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Leveraging on intra- and inter-organizational collaboration in Industry 4.0 adoption for knowledge creation and innovation

Marco Bettiol, Mauro Capestro, Eleonora Di Maria and Roberto Grandinetti
Department of Economics and Management, University of Padua, Padua, Italy

Abstract

Purpose – This paper aims to investigate the impact of Industry 4.0 (I4.0) technologies on knowledge creation for innovation purposes by assessing the relationships among the variety of I4.0 technologies adopted (breadth I4.0), the penetration of these technologies within the firm's value chain activities (depth I4.0) and the mediating role of both internal (inter-functional (IF)) and external [with knowledge-intensive business services (KIBS)] collaborations in this process.

Design/methodology/approach – The study employed a quantitative research design. By administering a survey to entrepreneurs, chief operation officers or managers in charge of the operational and technological processes of Italian manufacturing firms, the authors collected 137 useful questionnaires. To test this study's theoretical framework and hypotheses, the authors ran regression and mediation analyses.

Findings – First, the results highlight the positive link between breadth I4.0 and depth I4.0. Moreover, the results show the key role played by increased collaboration among the firm's business functions and by relationships with KIBS in creating knowledge to innovate processes and products when I4.0 technologies are adopted.

Research limitations/implications – The variety of I4.0 technologies adopted enables a firm to use such technologies in various value chain activities. However, the penetration of I4.0 into the firm's value chain activities (depth I4.0) does not *per se* directly imply the production of new knowledge, for which a firm needs internal collaboration among different business functions, in particular with the production area, or collaboration with external partners that favor I4.0 implementation, such as KIBS.

Practical implications – To achieve innovation goals by creating new knowledge, especially in the manufacturing industries, firms should encourage internal and external collaboration when I4.0 technologies are adopted. Moreover, policy makers should not only consider fiscal incentives for the adoption of such technologies, but also encourage the building of networks between adopting firms and external actors.

Originality/value – The study is one of the first attempt that provides empirical evidence of how I4.0 enables the creation of knowledge to innovate processes and products, highlighting the relevance of collaboration both within the company and with external partners.

Keywords Industry 4.0, Inter-functional collaboration, KIBS, Knowledge creation, Product innovation, Process innovation

Paper type Research paper

1. Introduction

The fourth industrial revolution, rooted in Industry 4.0 (I4.0), has drawn attention to the innovation opportunities linked to enhanced data gathering and elaboration within an

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interconnected organization (Schwab, 2017). From this perspective, the emerging technological scenario has crucial implications for manufacturing firms and their ability to strengthen their competitive advantage through adequate I4.0 adoption and implementation dynamics (Frank *et al.*, 2019), with positive consequences at a broader national level (Edquist *et al.*, 2021).

As with previous technological waves (Higón, 2012; Reypens *et al.*, 2016; Sawhney *et al.*, 2005), the new set of technologies promises to increase the knowledge available at the firm level by relying on internal dynamics as well as through external collaboration (Bettiol *et al.*, 2020). The novelty of digital technologies included under the umbrella term of I4.0 – from 3D printing to robotics and from big data to the Internet of Things (IoT) and artificial intelligence (AI) – refers to their different technological features and characteristics (Culot *et al.*, 2020). The variety of the I4.0 technological portfolio has diverse advantages in terms of the business domain of applications (Büchi *et al.*, 2020), new knowledge development and innovation of processes, products and services (Agostini *et al.*, 2020; Naeem and Di Maria, 2022).

A growing area of research is emphasizing that I4.0 may, in fact, sustain knowledge processes through knowledge creation and innovation to support decision-making (de Bem Machado *et al.*, 2022). Scholars have investigated and questioned the possibility of developing new knowledge, based on the huge amount of data generated by I4.0 technologies (Bettiol *et al.*, 2022; Pauleen and Wang, 2017). Studies focusing on collaboration suggest the contribution of openness to effective I4.0 adoption in terms of knowledge sharing and innovation results (Lepore *et al.*, 2022; Messeni Petruzzelli *et al.*, 2022).

Less attention has been devoted to evaluating how the variety of I4.0 technologies adopted is related to their penetration throughout the various firm's value chain activities – that is, their "depth" (Büchi *et al.*, 2020), thus going beyond a focus on manufacturing – and if/how such depth relates to knowledge creation (Bettiol *et al.*, 2022). The rise of I4.0 has opened up issues on the consequences of the contribution of manufacturing departments to innovation outcomes and on the broader knowledge creation dynamics that go beyond the firm's boundaries (Ballestar *et al.*, 2020; Büchi *et al.*, 2020; Culot *et al.*, 2020; Saucedo-Martínez *et al.*, 2018).

On the one hand, past research has suggested the relevance of inter-functional (IF) collaboration as a driver for knowledge creation and innovation (Ulrich and Eppinger, 2000). However, little attention has been given to how I4.0 could foster collaboration within (and beyond) the firm (Schuh *et al.*, 2014). In this respect, there is a need for research which further investigates the consequences of an intra-organizational collaboration driven by I4.0 technologies. More specifically, research should analyze whether there is a relationship among I4.0, collaboration among the different firm functions, or value chain activities, as highlighted by Porter (1985) and knowledge creation, based on the multiple cognitive perspectives of these functions (Dalenogare *et al.*, 2018).

On the other hand, past research has emphasized the contribution of a manufacturing firm's external partners, such as knowledge-intensive business services (KIBS), to its knowledge dynamics (Di Maria *et al.*, 2012) as an important driver of innovation (Amancio *et al.*, 2022; Muller and Doloreux, 2009). Therefore, greater importance should be ascribed to the possibility that firms can rely on KIBS for a successful implementation of I4.0 implementation in terms of knowledge creation and innovation.

The adoption and use of I4.0 technologies is a complex process for firms and, particularly, for small and medium-sized enterprises (SMEs) due to cognitive, organizational and financial resource constraints (Moeuf *et al.*, 2019; Roblek *et al.*, 2016). Nevertheless, research focusing on the role of KIBS in the adoption of I4.0 technologies and its consequences in regard to knowledge creation and innovation remains scant. Additional research is needed to provide a better understanding of the role of KIBS in firms' knowledge domains in relation to the I4.0 paradigm (Obradović *et al.*, 2021).

The current paper aims at providing evidence of how the adoption of I4.0 technologies in manufacturing firms could influence the process of knowledge creation to innovate processes and products. The study achieves this aim by assessing both the variety of technologies (breadth) adopted and their application in the various value chain activities (depth) within the firm (Büchi *et al.*, 2020) and the role of both intra- and inter-organizational collaboration in such a framework. Through the empirical analysis of 137 manufacturing adopting firms, the paper contributes to outlining the relevance of internal and external collaboration for knowledge creation (to innovate processes and products) rooted in I4.0 technologies. It also suggests moving away from the simplistic view of technological drivers for knowledge management at the firm level and stresses how the combination of inputs from multiple and different actors affects knowledge creation within the fourth industrial revolution.

2. Theoretical framework

2.1 From breadth to depth in the adoption of I4.0 technologies

The concept of I4.0 embraces a large set of technologies with very different characteristics (Agostini and Filippini, 2019; Culot *et al.*, 2020; Osterrieder *et al.*, 2020). There is no specific consensus on the wide array of technologies mapped within the umbrella term of I4.0 (Chiarello *et al.*, 2018; Zheng *et al.*, 2019). Several studies classify and group I4.0 technologies with respect to their impacts on production activities and/or other business processes. According to Frank *et al.* (2019), I4.0 technologies can be grouped as front-end and back-end technologies. The first group includes all technologies implemented in manufacturing and supply chain processes (e.g. robotics, traceability technologies) as well as at product level (e.g. 3D printing), enhancing business processes in terms of productivity, efficiency and flexibility and allowing the firm to cope with market requests. The second group represents the "backbone" technologies which enable improved data management and collaboration within the firm and with external actors (e.g. big data, IoT, cloud). Developing this breakdown, Bettiol *et al.* (2022) grouped I4.0 technologies based on their business area of application and the processes supported, identifying three clusters: technologies to improve operations and working activities (smart manufacturing); technologies enabling the opportunity to customize products based on interaction with customers (also involving marketing and R&D departments); and data-processing technologies.

Culot *et al.* (2020) propose a different view of I4.0 technologies by characterizing them according to physical/digital integration and network connectivity and grouping them in four clusters: physical/digital interface technologies, with a high share of hardware components and an extended (outside the firm) connectivity (e.g. IoT); network technologies, coupling software components and extended connectivity (e.g. cloud); physical/digital process technologies, coupling hardware components and within-firm connectivity (e.g. 3D printing); and data-processing technologies, coupling software components and within-firm connectivity (e.g. big data analytics).

Interest in the variety of I4.0 technologies and their specific characteristics is not merely descriptive, as each can exert its own specific influence on the competitiveness of the adopting firm in terms of increased efficiency, flexibility and innovation capability (Bettiol *et al.*, 2022; Ghobakhloo, 2018). The cumulative and sometimes synergic effect generated by the adoption of distinct technologies (Vogel-Heuser and Hess, 2016) is captured by the concept of technological breadth, which can be used on any set of technologies (e.g. Autry *et al.*, 2010) and which Büchi *et al.* (2020) applied to the context of I4.0 technologies. The authors, measuring breadth based on 10 different I4.0 technologies, showed that wide breadth enables the firm to exploit the opportunities offered by I4.0 more intensively. Using the same conceptual framework, Oltra-Mestre *et al.* (2021) highlighted the positive impact of breadth on the innovation performance of agri-food firms. In turn, the breadth

(Büchi *et al.*, 2020) or intensity (Messeni Petruzzelli *et al.*, 2022) of I4.0 technology adoption is positively associated with high levels of organizational and managerial practices (Agostini and Filippini, 2019; Laubengaier *et al.*, 2022).

The different particularities of the various I4.0 technologies may accommodate the requests and needs of the different activities within the value chain at the firm level or satisfy business functions, and the specificities of data and business goals may drive the technological adoption within each function (Saucedo-Martínez *et al.*, 2018). It follows that the more the firm extends the adoption of specific technologies to the different stages of its internal value chain, the higher its success in exploiting the benefits generated by the fourth industrial revolution. This point was captured by the concept of depth, as proposed by Büchi *et al.* (2020). Unlike the well-known contribution of Laursen and Salter (2006), who refer to depth to stress how intensively an external source of knowledge is used, in the perspective adopted by Büchi *et al.* (2020), depth aims at describing the extent to which I4.0 technologies are diffused along the internal value chain of the firm (Porter, 1985).

Büchi *et al.* (2020) address the depth of I4.0 technologies adopted by the firm as a factor which is distinct from their breadth but works alongside the latter to positively influence the firm's competitive performance. However, the typologies of I4.0 technologies proposed in the literature (Bettiol *et al.*, 2022; Culot *et al.*, 2020; Frank *et al.*, 2019) suggest a positive link between the variety of such technologies acquired by the firm (breadth) and the number of value chain activities impacted (depth) by the various technologies adopted. Such linkage takes on the dual form of integration and specialization. For instance, a manufacturing firm may introduce specialized robots or other devices in different activities of the value chain, while IoT allows the integration of these activities (Colombari *et al.*, 2023; Saucedo-Martínez *et al.*, 2018). In light of these considerations, our first hypothesis is as follows:

H1. The variety of I4.0 technologies adopted by a firm (breadth I4.0) is positively related to the penetration of these technologies along the value chain activities within the firm (depth I4.0).

2.2 I4.0 adoption, inter-functional collaboration and knowledge creation for innovation

A large and well-established literature on innovation management has shown that innovations developed by firms require the contribution of a plurality of value chain activities and interaction between them, that is, IF collaboration (de Medeiros *et al.*, 2014; Holland *et al.*, 2000). From a knowledge perspective at the firm level, internal actors (individuals or organizational units) with different specializations and backgrounds are relevant (from R&D to production to marketing) for the creation of new knowledge associated with innovation (Ganotakis *et al.*, 2013; Nonaka and Takeuchi, 1995; Spender, 1996; Zhou and Li, 2012). Knowledge creation can occur through the direct interaction between actors in a team or through one actor's autonomous use of knowledge acquired by others.

The development of information and communication technologies (ICT) gave new life to the link between cross-functional collaboration and knowledge creation for innovation. The potentialities of ICT for knowledge management and innovation have been widely explored in past research (Davenport, 2007; Davenport and Prusak, 2000). In this field, scholars have focused on how these technologies enable firms in their processes of exploring and exploiting knowledge to innovate processes and products (Bolisani and Scarso, 1999; Corso *et al.*, 2001). Attention has focused on workers' experience within the firm and their ability to enhance the firm's competitiveness through their knowledge (Davenport and Prusak, 1998). Technological solutions help firms to transfer such knowledge from the individual to the organizational level (Apostolou *et al.*, 2007). In particular, where codification and tacitness are tightly intertwined (Cowan *et al.*, 2000), firms can exploit the potential connectivity of ICT to transfer knowledge among the different business functions and co-create knowledge (Brown and Duguid, 2001).

I4.0 and the digital transition greatly expand the potentialities and opportunities which arose from the ICT revolution (Bettiol *et al.*, 2022). I4.0 technological advancements reflect a basket of new digital technologies that could define new ways to acquire and manage knowledge (Soto-Acosta and Cegarra-Navarro, 2016). In manufacturing firms, this information enrichment not only affects operations, but also the other business functions of the firm (Saucedo-Martínez *et al.*, 2018), such as marketing (Achrol and Kotler, 2022) and human resources (Pillai *et al.*, 2022). The huge amount of data that the new technologies enable firms to gather from deep within their value chain can be analyzed with more advanced data-processing analytics and AI solutions (Davenport, 2013, 2018), thus interconnecting different business functions (e.g. operations, marketing, sales, logistics). From this point of view, the firm can obtain additional knowledge related to its processes and products by integrating the multiple functions involved (Paschen *et al.*, 2019). Doing so lays the groundwork for developing not only process and/or product innovations (Ghobakhloo and Fathi, 2020; Szalavetz, 2019; Tan and Zhan, 2017), but also an entirely new business model (Müller *et al.*, 2018), as in the case of the disruptive digital servitization strategies pursued by both business-to-business (B2B) and business-to-consumer (B2C) manufacturing firms (Paiola *et al.*, 2022; Suppatvech *et al.*, 2019).

In this scenario, the collaboration among functions to support knowledge creation for innovation purposes, driven by I4.0 technological investments, gains in importance. IF collaboration includes different collaborative practices: (1) coordination (sharing resources and moving toward congruent goals), (2) cooperation (cross-functional activities) and (3) communication (information-sharing and sense-making activities that allow goals or visions of technological innovation to be promoted among the functional subunits of a firm) (Kim and Hur, 2022; Schuh *et al.*, 2014). In this framework, the variety of I4.0 technologies can favor collaboration along all three dimensions of collaborative practices by enhancing: a) coordination, for instance in terms of traceability of activities or end-to-end standardized reporting; b) cooperation, for example, through shared virtual objects (virtual reality or augmented reality); and c) communication, for example through data sharing and real-time communication dynamics.

In short, if knowledge creation for innovation purposes traditionally leverages IF collaboration, the latter now finds powerful support in I4.0 technologies. Indeed, these technologies increase the firm's wealth of information useful for innovation by connecting differently specialized activities within the firm with external sources of information. This connection fosters information exchange and collaboration among business functions and enhances the firm's ability to combine and process information and knowledge from different sources to produce new knowledge. Hence, the following hypotheses are proposed:

H2a. The penetration of I4.0 technologies along the value chain activities within the firm (depth I4.0) is positively related to IF collaboration.

H3a. IF collaboration positively affects knowledge creation for innovation.

H4a. IF collaboration positively mediates the relationship between depth I4.0 and knowledge creation for innovation.

2.3 I4.0 adoption, knowledge creation and the role of KIBS

Not only can internal inter-functional collaboration support knowledge creation at the firm level, but actors external to the organizational boundaries are as relevant as internal ones (Chesbrough, 2003; Laursen and Salter, 2006). Among the different actors a firm can involve, we are particularly interested in considering those private or institutional organizations commonly known as KIBS, since a large number of studies has shown that they are important collaborators in the innovation processes for other firms, in particular manufacturing firms (Amancio *et al.*, 2022; Muller and Doloreux, 2009). Muller and Zenker (2001, pp. 1503-1504) have identified the three common traits of KIBS that elucidate their role in helping others' innovation: "(1) the knowledge intensity of the service provided by KIBS for their clients (which distinguishes them from other types of services); (2) the function of consulting (which could be also expressed as problem-solving function); and (3) the strongly interactive or client-related character of the service provided". These characteristics are found in both categories into which KIBS have been divided: T-KIBS that are more focused on technology transfer and P-KIBS, where the role of professional services and competences connected to human resources is prevalent (Doloreux and Shearmur, 2010). This distinction partially overlaps with that between industrialized (more standardized) and customized services, although there are providers that combine elements of industrialized and customized knowledge-intensive services (Bettiol *et al.*, 2015).

From a knowledge management perspective, there are two reasons that KIBS represent relevant knowledge partners in supporting firms' innovation processes. First, they have an autonomous capability for innovation, as several empirical studies have shown (e.g. Cabigiosu and Campagnolo, 2019; Cainelli *et al.*, 2020). Second, they can act as knowledge brokers (Grandinetti, 2018), allowing indirect links between their clients and relevant external knowledge sources, such as universities, research centers and other producers of specialized knowledge. Considering the well-known difficulties of interaction between these knowledge-based organizations and SMEs (Rõigas *et al.*, 2018), KIBS have been described as key actors in innovation ecosystems (Amancio *et al.*, 2022; Sedita and Grandinetti, 2022).

In the scenario of I4.0, the firm aiming at adopting I4.0 technologies has to deal with a large set of challenges and barriers (Fatorachian and Kazemi, 2018; Mittal *et al.*, 2018; Schneider, 2018). Where SMEs are concerned, in particular, recent research has discussed the potential relevance of KIBS (and of the institutional and environmental context in which they operate) to an effective process of I4.0 adoption (Benitez *et al.*, 2020; Crupi *et al.*, 2020; Pagano *et al.*, 2020). The importance that I4.0 regional policies should assign to KIBS has been similarly emphasized (De Propris and Bellandi, 2021; Larrea and Estensoro, 2021; Vaillant *et al.*, 2021).

Clearly, those firms which pursue I4.0 adoption strategies characterized by technologies variety and a deeper use of them into their internal value chain will face particularly severe challenges and difficulties (Cugno *et al.*, 2021) due to the complexity of combining and integrating different technologies and the more complex nature of the innovations that they are seeking to develop. On the other hand, the greater the complexity of the problems to be solved, the greater the firm's need to access external problem-solving capabilities by collaborating with selected private or institutional KIBS (Grandinetti, 2018; Strambach, 2001). This assumption, in the specific case of I4.0 technologies, has not yet been empirically tested. However, some qualitative studies offer encouraging insights in this regard.

In their configurational analysis, Bustinza *et al.* (2022) show that collaboration with KIBS enhances the potentialities of product–service innovation enabled by I4.0 technologies (new product development within a smart manufacturing technological scenario). From this viewpoint, KIBS allow firms to overcome the challenges related to complex business shifts, such as moving towards servitization strategies and business model innovation. In this vein, the multiple case study conducted by Paiola *et al.* (2021) suggests that prior knowledge is relevant for the implementation of innovation strategies rooted in I4.0 potentialities and that connection with specialized KIBS as technology providers is crucial to an effective path of adoption by combining existing stocks of knowledge with additional external inputs.

Hence, we predict that collaboration with KIBS, similarly to IF collaboration, is positively related to the adopter's knowledge creation process for innovation purposes as follows:

H2b. The penetration of I4.0 technologies along the value chain activities within the firm (depth I4.0) is positively related to the firm's collaboration with KIBS.

H3b. Collaboration with KIBS positively affects knowledge creation for innovation.

H4b. Collaboration with KIBS positively mediates the relationship between depth I4.0 and knowledge creation for innovation.

Figure 1 summarizes all the hypotheses developed into a conceptual framework.

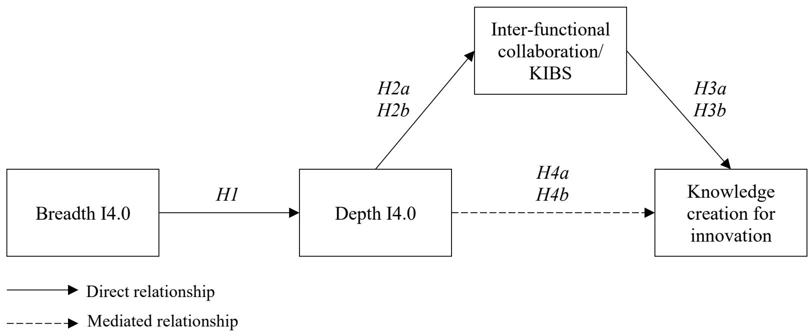


Figure 1.
Conceptual framework

3. Methods

3.1 Research setting

The study focuses on the manufacturing firms of so-called "Made-in-Italy" sectors (automotive, rubber and plastics, electronic appliances, lightning, furniture, eyewear, jewelry, sports equipment and textile–clothing–footwear) located in Northern Italy. The Italian case is an interesting empirical setting for the analysis of collaboration for I4.0 technology adoption for knowledge creation and innovation. Italy has been widely recognized as an important manufacturing country in Europe and internationally and Made-in-Italy industries show a strong international competitiveness for both final and intermediate products (OECD, 2020). Moreover, firms located in Northern Italy are particularly important to Italy's gross domestic product (GDP) and national competitiveness in international markets and are thus suitable for comparison with other European Western countries (Lagravinese, 2015; Lamorgese and Olivieri, 2017). In addition, the Italian industrial structure, characterized by SMEs and industrial districts (Becattini *et al.*, 2009), allows a deeper understanding of the implications of I4.0 technologies for knowledge creation in local manufacturing systems that rely on inter-organizational dynamics and KIBS involvement for innovation purposes in general (Baldoni *et al.*, 2022; Camuffo and Grandinetti, 2011). Finally, following the I4.0 initiative in Germany, since 2016 the Italian government has promoted a National Plan for I4.0 that provides financial and fiscal support to spread the adoption of I4.0 technologies, sustaining firms in their digital transformation strategies.

The population of our study consists of 8,022 firms specializing in Made-in-Italy industries located in the Northern Italian regions (Piedmont, Lombardy, Veneto, Trentino-Alto Adige, Friuli Venezia Giulia and Emilia-Romagna) and with a turnover higher than EUR 1 million. These firms were drawn from the Aida–Bureau van Dijk database, which contains comprehensive financial and economic information on companies in Italy. Taking into consideration the focus also on manufacturing industries characterized by the presence of industrial districts (i.e. furniture, eyewear, jewelry), we also included small and micro-firms with a turnover of less than EUR 1 million, which, according to the literature on industrial districts (Becattini *et al.*, 2009), can be competitive by offering high specialization within the local value chain.

To test the research hypotheses and verify our theoretical model, we carried out a survey between March and December 2017 – this being the first period of application of the I4.0 policy by the Italian Government – submitting a structured questionnaire to the population of firms through computer-assisted web interviews (CAWI) (appropriate for contacting a large sample) with entrepreneurs, chief operation officers, or managers in charge of manufacturing and technological processes. The general aim of the study was to analyze either the drivers, processes of adoption and outcomes of I4.0 technologies or the reasons for their non-adoption by those firms which have not invested in I4.0 technologies. A total of about 1,400 firms made up the collective sample; however, the present paper specifically focuses on I4.0 adopters (an initial sample of about 200 adopters and a cleaned sample of 137 firms, as described below).

3.2 Variables and measures

Grounded in the literature, the questionnaire first aimed to assess (binary variable, Yes = 1; No = 0) the adoption of the following I4.0 technologies: (1) autonomous robots, (2) additive manufacturing, (3) big data/cloud, (4) augmented reality, (5) IoT and smart products, (6) laser cutting and (7) 3D scanners. The first five technologies are those most mentioned in the Italian production context (Zheng *et al.*, 2019), in part because they are supported by the Italian Ministry of Economic Development regulation launched in 2016 (Agostini and Filippini, 2019). In addition, we consider the adoption of digital laser cutting and 3D scanners for two main reasons. First, intelligent machine tools such as these are included in the I4.0 paradigm because of their relevance for smart manufacturing (Tong *et al.*, 2020) and operational excellence (Miandar *et al.*, 2020), supporting the customization processes of specific industries (e.g. automotive) to evolve. Second, they are very important for the digital transformation of the Made-in-Italy sectors investigated (Bonfanti *et al.*, 2018), which frequently require specific technologies to produce "tailoring goods" (Di Roma, 2017).

Then, to estimate the effect of I4.0 on value chain activities, we determined (binary variable, Yes = 1; No = 0) the activities/processes to which a firm applied the technologies adopted, considering the following: (1) new product development, (2) prototyping, (3) manufacturing activities, (4) production process management, (5) logistic and supply chain management, (6) sales/marketing activities and (7) post-sales services (including spare parts).

For our research purposes, grounded in the recent literature (Büchi *et al.*, 2020; Cugno *et al.*, 2021), we assessed breadth I4.0 creating a counting variable as sum of the various technologies adopted and depth I4.0 creating a counting variable as sum of the value chain activities in which I4.0 technologies have been used. Both variables range from 1 to 7 (technologies adopted, value chain activities involved).

In addition to the evaluation of I4.0 investment, we considered the mediating role of relationships and collaborations within the firm as well as with external actors (KIBS) linked to I4.0 investment. As far as intra-firm relationships are concerned (Brodeur *et al.*, 2021), we used a 5-point Likert scale (Not at all = 1; Very much = 5) to assess whether the technologies adopted enabled an increase in the IF collaboration, specifically between production area and other business functions. In regard to external relationships (Bustinza *et al.*, 2022), we used a binary variable (Yes = 1; No = 0) to assess the relationship with the various KIBS that supported the firm in the adoption and implementation of technologies adopted, considering the following actors: (1) I4.0 suppliers, (2) system integrators, (3) machinery suppliers, (4), consultants, (5) universities/research centers, (6) technology transfer centers and (7) others. Then, we created the variable KIBS (ranging from 0 to 7) as the sum of the seven items.

As dependent variable, we considered the knowledge creation for innovation as the mean of two items (5-point Likert scale, Not at all = 1; Very much = 5) that assess whether the technologies adopted allowed the firm to create knowledge for the innovation of (1) production processes and (2) products (Hughes *et al.*, 2022).

Finally, as control variables, we considered a set of firm characteristics that may affect the I4.0 implementation process (Mittal *et al.*, 2018): firm size in terms of employees; industry, clustering the firms into two main technological groups following both the Statistical Nomenclature of Economic Activities in the European Community (NACE) code and European Union (EU) classification (Low or Medium-low tech industry = 0; Medium-high or High tech industry = 1); R&D expenditure and export as percentage on annual turnover; type of market served: B2B = 0; B2C = 1); and, finally, the level of customization of the technologies adopted. This latter variable is a continuous variable ranging from 0 (no customization) to 5 (highest customization), derived from the average of three items measured by a 5-point Likert scale, specifically hardware customization, software customization and integration with the firm's technological assets.

3.3 Sample and descriptive statistics

Through the survey, we were able to collect data from more than 200 firms that had adopted at least one of the seven I4.0 technologies. After cleaning the sample and excluding uncompleted questionnaires, we obtained a final sample of 137 adopting firms. Table 1 shows

Descriptive	Frequency	Percentage (%)
Firm size		
Micro	44	32.1
Small	59	43.1
Medium	26	19.0
Large	8	5.8
Industry		
Textile and clothing	27	19.7
Furniture	26	19.0
Fashion	26	19.0
Automotive	19	13.9
Lighting	14	10.2
Leather/Footwear	11	8.0
Electrical motors and parts	8	5.8
Rubber and plastic goods	6	4.4
Industry technology level		
Low/Medium-low	96	70.1
Medium-high/High	41	29.9
Market		
Business-to-Business (B2B)	84	61.3
Business-to-Consumer (B2C)	53	38.7
Industry 4.0 adoption rate		
Laser cutting	71	51.8
Robotics	67	48.9
Big data and cloud	59	43.1
Additive manufacturing	50	36.5
IoT and smart products	34	24.8
3D scanner	28	20.4
Augmented reality	20	14.6
1 technology	41	29.9
2 or more technologies	96	70.1

Note(s): N = 137

Table 1.
Sample characteristics

Variables	Min	Max	Mean	SD	1	2	3	4	5	6	7	8	9	10
1. Breadth I4.0	1	7	2.40	1.390	–	–	–	–	–	–	–	–	–	–
2. Depth I4.0	1	7	2.47	1.356	0.331***	–	–	–	–	–	–	–	–	–
3. Inter-functional (IF) collaboration	1	5	2.57	1.205	0.218*	0.333***	–	–	–	–	–	–	–	–
4. Collaboration with KIBS	0	5	1.72	1.005	0.228**	0.410***	0.301***	–	–	–	–	–	–	–
5. Knowledge creation for innovation	1	5	3.259	0.920	0.246**	0.278**	0.486***	0.353***	–	–	–	–	–	–
6. Technology customization	0	5	2.404	1.627	0.198*	0.282***	0.278***	0.349***	0.178*	–	–	–	–	–
7. Employees (log)	0.30	2.97	1.449	0.480	0.362***	0.221*	0.281**	0.272**	0.153	0.267**	–	–	–	–
8. Industry tech level	0	1	0.30	0.460	0.064	−0.017	−0.084	0.006	0.024	−0.074	0.113	–	–	–
9. Type of market (B2B-B2C)	0	1	0.39	0.489	−0.046	0.154°	−0.040	0.040	−0.012	−0.053	−0.012	0.037	–	–
10. Export (% on turnover)	0	100	38.94	34.514	0.024	0.008	−0.017	−0.049	0.053	0.091	0.132	0.035	0.193*	–
11. R&D (% on turnover)	0	64	4.668	8.152	0.091	0.186*	0.124	0.026	0.106	−0.046	−0.090	0.048	−0.030	0.065

Note(s): N = 137; $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.005$; $^{\circ}\ p < 0.10$

Table 2.
Sample descriptive statistics

the sample characteristics, including the firm's size (EU turnover classes), industry and type of market.

Table 2 shows the descriptive statistics (min and max values, mean scores and standard deviations) and the correlations of the variables included in the analyses. As expected, there are some different positive correlations, such as between breadth I4.0 and depth I4.0 and both are positively correlated with increased IF collaboration within the firm, with inter-organizational collaboration with KIBS and with knowledge creation. Moreover, all the main variables of the model are positively correlated with technology customization. Instead, it is interesting to note that firm size is positively linked to I4.0 investment as well as to collaborations and relationships within and outside the firm, but it is not related to the creation of new knowledge. All the other correlation values are lower than the threshold of 0.5 (Hinkle *et al.*, 2003); thus, no risk of multicollinearity arises from this study.

3.4 Data analysis method

The main goal of the study is to assess whether I4.0 (in terms of breadth and depth) enables the creation of knowledge to innovate processes and products in manufacturing firms and the process that allows this outcome to be reached, taking into consideration internal and external collaborations. To achieve this goal, we performed a two-step regression analysis. First, we assessed the direct relationship between breadth I4.0 and depth I4.0; then, we assessed the role of mediators run by the increased IF collaboration (first mediation analysis) and collaboration with KIBS (second mediation analysis).

Concerning the regression analyses, collectively hypotheses 1, 2a,b and 3a,b suggest direct effects among the different variables investigated, namely breadth I4.0, depth I4.0, increased IF collaboration (first), KIBS (second) and knowledge creation for innovation. Hypotheses 4a and 4b test the mediation effects. The mediation analysis primarily aims at assessing the indirect effect because of its relevance on the causal relationship between the predictor X and the outcome Y (Iacobucci, 2008). To test the significance of the indirect effect(s), the Sobel test is preferred, being more powerful than the stepwise procedure proposed by Baron and Kenny (1986) because it addresses mediation directly (Preacher and Hayes, 2004). However, also the Sobel test has its own limitations because it rests on the assumption that the indirect effects are normally distributed. In addition to Sobel test, bootstrapping is recommended. Based on the application of bootstrapped confidence intervals (CIs), it is possible to avoid power problems introduced by asymmetric and other non-normal sampling distributions of an indirect effects model (MacKinnon *et al.*, 2002).

However, to estimate the extent to which the mediation process explains the relationship between X and Y, it is also necessary to consider the direct effect of X on Y that is not explained by the mediator (Hayes, 2013). In this case, if the direct effect is significant, we have a partial mediation, instead if the direct effect is no significant, we have a full mediation (Iacobucci, 2008). Hence, the mediation hypotheses (4a and 4b) were tested using the statistical package for the social sciences SPSS and, spceficially, the macro PROCESS developed by Hayes (2013), which includes both a normal theory approach (i.e. the Sobel test) and a bootstrap approach to obtain CIs, which facilitated the estimation of the indirect effects ab.

4. Results

4.1 Main results

The results of the regression analyses, reported in Table 3, allow us to confirm all the hypotheses developed. As regards hypothesis 1, breadth I4.0 (i.e. the number of I4.0 technologies adopted) positively affects depth I4.0, which refers to the penetration of the technologies adopted along the value chain activities within the firm I4.0 ($\beta = 0.243$, $t = 2.889$, $p = 0.005$). The higher the number of I4.0 technologies a firm has adopted, the higher the number of value chain activities involved

Table 3. Main regression and mediation results

Regression analyses	Results					
Linear regression	ß	*SE*	t	p	LLCI	ULCI
Breadth I4.0 regressed on depth I4.0[1]	0.243	0.082	2.889	0.005	0.052	0.431
Mediation analysis with IF Collaboration as mediator						
Direct effects	ß	SE	t	p	LLCI	ULCI
IF collaboration regressed on depth I4.0	0.199	0.073	2.573	0.011	0.046	0.352
Knowledge creation for innovation regressed on IF collaboration[2]	0.340	0.065	5.234	0.000	0.212	0.469
Knowledge creation for innovation regressed on depth I4.0[3]	0.088	0.059	1.498	0.137	−0.028	0.204
Total (mediation) effect of depth I4.0						
Knowledge creation for innovation regressed on depth I4.0, controlling for IF collaboration[4]	0.156	0.063	2.479	0.014	0.031	0.280
Indirect effect and significance using normal distribution	Value	SE	z	*p*		
Sobel	0.068	0.030	2.276	0.023		
Bootstrap results for indirect effects	M	SE			LLCI	ULCI
Effect	0.068	0.031			0.019	0.147
Mediation analysis with KIBS as mediator						
Direct effects	ß	SE	t	*p*	LLCI	ULCI
IF collaboration regressed on depth I4.0	0.228	0.063	3.646	0.000	0.104	0.352
Knowledge creation for innovation regressed on KIBS[5]	0.255	0.086	2.965	0.004	0.085	0.424
Knowledge creation for innovation regressed on depth I4.0[6]	0.098	0.064	1.525	0.130	−0.029	0.224
Total (mediation) effect of depth I4.0						
Knowledge creation for innovation regressed on depth I4.0, controlling for KIBS[7]	0.156	0.063	2.479	0.014	0.031	0.280
Indirect effect and significance using normal distribution	Value	SE	z	*p*		
Sobel	0.058	0.026	2.250	0.024		
Bootstrap results for indirect effects	M	SE			LLCI	ULCI
Effect	0.058	0.024			0.018	0.113

Note(s): N = 137. Unstandardized regression coefficients are reported. Bootstrap sample size = 5,000. LLCI = lower limit of 95% confidence interval; ULCI = upper limit of 95% confidence interval

[1] R = 0.487, R^2 = 0.237, F = 5.726 and p = 0.000. All control variables are included in the regression models: technology customization (β = 0.230) is significant at 0.01 level; type of market (B2B) and R&D expenditure are significant (respectively, β = 0.202 and β = 0.198) at the 0.05 level

[2] R = 0.453, R^2 = 0.205, F = 4.753 and p = 0.000. Firm size (β = 0.548) is significant at the 0.05 level

[3] R = 0.510, R^2 = 0.261, F = 5.639 and p = 0.000. None of the control variables is significant

[4] R = 0.320, R^2 = 0.102, F = 2.102 and p = 0.048. None of the control variables is significant

[5] R = 0.505, R^2 = 0.255, F = 6.304 and p = 0.000. Technology customization (β = 0.144) is significant at the 0.01 level

[6] R = 0.400, R^2 = 0.160, F = 3.049 and p = 0.004. None of the control variables is significant

[7] R = 0.320, R^2 = 0.102, F = 2.102 and p = 0.048. None of the control variables is significant

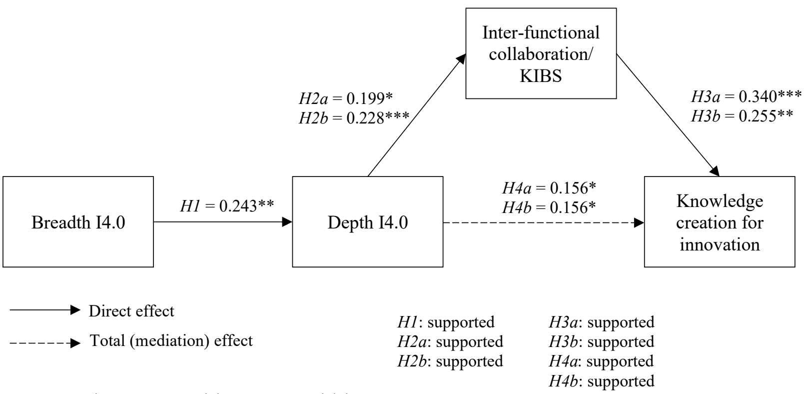
in the I4.0 investment and, thus, in which the technologies have been used. This observation was confirmed with the variance inflation factors, that were less than 5, which is an acceptable threshold. In the relationship between breadth I4.0 and depth I4.0, two firm characteristics have a significantly positive role: the market served (specifically B2B; β = 0.202, t = 2.565, p = 0.011) and the firm's R&D expenditure (β = 0.198, t = 2.523, p = 0.013). In addition, technology customization has a positive role in the regression between breadth I4.0 and depth I4.0 (β = 0.230, t = 2.834, p = 0.005).

In terms of hypotheses 2a and 2b, as reported in Table 3, the analysis shows that depth I4.0 positively affects both the increased IF collaboration (β = 0.199, t = 2.573, p = 0.011) activated through the I4.0 technologies adopted and the collaboration with KIBS (β = 0.228, t = 3–646, p = 0.000) that support a firm in the adoption and use of I4.0 technologies. Therefore, hypotheses 2a and 2b are confirmed.

Our results also support hypotheses 3a and 3b by showing a positive relationship between both increased IF collaboration and KIBS variables and knowledge creation for innovation (product and process). This is indicated by the significant unstandardized regression coefficients: β = 0.340 (t = 5.234, p = 0.000) for IF collaboration and β = 0.255 (t = 2.965, p = 0.004) for the KIBS (see Table 3).

Finally, the results of the mediation analysis also offer support for hypotheses 4a and 4b, showing that depth I4.0 exerts a significant positive effect on knowledge creation for innovation (see Table 3) through the mediation of both increased IF collaboration (β = 0.156, t = 2.479, p = 0.014) and collaboration with KIBS (β = 0.156, t = 2.849, p = 0.005). The results, reported in Table 3, show a total (mediation) effect of depth I4.0 on knowledge creation for innovation that is the same for both mediators (β = 0.156). For the mediation with IF collaboration, the direct effect is 0.088 and the indirect effect is 0.068 (direct effect = 0.088 + indirect effect = 0.068 → total mediation effect = 0.156; p = 0.031), while for the mediation with KIBS, the direct effect is 0.098 and the indirect effect is 0.058 (direct effect = 0.098 + indirect effect = 0.058 → total mediation effect = 0.156; p = 0.031). The formal two-tailed significance test (assuming a normal distribution) demonstrated that indirect effects of both mediators were significant (IF collaboration: β = 0.68, Sobel z = 2.276, p = 0.023; KIBS: β = 0.58, Sobel z = 2.250, p = 0.024). For both mediators, to check the robustness of the total mediation effect, a bootstrap analysis (5,000 samplings, CI 5 95%) was run. The bootstrap results confirmed the Sobel test, with a bootstrapped 95% CI around the indirect effect not containing zero. Thus, hypotheses 4a and 4b are supported. Moreover, we can observe that for both cases, the effect of depth I4.0 on knowledge creation for innovation emerge as results of a full mediation because of the no significant direct effect of depth I4.0 on knowledge creation for innovation (see Table 3). Figure 2 summarizes the results of all hypotheses tested in this study.

From the viewpoint of control variables in the mediation analysis with IF collaboration as mediator, only firm size (number of employees) plays a positive role (β = 0.578, t = 2.571, p = 0.011) in the relationship between depth I4.0 and IF collaboration. Instead, in the mediation analysis with collaboration with KIBS as mediator, technology customization (β = 0.144, t = 2.819, p = 0.006) has a significant positive effect on the relationship between depth I4.0 and collaboration with KIBS.



Note(s): *p < 0.05; **p < 0.01; ***p < 0.001

Figure 2.
Main results

4.2 Robustness checks and heterogeneity results

To test the reliability of the proposed models, in addition to the robustness of mediation tested through the bootstrap analysis other regression analyses were run to check the robustness of the results. As a first analysis (Models 1a andb), other control variables were included in the regression analysis to reduce the impact of the omitted variables. We added the age of firm, the turnover (log) and the possibility a company offers to customize products (Karhade and Dong, 2021). Then (Models 2a and b), we ran the mediation without control variables to test the hypothesized relationships with the aim of avoiding structural effects (see Table 4).

In the second step of robustness checks (Models 3a and b and 4a and b), two alternative types of depth I4.0 and knowledge for innovation were considered. Specifically, we created a depth I4.0 which reflects the use of I4.0 technologies mainly in the production domain (sum of manufacturing activities, prototyping, production process management and logistic and supply chain management), which we named production depth I4.0. A second depth I4.0 was created as the sum of activities strictly related to the marketing domain (sum of prototyping, new product development, sales/marketing activities and post-sales services), which we named marketing depth I4.0. Prototyping activities were included in both measures of depth because of the relevance that this type of activities could have for both product and process innovation (Piening and Salge, 2015). We used these two alternative measures of depth I4.0 to regress them on, respectively, knowledge creation for (only) process innovation and knowledge creation for (only) product innovation. The results of these last two models are reported in Table 5. All the robustness check results (Models 1a and b; Models 2a and b; Models 3a and b and Models 4a and b) confirm the originally supported hypotheses; thus, the reliability of the proposed models is verified.

Finally, we have explored company heterogeneity running the mediation analysis considering micro-small (turnover less than EUR 10 million) firms (Models 5a and b) and medium-large (turnover at least EUR 10 million) firms (Models 6a and b). As shown in Table 6,

	Model 1a	Model 1b	Model 2a	Model 2b
Regressions	ß	ß	ß	ß
Depth I4.0	0.098	–	0.089	–
IF collaboration	0.327***	–	0.338***	–
Depth I4.0 mediated by IF collaboration	0.182**	–	0.278**	–
Depth I4.0	–	0.105	–	0.109
KIBS	–	0.268**	–	0.262**
Depth I4.0 mediated by KIBS	–	0.182**	–	0.278**
Control variables				
Technology customization	0.484	0.253	–	–
Employees (log)	0.036	0.297	–	–
Industry	0.094	0.009	–	–
Market type	−0.014	−0.022	–	–
Export (% on turnover)	0.002	0.002	–	–
R&D expenditure	0.001	0.005	–	–
Turnover (log)	−0.050	−0.209	–	–
Firm's age	−0.006	−0.011	–	–
Product customization	0.119	0.208	–	–

Note(s): N = 137. Dependent variable = knowledge for product and process innovation. ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. Unstandardized regression coefficients are reported. Models 1a and b: R = 0.366, $R^2 = 0.134$. Models 2a and b: R = 0.278, $R^2 = 0.077$. Bootstrap sample size = 5,000. LLCI = lower limit of 95% confidence interval; ULCI = upper limit of 95% confidence interval. Models 1a and b: SE = 0.061; z = 2.992; $p = 0.003$; LLCI = 0.062; ULCI = 0.303. Models 2a and b: SE = 0.059; z = 3.362; $p = 0.001$; LLCI = 0.078; ULCI = 0.299

Table 4. Robustness results with several and without control variables

Table 5.
Robustness results for different depth I4.0 and knowledge creation

	Model 3a	Model 3b	Model 4a	Model 4b
	Knowledge for process		Knowledge for product	
Main variables	ß	ß	ß	ß
Production depth I4.0	0.056	–	–	–
Marketing depth I4.0	–	–	0.151	
IF collaboration	0.376***	–	0.298***	–
Production depth I4.0 mediated by IF collaboration	0.204*	–	–	–
Marketing depth I4.0 mediated by IF collaboration	–		0.204*	–
Production depth I4.0	–	0.118	–	–
Marketing depth I4.0	–	–		0.125
KIBS	–	0.227*	–	0.324**
Production depth I4.0 mediated by KIBS	–	0.204*	–	–
Marketing depth I4.0 mediated by KIBS	–	–	–	0.204*
Control variables				
Technology customization	−0.066	−0.253	0.968	0.716
Employees (log)	0.182	0.460	−0.023	0.230
Industry	0.097	−0.020	0.147	0.069
Market type	0.068	0.063	−0.102	−0.099
Export (% on turnover)	0.002	0.002	0.003	0.003
R&D expenditure	0.002	0.007	0.002	0.005
Turnover (log)	−0.032	−0.170	−0.149	−0.348
Firm's age	−0.009	−0.015	−0.002	−0.007
Product customization	0.276	0.184	−0.007	0.070

Note(s): N = 137. Dependent variable Models 3a and b = knowledge for process innovation. Dependent variable Models 4a,b = knowledge for product innovation. Unstandardized regression coefficients are reported. Models 3a and b: R = 0.377, R^2 = 0.142. Models 4a and b: R = 0.286, R^2 = 0.082. Bootstrap sample size = 5,000. LLCI = lower limit of 95% confidence interval; ULCI = upper limit of 95% confidence interval. Models 3a and b: SE = 0.098; z = 2.082; p = 0.039; LLCI = 0.010; ULCI = 0.398. Models 4a and b: SE = 0.096; z = 2.137; p = 0.035; LLCI = 0.015; ULCI = 0.394

the role of internal and external collaborations, especially with KIBS, is very important for micro-small firms, where both IF collaboration and KIBS allow to have a significant (mediated) effect of depth I4.0 on knowledge creation for (process and product) innovation.

5. Discussion

The study offers an original contribution on the link between I4.0 and knowledge management and provides empirical evidence of the way I4.0 technologies may lead to the creation of new knowledge for the innovation of both processes and products within the manufacturing context. A first preliminary result refers to the positive effect of the adoption of various I4.0 technologies (breadth I4.0) on the penetration (and use) of I4.0 technologies along the value chain activities within the firm (depth I4.0). It suggests that firms that adopt various I4.0 technologies are able to exploit them in different stages of the internal value chain. Simultaneously, as the second main result of the study, the use of I4.0 technologies adopted along the value chain activities within the firm (depth I4.0) does not *per se* directly lead to the creation of new knowledge for product and process innovation. If new technologies enable a potential transformation of how firms organize and innovate their internal activities and processes to improve new product and service development, their adoption is only a starting point.

In the first stage of I4.0 spread, in particular, collaborating with others, within and outside the firm's boundaries, can increase knowledge of this phenomenon and how to obtain higher innovation performances. Indeed, the third couple of findings concern the significant

	Model 5a	Model 5b	Model 5a	Model 5b
	Micro-small firms		Medium-large firms	
Main variables	ß	ß	ß	ß
Depth I4.0	0.157	–	−0.005	–
IF collaboration	0.274**	–	0.446**	–
Depth I4.0 mediated by IF collaboration	0.225**	–	0.130	–
Depth I4.0	–	0.112	–	0.078
KIBS	–	0.347**	–	0.168
Depth I4.0 mediated by KIBS	–	0.225**	–	0.130
Control variables				
Technology customization	0.090	−0.193	1.509	1.030
Employees (log)	−0.239	−0.118	0.141	1.001
Industry	−0.031	−0.102	0.032	−0.080
Market type	−0.022	−0.058	−0.192	−0.513
Export (% on turnover)	0.002	0.003	0.008	0.011
R&D expenditure	0.002	0.005	−0.011	−0.012
Turnover (log)	−0.140	−0.332	−0.387	−0.644
Firm's age	−0.010	−0.018*	0.007	0.010
Product customization	0.212	0.297	−0.335	−0.601

Note(s): N Models 5a and b = 103; N Models 6a and b = 34. Dependent variable = knowledge for product and process innovation. Unstandardized regression coefficients are reported. Models 5a and b: R = 0.403, R^2 = 0.122. Models 6a and b: no-significant R = 0.538, R^2 = 0.082. Bootstrap sample size = 5,000. LLCI = lower limit of 95% confidence interval; ULCI = upper limit of 95% confidence interval. Models 5a and b: SE = 0.082; z = 2.750; p = 0.007; LLCI = 0.063; ULCI = 0.388. Models 6a and b: no-significant

Table 6.
Heterogeneity results

mediating role that IF collaboration and collaboration with KIBS plays in linking depth I4.0 with the creation of knowledge to improve the innovation of both product and production processes. Specifically, the penetration of I4.0 along value chain activities favored by the adoption of various technologies allows for an increase in collaboration within the firm (specifically between the production and other business functions) as well as positively affecting the relationship with external actors, such as KIBS (that have and offer specific knowledge-based services). Collaborations within and outside favor a firm's innovation in the context of I4.0; thus, they play a significant role in the firm's capability to develop new knowledge to innovate both product and production processes through the technologies adopted. As regards the collaboration with KIBS, we find that that the collaboration is particularly relevant for small firms than for medium and large firms. This result is in line with the literature (Di Maria *et al.*, 2012; Shearmur and Doloreux, 2019).

Those results may offer a first explanation of the complexity of the fourth industrial revolution. To grasp the benefit of I4.0 technologies, firms need to fully deploy their technological potential in more than one technological direction, given the interdependencies between them and symmetrically in more than one area of the value chain interconnecting several internal activities and processes. According to our results, the creation of knowledge for innovation purposes is connected not only to the variety of I4.0 (various technologies rather than a single technology), but also to collaboration within and outside the firm's boundaries. This evidence provides an innovative view of the topic explored, enriching previous findings on the relationship between specific technologies and knowledge-related processes, for example the big data management and its implications for knowledge creation through enhanced decision-making systems discussed by Pauleen and Wang (2017).

A further explanation has to do with the learning curve (Argote, 1999). Firms need time and experience to learn (and thus to develop new knowledge of) how to use I4.0 technologies to reach their specific strategic goals, taking into consideration the firm's organizational context and processes. That is not straightforward: firms have to adjust to the new possibilities offered by technologies and change how activities are organized up to transformation at the strategic level. This is an explorative process that can be more or less challenging but, in any case, is based on learning-by-doing dynamics. In this vein, collaborations within and outside the firm's boundaries support this learning process, fully implementing the potential of new technologies in terms of knowledge creation and innovation.

On the one hand, IF collaboration is key to achieving many business goals (De Luca and Atuahene-Gima, 2007), including the successful exploitation of I4.0 technologies. Specifically, the collaboration between the production area of a manufacturing firm and the other business functions allows exploitation of the benefits of I4.0 that links manufacturing processes to data and other communication technologies to respond quickly to market changes through the creation of new knowledge for innovation purposes. Indeed, the adoption of a new technology in one function of the firm, such as manufacturing operations, may have important connections and implications for other functions, such as marketing, customer services, or new product development. These interdependencies cannot be fully known in advance and, therefore, cannot be planned for, but they need to be discovered through IF interactions to achieve an effective outcome, such as knowledge creation.

On the other hand, firms, especially small ones, do not usually have internally all the skills and competences required to master these new types of technologies (Corò *et al.*, 2021). Collaboration with competent external actors, such as KIBS, can become relevant for acquiring knowledge of both specific technologies and their interdependencies and of how to use them, with positive effects on the creation of new knowledge for product and process innovation. Although some scholars foresee a deep transformation of firms in terms of internal competences (Davenport, 2018), for example through the introduction of new professional profiles such as data scientists, it is unlikely that firms will be able to complete this change, particularly in the short term and in the case of SMEs. It is probably more important for the firm to build a network of specialized partners to interact with for the implementation of I4.0 opportunities. In alignment with Vaillant *et al.* (2021), we highlight the role of KIBS as relevant partners in the I4.0 evolution of firms (their customers) by virtue of the knowledge they accumulate internally, the network of relationships they maintain and their ability to customize the technologies introduced by their customers (Grandinetti, 2018).

6. Conclusions

To the best of the authors' knowledge, this study is one of the first that provides empirical evidence of how I4.0 enables the development of new knowledge to innovate processes and products by linking the concept of breadth and depth in technological adoption for I4.0. While the I4.0 literature has mainly focused on the positive impacts on both knowledge and innovation as outcomes of the use of technologies (Bettiol *et al.*, 2022; de Bem Machado *et al.*, 2022), our results show that these effects depend on collaboration within the company (among the different business functions) and with external partners. Indeed, in this sense, the paper enriches the literature on the relationship between I4.0 and the creation of new knowledge for innovation by emphasizing the relevance of networking. To ensure wider use of I4.0 on different value chain activities (depth I4.0), a firm has to adopt various I4.0 technologies (breadth I4.0). However, the depth I4.0 *per se* is not enough to create new knowledge to innovate products and processes.

The lack of a significant direct relationship between depth I4.0 and knowledge creation for innovation leads to the second contribution, which refers to the (key) mediating role of both IF collaboration and collaboration with KIBS that enable a firm to create new knowledge to innovate processes and products through the use of I4.0 technologies adopted within its internal value chain activities. Collaboration among internal and with external actors seems, therefore, to be a relevant condition to trigger the firm's learning process, especially for SMEs. In fact, only when the adoption of I4.0 technologies is coupled with collaboration (internal and external), knowledge creation can be observed. In particular, the role played by external actors, such as KIBS, is often overlooked in the I4.0 literature (Frank *et al.*, 2019), where adoption seems to be related only to the skills and capabilities of the firm. The results of our research confirm the importance of these value-added business service providers in supporting companies' innovation processes, which has been highlighted by previous studies (Muller and Doloreux, 2009). This has also to be considered in terms of technology customization, as I4.0 does not necessarily refer to "off-the-shelf" technologies that firms purchase and use immediately but, rather, to those that require adaptation to the firm's needs and in which KIBS have a role. In general, our study contributes to providing a framework that aims at filling a gap since the variables IF collaboration and collaboration with KIBS have never been considered in relation to the link between I4.0 adoption and knowledge creation for innovation.

Theoretically, our findings mean that knowledge creation and innovation are related not only to an enabling technological infrastructure, but also to a specific set of relationships the firm has developed within and outside its boundaries. This is perfectly consistent with the open innovation paradigm (Bigliardi *et al.*, 2021; Frank *et al.*, 2022) to which our work contributes to extend to the I4.0 landscape (Obradović *et al.*, 2021).

Our study has several managerial implications. From a managerial point of view, firms should encourage internal and external collaboration when I4.0 technologies are adopted. Teams composed of managers coming from different functions of the firm should be in charge of adoption in order to fully grasp the potential of the implementation of a new technology. As our results reveal, the complexity of this fourth revolution requires more than a narrow functional focus. Its consequences impact on several areas across the firm. In addition, managers should favor collaboration with valuable partners that could help the firm redesign their processes and products. Selection of and dialog with those partners seem to be strategic skills firms need to master.

Our study provides evidence of the dynamics underlying I4.0 investment decisions for the firms interviewed and offers initial suggestions in terms of policy implications. According to the results of the study, in order to benefit from the fourth industrial revolution rooted in the I4.0 paradigm, it is important for adopters to rely on networks with external actors (Muscio and Ciffolilli, 2019), thus reframing the fiscal incentives for the adoption of those technologies included into I4.0 policies within a wider framework of collaboration requirements, as is consistent with other studies on I4.0 incentives (Cugno *et al.*, 2021). The quality of this network has very important consequences for the outcomes of the adoption of new technologies innovation-wise. From this perspective, research stresses the relevance of having KIBS at the local level in order to support the knowledge upgrading of firms which follow such paths of digital transformation (Messeni Petruzzelli *et al.*, 2022).

The study has some limitations. It refers to Italian manufacturing SMEs. In this sense, future research should aim to verify whether manufacturing firms located in other countries have similar strategies and results, while exploring the size factor. Additional variables to capture the collaborative dimension within and outside organizations can also be adopted, for example the actors considered or intensity of collaboration, to further study the knowledge management implications of technological adoption. To better assess the relationship between breadth and depth of I4.0, future research should consider how specific sets of technologies (approached as bundles of interrelated technologies, such as the more general big data and cloud or the more specific robotics and 3D scanners) impact the various business processes for product and process innovation purposes. In addition, future research should take into consideration specific types of knowledge (tacit vs. codified) and the role of a firm's digital competences and capabilities to define more detailed cause-and-effect models. Moreover, further studies can deepen the analysis by not only considering knowledge creation specifically related to process/product innovation and by deepening the link between the internal and external networks. In line with emergent literature on the role of serendipity in management (Balzano, 2022), future research could also consider if network building within and outside the company could increase the possibility of "unintended discovery" (Dew, 2009) and, as a consequence, the firm's innovation capability. In particular, understanding whether serendipity has a mediating effect on the unintended use of I4.0 and the knowledge produced could be important. Future research should also consider the learning dynamics occurring at the firm level over time.

References

Achrol, R.S. and Kotler, P. (2022), "Distributed marketing networks: the fourth industrial revolution", *Journal of Business Research*, Vol. 150, pp. 515-527.

Agostini, L. and Filippini, R. (2019), "Organizational and managerial challenges in the path toward Industry 4.0", *European Journal of Innovation Management*, Vol. 22 No. 3, pp. 406-421.

Agostini, L., Galati, F. and Gastaldi, L. (2020), "The digitalization of the innovation process: challenges and opportunities from a management perspective", *European Journal of Innovation Management*, Vol. 23 No. 1, pp. 1-12.

Amancio, I.R., Mendes, G.H.D.S., Moralles, H.F., Fischer, B.B. and Sisti, E. (2022), "The interplay between KIBS and manufacturers: a scoping review of major key themes and research opportunities", *European Planning Studies*, Vol. 30 No. 10, pp. 1919-1941.

Apostolou, D., Abecker, A. and Mentzas, G. (2007), "Harmonising codification and socialisation in knowledge management", *Knowledge Management Research and Practice*, Vol. 5 No. 4, pp. 271-285.

Argote, L. (1999), *Organizational Learning: Creating, Retaining and Transferring Knowledge*, Kluwer, Boston, MA.

Autry, C.W., Grawe, S.J., Daugherty, P.J. and Richey, R.G. (2010), "The effects of technological turbulence and breadth on supply chain technology acceptance and adoption", *Journal of Operations Management*, Vol. 28 No. 6, pp. 522-536.

Baldoni, E., De Propris, L. and Storai, D. (2022), "Territorial servitisation in Italian industrial districts: the role of technological and professional KIBS", *Competitiveness Review: An International Business Journal*, Vol. 32 No. 5, pp. 743-759.

Ballestar, M.T., Díaz-Chao, Á., Sainz, J. and Torrent-Sellens, J. (2020), "Knowledge, robots and productivity in SMEs: explaining the second digital wave", *Journal of Business Research*, Vol. 108, pp. 119-131.

Balzano, M. (2022), "Serendipity in management studies: a literature review and future research directions", *Management Decision*, Vol. 60 No. 13, pp. 130-152.

Baron, R.M. and Kenny, D.A. (1986), "The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations", *Journal of Personality and Social Psychology*, Vol. 51 No. 6, pp. 1173-1182.

Becattini, G., Bellandi, M. and De Propris, L. (2009), *A Handbook of Industrial Districts*, Edward Elgar, Cheltenham.

Benitez, G.B., Ayala, N.F. and Frank, A.G. (2020), "Industry 4.0 innovation ecosystems: an evolutionary perspective on value cocreation", *International Journal of Production Economics*, Vol. 228, p. 228, doi: 10.1016/j.ijpe.2020.107735.

Bettiol, M., Di Maria, E. and Grandinetti, R. (2015), "Service customisation and standardisation in combinatory knowledge-intensive business services", *International Journal of Knowledge-Based Development*, Vol. 6 No. 3, pp. 241-260.

Bettiol, M., Di Maria, E. and Micelli, S. (Eds) (2020), *Knowledge Management and Industry 4.0: New Paradigms for Value Creation*, Springer, Cham.

Bettiol, M., Capestro, M., Di Maria, E. and Micelli, S. (2022), "Disentangling the link between ICT and Industry 4.0: impacts on knowledge-related performance", *International Journal of Productivity and Performance Management*, Vol. 71 No. 4, pp. 1076-1098.

Bigliardi, B., Ferraro, G., Filippelli, S. and Galati, F. (2021), "The past, present and future of open innovation", *European Journal of Innovation Management*, Vol. 24 No. 4, pp. 1130-1161.

Bolisani, E. and Scarso, E. (1999), "Information technology management: a knowledge-based perspective", *Technovation*, Vol. 19 No. 4, pp. 209-217.

Bonfanti, A., Del Giudice, M. and Papa, A. (2018), "Italian craft firms between digital manufacturing, open innovation, and servitization", *Journal of the Knowledge Economy*, Vol. 9 No. 1, pp. 136-149.

Brodeur, J., Pellerin, R. and Deschamps, I. (2021), "Collaborative approach to digital transformation (CADT) model for manufacturing SMEs", *Journal of Manufacturing Technology Management*, Vol. 33 No. 1, pp. 61-83.

Brown, J.S. and Duguid, P. (2001), "Knowledge and organization: a social-practice perspective", *Organization Science*, Vol. 12 No. 2, pp. 198-213.

Büchi, G., Cugno, M. and Castagnoli, R. (2020), "Smart factory performance and Industry 4.0", *Technological Forecasting and Social Change*, Vol. 150, pp. 1-10, doi: 10.1016/j.techfore.2019.119790.

Bustinza, O.F., Opazo-Basaez, M. and Tarba, S. (2022), "Exploring the interplay between smart manufacturing and KIBS firms in configuring product-service innovation performance", *Technovation*, Vol. 118, pp. 1-10, doi: 10.1016/j.technovation.2021.102258.

Cabigiosu, A. and Campagnolo, D. (2019), "Innovation and growth in KIBS: the role of clients' collaboration and service customization", *Industry and Innovation*, Vol. 26 No. 5, pp. 592-618.

Cainelli, G., De Marchi, V. and Grandinetti, R. (2020), "Do knowledge-intensive business services innovate differently?", *Economics of Innovation and New Technology*, Vol. 29 No. 1, pp. 48-65.

Camuffo, A. and Grandinetti, R. (2011), "Italian industrial districts as cognitive systems: are they still reproducible?", *Entrepreneurship and Regional Development*, Vol. 23 Nos 9-10, pp. 815-852.

Chesbrough, H.W. (2003), "The era of open innovation", *MIT Sloan Management Review*, Vol. 44 No. 3, pp. 35-41.

Chiarello, F., Trivelli, L., Bonaccorsi, A. and Fantoni, G. (2018), "Extracting and mapping industry 4.0 technologies using Wikipedia", *Computers in Industry*, Vol. 100, pp. 244-257.

Colombari, R., Geuna, A., Helper, S., Martins, R., Paolucci, E., Ricci, R. and Seamans, R. (2023), "The interplay between data-driven decision-making and digitalization: a firm-level survey of the Italian and US automotive industries", *International Journal of Production Economics*, Vol. 255, pp. 1-11, doi: 10.1016/j.ijpe.2022.108718.

Corò, G., Plechero, M., Rullani, F. and Volpe, M. (2021), "Industry 4.0 technological trajectories and traditional manufacturing regions: the role of knowledge workers", *Regional Studies*, Vol. 55 Nos 10-11, pp. 1681-1695.

Corso, A., Martini, A., Paolucci, E. and Pellegrini, L. (2001), "Knowledge management in product innovation: an interpretative review", *International Journal of Management Reviews*, Vol. 2 No. 4, pp. 341-352.

Cowan, R., David, P.A. and Foray, D. (2000), "The explicit economics of knowledge codification and tacitness", *Industrial and Corporate Change*, Vol. 9 No. 2, pp. 211-253.

Crupi, A., Del Sarto, N., Di Minin, A., Gregori, G.L., Lepore, D., Marinelli, L. and Spigarelli, F. (2020), "The digital transformation of SMEs: a new knowledge broker called the digital innovation hub", *Journal of Knowledge Management*, Vol. 24 No. 6, pp. 1263-1288.

Cugno, M., Castagnoli, R. and Büchi, G. (2021), "Openness to Industry 4.0 and performance: the impact of barriers and incentives", *Technological Forecasting and Social Change*, Vol. 168, 120756.

Culot, G., Nassimbeni, G., Orzes, G. and Sartor, M. (2020), "Behind the definition of Industry 4.0: analysis and open questions", *International Journal of Production Economics*, Vol. 226, doi: 10.1016/j.ijpe.2020.107617.

Dalenogare, L.S., Benitez, G.B., Ayala, N.F. and Frank, A.G. (2018), "The expected contribution of Industry 4.0 technologies for industrial performance", *International Journal of Production Economics*, Vol. 204, pp. 383-394.

Davenport, T.H. (2007), "Information technologies for knowledge management", in Ichijo, K. and Nonaka, I. (Eds), *Knowledge Creation and Management: New Challenges for Managers*, Oxford University Press, Oxford, pp. 97-120.

Davenport, T.H. (2013), "Analytics 3.0", *Harvard Business Review*, Vol. 91 No. 12, pp. 64-72.

Davenport, T.H. (2018), "From analytics to artificial intelligence", *Journal of Business Analytics*, Vol. 1 No. 2, pp. 73-80.

Davenport, T. and Prusak, L. (1998), *Working Knowledge: Managing what Your Organization Knows*, Harvard Business School Press, Cambridge.

Davenport, T. and Prusak, L. (2000), *Working Knowledge: How Organizations Manage what They Know*, Harvard Business School Press, Boston, MA.

de Bem Machado, A., Secinaro, S., Calandra, D. and Lanzalonga, F. (2022), "Knowledge management and digital transformation for Industry 4.0: a structured literature review", *Knowledge Management Research and Practice*, Vol. 20 No. 2, pp. 320-338.

De Luca, L.M. and Atuahene-Gima, K. (2007), "Market knowledge dimensions and cross-functional collaboration: examining the different routes to product innovation performance", *Journal of Marketing*, Vol. 71 No. 1, pp. 95-112.

de Medeiros, J.F., Ribeiro, J.L.D. and Cortimiglia, M.N. (2014), "Success factors for environmentally sustainable product innovation: a systematic literature review", *Journal of Cleaner Production*, Vol. 65, pp. 76-86.

De Propris, L. and Bellandi, M. (2021), "Regions beyond industry 4.0", *Regional Studies*, Vol. 55 Nos 10-11, pp. 1609-1616.

Dew, N. (2009), "Serendipity in entrepreneurship", *Organization Studies*, Vol. 30 No. 7, pp. 735-753.

Di Maria, E., Grandinetti, R. and Di Bernardo, B. (Eds) (2012), *Exploring Knowledge-Intensive Business Services: Knowledge Management Strategies*, Palgrave, London.

Di Roma, A. (2017), "Footwear design. The paradox of 'tailored shoe' in the contemporary digital manufacturing systems", *The Design Journal*, Vol. 20 No. 1, pp. 2689-2699.

Doloreux, D. and Shearmur, R. (2010), "Exploring and comparing innovation patterns across different knowledge intensive business services", *Economics of Innovation and New Technology*, Vol. 19 No. 7, pp. 605-625.

Edquist, H., Goodridge, P. and Haskel, J. (2021), "The Internet of Things and economic growth in a panel of countries", *Economics of Innovation and New Technology*, Vol. 30 No. 3, pp. 262-283.

Fatorachian, H. and Kazemi, H. (2018), "A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework", *Production Planning and Control*, Vol. 29 No. 8, pp. 633-644.

Frank, A.G., Dalenogare, L.S. and Ayala, N.F. (2019), "Industry 4.0 technologies: implementation patterns in manufacturing companies", *International Journal of Production Economics*, Vol. 210, pp. 15-26.

Frank, A.G., Benitez, G.B., Ferreira Lima, M. and Bonzanini Bernardi, J.A. (2022), "Effects of open innovation breadth on industrial innovation input–output relationships", *European Journal of Innovation Management*, Vol. 25 No. 4, pp. 975-996.

Ganotakis, P., Hsieh, W.L. and Love, J.H. (2013), "Information systems, inter-functional collaboration and innovation in Taiwanese high-tech manufacturing firms", *Production Planning and Control*, Vol. 24 Nos 8-9, pp. 837-850.

Ghobakhloo, M. (2018), "The future of manufacturing industry: a strategic roadmap toward Industry 4.0", *Journal of Manufacturing Technology Management*, Vol. 29 No. 6, pp. 910-936.

Ghobakhloo, M. and Fathi, M. (2020), "Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing", *Journal of Manufacturing Technology Management*, Vol. 31 No. 1, pp. 1-30.

Grandinetti, R. (2018), "The KIBS paradox and structural holes", *Knowledge Management Research and Practice*, Vol. 16 No. 2, pp. 161-172.

Hayes, A.F. (2013), *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach*, The Guilford Press, New York, NY.

Higón, D.A. (2012), "The impact of ICT on innovation activities: evidence for UK SMEs", *International Small Business Journal*, Vol. 30 No. 6, pp. 684-699.

Hinkle, D.E., Wiersma, W. and Jurs, S.G. (2003), *Applied Statistics for the Behavioral Sciences*, 5th ed., Houghton Mifflin Company, Boston, MA.

Holland, S., Gaston, K. and Gomes, J. (2000), "Critical success factors for cross-functional teamwork in new product development", *International Journal of Management Reviews*, Vol. 2 No. 3, pp. 231-259.

Hughes, L., Dwivedi, Y.K., Rana, N.P., Williams, M.D. and Raghavan, V. (2022), "Perspectives on the future of manufacturing within the Industry 4.0 era", *Production Planning and Control*, Vol. 33 Nos 2-3, pp. 138-158.

Iacobucci, D. (2008), *Mediation Analysis*, Sage, Thousand Oaks, CA.

Karhade, P.P. and Dong, J.Q. (2021), "Innovation outcomes of digitally enabled collaborative problemistic search capability", *MIS Quarterly*, Vol. 45 No. 2, pp. 693-718.

Kim, H. and Hur, D. (2022), "Feeling torn? The conflicting effects of market and entrepreneurial orientations on manufacturing SMEs' innovation performance", *European Journal of Innovation Management*, Vol. ahead-of-print No. ahead-of-print, pp. 1-30, doi: 10.1108/EJIM-12-2021-0623.

Lagravinese, R. (2015), "Economic crisis and rising gaps north-south: evidence from the Italian regions", *Cambridge Journal of Regions, Economy and Society*, Vol. 8 No. 2, pp. 331-342.

Lamorgese, A. and Olivieri, E. (2017), *Economie Regionali. L'economia Delle Regioni Italiane*, Banca d'Italia, Rome.

Larrea, M. and Estensoro, M. (2021), "Governance of Industry 4.0 policies: making knowledge services accessible for SMEs", *Regional Studies*, Vol. 55 Nos 10-11, pp. 1839-1850.

Laubengaier, D.A., Cagliano, R. and Canterino, F. (2022), "It takes two to tango: analyzing the relationship between technological and administrative process innovations in Industry 4.0", *Technological Forecasting and Social Change*, Vol. 180, pp. 1-13, doi: 10.1016/j.techfore.2022.121675.

Laursen, K. and Salter, A. (2006), "Open for innovation: the role of openness in explaining innovation performance among U.K. manufacturing firms", *Strategic Management Journal*, Vol. 27 No. 2, pp. 131-150.

Lepore, D., Dubbini, S., Micozzi, A. and Spigarelli, F. (2022), "Knowledge sharing opportunities for Industry 4.0 firms", *Journal of the Knowledge Economy*, Vol. 13, pp. 501-520.

MacKinnon, D.P., Lockwood, C.M., Hoffman, J.M., West, S.G. and Sheets, V. (2002), "A comparison of methods to test mediation and other intervening variable effects", *Psychological Methods*, Vol. 7 No. 1, pp. 83-104.

Messeni Petruzzelli, A., Murgia, G. and Parmentola, A. (2022), "How can open innovation support SMEs in the adoption of I4.0 technologies? An empirical analysis", *R&D Management*, Vol. 54 No. 4, pp. 615-632.

Miandar, T., Galeazzo, A. and Furlan, A. (2020), "Coordinating knowledge creation: a systematic literature review on the interplay between operational excellence and Industry 4.0 technologies", in Bettiol, M., Di Maria, E. and Micelli, S. (Eds), *Knowledge Management and Industry 4.0: New Paradigms for Value Creation*, Springer Nature, Cham, pp. 137-162.

Mittal, S., Khan, M.A., Romero, D. and Wuest, T. (2018), "A critical review of smart manufacturing and Industry 4.0 maturity models: implications for small and medium-sized enterprises (SMEs)", *Journal of Manufacturing Systems*, Vol. 49, pp. 194-214.

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E. and Eburdy, R. (2019), "Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs", *International Journal of Production Research*, Vol. 58 No. 5, pp. 1384-1400.

Muller, E. and Doloreux, D. (2009), "What we should know about knowledge-intensive business services", *Technology in Society*, Vol. 31 No. 1, pp. 64-72.

Muller, E. and Zenker, A. (2001), "Business services as actors of knowledge transformation: the role of KIBS in regional and national innovation systems", *Research Policy*, Vol. 30 No. 9, pp. 1501-1516.

Müller, J.M., Buliga, O. and Voigt, K.I. (2018), "Fortune favors the prepared: how SMEs approach business model innovations in industry 4.0", *Technological Forecasting and Social Change*, Vol. 132, pp. 2-17.

Muscio, A. and Ciffolilli, A. (2019), "What drives the capacity to integrate Industry 4.0 technologies? Evidence from European R&D projects", *Economics of Innovation and New Technology*, Vol. 29 No. 2, pp. 169-183.

Naeem, H.M. and Di Maria, E. (2022), "Customer participation in new product development: an Industry 4.0 perspective", *European Journal of Innovation Management*, Vol. 25 No. 6, pp. 637-655.

Nonaka, I. and Takeuchi, H. (1995), *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press, New York, NY.

Obradović, T., Vlačić, B. and Dabić, M. (2021), "Open innovation in the manufacturing industry: a review and research agenda", *Technovation*, Vol. 102, pp. 1-16.

OECD (2020), "Global value chains (GVCs): Italy", available at: http://www.oecd.org/sti/ind/gvcs%20-%20italy.pdf (accessed 28 December 2022).

Oltra-Mestre, M.J., Hargaden, V., Coughlan, P. and Segura-García del Río, B. (2021), "Innovation in the agri-food sector: exploiting opportunities for Industry 4.0", *Creativity and Innovation Management*, Vol. 30 No. 11, pp. 198-210.

Osterrieder, P., Budde, L. and Friedli, T. (2020), "The smart factory as a key construct of industry 4.0: a systematic literature review", *International Journal of Production Economics*, Vol. 221, pp. 1-16, doi: 10.1016/j.ijpe.2019.08.011.

Pagano, A., Carloni, E., Galvani, S. and Bocconcelli, R. (2020), "The dissemination mechanisms of Industry 4.0 knowledge in traditional industrial districts: evidence from Italy", *Competitiveness Review: An International Business Journal*, Vol. 31 No. 1, pp. 27-53.

Paiola, M., Schiavone, F., Khvatova, T. and Grandinetti, R. (2021), "Prior knowledge, industry 4.0 and digital servitization: an inductive framework", *Technological Forecasting and Social Change*, Vol. 171, pp. 1-12, doi: 10.1016/j.techfore.2021.120963.

Paiola, M., Agostini, L., Grandinetti, R. and Nosella, A. (2022), "The process of business model innovation driven by IoT: exploring the case of incumbent SMEs", *Industrial Marketing Management*, Vol. 103, pp. 30-46.

Paschen, J., Kietzmann, J. and Kietzmann, T.C. (2019), "Artificial intelligence (AI) and its implications for market knowledge in B2B marketing", *Journal of Business and Industrial Marketing*, Vol. 34 No. 7, pp. 1410-1419.

Pauleen, D.J. and Wang, W.Y. (2017), "Does big data mean big knowledge? KM perspectives on big data and analytics", *Journal of Knowledge Management*, Vol. 21 No. 1, pp. 1-6.

Piening, E.P. and Salge, T.O. (2015), "Understanding the antecedents, contingencies, and performance implications of process innovation: a dynamic capabilities perspective", *Journal of Product Innovation Management*, Vol. 32 No. 1, pp. 80-97.

Pillai, R., Yadav, S., Sivathanu, B., Kaushik, N. and Goel, P. (2022), "Use of 4.0 (I4.0) technology in HRM: a pathway toward SHRM 4.0 and HR performance", *Foresight*, Vol. 24 No. 6, pp. 708-727.

Porter, M. (1985), *Competitive Advantage*, The Free Press, New York, NY.

Preacher, K.J. and Hayes, A.F. (2004), "SPSS and SAS procedures for estimating indirect effects in simple mediation models", *Behavior Research Methods, Instruments, and Computers*, Vol. 36 No. 4, pp. 717-731.

Reypens, C., Lievens, A. and Blazevic, V. (2016), "Leveraging value in multi-stakeholder innovation networks: a process framework for value c-creation and capture", *Industrial Marketing Management*, Vol. 56, pp. 40-50.

Roblek, V., Meško, M. and Krapež, A. (2016), "A complex view of Industry 4.0", *SAGE Open*, Vol. 6 No. 2, pp. 1-11.

Rõigas, K., Mohnen, P. and Varblane, U. (2018), "Which firms use universities as cooperation Partners? A comparative view in Europe", *International Journal of Technology Management*, Vol. 76 Nos 1-2, pp. 32-57.

Saucedo-Martínez, J.A., Pérez-Lara, M., Marmolejo-Saucedo, J.A., Salais-Fierro, T.E. and Vasant, P. (2018), "Industry 4.0 framework for management and operations: a review", *Journal of Ambient Intelligence and Humanized Computing*, Vol. 9 No. 3, pp. 789-801.

Sawhney, M., Verona, G. and Prandelli, E. (2005), "Collaborating to create: the Internet as a platform for customer engagement in product innovation", *Journal of Interactive Marketing*, Vol. 19 No. 4, pp. 4-17.

Schneider, P. (2018), "Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field", *Review of Managerial Science*, Vol. 12 No. 3, pp. 803-848.

Schuh, G., Potente, T., Wesch-Potente, C., Weber, A.R. and Prote, J.P. (2014), "Collaboration mechanisms to increase productivity in the context of Industrie 4.0", *Procedia CIRP*, Vol. 19, pp. 51-56.

Schwab, K. (2017), *The Fourth Industrial Revolution*, Crown Business, New York, NY.

Sedita, S.R. and Grandinetti, R. (2022), "Beyond R&D: a configurational approach to open innovation in the Veneto region", *European Planning Studies*, pp. 1-20, doi: 10.1080/09654313.2022.2114316.

Shearmur, R. and Doloreux, D. (2019), "KIBS as both innovators and knowledge intermediaries in the innovation process: intermediation as a contingent role", *Papers in Regional Science*, Vol. 98 No. 1, pp. 191-209.

Soto-Acosta, P. and Cegarra-Navarro, J.G. (2016), "New ICTs for knowledge management in organizations", *Journal of Knowledge Management*, Vol. 20 No. 3, pp. 417-422.

Spender, J.C. (1996), "Making knowledge the basis of a dynamic theory of the firm", *Strategic Management Journal*, Vol. 17, pp. 45-62.

Strambach, S. (2001), "Innovation processes and the role of knowledge-intensive business services (KIBS)", in Koschatzky, K., Kulicke, M. and Zenker, A. (Eds), *Innovation Networks*, Physica-Verlag, Heidelberg, pp. 53-68.

Suppatvech, C., Godsell, J. and Day, S. (2019), "The roles of internet of things technology in enabling servitized business models: a systematic literature review", *Industrial Marketing Management*, Vol. 82, pp. 70-86.

Szalavetz, A. (2019), "Industry 4.0 and capability development in manufacturing subsidiaries", *Technological Forecasting and Social Change*, Vol. 145, pp. 384-395.

Tan, K.H. and Zhan, Y. (2017), "Improving new product development using big data: a case study of an electronics company", *R&D Management*, Vol. 47 No. 4, pp. 570-582.

Tong, X., Liu, Q., Pi, S. and Xiao, Y. (2020), "Real-time machining data application and service based on IMT digital twin", *Journal of Intelligent Manufacturing*, Vol. 31, pp. 1113-1132.

Ulrich, K. and Eppinger, S.D. (2000), *Product Design and Development*, McGraw-Hill, New York, NY.

Vaillant, Y., Lafuente, E., Horváth, K. and Vendrell-Herrero, F. (2021), "Regions on course for the fourth industrial revolution: the role of a strong indigenous T-KIBS sector", *Regional Studies*, Vol. 55 Nos 10-11, pp. 1816-1828.

Vogel-Heuser, B. and Hess, D. (2016), "Industry 4.0: prerequisites and visions", *IEEE Transactions on Automation Science and Engineering*, Vol. 13 No. 2, pp. 411-413.

Zheng, T., Ardolino, M., Bacchetti, A., Perona, M. and Zanardini, M. (2019), "The impacts of Industry 4.0: a descriptive survey in the Italian manufacturing sector", *Journal of Manufacturing Technology Management*, Vol. 31 No. 5, pp. 1085-1115.

Zhou, K.Z. and Li, C.B. (2012), "How knowledge affects radical innovation: knowledge base, market knowledge acquisition, and internal knowledge sharing", *Strategic Management Journal*, Vol. 33 No. 9, pp. 1090-1102.

Corresponding author
Mauro Capestro can be contacted at: mauro.capestro@unipd.it