 0 to 1, where 1 indicates a perfect technological relatedness between university and SME.

Social proximity. The authors measured social proximity between university and SME by evaluating their common past R&D collaborations (Steinmo & Rasmussen, 2016; Villani et al., 2017). In particular, the authors added a discrete variable (*PrevJointPats*), equal to the number of patents jointly filed by the same organizations in the previous 5 years up to the filing date of the focal joint patent.

Geographical proximity. In line with Presutti, Boari, and Majocchi (2011), the authors measured geographical proximity by computing the geodesic distance between the headquarters of the partnering organizations (*GeoDist*), in logarithm.

Technologically-close knowledge spillovers in the SME's RIS. To measure the level of technologically-close knowledge spillovers in the SME's RIS, the authors computed the number of patents applied in the same NUTS2 (Nomenclature des Unités Territoriales Statistiques) region of the SME during the 5 years before the filing of the focal joint patent, and with at least one International Patent Classification (IPC) code among those included in this joint patent (*SMERegClosePatent*), divided per million of inhabitants of the same region.

Control variables. The previous literature identifies several variables that may influence the technological impact of a patent. For this reason, the authors added further variables in this analysis, checking for effects related to both patent and applicants. Exactly, among the patent-related variables, the authors added the number of claims (*Claims*) (Tong & Frame, 1994) and 3-digit IPC classes assigned to the patent (*Scope*) (Moser & Nicholas, 2004). Similarly, the authors added the number of patent offices where the patent was applied (*FamSize*) (Harhoff et al., 2003). The authors controlled also for the number of non-patent references (*ScientRef*), as well as for the number of backward citations, excluding self-citations (*BackCit*) (Harhoff et al., 2003). Moreover, the authors checked for the number of inventors of the patent (*TeamSize*) (Mariani, 2004). Finally, the authors included a discrete variable (*PubYear*), which is equal to the publication year of the patent. The inclusion of this variable mitigates the effect of different truncation of the forward citations of the patents in the sample, as well as issues related to the overall variations of citing propensity in the last years (Acosta et al., 2012).

Among the applicants-related variables, the authors identified control variables associated with the SME and the university. Concerning the SME, the authors measured its human capital, by computing the number of its employees (*SMESize*), and its age (*SMEAge*), equal to the difference between the filing year of the focal joint patent and its foundation year (Sorensen & Stuart, 2000). The authors evaluated also if the SME is an academic spin-off company, where the presence of professors among the founders may guarantee a better alignment of incentives with the university, especially in the case of collaboration with the parent university (Johansson et al., 2005). Hence, the authors introduced a binary variable (*Spinoff*), which is equal to 1 if the partnering SME is an academic spin-off company, 0 otherwise. An SME is considered as an academic spin-off company if there is either a university or some academics among its founders (Fini et al., 2009). The authors measured also the public status of the SME (*PublicSME*), through a binary variable equal to 1 if the SME was publicly traded at the filing date of the focal patent, 0 otherwise (Messeni Petruzzelli & Rotolo, 2015). Finally, the authors considered the SME’s industrial sector (*SMESector*), by adding SIC codes dummy variables, at the section level (Terjesen & Patel, 2017).

Concerning the university, the authors added several variables to take into account the high heterogeneity among universities. The authors firstly measured its absorptive capacity, since the university should be capable to correctly search and absorb the knowledge related to the R&D collaboration, which may come from the SME partner or from external sources. The development of this ability may be favoured by the university’s technological capital, which reveals its technological competencies (Nooteboom et al., 2007), other than its experience in innovation development (Phene et al., 2006). Thus, the authors added a variable that measures the overall technological capital (*UniTechCap*), equal to the number of patents applied by the university in the 5 years before the filing of the focal joint patent. Nevertheless, the technological capital of a university is generally related to different research fields of interest of its scientists, while absorptive capacity is affected by the prior knowledge cumulated by an organization only in the technological fields connected to the joint patent under analysis (Cohen & Levinthal, 1990). For this reason, the authors measured university specialization, which is the share of university technological capital directly related to these technological fields (Messeni Petruzzelli & Murgia, 2019). University specialization (*UnivSpec*) is computed starting from the number of patents applied by the university in the 5 years before the filing of the focal joint patent, and with at least one IPC code among those included in this joint patent. *UnivSpec* is computed as the ratio of the number of these patents to the number of patents applied by all the national universities in the same period, with at least one IPC code among those included in the focal joint patent. As well as for the SME, the authors considered also a human capital indicator for the university, by including the number of its academics (*UniSize*), in logarithm. The authors included in the model a binary variable (*Germany*) to check for patents applied by a German (1) or an Italian university (0). Since the systematic differences between German general universities and universities of applied sciences (Fachhochschule), the authors included a binary variable (*Hochschule*) equal to 1 if the university is a Fachhochschule, 0 otherwise. Likewise, since the systematic differences between Italian general and polytechnic universities, the authors included a binary variable (*Polytechnic*) equal to 1 if the university is a polytechnic, 0 otherwise. Moreover, the authors added a binary variable to check for the public nature of the university (*UniPublic*), equal to 1 if the university is state-owned, 0 otherwise (Natalicchio et al., 2017). The authors added also three different variables to evaluate the university reputation, since it might increase the propensity of innovative SMEs to collaborate with the university (Hemmert et al., 2014). First, the authors added the age of the university (in natural logarithm) at the filing of the focal joint patent (*UniAge*), since more ancient universities are often evaluated as more prestigious (Bornmann & Daniel, 2006). Second, the authors included the university ranking (*UnivRank*), as measured in the QS World University Rankings® 2018. This ranking is based on different criteria, such as teaching commitment, internationalization, research impact, and academic and employer reputation. The authors operationalized *UnivRank* as a discrete variable equal to 5 for universities graded in the first 200 standings in the QS ranking, 4 for those graded from the 201st to the 400th standing, till to 0 for those completely excluded by the QS ranking. Third, the authors added a discrete variable equal to the number of Nobel Prize winners affiliated with the university (*UniNobel*) (Natalicchio et al., 2017). This paper also evaluates the effectiveness of universities in the collection of third party funding for specific projects. For each university, the authors measured the third party funding per academic (in natural logarithm), differentiating into public (*UniPubThirdFund*) and private (*UniPrivThirdFund*) funding, on the base of the legal nature of the sponsor (D'Este & Patel, 2007).

Concerning the Regional Innovation System where the SME is located, the authors considered also other variables that might influence the total level of regional knowledge spillovers. By using EUROSTAT data, the authors computed the level of Gross Domestic Expenditure on R&D (GERD) by business enterprise sector in the same NUTS2 region of the SME (*SMERegR&Dbus*), in the previous 5 years up to the filing date of the focal joint patent, in logarithm. Similarly, in line with Acosta et al. (2012), the authors computed also the level of GERD by the Higher education sector in the same NUTS2 region of the SME (*SMERegR&Dhei*), in the previous 5 years up to the filing date of the focal joint patent, in logarithm.

3.3 Estimation method

In order to test if and how the technological impact of a university-SME joint patent is affected by variables related to the partnering organizations and their regions, the authors adopted a multilevel regression model. Such a model can take account of the nested hierarchical nature of these variables, since each region may be characterized by the presence of more universities, each of which may co-file a patent with an SME. The adoption of a multilevel model allows better dealing with the problem related to the effect of some unobserved variables at the university level, for example the incentives to patenting for the academics, and at the regional level, for example the demand for technology by local firms (Acosta et al., 2012). Besides, by using a multilevel model the present study can solve the problem related to the non-independence of the observations, which can affect the computation of the standard error and significance level, specifically for the variables at the university and regional level (Hofmann, 1997).

In order to define the exact structure of the multilevel regression model, the authors computed the residual variance at the university and regional level. Since the residual variance at the regional level is extremely low, in line with the results of the likelihood-ratio test contrasting the nested models with and without the regional random effect, the authors decided to adopt a two-level model, defined by the following equation:

$$Y_{ij} = \beta_0 + \beta_1 P_{ij} + \beta_2 O_j + e_{ij} + z_j$$

where P and O represent, respectively, the variables associated with the level 1 (joint patent) and 2 (university), while e_{ij} and z_j represent, respectively, the random effects associated with the joint patent and the university. In particular, this study adopts a random intercept model, where the coefficients β are common to all the universities, while the intercept can vary among the different universities.

Because of the count nature of the dependent variable (*JointPatImp*), the present study adopts a multilevel mixed-effects Poisson regression. To solve possible issues due to multicollinearity, the authors excluded all the variables characterized by a variance inflation factor above the cut-off value of 10 (Neter et al., 1996).

4 Results

Table 1 presents the pairwise correlations with significance levels of the variables inserted in the models under analysis, as well as their descriptive statistics. *UniSize* is highly correlated with *UnivRank* (0.641), as well as with *UniPubThirdFund* (0.685) and *UniPrivThirdFund* (0.720). These last variables are highly correlated with each other (0.863). Despite these correlations, all these variables have a value of variance inflation factor under the threshold of 10 (Kleinbaum et al., 1998), so this study keeps them in the regression results. Notwithstanding, this study tests the effect of their exclusion as a robustness check.

TABLE 1

Table 2 presents the output of the Poisson multilevel regression models. Model 1 is the baseline model, since it contains only the control variables. Model 2 contains also the effect of the SME's absorptive capacity, while Models 3-5 add also the effect of the variables related to the different forms of proximity between the partners, respectively cognitive, social and geographical proximity. Finally, Model 6 includes also the effect of the technologically-close knowledge spillovers in the SME's RIS. Before discussing the effect of the variables presented in each model, the characteristics of the whole models are briefly illustrated. In particular, all the regression models are characterized by a residual variance at the university level that ranges from 0.517 to 0.547. In addition, the results of the Likelihood-Ratio (LR) test suggest that the choice of a multilevel Poisson model is most suitable than the adoption of a simple Poisson model.

The baseline model shows that the technological impact of the joint patents increases with the number of claims ($\beta = 0.008$, $p < 0.01$), patent scope ($\beta = 0.069$, $p < 0.001$), family size ($\beta = 0.109$, $p < 0.001$), number of references to scientific knowledge ($\beta = 0.002$, $p < 0.05$), backward citations ($\beta = 0.016$, $p < 0.001$), and inventors ($\beta = 0.028$, $p < 0.01$). The negative and significant coefficient for *PubYear* ($\beta = -0.246$, $p < 0.001$) confirms that the more ancient joint patents receive more forward citations by subsequent patents. Across the six models, these coefficients are consistent and stable. Among the control variables related to the SME, *SMESize* shows a positive and significant coefficient ($\beta = 0.002$, $p < 0.05$), even if only in Models 1-3, thus demonstrating the importance of SME's human capital for the development of joint patents with a high technological impact. Regarding the control variables associated with the university, *UnivSpec* shows a positive and significant coefficient ($\beta = 1.172$, $p < 0.05$), differently from *UniTechCap*, hence suggesting that only the share of university's technological capital closely related to the joint patents may affect their development.

TABLE 2

The effect of *UnivSpec* is confirmed in all the six models, as well as that associated with *Germany* ($\beta = 0.573$, $p < 0.05$), which demonstrates that joint patents applied by German universities have a higher technological impact than those filed by Italian universities. Finally, among the control variables associated with the SME's RIS, only *SMERegR&Dbus* shows a positive and significant coefficient ($\beta = 0.202$, $p < 0.001$), thus suggesting the importance of the total knowledge spillovers generated by the R&D investments made by local enterprises. Nevertheless, its effect becomes not significant in Model 6, where a more specific variable related to regional knowledge spillovers, *SMERegClosePatent*, is included.

Concerning the independent variables related, Model 2 shows a not significant and negative effect of *SMETechCap* ($\beta = -0.002$, $p > 0.01$). This effect is reversed in the other models, and becomes scarcely significant in Models 5 and 6, thus weakly supporting *H1*.

Concerning the variables associated with the different forms of proximity between SME and university, the variables related to technological relatedness (*TechRel*) show not significant coefficients, thus not supporting the inverted U-shaped effect of cognitive proximity (*H2*). Conversely, Model 4 shows a positive and significant effect of *PrevJointPats* ($\beta = 0.139$, $p <$

0.001), thus confirming the positive impact of social proximity (*H3*). Similarly, Model 5 highlights a negative and significant effect of *GeoDist* (β = -0.001, p < 0.001), thus confirming the positive impact of geographical proximity (*H4*).

Concerning the variables related to the RIS where the SME is located, the level of technologically-close knowledge spillovers (*SMERegClosePatent*) has a positive and significant effect (β = 0.005, p < 0.01), thus confirming *H5*.

As a robustness check, the authors carried out some additional analyses, starting from the computation of a model that excludes the variables with a higher level of correlation so to further lessen the potential multicollinearity issues. The authors computed a model excluding *UniSize* and *UniPrivThirdFund*, and the results are quite similar to those shown in Model 6. Second, the authors tested an alternative operationalization of the variable related to geographical proximity. Specifically, in line with Messeni Petruzzelli and Murgia (2019), the authors tested an alternative operationalization of the geographical proximity between university and SME by using a binary variable (*SameRegion*), equal to 1 if the partners are located in the same NUTS2 region, 0 otherwise. This operationalization is motivated by the fact that an SME and a university located in the same NUTS2 region can benefit, other than from a limited spatial distance, from the same institutional context. The results of the model including *SameRegion* in place of the variable *GeoDist* are quite similar to those showed in Model 6, except for the not significant effect of *SMETechCap* (β = 0.007, p > 0.01) and *Scope* (β = 0.031, p > 0.01), and the negative and scarcely significant effect of *Hochschule* (β = -0.575, p < 0.01). Third, the authors tested an alternative operationalization of the variable that evaluates if the SME is an academic spin-off company. In particular, the authors computed a binary variable (*UnivSpin*), equal to 1 if the joint patent is developed by a collaboration between an academic spin-off company and its parent university, 0 otherwise. The authors computed a model including *UnivSpin* in place of the variable *Spinoff*, and the results are similar to those shown in Model 6. Finally, the authors computed an alternative model to evaluate if the effect of technological relatedness is linear, rather than curvilinear as assumed in *H2*. The computation of this alternative model shows that, while the other coefficients are quite similar to those obtained in Model 6, the term associated with *TechRel* is negative and significant (β = -0.455, p < 0.001). This result, which is coherent with that obtained by Messeni Petruzzelli and Rotolo (2015), can be explained by considering also the effect of university specialization. Indeed, both university specialization and technological relatedness may contribute to the level of cognitive proximity between the partnering organizations, since both these variables measure, in a different way, their previous experience in the technological fields related to the innovation developed. For this reason, the present analysis seems to provide no conclusive results about the effect of cognitive proximity, and specifically about the interplay between basic and specialized knowledge of university and SME.

5 Discussion

The present multilevel analysis highlights that the technological impact of the innovations developed by R&D collaborations between university and SME depends on several variables, which are related to the characteristics of the single innovation, each partnering organization, their level of proximity, and the regional context. In particular, these analyses show the positive and significant effect of SME's absorptive capacity, as well as of the university specialization in the technological fields related to the innovation under analysis. Second, while the effect of cognitive proximity appears to be not evident, the findings demonstrate that both social and geographical proximities have a positive and significant effect on the technological impact of the innovations developed by R&D collaborations between university and SME. Finally, the technological impact is significantly improved even by the level of technologically-close knowledge spillovers in the SME region.

These results provide a number of interesting insights that can contribute to several topics discussed in the recent literature on innovation management. First, the study enhances existing knowledge on the processes of innovation development carried out by SMEs (Teirlinck & Spithoven, 2013), especially those based on a collaboration with a university (Bstieler et al., 2015; Dornbusch & Neuhäusler, 2015; Kodama, 2008). These processes may be strengthened by the combined effect of the SME's absorptive capacity, its relationship with a university partner, and the support provided by the local RIS. The systematic and multilevel approach undertaken in this study improves the understanding of the impact of each variable, as well as the relationships between variables at different levels.

Second, in accordance with previous studies (Fernández-Esquinas et al., 2016; Roper & Hewitt-Dundas, 2012), the present analysis shows that SME's absorptive capacity represents a significant factor for the development of innovations with a high technological impact. Indeed, this study reveals that the level of absorptive capacity affects SMEs' ability to search, absorb, and reuse relevant external knowledge. As shown the result of the present study, this knowledge may come from both the context in which the SME operates, especially the RIS, and the university partner.

Third, the assimilation of the knowledge provided by the university partner may be favoured by a certain level of university specialization in the technological fields related to the innovation developed. In this sense, the positive effect of university specialization suggests that university-SME collaborations may be enhanced in presence of a higher similarity between the basic knowledge of the partnering organizations (Messeni Petruzzelli & Murgia, 2019). This requirement confirms the significance of the relative absorptive capacity framework (Lane & Lubatkin, 1998), especially in collaborations with SMEs that, because of their limited R&D investments and human capital, cannot easily absorb external knowledge distant from their technological fields of specialization.

Fourth, this analysis confirms the relevance of social and geographical proximity for the innovation management carried out by SMEs in collaboration with partnering organizations. Indeed, the development of innovations with a high technological impact seems to be supported by the presence of partnering organizations with a past joint experience and located at a limited distance. As shown in previous studies (Hohberger, 2014; Kim & Song, 2007), both these factors may improve the interactive learning processes in an R&D collaboration between a university and an SME, since they reduce the physical and psychological barriers to an effective sharing of tacit knowledge between the partners.

Fifth, this analysis shows that the effectiveness of an R&D collaboration between a university and an SME may be affected also by some characteristics of the RIS where the SME is located. Specifically, the technological impact of the innovations developed by these R&D collaborations may be positively influenced by the level of local knowledge spillovers that are close to the technological fields of these innovations. In fact, SMEs can absorb and reuse these spillovers since they may be more coherent and complementary with the innovation under development (Ahuja & Morris Lampert, 2001; Wang & Li, 2008). Besides, these spillovers are available at the local level, hence reachable even by SMEs characterized by fewer resources and absorptive capacity than large firms (Rodríguez-Pose & Refolo, 2003). This result highlights how the amount and the scope of regional R&D investments may affect the development of innovations by local firms, thus clarifying the role of regional embeddedness on SMEs' innovation capabilities and strategies (Grillitsch & Nilsson, 2015). Besides, this result provides a better comprehension of the relationship between the characteristics of RIS, analysed by economic geography, and the innovation strategies adopted by SMEs, discussed by the strategic management literature. Even if still in its infancy (Crescenzi & Gagliardi, 2018), the cross-fertilization of these theoretical perspectives can improve the analysis of SMEs' innovation strategies, which may be strongly affected by the benefits and barriers resulting from their RIS.

For this reason, this study may provide useful practical contributions that may support public policy-makers, university and SME managers. First, its results may favour the definition of more effective policies aiming at improving the impact of RIS on local SMEs. In particular, its results seem to support innovation policies, like the "Smart Specialisation" approach, that promote a stronger alignment between the technological specialization of the RIS and the innovation strategies adopted by the local SMEs (D'Adda et al., 2018; Foray et al., 2011). These policies may be based on a bottom-up approach (McAdam et al., 2014), thus encouraging SMEs to search knowledge spillovers outside their organizational boundaries, with a special emphasis on those available in their RIS that can be more easily detected and assimilated.

Second, the present study may strengthen the ability of universities in the development of more effective collaborations with SMEs. Indeed, in line with Messeni Petruzzelli and Murgia (2019), this paper suggests how university specialization may increase the university's ability to transmit cutting-edge knowledge and promote interactive learning processes in the collaborations with SMEs. At this aim, university managers can address their effort, especially in technological transfer, on the technological domains that are closer to the specialization of local SMEs.

Third, the present analysis may support SME managers in the development of their innovation projects so to take carefully into account the possible determinants of the technological impact. The development of innovations with a high technological impact may improve SMEs' future innovation performance and reputation (Goldberg et al., 2003; O'Cass & Sok, 2014). In this sense, a critical step in the development of innovations with a high technological impact is related to the selection of the partnering organizations. The present paper provides several practical contributions related to the selection of a university partner by an SME, suggesting the importance not only of university specialization, but also of some forms of proximity, as pointed out also by Johnston and Huggins (2018). Specifically, these findings reveal that SMEs may select spatially close university partners, and cultivate long term relationships with them. Besides, the present paper suggests that managers can improve the innovation management in SMEs by enhancing the alignment between the technological domains of their innovation projects and the technological specialization of the RIS where SMEs are located. Such strategies may represent a feasible alternative approach for SMEs located in non-core regions that may have difficulties in searching for knowledge outside their region (Grillitsch & Nilsson, 2015).

6 Conclusion

The present study reveals how SME's ability to develop innovation with a high technological impact may be influenced, other than by its absorptive capacity, by some external factors that may affect the search and absorption of useful knowledge. This knowledge may result from the interactive learning triggered by the collaboration with a university partner, which may provide cutting-edge knowledge that an SME can difficulty absorb from other sources. In this sense, the approach adopted by the present paper allows investigating, in a more direct way, the innovation output of R&D collaboration between university and SMEs. Future research may adopt a similar approach to the analysis of other innovation output of these collaborations (Perkmann et al, 2013; Vega et al., 2012), thus overcoming a limitation of the present paper that is focused only to joint-patents.

The second source of external knowledge investigated in the present paper is the RIS where an SME is located. This work shows how an SME can avail of the knowledge spillovers coming from its RIS and associated with the same technological domains of the innovation under analysis. This result provides more direct evidence of the potential benefits of RIS for SME's innovation management. Future research, even based on more qualitative approaches, may provide further evidence of the relevancy of regional knowledge spillovers in the innovation projects carried out by SMEs.

Even other limitations of the present work might stimulate new research lines. As mentioned above, the authors did not adopt a complete operationalization of cognitive proximity, which can address the interplay between basic and specialized knowledge of university and SME. In this sense, the analysis of cognitive proximity does not consider also the possible substitutive or complementary effect of social and geographical proximity (Villani et al., 2017). Accordingly, future studies may overcome this limitation by testing the interaction effects among the different forms of proximity. Second, the analysis is limited to some forms of proximity, but neglects the role of other two proximities, namely the organizational and institutional ones, that may strongly affect an R&D collaboration between university and SME (Cassi & Plunket, 2014; Mattes, 2012; Villani et al., 2017). Finally, the present study is based only on German and Italian contexts. Even if this choice is justified for the motivations presented above, future studies might apply similar models to other countries, characterized by a different university patenting and innovation systems. This may enhance the generalizability of the current results, as well as discover similarities and differences with other countries.

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TABLE 1.

Descriptive statistics and pairwise correlation matrix (*N* = 630).

Variable	Mean	S. D.	Min.	Max.	1.	2.	3.
1. JointPatImp	2.894	6.055	0	61			
2. SMETechCap	2.978	6.405	0	56	-0.014		
3. TechRel	0.268	0.317	0	0.979	0.041	0.401***	
4. PrevJointPats	0.479	1.249	0	10	0.069†	0.254***	0.344***
5. GeoDist	2.662	2.419	0	7.37	-0.099*	0.096*	0.070†
6. SMERegClosePatent	17.474	19.166	0.011	157.596	0.251***	0.094*	0.178***
7. Claims	16.614	9.241	1	77	0.156***	0.077†	0.095*
8. Scope	1.971	1.172	1	10	0.307***	0.000	0.107**
9. FamSize	3.794	3.226	1	23	0.377***	-0.044	0.051
10. ScientRef	12.749	30.810	0	214	0.296***	0.013	0.107**
11. BackCit	7.800	9.386	0	126	0.317***	0.044	-0.018
12. TeamSize	3.786	1.926	1	14	0.007	0.143***	0.075†
13. PubYear	9.044	3.068	3	15	-0.357***	0.048	-0.088*
14. SMESize	32.292	45.455	1	235	0.002	0.273***	0.079*
15. SMEAge	10.641	14.791	0.000	154.077	-0.105**	0.156***	-0.028
16. Spinoff	0.544	0.498	0	1	0.159***	0.045	0.119**
17. PublicSME	0.014	0.119	0	1	0.020	0.136***	0.075†
18. UniTechCap	83.976	110.462	0	498	-0.026	0.090*	0.004
19. UnivSpec	0.055	0.096	0	1	-0.054	0.037	0.013
20. UniSize	8.025	0.873	4.489	9.210	0.158***	0.133***	0.188***
21. Germany	0.744	0.437	0	1	0.138***	0.119**	0.133***
22. Hochschule	0.083	0.275	0	1	-0.040	-0.064	-0.107**
23. Polytechnic	0.113	0.316	0	1	-0.089*	-0.034	-0.033
24. UniPublic	0.003	0.056	0	1	-0.008	-0.022	-0.048
25. UniAge	23.392	21.454	0.300	92.600	0.027	0.024	0.067†
26. UnivRank	3.168	1.940	0	5	0.110**	0.092*	0.113**
27. UnivNobel	5.689	10.362	0	44	0.166***	0.088*	0.143***
28. UniPubThirdFund	16.670	1.914	0.000	18.430	0.086*	0.073†	0.100*
29. UniPrivThirdFund	15.958	2.481	0.000	18.580	0.116**	0.087*	0.106**
30. SMERegR&Dbus	5.815	0.862	1.946	7.262	0.066†	0.112**	0.077†
31. SMERegR&Dhei	4.738	0.400	1.528	6.476	-0.063	0.102*	0.060

† $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Variable	4.	5.	6.	7.	8.	9.
5. GeoDist	-0.167***					
6. SMERegClosePatent	0.023	-0.055				
7. Claims	0.030	-0.036	0.165***			
8. Scope	0.113**	-0.114**	0.479***	0.216***		
9. FamSize	0.089*	-0.070†	0.263***	0.143***	0.398***	
10. ScientRef	-0.029	-0.013	0.252***	0.107**	0.344***	0.390***
11. BackCit	-0.042	-0.007	0.222***	0.083*	0.237***	0.277***
12. TeamSize	0.004	0.018	-0.025	0.052	-0.080*	-0.098*
13. PubYear	0.068†	0.012	-0.077†	-0.104**	-0.130**	-0.126**
14. SMESize	0.247***	0.026	-0.076†	0.012	-0.033	-0.001
15. SMEAge	0.014	0.089*	-0.144***	-0.074†	-0.092*	-0.153***
16. Spinoff	0.093*	-0.208***	0.270***	0.112**	0.206***	0.264***
17. PublicSME	-0.014	0.024	0.071†	-0.011	0.037	0.091*
18. UniTechCap	0.077†	-0.057	0.142***	0.019	0.063	-0.034
19. UnivSpec	0.158***	-0.063	-0.174***	-0.094*	-0.098*	-0.052
20. UniSize	0.086*	-0.023	0.357***	0.195***	0.214***	0.182***
21. Germany	-0.043	-0.012	0.346***	0.109**	0.191***	0.069†
22. Hochschule	-0.037	0.005	-0.101*	-0.076†	-0.081*	-0.120**
23. Polytechnic	0.157***	-0.057	-0.235***	-0.115**	-0.107**	-0.030
24. UniPublic	-0.022	0.000	-0.031	-0.016	-0.023	-0.023
25. UniAge	-0.074†	0.013	0.107**	0.155***	0.032	0.020
26. UnivRank	0.139***	-0.044	0.238***	0.118**	0.108**	0.186***
27. UnivNobel	0.033	-0.026	0.327***	0.248***	0.164***	0.185***
28. UniPubThirdFund	0.083*	-0.096*	0.174***	0.061	0.139***	0.092*
29. UniPrivThirdFund	0.068†	-0.080*	0.225***	0.069†	0.149***	0.119**
30. SMERegR&Dbus	0.087*	-0.099*	0.530***	0.152***	0.155***	0.060
31. SMERegR&Dhei	-0.023	0.006	0.299***	0.088*	0.058	-0.012

Variable	10.	11.	12.	13.	14.	15.
11. BackCit	0.330***					
12. TeamSize	-0.021	-0.031				
13. PubYear	-0.013	-0.026	0.037			
14. SMESize	-0.116**	-0.043	0.102*	0.003		
15. SMEAge	-0.137***	-0.045	0.101*	0.124**	0.508***	
16. Spinoff	0.203***	0.115**	-0.062	-0.079*	-0.270***	-0.420***
17. PublicSME	0.023	0.021	0.097*	0.024	0.074†	0.002
18. UniTechCap	0.003	0.033	-0.024	0.269***	-0.089*	0.010
19. UnivSpec	-0.113**	-0.058	0.051	0.085*	0.202***	0.158***
20. UniSize	0.157***	0.072†	-0.019	-0.072†	-0.042	-0.086*
21. Germany	0.149***	0.142***	-0.086*	-0.060	-0.141***	-0.103*
22. Hochschule	-0.096*	-0.004	-0.054	-0.023	0.029	0.056
23. Polytechnic	-0.128**	-0.086*	0.053	0.055	0.264***	0.125**
24. UniPublic	0.007	-0.002	-0.008	0.045	0.036	0.022
25. UniAge	0.052	-0.030	0.048	-0.048	-0.011	-0.024
26. UnivRank	0.077†	-0.026	0.040	0.011	0.047	-0.041
27. UnivNobel	0.169***	0.001	-0.012	-0.147***	-0.063	-0.124**
28. UniPubThirdFund	0.093*	0.065	-0.034	-0.008	-0.014	-0.042
29. UniPrivThirdFund	0.082*	0.077†	-0.032	-0.054	-0.032	-0.066†
30. SMERegR&Dbus	0.059	-0.020	-0.088*	0.128**	0.012	0.015
31. SMERegR&Dhei	0.076†	-0.033	0.013	0.270***	-0.088*	0.002

Variable	16.	17.	18.	19.	20.	21.
17. PublicSME	0.030					
18. UniTechCap	0.137***	-0.031				
19. UnivSpec	-0.148***	-0.013	0.021			
20. UniSize	0.213***	0.025	0.465***	0.026		
21. Germany	0.217***	0.009	0.446***	-0.361***	0.393***	
22. Hochschule	-0.154***	-0.036	-0.195***	-0.123**	-0.502***	0.176***
23. Polytechnic	-0.188***	-0.001	-0.271***	0.597***	-0.165***	-0.608***
24. UniPublic	-0.062	-0.007	-0.043	-0.032	-0.206***	0.033
25. UniAge	0.055	-0.017	0.045	-0.065	0.379***	-0.009
26. UnivRank	0.144***	0.052	0.289***	0.283***	0.641***	-0.098*
27. UnivNobel	0.241***	-0.021	0.047	-0.101*	0.486***	0.274***
28. UniPubThirdFund	0.170***	0.021	0.417***	0.048	0.685***	0.444***
29. UniPrivThirdFund	0.154***	0.001	0.387***	0.031	0.720***	0.429***
30. SMERegR&Dbus	0.084*	-0.011	0.249***	-0.027	0.342***	0.363***
31. SMERegR&Dhei	0.124**	0.067†	0.300***	-0.194***	0.223***	0.415***

Variable	22.	23.	24.	25.	26.	27.
23. Polytechnic	-0.107**					
24. UniPublic	0.188***	-0.020				
25. UniAge	-0.271***	-0.159***	-0.059			
26. UnivRank	-0.490***	0.301***	-0.092*	0.252***		
27. UnivNobel	-0.165***	-0.168***	-0.031	0.369***	0.442***	
28. UniPubThirdFund	-0.248***	-0.109**	-0.121**	0.190***	0.273***	0.226***
29. UniPrivThirdFund	-0.256***	-0.084*	-0.220***	0.190***	0.357***	0.237***
30. SMERegR&Dbus	-0.012	-0.147***	0.002	-0.004	0.295***	0.322***
31. SMERegR&Dhei	-0.006	-0.340***	0.029	-0.002	0.089*	0.173***

Variable	28.	29.	30.
29. UniPrivThirdFund	0.863***		
30. SMERegR&Dbus	0.197***	0.302***	
31. SMERegR&Dhei	0.160***	0.134***	0.513***

TABLE 2.

Poisson multilevel regression models.

Dependent variable: JointPatImp	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
SMETechCap		-0.002 (0.005)	0.005 (0.005)	0.005 (0.005)	0.008† (0.005)	0.009† (0.005)
TechRel			-0.058 (0.318)	-0.080 (0.320)	0.022 (0.318)	-0.026 (0.316)
TechRel^2			-0.306 (0.402)	-0.550 (0.406)	-0.635 (0.404)	-0.575 (0.401)
PrevJointPats				0.139*** (0.023)	0.114*** (0.024)	0.121*** (0.024)
GeoDist					-0.001*** (0.000)	-0.001*** (0.000)
SMERegClosePatent						0.005** (0.002)
Claims	0.008** (0.003)	0.009** (0.003)	0.008* (0.003)	0.008* (0.003)	0.006† (0.003)	0.007* (0.003)
Scope	0.069*** (0.018)	0.069*** (0.018)	0.078*** (0.018)	0.071*** (0.018)	0.071*** (0.018)	0.038† (0.021)
FamSize	0.109*** (0.008)	0.109*** (0.008)	0.108*** (0.008)	0.105*** (0.008)	0.108*** (0.008)	0.112*** (0.008)
ScientRef	0.002* (0.001)	0.002* (0.001)	0.002* (0.001)	0.003*** (0.001)	0.002** (0.001)	0.002** (0.001)
BackCit	0.016*** (0.002)	0.016*** (0.002)	0.015*** (0.002)	0.015*** (0.002)	0.014*** (0.002)	0.011*** (0.002)
TeamSize	0.028† (0.015)	0.029† (0.015)	0.036* (0.015)	0.038* (0.015)	0.042** (0.015)	0.044** (0.015)
PubYear	-0.246*** (0.016)	-0.246*** (0.016)	-0.248*** (0.016)	-0.259*** (0.016)	-0.263*** (0.017)	-0.262*** (0.017)
SMESize	0.002* (0.001)	0.002* (0.001)	0.002* (0.001)	0.001 (0.001)	0.000 (0.001)	0.001 (0.001)
SMEAge	-0.003 (0.003)	-0.003 (0.003)	-0.003 (0.003)	-0.002 (0.003)	-0.001 (0.003)	-0.001 (0.003)
Spinoff	0.126 (0.079)	0.129 (0.079)	0.127 (0.079)	0.102 (0.081)	0.034 (0.082)	0.012 (0.082)
PublicSME	-0.029 (0.239)	-0.023 (0.241)	-0.079 (0.241)	0.029 (0.243)	-0.097 (0.259)	-0.041 (0.257)
UniTechCap	0.001 (0.001)	0.001 (0.001)	0.000 (0.001)	0.000 (0.001)	0.000 (0.001)	0.000 (0.001)
UnivSpec	1.172* (0.582)	1.175* (0.584)	1.164* (0.577)	1.165† (0.610)	1.341* (0.612)	1.475* (0.607)
UniSize	-0.294 (0.194)	-0.294 (0.194)	-0.283 (0.192)	-0.312 (0.194)	-0.266 (0.197)	-0.266 (0.198)
Germany	0.573* (0.292)	0.579* (0.291)	0.617* (0.290)	0.685* (0.292)	0.682* (0.298)	0.694* (0.298)
Hochschule	-0.419 (0.318)	-0.422 (0.318)	-0.434 (0.315)	-0.488 (0.318)	-0.491 (0.324)	-0.494 (0.325)
Polytechnic	-0.018 (0.619)	-0.024 (0.618)	-0.044 (0.613)	-0.123 (0.619)	-0.228 (0.631)	-0.202 (0.631)
UniPublic	0.299 (0.855)	0.294 (0.854)	0.282 (0.848)	0.252 (0.852)	0.285 (0.863)	0.315 (0.866)
UniAge	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)	0.002 (0.004)	0.001 (0.004)	0.000 (0.004)
UnivRank	0.067 (0.077)	0.067 (0.076)	0.072 (0.076)	0.078 (0.077)	0.077 (0.078)	0.073 (0.078)
UnivNobel	0.003 (0.012)	0.003 (0.012)	0.004 (0.011)	0.003 (0.012)	0.004 (0.012)	0.005 (0.012)
UniPubThirdFund	0.019 (0.074)	0.019 (0.074)	0.022 (0.074)	0.019 (0.074)	-0.003 (0.078)	-0.010 (0.078)
UniPrivThirdFund	-0.022 (0.062)	-0.022 (0.062)	-0.029 (0.062)	-0.028 (0.062)	-0.031 (0.065)	-0.022 (0.066)
SMERegR&Dbus	0.202*** (0.056)	0.202*** (0.056)	0.222*** (0.056)	0.222*** (0.058)	0.180** (0.062)	0.087 (0.068)
SMERegR&Dhei	-0.073 (0.131)	-0.073 (0.131)	-0.122 (0.133)	-0.121 (0.134)	-0.116 (0.156)	-0.106 (0.155)
FirmSector dummies	Included	Included	Included	Included	Included	Included
Constant	2.726* (1.229)	2.716* (1.227)	2.833* (1.218)	3.239** (1.23)	3.741** (1.293)	4.143** (1.297)
Level 2 (University) variance RE	0.531	0.527	0.517	0.527	0.547	0.546
LR test Poisson vs ML Poisson	247.23***	240.75***	244.49***	227.76***	234.86***	239.64***
Log Likelihood	-1429.099	-1429.031	-1424.134	-1407.278	-1388.841	-1384.014
Observations	630	630	630	630	630	630

Standard errors in parentheses. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

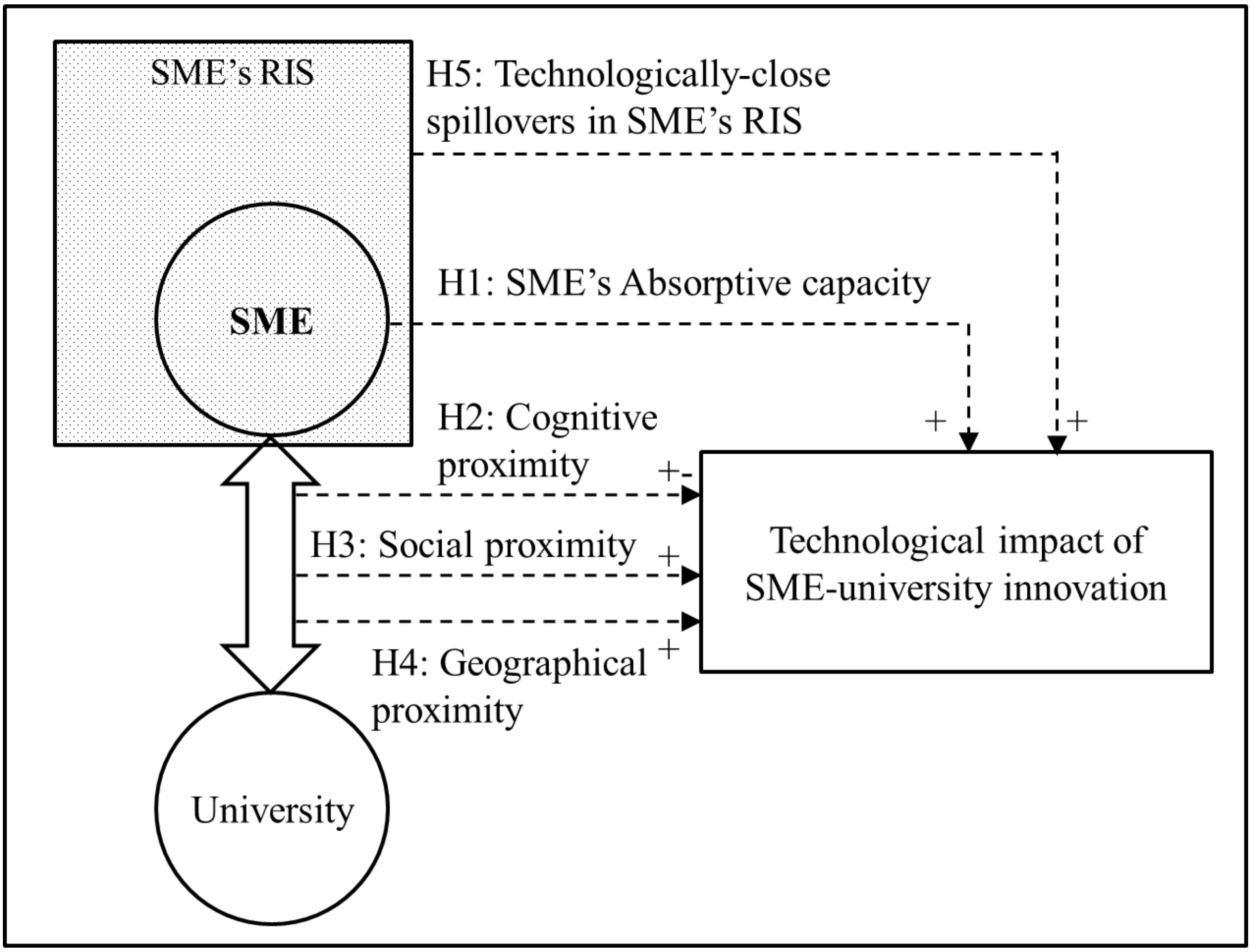

FIGURE 1.

Conceptual framework and hypotheses