R&D MANAGEMENT

How can open innovation support SMEs in the adoption of I4.0 technologies? An empirical analysis

Antonio Messeni Petruzzelli[1], Gianluca Murgia[2] and Adele Parmentola[3,*]

[1]Department of Mechanics, Mathematics, and Management, Polytechnic of Bari, Viale Japigia 182 – 70126, Bari, Italy. antonio.messenipetruzzelli@poliba.it
[2]Department of Information Engineering and Mathematics, University of Siena, Via Roma 56 – 53100, Siena, Italy. murgia@unisi.it
[3]Department of Management and Quantitative Studies, University of Naples Parthenope, Via Generale Parisi – 80132, Napoli, Italy. adele.parmentola@uniparthenope.it

The adoption of Industry 4.0 technologies may represent an interesting opportunity for many SMEs, but the implementation of these technologies may be hindered by the lack of several resources. In this paper, we investigate how Open Innovation (OI) can help SMEs in the adoption of I4.0 technologies. Specifically, we show that both OI breadth and depth may be positively related to the adoption of these technologies. Besides, we highlight how the effect of OI depth is positively moderated by the technological intensity of the industry where the SME operates. Our results offer theoretical contribution to the literature on SMEs' I4.0 technologies' adoption, as well as that on OI. Finally, our findings can support both managers and policy makers in the implementation of I4.0 technologies.

1. Introduction

The concept of Industry 4.0 (hereinafter I4.0), identified as the Fourth Industrial Revolution, was initially introduced in Germany in 2011 (Sanders et al., 2016) with reference to the integration of physical objects, human actors, intelligent machines, production lines, and processes across the whole value network, in the attempt to create a system in which all processes are integrated and share real-time information (Basl, 2017). I4.0 is based on the application of several technologies, such as Big Data and Analytics, Autonomous Robots, Simulation, Horizontal and Vertical System Integration, Industrial Internet of Things, Cyber-Security, Cloud, Additive Manufacturing, and Augmented Reality (Rüßmann et al., 2015). The integrated implementation of these different technologies can support the collection, transmission, analysis, and use of the data related to the activities of the firm's value chain (Lu and Weng, 2018; Frank et al., 2019). Kagermann et al. (2013) argue that I4.0 technologies can help companies to reorganize different activities, such as smart factories, cyber-physical systems, self-organization, new systems in distribution and procurement, new systems in the development of products and services, adaptation to human needs and corporate social responsibility. Indeed, these reorganizations can generate changes in companies' business processes, operational routines, and organizational capabilities (Müller et al., 2018). Consequently, not all companies show the same propensity to adopt these new solutions, hence differing greatly in terms of typology, number, and implementation degree (Frank et al., 2019).

In particular, some empirical studies argue that, compared to large companies and MNEs, SMEs are less inclined to adopt I4.0 technologies (Mittal et al., 2018; Horváth and Szabó, 2019). Even if I4.0 technologies can generate significant benefits for SMEs, as increasing flexibility, reducing costs, improving productivity and quality, and reducing delivery time (Ballestar et al., 2020; Buchi et al., 2020), their implementation often requires a reorganization of the business model (Müller et al., 2018; Agostini and Filippini, 2019) that many SMEs cannot effectively deal with because of their lack of human, financial, and managerial resources (Mittal et al., 2018; Horváth and Szabó, 2019). Indeed, this lack may reduce the ability of SMEs to correctly assess the benefits and costs of these new technologies, and to effectively plan and execute their implementation (Simmons et al., 2008; Nguyen et al., 2015).

In order to overcome this lack and effectively adopt I4.0 technologies, SMEs can leverage their external networks (Mittal et al., 2018). In fact, external partners can support SMEs, by increasing the awareness of the benefits and challenges of I4.0 technologies and providing useful knowledge and support for their implementation, thus reducing the reluctance to invest in them (Bourke and Roper, 2019). In particular, by adopting an Open Innovation (OI) approach (Chesbrough, 2003) SMEs can compensate for the scarcity of internal resources and competences, being hence able to strategically adopt new technological solutions (Lichtenthaler, 2008). OI can support the transformation of SMEs' processes and products provoked by the adoption of I4.0 technologies, because the required resources can be made available through the cooperation with other organizations (Terjesen and Patel, 2017). Although OI is commonly included in maturity models to assess a firm's readiness to I4.0 (e.g. Prause, 2015; Schumacher et al., 2016), its effect on the adoption of the related technologies has not been deeply analysed. Indeed, extant studies privilege the focus on analysing how I4.0 is able to support OI by fostering the collaboration at the micro-level (between people and machines), mid-level (across systems or vendors), and macro levels (across factories or companies) (Wollschlaeger et al., 2017; Mubarak and Petraite, 2020). Conversely, the opposite effect has been almost neglected by the management literature. Moreover, studies on SMEs and I4.0 technologies tend to focus on the obstacles that hamper their adoption without focusing on the strategy that they can adopt to overcome their problems (Horváth and Szabó, 2019). Accordingly, our paper aims at covering this gap by investigating how SMEs can adopt a larger number of I4.0 technologies by leveraging OI. To analyse OI, we consider the dimensions proposed by Laursen and Salter (2006), namely search breadth, which captures the number of different types of partners that firms rely upon for their innovative activities, and search depth, which instead captures the extent to which firms draw deeply from the different types of partners to innovate. In line with this theoretical approach, we analyse the effects of both OI dimensions on SMEs adoption of I4.0 technologies. Exactly, we assume that collaborations with different partners (breadth) may provide a large variety of, potentially complementary, resources that may support SMEs in dealing with the uncertain and complex implementation of I4.0 technologies (Gopalakrishnan and Damanpour, 1994). Conversely, we assume that only intense collaborations with these partners (depth) may support the absorption of some resources, like tacit knowledge, that may improve the implementation of I4.0 technologies (Terjesen and Patel, 2017).

The effectiveness of OI in supporting the adoption of I4.0 technologies by SMEs may be strongly affected by some environmental factors, like the technological level of the industry (Keupp and Gassmann, 2009). Indeed, SMEs operating in a high-tech industry may perceive a stronger urgency and higher benefits from the implementation of radically new technologies (Peltier et al., 2012). Besides, the technological level of the industry may affect SMEs' ability to search widely (breadth) and deeply (depth) (Laursen and Salter, 2006). Accordingly, we study also the moderating effect of the industry's technological intensity on the relationship between both OI dimensions and I4.0 adoption.

In sum, our paper aims at answering to the following research questions: To what extent does OI strategies support SMEs' adoption of I4.0 technologies?

To answer our research question, we conducted an econometric analysis on a sample of 107 SMEs in the Campania region, in the South of Italy. Campania region has been classified by European Union as a low-moderate innovator, since the regional economy is mainly based on SMEs operating in both high-tech and low-tech industries. Moreover, the regional government has recently invested in relevant policies aimed at supporting the local firms' digitalization. Consequently, Campania region represents an interesting territory to catch the complexity of SMEs' behaviors towards the adoption of I4.0 technologies. Through a survey targeted to the CEOs, we gathered information on SMEs' cooperation with partners and their adoption of I4.0 technologies, other than on the firm and CEO's profile.

Our results show that OI is related to SMEs' I4.0 implementation. Specifically, both OI breadth and depth may favor the adoption of I4.0 technologies by SMEs. Besides, the technological intensity of the industry may positively moderate the effect of OI depth on I4.0 implementation.

These results may support a better understanding of I4.0 adoption by SMEs, thus providing a further contribution to the literature on the technology adoption by SMEs. In particular, our results may provide further light on the potential benefits of both OI dimensions especially for SMEs, since, until now, the managerial literature has given a little attention on their impact on technology adoption. Besides, our paper shows how the impact of OI on I4.0 adoption is influenced by the technological intensity of the SME industry, hence supporting a more complete understanding of the role of the industry on the technology adoption by the firms (Pavitt, 1984). Our paper can also give some suggestions to managers interested in adopting I4.0 technologies, who may reduce the related cost and risk by cultivating their collaboration network. Finally, our results can support the definition of more effective policies by policy-makers who aim at increasing the diffusion of I4.0 technologies in local SMEs.

The remainder of the paper is organized as follows. Section 2 explores the links between OI and I4.0 implementation and develops the research hypotheses. Then, Section 3 presents methodology, data, and empirical approach. Finally, Section 4 discusses the results, and Section 5 draws main conclusions and implications.

2. Theoretical background

OI implies an extensive use of inter-organizational relationships to increase the economic return of the firm's innovative activities. This result may be obtained by supporting the firm's capabilities to in-source external ideas and resources, to co-develop new products and processes with external partners, and to market internal ideas that fall outside the firm's current business model (Enkel et al., 2009). Using external knowledge sources can help companies not only having access to new knowledge, but also to favor the assimilation of the future one by increasing their potential absorptive capacity (Zahra and George, 2002). At this aim, the innovating firm has to establish relationships with a variety of partners, such as universities and research institutions (Perkmann and Walsh, 2007), suppliers (Emden et al., 2006), and users (West and Lakhani, 2008).

OI practices are highly relevant for SMEs, since they struggle with the liability of smallness, which means facing resource constraints and scale limitations, and having fewer technological assets to bargain with (Narula, 2004; Dahlander and Gann, 2010). Therefore, smaller firms have to open up more than their larger counterparts to acquire the necessary resources and capabilities for the development of either product or process innovations. The argument above is particularly true for the innovations related to the adoption of I4.0 technologies (Schneider, 2018), which often require heavy investments, are characterized by a high level of variety and technical complexity, and may trigger several organizational challenges in their implementation (Moeuf et al., 2018). SMEs are further affected by these challenges while adopting I4.0 technologies, because of their lack of financial, human, and managerial resources (Horváth and Szabó, 2019).

Human resources are crucial for SMEs, because they often struggle to find employees with appropriate competences for the implementation of I4.0 technologies. At an HR level, I4.0 propagates the idea of workers that increasingly will focus on creative, innovative, and communicative activities (Erol et al., 2016). Indeed, all the challenges that I4.0 poses require continuous innovation and learning, which depend on people capabilities (Shamim et al., 2016). Therefore, I4.0 requires a labor force with high skill levels (Kagermann et al., 2013; Balasingham, 2016; Sirotek, 2016).

Financial resources and profitability pose a high barrier for SMEs, since these companies have often a lack of these resources, thus being unable to invest in new technologies. A huge amount of investments is required to embrace I4.0 (Davies, 2015). These financial efforts can be particularly overwhelming for SMEs that often do not have the resources required to pursue these investments. The recent contribution by Moeuf et al. (2018) shows that carrying out I4.0 projects in SMEs is still a cost-driven initiative and the business transformation advantages are still not demonstrated (Sommer, 2015).

In addition, the introduction of I4.0 technologies requires also managers that are able to identify the additional business opportunities offered by these solutions. Past research has proved that CEO's support is fundamental in the adoption of the new technologies (e.g. Premkumar and Roberts, 1999), in the success of the innovative projects (Young and Jordan, 2008), and for the integration of technologies into business processes, which in turn facilitates the adoption and usage of I4.0 technologies (Ooi et al., 2018). Evolving digital technologies allows new ways to collect and analyze data, which might contribute to improving company's performance, but to achieve this result managers need to change their decision-making culture and to increase the degree of collaboration in the decision-making process (Frisk and Bannister, 2017). In line with previous theories, some managers' characteristics as high education level, lower age, and tenure may influence the manager's ability to drive the cultural change imposed by I4.0 technologies because they are associated with higher risk propensity and openness to new practices (Datta et al., 2003).

Having fewer resources, SMEs face some difficulties in exploiting the potential of I4.0 transition. For these reasons, many of them have established a set of relationships with external partners, not only suppliers and customers, but also technology providers and innovative organizations to support the adoption of I4.0 technologies (Tortorella and Fettermann, 2017; Müller et al., 2018). In particular, SMEs can adopt OI behaviors aiming at improving their search capabilities, which may enhance their ability to find the necessary external resources to correctly assess the benefits and costs of I4.0 technologies, and to effectively plan and execute their implementation (Nguyen et al., 2015). The variety of useful sources, from which firms can acquire the necessary resources (Leiponen and Helfat, 2010), requires that SMEs identify an effective OI to search and connect with them.

In this sense, Laursen and Salter (2006) have emphasized how OI strategies can be characterized by a specific level of two search dimensions, e.g. search breadth, reflecting the number of different external sources that firms rely upon for their innovative activities, and search depth, which indicates the extent to which firms draw deeply from the different external sources for innovating. Van Wijk and colleagues (2001) confirm that the breadth and depth of knowledge exposure positively influence also the future firm's propensity to explore new knowledge. Clearly, firms acquire knowledge from different sources in their environment, and the diversity of these sources significantly influences the development of future capabilities, like their potential absorptive capacity (Zahra and George, 2002). The link between these OI dimensions and I4.0 adoption has been recently investigated by Lorenz et al. (2020) that conduct an empirical analysis on a sample of Swiss firms. Nevertheless, the results of this latter paper cannot be easily applied to SMEs, since their sample is made up also by large firms and they do not include several control variables that, in accordance with the previous literature, may affect the technology adoption by SMEs, such as their absorptive capacity, the level of expertize of their workforce, and the personal characteristics of the entrepreneur.

The analysis of the relationship between OI and I4.0 adoption still lacks considering that both can be affected by some environmental characteristics. In particular, many empirical works reveal how the adoption of I4.0 technologies is also strongly dependent on the specific industry in which the company operates (Akdil et al., 2018). Some companies' characteristics that are strictly linked to their industry, such as the level of research and development, the nature of products, and the technological knowledge (Pavitt, 1984), have been proved to affect the firm's maturity in embracing the I4.0 paradigm (Mittal et al., 2018). In particular, in order to adopt I4.0 technologies, SMEs operating in low-tech industries need to change their business model in a more radical way than SMEs working in high-tech industries (Agostini and Filippini, 2019). Indeed, low-tech SMEs face higher implementation barriers because of the more limited technical competences of their employees (Mourtzis et al., 2018). Similarly, their managers are more adverse to change, since they usually work in a less dynamic environment (Wolter et al., 2015). Consequently, the collaboration with other organizations may be particularly important for SMEs working in low-tech industries, but its effect on the adoption of I4.0 technologies is not so obvious, because their limited absorptive capacity can affect their ability to assimilate new knowledge.

Indeed, the technological intensity of the industry affects also the effective implementation of OI practices. Some studies reveal that high-tech and low-tech industries create distinct contexts for knowledge creation and sharing, thereby benefiting from different levels of OI (Keupp and Gassmann, 2009; Denicolai et al., 2014). In particular, Laursen and Salter (2006) point out that the relationship between OI breadth and depth, and companies' performance is influenced by the degrees of complexity in industrial knowledge bases (see also Katila and Ahuja, 2002). Indeed, the specific process of knowledge creation and sharing that characterizes each industry may affect not only the level of R&D expenses (Covin et al., 1990), but also the sources of competitive advantage (Alcalde Heras, 2014; Martín-de Castro, 2015), and the risks of organizational failure (George et al., 2001). All these factors may influence the SMEs' propensity and effectiveness to adopt OI based on wide and/or intense relationships with external partners. For this reason, we aim at filling an existing gap in the literature by investigating the moderation exerted by the technological intensity of the SMEs' industry on the relationship between OI and I4.0 technologies adoption.

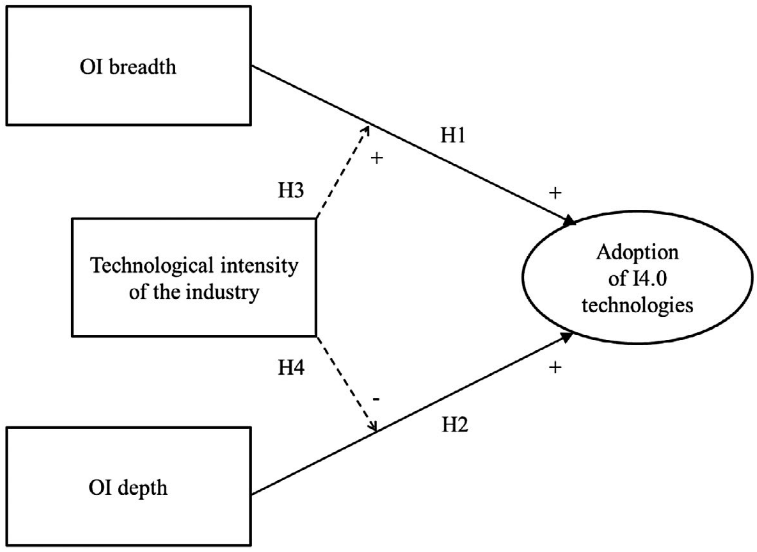

Figure 1. Description of the hypotheses.

In sum, as shown in Figure 1 and discussed with more details in the next sections, we hypothesize that OI, in both its dimensions (breadth and depth), has a positive impact on I4.0 technologies adoption by SMEs. Finally, we hypothesize a different moderation effect of the technological intensity of the SME industry on the two OI dimensions.

2.1. Hypotheses development

External knowledge sourcing may span various kinds of external innovation partners, which can in turn provide access to very different and potentially complementary resources (von Hippel, 1998; Sidhu et al., 2004). Thus, a higher OI breadth may help SMEs to reduce the barriers to I4.0 implementation.

For example, cooperation with universities can help SMEs to overcome the barriers linked to the qualification of employees. Moreover, workshops and skill-oriented seminars, co-developed with universities, may help the SMEs' employees in exchanging their viewpoints and insights with the other participants (Kiel et al., 2017). In addition, relationships with research centers, technology parks, and innovation agencies can support SMEs in accessing knowledge, resources, and assets, but also in promoting the exchange of good practices, success stories, and approaches to overcome a negative managerial attitude toward the adoption of new technologies (Zangiacomi et al., 2020). Besides, networking with suppliers and customers is essential to better understand and implement the I4.0 technologies, since the contacts with these actors may increase the SME's awareness of the benefits and challenges of these technologies and provide inspiration and support for their implementation (Jones et al., 2014; Bourke and Roper, 2019). Also horizontal collaborations with competitors and other firms are useful. Indeed, being investments in digital technologies high and often risky, SMEs can share platforms for I4.0 implementation with other players (Shin et al., 2014); hence, reducing their financial resource gap. Moreover, advice from professional consulting companies can be useful for small business management, especially when they do not have sufficient experience or understanding of I4.0 technologies (Nguyen et al., 2015).

These examples show how SMEs can exploit their collaborations, with other external actors to access useful resources and knowledge that may support the implementation of I4.0 technologies. Moreover, collaboration with a wide range of partners (high OI breath) can help SMEs to access an adequate set of different and complementary resources (Gopalakrishnan and Damanpour, 1994). For this reason, we assume that SMEs that cooperate with a wide range of partners are in a better position to adopt I4.0 technologies. Thereby, we formulate the following hypothesis:

H 1 SME's open innovation breadth is positively related to the intensity of I4.0 technologies' adoption.

Usually SMEs tend mainly to adopt only specific technologies, like cloud computing (Alcácer and Cruz-Machado, 2019), while other technologies, like Autonomous Robots, Horizontal and Vertical

System Integration, and Industrial Internet of Things are still far from being widely adopted. Indeed, the implementation of these technologies needs a more radical redesign of SMEs, hence requiring the acquisition of particular knowledge and the development of capabilities that often these firms do not possess (Torn and Vaneker, 2019; Won and Park, 2020). In order to access and develop these resources, SMEs cannot simply increase the range of external partners, thus pursuing OI breadth, but they have to establish an intense cooperation with these actors, thus pursuing OI depth (Kobarg et al., 2019). Only intense relationships can support the assimilation of resources, like complex and tacit knowledge, and the triggering of learning processes that are necessary to improve SME capabilities (Terjesen and Patel, 2017).

For example, in some case SMEs need to develop intense relationships with the providers of I4.0 technologies, in order to assimilate the external knowledge to use that solution. Similarly, the improvement of the level of expertize of the workforce, which is one of the most critical success factors for technology adoption in SMEs (Nguyen et al., 2015), can be supported by an active cooperation with universities and other educational organizations aiming at developing educational programs targeted to the SME's future employees. These programs may cover fields like mathematics, engineering, programming, data analysis and processing, which are fundamental to sustain the implementation of I4.0 technologies (Giotopoulos et al., 2017). Even intense cooperation with competitors enables firms to access to technological abilities that can be difficult, time-consuming, and costly to develop alone (Shin et al., 2014).

More than anything, SMEs tend to develop intense relationships with suppliers and customers, since their importance for the development and marketing of products and/or services (Nguyen et al., 2015). Intense vertical cooperation may enable interactive learning processes among the actors in the supply chain that may support SMEs in the assimilation of useful knowledge for the implementation of I4.0 technologies (Thomä and Zimmermann, 2020). The importance of intense vertical cooperation of SMEs is further enhanced by the complementarities among the I4.0 technologies implemented by the different actors in the supply chain (Dong et al., 2009; Hahn, 2020). Indeed, I4.0 technologies can help SMEs to manage effectively the relationships along the supply chain, but at the same time require that all the supply chain members coherently invest in these new technology solutions (Dalmarco and Barros, 2018). Consequently, SMEs that have strong and long term relationships with other partners in the supply chain are more inclined to invest in I4.0 technologies because they are in a better position to repay the investments compared to SMEs that have only occasional relationships.

In other words, the implementation of I4.0 technologies requires that SMEs not only cooperate with many partners, but also claim for intense and not occasional collaborations. Only intense cooperation can in fact help SMEs to have enough time to acquire the necessary knowledge to successfully adopt I4.0 technologies. Hence, we formulate the following hypothesis:

H 2 SME's open innovation depth is positively related to the intensity of I4.0 technologies' adoption.

Both the adoption of I4.0 technologies by SMEs and the OI dimensions may be influenced by some environmental factors, like the technological intensity of the industry. For this reason, we suppose that this latter variable may have a specific moderating effect on each of the OI dimensions.

In fact, high-tech and low-tech industries are characterized by distinct contexts for knowledge creation and sharing, thus benefiting from different degrees of OI breadth (Denicolai et al., 2014). High-tech industries are characterized by high levels of technological sophistication and extensive R&D activities (Covin et al., 1990). Firms of these of high-tech industries, such as pharmaceuticals, genetics biotechnology, and nanomaterial, base their innovation strategy on Science and Technology Innovation (STI) mode of innovation that refers to the way firms use and develop scientific knowledge to introduce new products and technologies within the firm, through investments on formal R&D. The knowledge generated through the STI mode is mostly "analytical knowledge" (Moodysson et al., 2008), which includes scientific principles, discoveries, and formulas, and, to a lesser extent, "synthetic knowledge", that is, recombination of different analytical knowledge bases with a practical or problem-solving purpose (Parrilli and Heras, 2016). Consequently, firms, especially SMEs, working in these industries require a broad range of external partners to remain competitive in their rapidly changing business environments (Alcalde Heras, 2014; Martín-de Castro, 2015) and often collaborate with science-based partners, like universities, research centers, and innovative companies, due to their need to acquire a heterogeneous pool of resources and capabilities (Jensen et al., 2007; Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013). Thus, high-tech firms are more inclined to enter into multiple alliance agreements to overcome uncertainty and optimize risks of organizational failure, and to access multiple knowledge and skills (George et al., 2001).

On the contrary, firms operating in low-tech industries exhibit lower levels of external search breadth (Laursen and Salter, 2006). Innovation in low-tech industries is driven by customer-related and practical knowledge (Hirsch-Kreinsen, 2008; Heidenreich, 2009), and it is usually not related to the latest scientific or technological discoveries (Som, 2012). Low-tech companies have not enough resources and competences to search for and profit from a wide range of external partners (Aslesen and Freel, 2012); so, it is more difficult for them to enlarge their partners' network also for the adoption of I4.0 technologies. Furthermore, high-tech firms have more resources to dedicate to partners' scanning and selection, so it is simpler for them to cooperate with a large variety of subjects and use these collaborations also to support the adoption of I4.0 technologies. Moreover, they already cooperate with partners like universities and high-tech service providers that can be useful to implement I4.0 solutions.

Consequently, we image that, starting from the same level of breadth, high-tech SMEs are more able to take advantages by extensive cooperation, because they are more used to establish relationships with a wide range of partners, and can leverage on the existing cooperation also to acquire knowledge on I4.0 technologies. Therefore, we believe industry's technological intensity moderates the relationship between OI breadth and the adoption of I4.0 technological solutions. Consequently, we formulate the following hypothesis:

H 3 The level of technological intensity of SMEs' industry positively moderates the relationship between open innovation breadth and the intensity of I4.0 technologies' adoption.

Keupp and Gassmann (2009) have found that industrial differences matter in the degree of OI depth; hence, these reveal that low-tech companies tend to have higher depth than firms in high-tech industries. Indeed, firms working in low-tech industries cooperate with a low range of partners, thus showing a strong dependence on the provision of their equipment and knowledge (Heidenreich, 2009). These companies adopt the Doing Using Innovation (DUI) mode emphasizing experience-based innovation that relies on learning-by-doing, by-using, and by-interacting. Here, innovation is mostly generated by the capacity of the firm to develop informal and formal learning, and interactions both within the firm and with suppliers, customers and competitors (Hervas-Oliver et al., 2011; Fitjar and Rodríguez-Pose 2013). These external knowledge sources allow low-tech firms to access knowledge that would be difficult to obtain elsewhere, and to better understand new markets and demand trends (Hirsch-Kreinsen, 2008). To be effective, these results ask low-tech companies to cooperate with these partners implementing close and strong relationships (Pellegrini et al., 2014). Consequently, despite the fact that low-tech firms tend to cooperate with a low variety of partners, they prefer to implement intense relationships with these partners. As explained above, the establishment of intense relationships, especially with the partners along the supply chain, is also a driver for the successful implementation of I4.0 technologies, since it helps companies to gain complementary resources. Consequently, low-tech SMEs may be more able to take advantage of their deep relationships also in the implementation of I4.0 technologies. Hence, we formulate our last hypothesis as follows:

H 4 The level of technological intensity of SMEs' industry negatively moderates the relationship between open innovation depth and the intensity of I4.0 technologies adoption.

3. Data and methods

3.1. Sampling strategy

To test our hypotheses, we collected evidence on the adoption of I4.0 technologies from a firm's perspective, at the individual firm level. To ensure internal validity, we selected a specific regional context (Campania, in Southern Italy) to control for normative environment, contextual munificence, and entrepreneurial opportunities (Beckman and Burton, 2008). According to EU Regional Innovation Scoreboard (Hollanders et al., 2019), Campania is considered a low moderate innovative regions, with an R&D expenditure of business sector of 35% of GDP. The non-R&D expenditure is about 61% of the GDP, thus confirming that Campania has a prevailing DUI mode (Parilli et al., 2020). These latter data are confirmed by the fact that marketing and organizational innovations prevail on product and process innovations (50% vs 42%) (Hollanders et al., 2019). Campania region is characterized by a large prevalence of SMEs, since they employ more than 90% of the regional workforce (ISTAT, 2019). SMEs are mainly concentrated in low-tech industries since only 38% of the workforce is employed in high-tech manufacturing and knowledge-intensive service. At the same time, Campania is the first region in Southern Italy for number of innovative startups demonstrating a change in the productive system toward more innovative companies. On the other hand, Campania SMEs manifest a low tendence in cooperation (46% of SMEs realize in-house innovative activities, while only 10% cooperate with others to generate innovations) (Hollanders et al., 2019). In accordance with a study of the Italian Ministry of the Economic Development (MISE, 2018), Campania is also one of the Italian regions with the highest percentage of firms that are moving toward I4.0. Indeed, in the last decade, the Regional Government has launched a number of plans and ad-hoc interventions to stimulate firms' digitalization and the adoption of I4.0 technologies. Consequently, considering the peculiar structure of the regional economy mainly based on SMEs operating in both high-tech and low-tech industries and the recent regional policies aiming at accelerating digitalisation, Campania region represents an interesting territory to catch the complexity of SMEs behaviors toward the adoption of I4.0 technologies.

To build our sample, we contacted the five provincial sections of the Confindustria Campania (the Campania regional section of the Italian National Industrial Association) and asked them to provide contact information for all their affiliated firms. From this list that contains companies of different dimensions and working in different industries, we selected only SMEs defined according to European Union as companies that employed less than 250 persons and had a turnover lower than 50 million of euros. We contacted these firms and sent them an online structured questionnaire addressed to their CEO. After three rounds of e-mails and phone calls, we collected a total of 107 questionnaires. The data collection started in November 2018 and was completed by the end of February 2019. Our final sample is made up of 37 micro, 33 small, and 37 medium firms, while only 9 firms in the sample are younger than 5 years. They are mainly led by entrepreneurs older than 40 years (in 63% of the firms our sample), with an organizational tenure longer than 10 years (in 52% of the firms), and with a university degree (in 74% of the firms).

3.2. Questionnaire

We developed a survey to collect primary data directly from the SMEs' CEOs. We gathered information on firms' characteristics, including age, R&D investments, employees' qualification, and on the entrepreneurs' personal characteristics, such as education, age, and tenure. The questionnaire was divided into sub-sections (CEO profile, company's characteristics, I4.0, open innovation) to take into account the different aspects considered by literature on open innovation, I4.0, and SMEs competitiveness. In particular, for I4.0 we have followed the approach adopted by some studies like Buchi et al. (2020) asking SMEs about the frequence of the adoption of different I4.0 technologies. These technologies are classified following Rüßmann et al. (2015), as done also by Alcácer and Cruz-Machado (2019). Differently from other studies (Agostini and Filippelli, 2019), we have asked companies about the effective adoption of the technologies.

In addition, considering the literature that affirms that some companies' characteristics (financial resources, employees qualification, company absorptive capacity) may affect the adoption of I4.0 technologies, we have dedicated a section of the questionarie to this latter aspect following the approach proposed by Horváth and Szabó (2019). Among the companies's characteristics, we considered their industry, for which we adopt an approach similar to that implemented by the European Community Innovation Survey (CIS). Moreover, especially in SMEs, companies behavior toward change and innovation is strongly influenced by some CEO's characteristics, such as age, tenure, and education. Thus, according to upper echelon theory, we have explored this aspect in the questionnaire with specific questions (Wiersema and Bantel, 1992; Datta et al., 2003). Concerning OI, we have used the same approach of Laursen and Salter (2006) to define the variety of partners and the intensity of cooperations with them.

Finally, we conducted a small-scale field pre-test to obtain feedback about question phrasing, time needed to respond, and whether the questionnaire covered all the necessary areas to meet the objective of the research. To this purpose, the questionnaire has been addressed to a panel of 10 entrepreneurs, who provided valuable feedback to improve the clarity of the questions. No major inconsistencies emerged. To triangulate the data, we verified the validity of firm-level information by using the AIDA database.

3.3. Variables

In order to test our hypotheses, we included in our models several dependent, independent, moderator, and control variables. These variables are measured by coding the answers provided by the CEOs to our questionnaire. The description of the operationalization of these variables is presented below and summarized in Table 1.

3.3.1. Dependent variable

The intensity of I4.0 technologies' adoption was measured by using a variable (*I4.0adoption*) that counts the number of fundamental I4.0 technologies already

Table 1. Description of the variables

Name	Description	Range	Questions	References
I4.0adoption	Number of fundamental I4.0 technologies already implemented by the SME	0 (no I4.0 technologies adopted by the SME) – 9 (all the fundamental I4.0 technologies adopted by the SME)	Q12; Q13	Buchi et al. (2020), Rüßmann et al. (2015), Alcácer and Cruz-Machado (2019)
OIbreadth	Number of different types of organizations that collaborate with the SME	0 (no collaboration with any type of external organizations) – 8 (collaboration with all the possible different types of external organizations)	Q14	Laursen and Salter (2006)
OIdepth	Number of different types of organizations that collaborate intensively ("very often") with the SME	0 (not intense collaboration with any type of external organizations) – 8 (intense collaboration with all the possible different types of external organizations)	Q14	Laursen and Salter (2006)
TechIntIndustry	Technological intensity of the SME industry	1 (manufacturing SMEs with a NACE code classified as high-technology or medium-high-technology, or service SMEs with a NACE code classified as knowledge-intensive services), 0 otherwise	Q8	Community Innovation Survey, Laursen and Salter (2006)
SMEAge	SME's age at the time of the survey	1–284	Q6	Kelly and Amburgey (1991)
SMESize	SME's size at the time of the survey	0 (micro firm), 1 (small firm), 2 (medium firm)	Q7	European Union recommendation 2003/361
SMER&DExp	Percentage of the SME's R&D expenses on total revenues	0 (percentage lower than 5%), 1 (between 5% and 10%), 2 (between 11% and 20%), 3 (between 21% and 30%), 4 (higher than 30%)	Q10	Zahra and George (2002)
SMEPatents	Number of the patents filed by the SME in the last 10 years	0 (no patent), 1 (1 patent), 2 (from 2 to 4 patents), 3 (more than 4 patents)	Q9	Zahra and George (2002)
STEMEmpl	Percentage of SME employees with a STEM degree	0 (percentage lower than 5%), 1 (between 5% and 10%), 2 (between 11% and 20%), 3 (between 21% and 30%), 4 (between 31% and 50%), 5 (higher than 50%)	Q11	Eller et al. (2020), Horváth and Szabó (2019), Agostini and Filippelli (2019), Giotopoulos et al. (2017)
CEOEduc	Education level of SME's CEO	5 (PhD.), 4 (MBA), 3 (MsC.), 2 (BsC.), 1 (High school diploma), 0 (Lower educational level)	Q3	Wiersema and Bantel (1992), Li et al. (2018)
CEOAge	Age of SME's CEO at the time of the survey	25–76	Q2	Datta et al. (2003)
CEOTenure	Organizational tenure of SME's CEO at the time of the survey	1–49	Q4	Datta et al. (2003)

implemented and used by each SME. Specifically, the list of fundamental I4.0 technologies corresponds to the nine building blocks of I4.0 (Big Data and Analytics, Autonomous Robots, Simulation, Horizontal and Vertical System Integration, Industrial Internet of Things, Cyber-Security, Cloud, Additive Manufacturing, Augmented Reality) presented by Rüßmann et al. (2015) and adopted also by Alcácer and Cruz-Machado (2019). The integrated implementation of different I4.0 technologies allows SMEs to take full advantage of the digitalization of their value chain activities (Lu and Weng, 2018; Frank et al., 2019). For example, data collected by Industrial Internet of Things technologies can be efficiently and safely shared in the value network by using Horizontal and Vertical System Integration, Cyber-Security, and Cloud technologies. These data can be analysed by using Big Data and Analytics technologies, and finally used in product development and manufacturing thanks to Additive Manufacturing, Augmented Reality, Simulation, and Autonomous Robots.

3.3.2. Independent variables

We measured OI breadth (*OIbreadth*) and OI depth (*OIdepth*) by using the same approach proposed by Laursen and Salter (2006). Specifically, *OIbreadth* was computed as the number of different types of organizations (suppliers, customers, competitors, financial companies, consulting companies, other private companies, universities and research centres, other public organizations) that collaborate with the SME. Similarly, *OIdepth* considers the SME collaborations with the same types of organizations used for *OIbreadth*, but, differently from this latter variable, evaluates the intensity of these collaborations. Thus, *OIdepth* is computed as the number of different types of organizations that collaborate intensively ("very often") with the SME.

3.3.3. Moderator

In order to test the last hypotheses, we computed a binary variable (*TechIntIndustry*), which is equal to 1 when the SME operates in a high-tech industry, 0 otherwise. Exactly, we classified the NACE Rev. 2 code of each SME in accordance with the Eurostat indicators on high-tech industry and knowledge. This sectorial classification is based on the level of technological intensity, measured as the ratio of R&D expenditure to value added, coherently with the classification used by Laursen and Salter (2006) in emphasizing the effect of industry on search breadth and depth. Specifically, we considered as high-tech industries all the manufacturing sectors classified by Eurostat as either high- or medium-high-technology, and all the service sectors classified as knowledge-intensive services.

3.3.4. Control variables

We included in our analysis several variables that, in accordance with the literature, may affect the adoption of new technologies by the SMEs. Specifically, we considered some variables related to some general characteristics of the SME, while others more focused on its human resources.

Concerning the general characteristics of the SME, we included its age at the time of the survey, by using the discrete variable *SMEAge*. Indeed, compared to younger firms, older firms may be more affected by organizational inertia (Kelly and Amburgey, 1991) that may reduce their propensity to adopt I4.0 technologies, since their radical impact on the SME's internal competences and routines. We also controlled for the size of the SME, since smaller SMEs may be characterized by a lower adoption of digital technologies because of a lack of human and financial resources (Arbore and Ordanini, 2006; Horváth and Szabó, 2019). The related variable *SMESize* classified SMEs into micro, small, or medium firms and took into account both SMEs' employees and financial assets. Besides, we included also two variables that measure different dimensions of the SME's absorptive capacity, which may influence its ability to assimilate and reuse external knowledge useful for the effective adoption of I4.0 technologies (Cassetta et al., 2020). Specifically, in line with Zahra and George (2002), we considered variables related to both potential and realized absorptive capacity. In order to measure potential absorptive capacity, that is the capability to assimilate external knowledge, but not to exploit it, we added the percentage of the SME's R&D expenses on total revenues (*SMER&DExp*). In order to measure realized absorptive capacity, that is the observed capacity to exploit external knowledge, we added the number of the patents filed by the SME in the last 10 years (*SMEPatents*).

The SME's ability to adopt I4.0 technologies strongly depends on the digital skills of its human resources (Agostini and Filippelli; 2019; Horváth and Szabó, 2019; Eller et al., 2020). Since the development of these skills is specifically promoted by an education in scientific fields (Giotopoulos et al., 2017), we measured the percentage of employees with a STEM degree by using the variable *STEMEmpl*. While the education of the employees may constraint the adoption of I4.0 technologies in an SME, the education of its CEO may have even a stronger impact, because of her/his leading role in the SME's digital transformation (Li et al., 2018). Indeed, in line with Upper Echelons Theory, the presence of a CEO with a high education level may positively affect such organizational change, because it may improve the SME's information search and processing (Wiersema and Bantel, 1992). For this reason, we added the discrete variable *CEOEduc* that measures the highest education level of the CEO. Other than the education level, other CEO demographics have been considered by Upper Echelons Theory among the potential determinants of organizational change, such as the CEO's age and tenure. In particular, CEO's lower age and organizational tenure are associated with higher risk propensity and openness to new practices (Datta et al., 2003). Hence, we added also two variables, *CEOAge* and *CEOTenure*, which respectively measure the age and the organizational tenure of the CEO at the time of the survey.

3.4. Estimation method

In order to test our hypotheses, we tested five different regression models. Specifically, because of the count nature of our dependent variable (*I4.0adoption*), we adopt a negative binomial regression approach. Differently from Poisson regression, negative binomial regression can be appropriate even in presence of over-dispersion. We computed our regression models by assuming robust standard errors so to deal with heteroskedasticity (White, 1980).

In order to solve possible issues due to multicollinearity, we checked the value of variance inflation factor that resulted below the cut-off value of 10 for all the variables included in our models (Neter et al., 1996).

4. Results

Before analyzing the results of the regression models, we briefly present some descriptive statistics of our variables. Concerning the single I4.0 technologies, the most adopted one is Cloud (implemented by 33.6% of the SMEs in our sample), followed by Big Data and Analytics (18.7%), Autonomous Robots (17.8%), Additive Manufacturing (15.9%), Cyber-Security (9.3%), Augmented Reality (8.4%), Industrial Internet of Things (2.8%), Horizontal and Vertical System Integration (1.9%), while none adopted Simulation.

As shown in Table 2, all the pairwise correlations among the variables included in our models are limited. The highest correlation is between the two independent variables *OIbreadth* and *OIdepth* (0.435), while, among the control variables, *STEMEmpl* is correlated with both *I4.0adoption* (0.406) and *TechIntIndustry* (0.431).

Table 2. Descriptive statistics and pairwise correlation matrix (number = 107)

Variable	Mean	SD	1	2	3	4	5
1. I4.0adoption	1.084	1.214					
2. OIbreadth	5.897	2.000	0.276**				
3. OIdepth	1.121	1.534	0.253**	0.435***			
4. TechIntIndustry	0.383	0.488	0.263**	0.244*	0.202*		
5. SMEAge	30.234	40.194	0.064	−0.098	−0.127	−0.149	
6. SMESize	1.000	0.836	0.130	0.090	−0.029	−0.069	0.226*
7. SMER&DExp	0.963	1.181	0.147	0.314**	0.294**	0.270**	−0.126
8. SMEPatents	0.467	0.894	0.250**	0.128	−0.118	−0.112	0.078
9. STEMEmpl	1.477	1.814	0.406***	0.269**	0.227*	0.431***	−0.110
10. CEOEduc	2.785	1.401	0.161†	0.164†	0.074	0.246*	0.072
11. CEOAge	45.907	11.560	0.088	0.030	0.075	0.217*	−0.075
12. CEOTenure	14.636	10.945	0.011	−0.091	−0.128	0.023	0.189

Variable	6	7	8	9	10	11
7. SMER&DExp	−0.268**					
8. SMEPatents	0.354***	−0.019				
9. STEMEmpl	0.025	0.286**	0.088			
10. CEOEduc	0.266**	0.155	0.126	0.230*		
11. CEOAge	0.052	−0.049	0.059	0.193*	−0.127	
12. CEOTenure	0.183	−0.170	0.084	0.118	−0.105	0.518

†$P < 0.10$, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Table 3 illustrates the output of the negative binomial regression models. Model 1 is the baseline model, since it contains only the control variables. Model 2 includes also the effect of the *OIbreadth*, while Models 3 includes the effect of *OIdepth*. Finally, Model 4 adds also the moderation effect of *TechIntIndustry* on *OIbreadth*, while Model 5 adds the moderation effect of the moderator on *OIdepth*.

The baseline model shows that the adoption of I4.0 technologies is positively and significantly affected by both the number of patents filed by the SME (β = 0.198, P < 0.1) and the percentage of its employees with a STEM degree (β = 0.215, P < 0.001). While the effect of *STEMEmpl* is stable and significant also in the other regression models, the coefficient related to *SMEPatents* is less stable, becoming not significant in Model 2. The other control variables, as SMEs R&D expenses and CEO's characteristics, have always a not significant effect on our dependent variable, except *SMEAge* that shows a significant and positive effect in Models 2 and 4.

Concerning the independent variables, Model 2 shows a significant and positive effect of *OIbreadth* (β = 0.119, P < 0.1), thus supporting H1. Similarly, Model 3 shows a significant and positive effect of *OIdepth* (β = 0.123, P < 0.05), hence confirming H2.

Concerning the moderation effect of *TechIntIndustry* hypothesized respectively on *OIbreadth* and *OIdepth*, Model 4 does not support H3, since the non significant coefficient (β = −0.008, P > 0.1) related to the moderation effect of the technological intensity of the SME industry on the relationship between its collaboration breadth and the adoption of I4.0 technologies. Also Model 5 does not support H4, since the significant, but positive coefficient (β = 0.256, P < 0.05) related to the moderation effect of the technological intensity of the SME industry on the relationship between its collaboration depth and the adoption of I4.0 technologies. This result seems to suggest that, especially in high-tech industries, OI depth may support the implementation of I4.0 technologies. Contrary to our hypothesis, the benefits of OI depth are higher for SMEs operating in high-tech, rather than low-tech industries. Indeed, high-tech SMEs operate in a more dynamic environment that implies a strong uncertainty in the implementation of new technologies, as the case of I4.0 solutions. While we have assumed that high-tech SMEs can face this uncertainty by enhancing OI breadth, our results show,

Table 3. Negative binomial regression models

Dependent variable: I4.0adoption	Model 1	Model 2	Model 3	Model 4	Model 5
OIbreadth		0.119† (0.061)		0.116 (0.071)	
OIdepth			0.123* (0.061)		−0.035 (0.088)
TechIntIndustry				0.373 (0.935)	−0.024 (0.286)
OIbreadth * TechIntIndustry				−0.008 (0.135)	
OIdepth * TechIntIndustry					0.256* (0.115)
SMEAge	0.003 (0.002)	0.003† (0.002)	0.003 (0.002)	0.003* (0.002)	0.003 (0.002)
SMESize	0.070 (0.139)	0.028 (0.140)	0.022 (0.133)	0.026 (0.137)	−0.037 (0.123)
SMER&DExp	0.065 (0.087)	0.025 (0.091)	0.025 (0.089)	0.019 (0.096)	0.045 (0.086)
SMEPatents	0.198† (0.111)	0.185 (0.118)	0.238* (0.111)	0.216† (0.123)	0.315** (0.106)
STEMEmpl	0.215*** (0.051)	0.200*** (0.052)	0.201*** (0.051)	0.171** (0.055)	0.180** (0.056)
CEOEduc	0.028 (0.073)	0.016 (0.074)	0.024 (0.075)	−0.002 (0.078)	0.012 (0.075)
CEOAge	0.004 (0.010)	0.003 (0.010)	0.000 (0.010)	−0.001 (0.01)	−0.002 (0.009)
CEOTenure	−0.010 (0.011)	−0.009 (0.012)	−0.007 (0.011)	−0.008 (0.012)	−0.011 (0.011)
Constant	−0.807† (0.453)	−1.336* (0.566)	−0.725† (0.426)	−1.229† (0.646)	−0.477 (0.426)
Wald χ^2	29.48***	35.15***	36.68***	38.76**	58.31**
Log likelihood	−136.238	−134.328	−134.198	−133.361	−130.734
Pseudo R^2	0.090	0.103	0.104	0.110	0.127
Observations	107	107	107	107	107

Robust standard errors in parentheses.
$^{\dagger}P < 0.10$, $*P < 0.05$, $**P < 0.01$, $***P < 0.001$.

instead, that it can be better dealt with by strengthening OI depth.

As a robustness check, we classified I4.0 technologies in accordance with the SME maturity in their adoption. Following the classification proposed by Rauch and Matt (2021), we computed three discrete variables that measure, respectively, how high (Horizontal and Vertical Integration, Cloud, Industrial Internet of Things, Big data and Analytics), medium (Autonomous Robots, Simulation, Cyber-Security), and low-mature (Additive Manufacturing, Augmented Reality) I4.0 technologies are adopted by the SMEs in our sample. We computed the same negative binomial regression models discussed above replacing the dependent variable with each of these three discrete variables. These models show that the adoption of high-mature I4.0 technologies is significantly affected only by *OIbreadth* (β = 0.136, P < 0.1). Conversely, the adoption of low-mature I4.0 technologies is significantly affected by *OIdepth* (β = 0.187, P < 0.1) and by a positive moderation effect of *TechIntIndustry* on *OIdepth* (β = 0. 751, P < 0.01). Finally, the adoption of medium-mature I4.0 technologies is not significantly affected by any independent and moderator variable. As further robustness check, we also evaluated the effect of the relationship with each type of partner by replacing the independent variable *OIbreadth* with a set of dummy variables, equal to 1 when the focal SME has already established a collaboration with a certain type of partner, 0 otherwise. We tested different regression models including either all these dummy variables or only those associated with some partners, like extra-industry organizations and those with knowledge and resources more useful for the implementation of I4.0 technologies. All these regression models show that only the relationship with other private companies has a positive and significant effect on I4.0 adoption.

5. Discussion and conclusion

Our results show that the adoption of I4.0 technologies is positively related to the OI approach implemented by SMEs, as shown by the significant impact exerted by both the OI dimensions investigated, i.e., breadth and depth. Concerning the moderating impact of the technological intensity of the SME industry, our findings reveal a significant effect only on OI depth. Nevertheless, contrary to H4, the moderation effect of the technological intensity of the SME industry on OI depth is positive. Considering the controlling variables, our results show that qualification of SMEs employees (STEM degree) positively affects the adoption of I4.0 technologies, in line with previous studies (Horváth and Szabó, 2019), while other variables considered by the literature are not significant.

In particular, our findings show a positive and significant relationship of both OI breadth and depth andI4.0 technologies' adoption rate by SMEs. Indeed, on the one hand, collaborating with a higher number of different organizations may increase the SMEs' ability to access to the complementary resources that are necessary to an effective adoption of these technologies. On the other hand, the access to these resources may be favored by a higher number of intense collaborations, which allow SMEs to better assimilate the technologies and knowledge shared within their value network. Thus, both the breadth and the OI depth may support SMEs in overcoming their intrinsic limitations and implementing more effectively a digital transformation, like that related to the adoption of I4.0 paradigm. This result contrasts with previous studies in the literature (Laursen and Salter, 2006; Lorenz et al., 2020) that reveal an opposing effect of the OI dimensions on innovation generation, while our paper does not find contrasting results for technology adoption. The effect of the OI dimensions may be better understood by considering the different level of maturity of I4.0 technologies. Indeed, as shown by our robustness check, the adoption of mature I4.0 technologies is positively influenced by OI breadth, since these technologies are already implemented by many firms, which can trigger the adoption by our SMEs by providing them with the necessary knowledge and expertize. Conversely, the implementation of scarcely diffused I4.0 technologies is positively affected by OI depth. Indeed, only by intense collaborations, especially in high-tech industries, can convey the necessary knowledge for the implementation of these technologies.

Moreover, our findings show how the percentage of SME employees with a STEM degree may have a positive effect on the implementation of I4.0 technologies, hence confirming the results of previous studies (Horváth and Szabó, 2019) that analyze how the qualification of human resources affects the adoption of I4.0 technologies by SMEs.

This finding represents an innovative contribution to the literature on the relationship between the adoption of I4.0 technologies and OI. Indeed, up until now, this literature has mainly pointed out the role of I4.0 technologies as enablers of OI (Wollschlaeger et al., 2017), while the opposite effect has been almost neglected. Moreover, most OI studies emphasize its importance for the improvement of firm's ability to develop new products, while only few papers discuss its impact on process innovation (Terjesen and Patel, 2017), and, more specifically, on that related to the adoption of new technologies (Lorenz et al., 2020).

Furthermore, our paper may shed further light on I4.0 technologies and SMEs, thus contributing to the literature on the technology adoption by SMEs (Nguyen et al., 2015) showing that qualification of employees represents the most important variable in the adoption of I4.0 technologies more than other variables that are often considered by literature (as R&D expenses), thus suggesting managers to strongly invest on qualified workers and educational programs.

Our paper shows also that the effect of OI in the adoption of I4.0 technologies is influenced by the industry where the SME operates. While previous studies have already highlighted the importance of some industry's characteristics for the technology adoption by SMEs (Pavitt, 1984; Peltier et al., 2012), none, to the best of our knowledge, has analyzed how these characteristics may moderate the effect of OI. Our results show that OI breath is equally important to stimulate I4.0 technologies adoption for both high- and low-tech SMEs. This result suggests that a wide network of relationships that includes more partners important for SMEs, independent of the technological intensity of the industry.

While previous contributions affirm that low-tech SMEs implement a DUI mode, thus generating innovation through the collaboration especially with suppliers and customers, our paper shows that these latter companies have to cooperate also with other kinds of partners for technology adoption. Moreover, our results show that the technological intensity of the industry assumes more relevance for OI depth. This result, opposite to our hypothesis, may be explained by assuming that firms operating in high-tech industries face rapidly changing environment (Laursen and Salter, 2006) that increases the SMEs' need to access resources provided by external organizations. Thus, the significant and positive moderation effect of the technological intensity of the industry on the relationship between OI depth and the adoption of I4.0 technologies suggests enhancing OI depth is necessary especially for SMEs operating in a highly uncertain environment. Probably, SMEs operating in high-tech industry require more complex and customized I4.0 solutions that can be realized only through intense collaborations with external partners. Moreover, SMEs operating in high-tech industry tend to face continuous changes so they need to implement a stable dialogue with their partners to continual reprogramming their I.4.0 adoption. In other words, our paper gives a first, even if preliminary, insight on the fact that innovation adoption requires a different OI behavior, suggestions to explore the relationship between OI behavior and industry not only for the development of innovation, as many studies have already made, but also for the adoption of innovation.

Other than these theoretical contributions, our paper may provide also some practical contributions, especially to SME managers that are facing the digital transformation related to the adoption of I4.0 technologies, or are willing to face it. In particular, our paper shows that they can overcome the obstacles to an effective implementation of these technologies by adopting an OI approach based on both various and intense collaborations with external organizations. Our paper shows indeed that cooperation is necessary not only to generate innovations but also to support the unavoidable process of SME digitalization. To support the adoption of I4.0 technologies, managers have not only to exploit the firm's internal resources but have also to leverage its networking capabilities. This may increase the access to the necessary resources for the adoption of I4.0 paradigm, making OI no longer a choice but a necessity. Compared to other strategies that can support the implementation of new technologies, OI may be less costly and risky, but they require a strong openness to external actors, which may be opposite to the organizational culture of many SMEs. Managers have to create an internal environment enhancing the culture of collaborations and reducing the not-invented-here syndrome, thus stimulating SMEs to cooperate and enlarge the partners' portfolio. Moreover, managers also need to project complex cooperation modes that create intense cooperation between SMEs and their partners since occasional cooperations may not generate enough knowledge sharing to guarantee positive returns in terms of OI adoption. Besides, as shown in our paper, the effectiveness of an OI strongly depends on some characteristics of the industry, which should be accurately evaluated by SME managers before the adoption of I4.0 paradigm. While the cooperation with a wide range of partners is equally important for both high-tech and low-tech SMEs, our study suggests that especially managers of high-tech companies need to create more intense relationships with partners.

The importance of OI highlighted in our study may also support a revision of public policies aiming at promoting digital transformation of local SMEs. In particular, while many national and regional governments, also in Italy, have recognized the importance of specific policies to support SMEs digitalization, some existing interventions are focused to provide SMEs with financial incentives or support the employees' education. Our findings support the foundations of these policies on the one hand, but, on the other hand, show that a complementary way to enhance SMEs digitalization is to create a system of incentives that promote collaborations among SMES. Policies aiming at stimulating interfirm-consortia, university-industry collaborations, cooperation between SMEs and innovative start-ups may be used to support not only the generation of innovation, but also the innovation adoption.

The development of more precise OI for SME I4.0 transition will require further studies that can overcome the limitations of the current paper. In this sense, both qualitative and quantitative studies may be carried out so to understand not only the effect of OI breadth and depth, but also the characteristics of the potential partners and collaborations that may better support the implementation of new technologies. Besides, a more detailed measure of SME adoption of I4.0 technologies may provide a better understanding of the role of OI in overcoming the problems that may emerge in the digital transformation. The extension of our study to other regions and settings may also improve the generalizability of our results. Indeed, even if the analysis of Campania region helps us to observe the behavior of both high-tech and low-tech SMEs, the extension of our study to other regions may better clarify the role of the incentives promoted by regional governments and the local economic context in the relationship between OI and I4.0 technologies adoption. Moreover, last but not least, the main shortcoming of our study is due to the nature of our data, which prevents us from controlling for the time-lags between collaboration and technology adoption, thus limiting our ability to disclose causal relationships between OI and I4.0 technologies adoption.

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Antonio Messeni Petruzzelli is a Full-time Professor of Innovation Management at the Politecnico di Bari. He is the author of more than 100 international publications and three international books on the topic of innovation management. His studies on this issue have been published in leading journals, as *Research Policy, Entrepreneurship Theory & Practice*, *Academy of Management Perspectives*, *Journal of Management and Long Range Planning*. He belongs to the editorial team of Journal of Knowledge Management and Technological Forecasting and Social Change. Finally, his studies have recently been awarded the Nokia Siemens Network Award in Technology Management for Innovation into the Future.

Gianluca Murgia, PhD, is an Assistant Professor in Engineering Management at University of Siena. He was also visiting scholar at K.U. Leuven. His present research interests mainly concern innovation management, with a special focus on the analysis of University-Industry collaborations. His studies have been published in journals such as *International Journal of Production Research*, *Journal of Technology Transfer*, *Journal of Informetrics, Science and Public Policy*, and *Electronic Commerce Research*. He teaches "Marketing and Innovation Management" in the Master Degree in Engineering Management at the University of Siena.

Adele Parmentola is Associate Professor at the Department of Management and Quantitative Studies of Parthenope University of Naples, where she teaches Business Management, Marketing, Innovation Management and International Innovation Network. She is the Data Manager of the Regional Entrepreneurship Development Program (REAP) of Massachusetts Institute of Technology (MIT) aimed at creating innovation ecosystems in emerging countries. She is also responsible and member of many research projects financed by Italian Ministry of Research and University and by the Campania Region on the topic of innovation and local development. She is the author of more than 60 publications on the topics of innovation management, university entrepreneurship and local innovation systems. Her studies are published in journals like *Small Business Economics*, *R&D Management*, and *Journal of Technology Transfer*.

