Journal of the Knowledge Economy (2022) 13:501–520
https://doi.org/10.1007/s13132-021-00750-9

Knowledge Sharing Opportunities for Industry 4.0 Firms

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Received: 5 March 2020 / Accepted: 19 January 2021 / Published online: 5 February 2021

Abstract

This paper focuses on the role that collaboration holds in supporting knowledge sharing mechanisms for the adoption of Industry 4.0 technologies. We develop a qualitative analysis based on four firms that show a collaborative approach both in the regional ecosystem in which they are included and within their organizational structure. The objective is twofold, i.e. to understand if and how the introduction of 4.0 technologies has changed the nature of the relationships with external knowledge sources, and if and how 4.0 technologies have redefined the collaborative culture within the organizational structure. The findings show that collaboration is imperative for introducing 4.0 technologies. The firms reveal to hold a mentoring role by supporting other less advanced firms in the adoption of 4.0 technologies and confirm that 4.0 technologies are facilitating the emergence of a collaborative culture in the regional ecosystem. On the other hand, both formal and informal collaborative approaches within their organization are found to support the adoption of new digital technologies.

Keywords Fourth industrial revolution · Industry 4.0 · Collaborative enablers · Innovation

Introduction

Nowadays, firms are faced with the growing interconnection between people, objects and systems, driven by Industry 4.0 technologies (Spath et al., 2013). The fourth industrial revolution, triggered by technologies equipped with "intelligence",

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is allowing information sharing between people and other objects, affecting the decision-making processes of businesses (Solima et al., 2016). These technologies are changing how knowledge is acquired, transmitted and used (Ediz, 2018).

In such a context, firms need to consider external knowledge sources that in turn can benefit organizational innovation (Ferraris et al., 2017). Therefore, as highlighted by the literature, there is a call for investigating which are the new collaborative needs emerging in Industry 4.0 (Camarinha-Matos et al., 2017).

We try to overcome this gap by focusing on knowledge sharing mechanisms of firms that have introduced 4.0 technologies and that were already collaborative both in their regional ecosystem, considering relationships with other firms, academia and institutions (Etzkowitz & Leydesdorff, 2000), and within their organization in terms of a collaborative culture (López et al., 2004).

Based on a multiple-case study (Baxter & Jack, 2008) by means of a qualitative and comparative analysis, we aim to capture evidence for understanding (1) if and how the introduction of 4.0 technologies affects relationships with external knowledge sources and (2) if and how the introduction of 4.0 technologies affects knowledge sharing mechanisms within the organization.

The analysis is based on the Italian region of Marche, representative of the Italian competitiveness in manufacturing (Vrontis et al., 2018). Moreover, the region under analysis is already focusing on building collaborative networks as a means for promoting entrepreneurial innovation.

This paper contributes to the emerging literature on how collaboration is shaping the development of Industry 4.0, providing evidence on how different collaborative models can be adopted outside and within the firm, identifying a set of collaborative enablers.

Specifically, we jointly contribute to the definition of industrial policies that can support firms in the adoption of 4.0 technologies (Bellandi et al., 2019; Buhr, 2017) and new managerial practices that can facilitate learning, knowledge and innovative capabilities (Shamin et al., 2017).

In the first part of the work, the theoretical background on knowledge sharing within and across the firm is reviewed, focusing on how knowledge is addressed in Industry 4.0. Secondly, the methodology and the cases are presented. In the third part, the results are discussed. Lastly, conclusions and policy implications are drawn, providing a future research agenda.

The Relationship Between Knowledge Sharing and Innovation

Firms in their innovation process, including technological innovation, depend increasingly on different types of knowledge sources (Freitas et al., 2011), which are associated with using ideas and developments resulting from access to infrastructure, human capital and partners' innovative capacities. Knowledge sources allow the flexible transfer of specific and commercially sensitive information, for instance, information about new product design, new production processes or market development, without the need to formalize contracts or inherent costs (Bönte & Keilbach, 2005; Freitas et al., 2011).

Competing markets, integration, globalization and development of information and communication technologies have made the use of external sources imperative (Rigby & Zook, 2002).

The idea of incorporating external knowledge in innovation processes rather than relying only on internal sources has been stressed in the literature on innovation. The ability to exploit external knowledge is a critical element of innovative capabilities. It is a function of the level of "prior related knowledge" (Cohen & Levinthal, 1990a, b, p. 128), which ultimately is linked to the firms' absorptive capacity. Firms' absorptive capacity is described by Cohen & Levinthal (1990a, b) as the ability of a firm to recognize the value of new, external information, assimilate it and apply it to commercial ends. Indeed, absorptive capacity refers not only to the acquisition or assimilation of information by an organization but also to the organization's ability to exploit it. Escribano et al. (2009) argue that those firms with higher levels of absorptive capacity can manage external knowledge flows more efficiently and stimulate innovative outcomes. Zhara and George (2002) suggest that absorptive capacity exists as two subsets of "potential" and "realized" absorptive capacity. "Potential" capacity comprises knowledge acquisition and assimilation capabilities, while "realized" capacity centres on knowledge transformation and exploitation as recognizing the value of new information, assimilate it and valorize it into the market.

Even if different studies have pointed out the importance of linking innovation and collaboration (Ponchek, 2016), taking advantage of external knowledge sources to enhance organizational innovation (Cohen & Levinthal, 1990a, b; Ferraris et al., 2017), a paradox may emerge when firms simultaneously share and protect their knowledge in an alliance with other organizations (Bogers, 2010).

In this sense, Estrada et al. (2016) underline that competitor collaboration has a significant positive impact on product innovation performance only when internal knowledge sharing mechanisms and formal knowledge protection mechanisms are present (Estrada et al., 2016). When a firm has put an effort into getting strong protection, sharing knowledge with partners becomes more likely. Different knowledge protection mechanisms can be applied, and the strategic use of these mechanisms is found to enhance knowledge sharing and innovation performance (Hurmelinna-Laukkanen, 2011).

Further, the use of external knowledge sources is frequently shown and measured in studies referring to the level of openness in firms' innovation processes (Ferraris et al., 2017). In this line of studies, Caldas et al. (2019) demonstrate that collaboration and innovation activities at the industry level affect firms' performance. The relationship between knowledge and innovation has been considered in terms of productivity (Capello & Lenzi, 2015), innovation efficiency (Shi et al., 2020) and resource allocation (Lee et al., 2017).

The open innovation perspective offers a framework to discuss the links between different agents since it consists of the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for its external use (Chesbrough, 2003). Open innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology" (Chesbrough, 2003, p. 1).

In this approach, collaborative networks, formed through several kinds of relationships between different actors in the system of innovative sources, are the result of collaborations between firms rather than from single organizations. Even if most open-innovation strategies positively influence innovation, some differences are identified depending on the search innovative strategy of the firm. Triguero and Fernández (2018) found that technological collaboration with universities, providers and external research and development (R&D) has a positive effect, while collaboration with customers and competitors is not significant.

In this context, one of the most important models is the triple helix (TH) used as a way of understanding the interconnection of three major components of national innovation systems: university, industry and government (Etzkowitz & Leydesdorff, 2000). In the TH model, interactions among universities, industry and government are identified as being the key to innovation, economic growth and competitiveness (Farinha et al., 2016). The main benefits for firms participating in TH networks, especially at the regional level, are based on knowledge access and improved ability to meet ongoing challenges (Elvekrok et al., 2018).

This means that innovation and technology policy should reinforce national absorptive capacity, which can allow updating the knowledge base of the institutions and actors that allow firms to recognize the value of external knowledge, assimilate it and apply it to commercial ends (Wegloop, 1995).

Such assumptions are even more relevant for Industry 4.0 where the development of a collaborative culture is required for firms' survival, calling for understanding which new collaborative needs must be addressed (Camarinha-Matos et al., 2017).

We overcome this gap by focusing on the collaborative models of firms that have already introduced 4.0 technologies and that were already collaborative in their regional ecosystem. Moreover, we do not consider only external collaboration by examining relationships in a TH model but also collaboration as knowledge sharing within the company based on a collaborative culture. In fact, researchers and practitioners have demonstrated that the organization's ability to facilitate the sharing and utilization of knowledge is critical for organizational effectiveness (Bock & Kim, 2002; Kogut & Zander, 1996; Nonaka & Takeuchi, 1995).

Knowledge sharing is one of the mechanisms under which knowledge transfer can take place not only outside but also inside organizations. Knowledge resides within individuals (Nonaka & Konno, 1998) who work in the company and apply knowledge in carrying out their tasks.

Consequently, the movement of knowledge across individual and organizational boundaries is dependent on individuals' knowledge-sharing behaviours (Bock et al., 2005). Many authors such as Ganesh et al. (2014) investigated the role of people in knowledge management sharing processes. Hughes (2012) underlines that individuals are determinant for successful information system projects stating that behavioural, cultural and cognitive perspectives are valuable aspects to consider. In the same line, McDermott (1999) highlights that the processing of knowledge requires a unique combination of human and information systems that will make information available and easily accessible, and at the same time ensure an organizational culture of knowledge sharing that will learn how to "think together". Cabrera and Cabrera (2005) suggest a set of

people management practices to encourage knowledge sharing among a wide range of organizational employees starting from work design, staffing, training and development, performance appraisal, compensation and rewards, culture and technology.

To promote such practices, a collaborative culture is required. Indeed, a collaborative culture, embracing employees' diversity for producing and sharing knowledge, is the key to generating new ideas and innovative working (Rodan & Galunic, 2004). Individuals' knowledge should be grouped in teams to facilitate interactions among members increasing the possibility of sharing knowledge (Avnet & Weigel, 2013).

A collaborative organizational culture facilitates the transformation of individuals' and groups' knowledge, skills and experiences (Jen-Te, 2007). Further, organizations that adopt values of trust, cooperation, open communication and embrace diversity represent cases of collaborative culture gain a superior performance (Sveiby & Simons, 2002). In this sense, Davenport and Prusak (1998) suggest that a culture that encourages collaboration among employees facilitates behaviours that are suitable for knowledge sharing. Bock et al. (2005) find that the attitudes toward knowledge sharing, subjective norms about knowledge sharing and the organizational climate have an impact on individuals' intentions to share knowledge.

Concerning the role of organizational reward system, a stream of literature finds that rewards and incentives (e.g. profit sharing, gain sharing, employee stock options) foster knowledge sharing within individuals (Bartol & Srivastava, 2002) while another stream of literature finds the opposite relationship: extrinsic rewards exert a negative effect on individuals' knowledge-sharing attitudes (Bock et al., 2005).

In general, organizational culture can influence knowledge sharing in two ways: (1) by creating an environment in which there are strong and shared social norms on the importance of knowledge sharing and (2) by creating an environment of trust that is important for encouraging individuals to share with others. Schein (2004) defines organizational culture as employees' shared beliefs on the organization and firm's environment.

More specifically, López et al. (2004) define a collaborative culture as a culture that values teamwork, mutual respect, communication and empowerment and influences the knowledge sharing. In a collaborative culture, individuals are encouraged to adopt change, offer divergent viewpoints and discuss problems to reach a constructive collaboration and consensus. In this sense, a collaborative culture encourages individuals to work together effectively by sharing knowledge, learning from one another (Bstieler & Hemmert, 2010).

The KS mechanism may be formalized. Formal sharing of knowledge contains all those knowledge sharing forms which are institutionalized by the management. Examples of these forms are activities, resources and services that are designed by the organization and are organized to help the sharing of knowledge and the learning from each other (Taminiau et al., 2009). On the contrary, informal knowledge sharing is determined as forms that exist together with all the institutionalized forms and examples are activities, resources and services that are used, but not necessarily designed, to increase knowledge exchange (Taminiau et al., 2009).

Managing Knowledge in the 4th Industrial Revolution

Today's economy is heading towards the fourth industrial revolution, characterized by cyber-physical systems, smart factories and service innovations (Lee & Kao, 2014). Industry 4.0 describes the increasing digitization of the entire value chain of industries and firms, together with the resulting interconnection between people, objects and systems through real-time data exchange (Spath et al., 2013).

As a result of these interconnections, products, machines and processes are equipped with artificial intelligence and are enabled to adapt to spontaneous changes in the environment independently. Smart objects become embedded in broader systems, which in turn enhance the creation of flexible and self-controlling production systems (Porter & Heppelmann, 2015).

Objects acquire intelligence and capacity of sharing information with people and other objects, affecting people's lives and the decision-making processes carried out within businesses (Solima et al., 2016). In fact, these new technologies affect how knowledge is acquired, transmitted and used (Ediz, 2018) and are calling for new managerial practices to facilitate learning, knowledge management and innovative capabilities (Shamin et al., 2017). Knowledge, as an organized combination of ideas, rules, procedures and information (Lee & Chang, 2007), is strongly linked with 4.0 technologies, acting as the key resource of business survival and success in the context of a knowledge economy (Teece, 1998).

A great majority of studies has been devoted to understanding technological innovation and its economic impact (Evangelista & Vezzani, 2010; Hervas-Oliver et al., 2015), especially from a regional perspective. Knowledge becomes relevant for regions in the form of Knowledge-based development (KBD) as a development paradigm stressing the importance of knowledge as the driver of regional success and development (Knight, 1995).

In the context of Industry 4.0, the exchange of knowledge in collaborative networks is presented as its enabler (Camarinha-Matos et al., 2017). Therefore, Industry 4.0 should be introduced as a policy-driven innovation discourse aiming at institutionalizing systemic innovation in manufacturing industries in a TH model amongst business, academia and politics (Reischauer, 2018). New digital technologies have even the potential to disrupt how and where activities are located and organized within global value chains (GVCs), and who captures the value-added within those chains (Strange & Zucchella, 2017).

KS can influence the technological innovation capability of the firms (Yao et al., 2020). Moreover, KS mechanisms can affect the selection and introduction of a specific 4.0 technologies through the use of intermediaries (Crupi et al., 2020). Intermediaries, so-called knowledge brokers, by supporting the sharing of knowledge can support firms, especially SMEs, in the adoption of 4.0 technologies (Crupi et al., 2020).

Further, regional strategies can incentivize the introduction of Industry 4.0 based on KS canals (Lepore & Spigarelli, 2020). For these reasons, industrial

policies should be designed to support firms and especially SMEs, in the adoption of 4.0 technologies (Bellandi et al., 2019). Technological tools should be introduced considering that decisions concerning knowledge innovation are ultimately based on people, knowledge assets and business objectives (Goh, 2005). Tasks' specialization resulting from technological innovation can contribute to redesigning models of production and business organization in terms of roles and skill recombination, factors' productivity, decision making and responsibilities and project and market performance (Mishra & Shah, 2009).

This is even more relevant in the fourth industrial revolution, where education, experience, skills and knowledge are used by employees to generate value to ensure firms' success (Agolla, 2018). However, to be competitive, it is necessary to upgrade knowledge, skills and competencies in job-related fields (Agolla, 2018). Workers must evolve to knowledge workers (Engelmann & Schwavem, 2018). Nelles et al. (2016) propose a new role of the human in industry 4.0 companies. Rather than being involved in routine work activities, humans should be put in the position where s/he can quickly make the right decisions in production planning and control.

The changes led by Industry 4.0 will affect human resource management. Industry 4.0 will change all steps from production to distribution, from distribution to marketing, and will incorporate radical innovations within the organization. At the centre of these innovations, there will be human resources (Bayraktar & Canan, 2018).

Moreover, new technologies can further support the sharing of knowledge among employees (Wagner & Bolloju, 2004) by simplifying the sharing of knowledge among people at work (Li et al., 2019).

However, in order to take advantage of Industry 4.0 enabling technologies, resources, organizational structures and cultural needs cannot be neglected (Li et al., 2019) by industrial policies. As demonstrated by Yao et al. (2020), IT support can help increase the level of explicit knowledge sharing in companies but has no direct impact on tacit knowledge sharing; only the management system promotes both explicit knowledge sharing and tacit knowledge sharing.

Methodology

A multiple-case study methodology is used in this paper to explore if and how 4.0 technologies can redefine knowledge sharing mechanisms even in firms that already hold a strong collaborative culture both in their regional ecosystem and within their organizational culture.

Information is retrieved from archival material and face-to-face semi-structured interviews of about 1.5 h (Appendix) with the innovation manager of each of the four firms between April 2018 and September 2019 to understand if after the adoption of 4.0 technologies:

(1) there have been changes in the relationships with institutions, firms and academia
(2) there have been changes in the collaborative culture within their organization

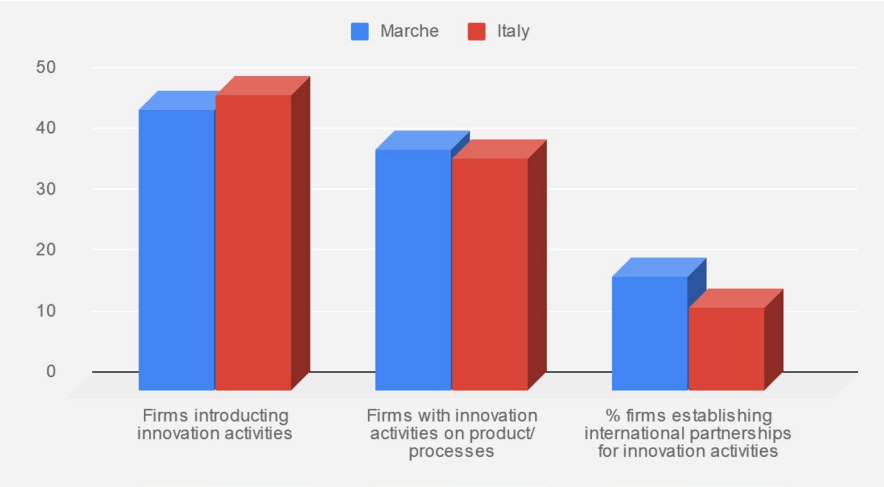

Fig. 1 Percentage of innovation activities in firms. Authors' elaboration based on Italian National Institute of Statistics (ISTAT, 2016)

Case studies are the most appropriate methodology to study a phenomenon within its real-life context, when relevant for understanding the phenomenon under study (Yin, 2003). Furthermore, we undertake a multiple-case study to explore differences within and between cases (Baxter & Jack, 2008; Stake, 1995) to provide contrasts and similarities (Vannoni, 2015). The evidence created from a multiple-case study is stronger and more reliable (Baxter & Jack, 2008), allowing a wider exploration of research questions and theoretical evolution (Eisenhardt & Graebner, 2007).

The Research Setting

The analysis is restricted to the Italian region of Marche. With respect to other European countries, Italy has been the last one to submit a national plan for Industry 4.0, which has been presented in 2016, becoming part of the Stability Law in 2017. However, already back in 2012, a National Cluster on Smart Factory was created to make companies aware of new technologies. The Italian manufacturing industry depends on a few highly competitive regional systems (Vrontis et al., 2018). Among these regional systems, the Marche region was recognized as one of the most industrialized Italian ones for its economic results, national, social and cultural richness (OECD, 2010). Nevertheless, the region, as underlined in its Smart Specialization Strategy needs to evolve towards a productive system embracing innovation by integrating research and production and promoting collaborative networks among enterprises.

As shown in Fig. 1, even if in 2016 the region registered a slightly lower percentage of firms undertaking innovation activities (46.3%) with respect to the Italian average (48.7%), the region recorded a higher percentage in process and

product innovation (39.6% vs 38.1%) and in international partnerships for innovation (18.7% vs 13.6%).

To ensure a representative sample of firms, we selected firms from the partnership base of the Business School, ISTAO (Instituto Adriano Olivetti), which acts as an expert intermediary, connecting regional academia, firms and institutions. The Business school is strongly involved in the regional territory and is supported by the main innovative firms of the region. The intermediary allowed us to select companies that are highly involved in the regional ecosystem and that have a strong collaborative culture based on teamwork, mutual respect, communication and empowerment as specified by López et al. (2004). Together with the intermediary, we considered the manufacturing sector, since the main technology areas in which Marche has a specific competitive advantage are positioned in the advanced manufacturing field, which is linked to the competitiveness of the Made in Italy sectors such as shoes, textiles and clothing, wood products and furniture, machines for wood carving and mechanics.[1] Then through the intermediary, we shortlisted only large enterprises with more than 250 employees as being more representative of the Italian context where large enterprises are the ones mainly adopting advanced technologies (Deloitte, 2018); Further, we considered firms that have all a history greater than 50 years and are formally involved in activities of institutions, universities, and other firms, as participation to regional clusters and networking projects.

Discussion

Introduction of Industry 4.0 Technologies

As shown in Table 1, the firms selected have introduced a wide range of 4.0 technologies, listed according to the National Industry 4.0 Plan. These technologies have been included mainly in production and logistics, expect from the company n.1, which has integrated 4.0 technologies in all the functions of the company. The first three companies have a specific 4.0 strategy, which is in its implementation stage, whereas the last company (company n.4) is still in an experimenting stage, where no strategy is yet defined. All four companies have invested in Advanced Manufacturing Solutions, Horizontal/Vertical Integration, Industrial Internet, Cloud, Cyber-security and Big Data and Analytics, whereas augmented reality is at an experimenting stage in company 2.

[1] Regional Innovation Monitor https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/marche https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/marche

Table 1 The four companies selected

	Company 1	Company 2	Company 3	Company 4
Sector	Manufacturing			
Product	Lighting equipment	Industrial plants	material processing machines	Boilers
Main market	B2B	B2B	B2B	B2C
No. of employees (2018)	1500	416	4208	6800
Turnover (201) millions	238	120	740	1.648.300
4.0 areas involved	All	< 50%	< 50%	< 50%
Recognized strategy 4.0	Implementation	Implementation	Implementation	No specific strategy
4.0 technologies				
Advanced Manufacturing Solutions	Yes	Yes	Yes	Yes
Additive manufacturing	No	Yes	Yes	Yes
Augmented reality	No	Yes	No	No
Simulation	No	Yes	Yes	Yes
Horizontal/vertical integration	Yes	Yes	Yes	Yes
Industrial Internet	Yes	Yes	Yes	Yes
Cloud	Yes	Yes	Yes	Yes
Cyber-security	Yes	Yes	Yes	Yes
Big data and analytics	Yes	Yes	Yes	Yes

The Impact of Industry 4.0 on Collaboration

The collaborative approaches of the four firms allowed to identify four kinds of collaborative models that we distinguish based on their level of formality and stability as summarized in Table 2.

Company 1—the Formalized and Stable Model

Considering the involvement of the company in the region, 4.0 technologies have not increased the number of relationships with external stakeholders since linkages with academia, other firms and regional institutions were already strong before Industry 4.0 in terms of number and intensity. However, when considering the relationships with other firms, a new role of mentoring was recognized. Indeed, suppliers usually refer to company n.1 for consultancy before introducing 4.0 technologies.

On the other hand, looking at their organizational culture, before the introduction of 4.0 technologies the entrepreneur has ensured a collaborative model based on sharing knowledge among employees of different hierarchical and functional levels. Such a

Table 2 Industry 4.0 collaboration

	Company 1	Company 2	Company 3	Company 4
External view				
Main changes in TH relationships	Mentoring role towards other firms	Involvement in regional programs for Industry 4.0; Collaboration with research centres and firms	Collaborative development of 4.0 solutions with clients; Training programs on Industry 4.0 for clients	Sharing best practices with advanced firms; Mentoring role towards other firms
Internal view				
Formality of KS mechanisms	High	Low	Low	High
Stableness of KS mechanism	High	High	Low	Low

model over the years has become formalized in procedures and practices. Formalized mechanisms have been introduced to incentivize employees in presenting suggestions aimed at fostering strategic and operative improvements. Their suggestions have also been correlated with their wage levels. Linking wages to suggestions of employees has proved to be beneficial for increasing their motivation and in turn productivity.

All these mechanisms focused on sharing knowledge have helped the company in the adoption of 4.0 technologies. Indeed, as specified by the innovation manager "the adoption of the new technologies followed the participative logics of the company, as for any other new investment and proved to be the best solution". Therefore, no relevant changes were perceived as necessary in changing existing practices or introducing new ones for increasing the current knowledge sharing opportunities. However, the knowledge that workers can share is broader since technologies 4.0 have allowed achieving a greater vision and control of the firm's processes. Nevertheless, the innovation manager stressed that for allowing employees to share knowledge among peers and at different levels, training was necessary to align their competencies to the new needs of Industry 4.0. Moreover, the introduction of 4.0 technologies led to hiring new roles in charge of analysing data. These technical roles, as stressed by the manager, should be promoters of knowledge sharing mechanisms within the company to exploit the potential of big data.

Company 2—the Non-formalized and Stable Model

Considering relationships in a TH model, the innovation manager of company 2 underlined that thanks to Industry 4.0, relationships have increased in number and intensity, especially with other firms and research centres. Instead, considering regional institutions, the company has been involved in projects for defining future policies aimed at supporting the adoption of 4.0 technologies in the region, especially for small medium-sized enterprises. However, when considering relationships with other firms, some problems have been experienced due to the lack of knowledge on Industry 4.0 by external agents. Therefore, training both partners and clients was the first step to ensure a successful knowledge exchange. Technology has also facilitated the exchange of knowledge by introducing forms of virtual collaboration based on the exploitation of cloud technologies, confirming the view of Li et al. (2019). In addition, company n.2 has developed a strong collaborative culture within the organization, even if not formalized in processes and procedures, as for company n.1. The company encourages in an informal way the knowledge sharing among different levels and functions. These features have not changed by introducing 4.0 technologies. The innovation manager stressed that "the collaborative culture based on sharing knowledge has allowed without obstacles the introduction of 4.0 technologies". Moreover, the new technologies have enhanced the area on which knowledge sharing is possible, involving more employees in planning ways to integrate technologies in existing processes since as underlined by the manager, "connectivity and integration are the main aspects of Industry 4.0". A great range of operative competences has been shifted to machines, enhancing control and strategic function to employees. Furthermore, employees have been empowered upskilling

their competences and skills through training organized within the company or by sending employees abroad, especially in Germany, to share knowledge with other employees from other units of the company. At the same time, new employees have been introduced, as the data analyst who is called to share knowledge about data with other units of the company.

Company 3—the Non-formalized and Empowered-Collaborative Model

Industry 4.0 has increased the number and intensity of collaborations for company n.3 changing the nature of the relationships based on the digital maturity of the B2B client. For advanced firms, a new area of collaboration has emerged in the collaborative development of 4.0 technologies. On the other hand, suppliers have become more integrated into the company by participating in the definition of innovative 4.0 integrated systems that can allow the adoption of smarts factories for B2B clients. Instead, for B2B clients, lacking on 4.0 competences, training has become a precondition to start sharing knowledge.

Looking at the collaborative culture of the company, the innovation manager states that 4.0 has required; "an improvement of the existing collaborative culture, which was already part of the company, even if yet not formalized. Introducing new technologies has led to the introduction of cross-functional teams to capture sharing knowledge advantages based on different competencies". This context has affected the way performance is evaluated by linking wages to the results of the team performance. Even for the company n.3, new functions have been included in charge of managing data deriving from the new technologies, as the data scientist, who, as underlined by the innovation manager, needs to share knowledge with all the other units of the company.

Company 4—the Formalized and Experimental Collaborative Model

The number and intensity of relationships in the regional ecosystem have not changed except for the recognized fact that now these relationships are strongly linked to Industry 4.0 topics. The only exception, even for company n.4, is recognized in the relationships with other firms. The company is currently sharing best practices with firms at the same level of technological development while supporting enterprises that are not at the same digital maturity level. Contrary to the previous cases, company n.4 does not have a 4.0 strategy but bases its decisions on which 4.0 technologies to adopt on a continuous process of technological scouting. The company n.4, as company n.1, has a collaborative model based on formalized procedures aimed at sharing knowledge within the company, encouraging suggestions by all functions and levels. Nevertheless, when it comes to selecting the 4.0 technology to adopt, company n.4 has redefined its collaborative models, testing different approaches overtime.

Firstly, a top-down approach was adopted requesting a formal plan to every plant manager to be presented to top management. Then after a year, the company moved to a more bottom-up approach. The next phase will mix the previous two approached centralizing all the decisions related to 4.0 at the strategic level keeping

active a tunnel model for new technology scouting. In this model, collaboration is encouraged among different functions but at the same hierarchical level to share different knowledge on Industry 4.0 between peers, allowing them to discuss which new technologies should be introduced in the company. In the meantime, the new technologies have led to empowering employees in sharing knowledge for suggesting operational improvements. For this reason, the company has empowered its communication tools through a newsletter, mailing list, and regular meetings focused on Industry 4.0.

The Industry 4.0 Collaborative Enablers

The experience of the four cases allowed to identify factors acting as collaborative enablers in Industry 4.0 both within the company (internal enabler) and externally when referring to relationships with other firms (external enabler). There two enablers led to reconsider the role of institutions and academia as represented in Fig. 1, which can act as drivers supporting such enablers.

Looking into internal enables within Industry 4.0, managers have recognized as a means to enhance knowledge sharing the enabling role of training employees and that of teamwork, especially in terms of cross-functional teams as company 3 has demonstrated. This latter finding is in line with Avnet and Weigel (2013), according to which teams can facilitate knowledge sharing.

Therefore, in reference to internal enablers, institutions and academia could promote training initiatives of companies' employees and provide the necessary soft skills.

Considering external enablers, the level of knowledge and experience in Industry 4.0 by other firms has redefined the nature of relationships. In fact, taking into account relationships with suppliers, partners or clients, a mentoring role is recognized for supporting less advanced companies that require knowledge of Industry 4.0. In line with Ferraris et al. (2017), the four firms have become a knowledge source for other firms. In opposition, sharing knowledge with firms at the same level of technological advancement has led to partnerships for developing new 4.0 technologies, as in company n.2.

In this sense, institutions and academia can help develop Industry 4.0 knowledge and experience in the regional territory by supporting companies become aware of the potential offered by the new technologies, favouring the acquisition of technical competencies and formally recognizing the mentoring role of leading Industry 4.0 firms.

Overall, the role of institutions and academia should be considered in a complementary way to that of Industry 4.0 technologies. Indeed, as the cases underlined, Industry 4.0 technologies themselves have strengthened the sharing of knowledge within the company, allowing employees to gain greater control of processes and strengthened relationships with external stakeholders in terms of virtual collaboration. (Fig. 2)

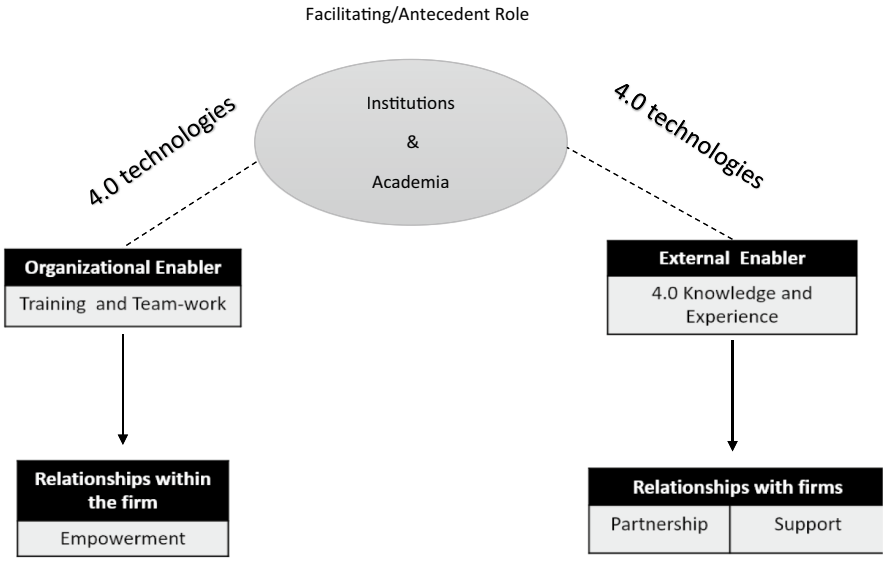

Fig. 2 Facilitating/Antecedent Role

Conclusions and Policy Implications

The cases selected show that collaboration is imperative for introducing 4.0 technologies. All firms recognized that their collaborative culture and relationships in the regional ecosystem have facilitated the introduction of new digital technologies. However, two main changes were identified in the nature of the relationships with other firms and in the content of knowledge shared by employees within the company.

The cases by proving that collaborative networks are an enabler for Industry 4.0 (Camarinha-Matos et al., 2017) allow drawing some first-policy implications based on the new collaborative needs that have been identified.

The mentoring role of the firms could be promoted by regional plans supporting Industry 4.0. In this sense, awareness and networking events led by leading firms could be launched for supporting the adoption of new technologies combined with the involvement of universities and research centres. Furthermore, policies should continue promoting training, which is found to be a precondition for sharing knowledge both among firms and within organizations. Therefore, as underlined by Reischauer (2018), policymakers could shape Industry 4.0 adoption by focusing on communication means that use soft policy instruments to motivate actors to innovate collaboratively.

In addition, even if collaboration is a common trait, it should be considered that a *one size fits all model* does not work as confirmed by the four firms, which report different ways of sharing knowledge, especially within their organizational structure.

Nevertheless, the study with its exploratory nature is based only on a qualitative approach. Collaboration and its impact on knowledge sharing should be further

investigated through quantitative methodologies extending the sample of reference. Moreover, the analysis could be extended to users considering a quadruple-helix architecture (see MacGregor et al., 2010).

On the other hand, the study also shows that 4.0 technologies have empowered employees in terms of knowledge workers in line with the findings of Engelmann and Schwavem (2018). In this regard, it would be of interest to analyse technological change as a transformation of skills and tasks in the process of production (Landesmann & Scazzieri, 2009) by measuring quantitatively the shift in competences from human (H) to machines (M).

Technologies that enable the emerging phenomenon of Industry 4.0 have the possibility to simplify the sharing of knowledge among people at work (Li et al., 2019). However, a collaborative environment is expected to be more ready to adopt the collaborative approaches that 4.0 technologies are favouring. Therefore, it would of interest to consider and compare the case of non-collaborative firms. Moreover, the research should also be extended to other Italian regions, including in the analysis firms of different sizes and sectors to identify similarities and differences in their collaborative enablers.

Appendix

Interview

1. Which Industry 4.0 technologies have been introduced in the company among those indicated in the National Plan *Industria 4.0*?
2. Advanced manufacturing solutions: interconnected and programmable collaborative robots
3. Additive manufacturing: 3D printers connected to digital software
4. Augmented reality: augmented reality supporting productive processes
5. Simulation: simulation between interconnected machines to optimize processes
6. Horizontal/vertical integration: integration of data along the supply chain
7. Industrial internet: multidirectional communication between productive processes and products
8. Cloud: management of big data in open systems
9. Cybersecurity: security during network operations online and in open systems
10. Big Data and Analytics: analysis of data to optimize products and productive processes

2. Which functions of the company have been affected by 4.0 technologies?
3. Have changes occurred considering:
   - Relationships with national/regional institutions?
   - Relationships with universities and research centres?
   - Relationships with other enterprises?

4. Have knowledge sharing mechanisms between human resources changed at hierarchical and functional levels?
5. Has collaboration in the company changed after the introduction of 4.0 technologies?

Declarations

Conflict of interest The authors declare that that they have no conflict of interest.

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