Knowledge and Digital Strategies in Manufacturing Firms: The Experience of Top Performers

Marco Bettiol, Mauro Capestro, Eleonora Di Maria, and Stefano Micelli

Abstract In the past few decades, ICT supported firms managing knowledge through both codification and social interaction, also at distance. Within the Industry 4.0 framework, firms can access knowledge through the cloud and rely on big data and AI to improve their processes and enhance their market comprehension. However, it is not fully explored how knowledge management should be organized in the fourth industrial revolution, since a lot of emphasis has been given to automatization in data management, while the relational dimension of knowledge management has received limited attention. Through an empirical analysis based on mixed method of a survey on 75 top performing Italian manufacturing firms and follow-up on 5 case studies, the chapter explores these questions to identify the implications of Industry 4.0 for firms' strategy.

1 Introduction

Knowledge is a strategic component of the modern firm (Drucker, 1995; Kogut & Zander, 1992; Nonaka & Takeuchi, 1995; Spender, 1996), and it is at the core of the elements that distinguishes one firm from another. Knowledge is idiosyncratic and firm-specific. The way firms manage knowledge is not just a matter of efficiency but it is crucial to compete in the markets and to sustain its competitive advantage. Alavi and Leidner (2001) affirm that "*Because knowledge-based resources are usually difficult to imitate and socially complex, the knowledge-based view of the firm posits that these knowledge assets may produce long-term sustainable competitive advantage*" (p. 107). This approach is rooted in the resource-based view of the firm that

M. Bettiol · M. Capestro · E. Di Maria (✉)
Department of Economics and Management 'Marco Fanno', University of Padova, Padova, Italy
e-mail: eleonora.dimaria@unipd.it

S. Micelli
Department of Management, Ca' Foscari University, Venice, Italy

M. Bettiol et al. (eds.), *Knowledge Management and Industry 4.0*, Knowledge Management and Organizational Learning 9,
https://doi.org/10.1007/978-3-030-43589-9_4

emphasizes the importance of how tangible resources are combined and used by virtue of the firm's know-how (Barney, 1991).

For those reasons, knowledge management (KM) literature plays an important role in the firm's strategy. The origin of the strategic importance of knowledge management can be traced back to Polanyi "*I shall reconsider human knowledge by starting from the fact that we can know more than we can tell.*" (1966, p. 4). This interpretation of knowledge as largely based on a tacit and unarticulated dimension at both individual and organizational levels has led to the definition of managerial practices for transforming the knowledge in a way that could be used by the firm. As Nonaka and Takeuchi maintain in their seminal book *The Knowledge Creating Company* (1995), the firm could improve its competitiveness leveraging on the distributed knowledge pools within its boundaries. The well-established SECI model elaborated by Nonaka and Takeuchi is a way to get access to *individual-tacit* knowledge and transform that in explicit and useful knowledge for the firm. The interplay between tacit and explicit knowledge is at the heart of the strategic relevance of knowledge.

Several KM initiatives conceived technology, in particular, information technology (IT), with the purpose of "*extracting*" knowledge and make this contextual and highly personal resource at the disposal of the firm as a whole. Around the 2000s, in coincidence with the rapid growth of the Internet and the development of new software for storing and managing information, KM focused on the use of those applications as *filters* through which information produced within the firm is captured and stored. KM projects implemented database and software for storing and processing information (i.e., Enterprise Resource Planning) with the idea that knowledge can be interpreted as oil,[1] an extraordinarily valuable resource distributed within the firm that just need to be discovered and put in the pipeline to be ready to use. Ironically, the same oil metaphor will come back later when we discuss the potential of Industry 4.0 in relation to big data.

Although those KM initiatives were effective for data and the management of simple tasks, they had difficulties in fostering knowledge in the firm (Davenport & Prusak, 1998). Database can store a lot of data and information, but it is questionable how those data and information can be transformed into knowledge especially when the process within the firm is complex. Indeed, some authors underline that tacit and explicit knowledge are strictly interconnected and that it is hard to separate one from the other (Alavi & Leidner, 2001). Tacit and explicit are two sides of the same coin. Brown and Duguid affirm (2000)*: "From the idea that tacit knowledge is "non-tradable" and needs to be converted into explicit form to circulate, we come instead to the idea not only that conversion (if it involves uprooting knowledge from the tacit) is problematic, but also that tacit knowledge is required to make explicit knowledge usefully tradable or mobile. Only by first spreading the practice in relation to which the explicit makes sense is the circulation of explicit knowledge*

[1] https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data

worthwhile (Cook and Brown, 1999). ***Knowledge, in short, runs on rails laid by practice.*** *" (p. 204, bold is ours*). It seems a paradox that to transform tacit into explicit more tacit knowledge is required.

Knowledge is not a treasure that waits to be discovered, but it is a more subtle object that needs a social context to be produced and shared. Paraphrasing a well-known book by Brown and Duguid (2000, 2001), we could say that information and knowledge have a social life: it relies, in other words, in a social fabric and a common understanding. Knowledge is not a regular good that can be transferred and produced mechanically, but it requires a social context and shared sense-making mechanisms.

From this perspective, the role of technology changes: from knowledge extraction to an enabler of collaboration and sharing among workers within and outside the firm. ICT (Information and Communications Technologies) supports humans in the production, memorization, sharing, and application of knowledge via tools that enhance collaboration and foster networking. The social and cultural facets of knowledge are not discarded and become central to the development of technologies. In particular, communication technologies take center stage. Conversions among people are crucial for sharing information and problem-solving. As confirmed by ethnographic research, humans produce and exchange knowledge through narratives and interactions (Orr, 1996). In this regard, a technology family called Groupware, composed of forum, discussion bulletin, email, etc. was widely used in KM projects for sustaining the interaction among workers. The objective was to foster the development of communities of workers within the firm to increase knowledge circulation.

The comparison between an extractive approach to KM practices based on IT and relational approach to KM practices based on communication technologies is useful to consider the new technological frontier of Industry 4.0 and its promise to have both an increased amount of data available from the production of an item to its consumption and new software capabilities (artificial intelligence) for processing information. The potential of this new technology (AI) is to transform traditional manufacturing and to create innovative services for the customer. Thanks to machine learning and deep learning, software can create knowledge in an automated way that could lead to better decision-making. From this perspective, Industry 4.0 is not only a new family of technologies for supporting knowledge production and sharing among people but also—and here is the novelty—an independent source of knowledge although generated algorithmically. At least potentially, machines could have the ability to put information into practice taking decision with limited human supervision (Floridi, 2016). Those technologies have the capability of acting in the physical world, facing and solving problems as robots that auto determine malfunctions and suggest possible interventions. More information and more computational power available seem to lead to a knowledge revolution that will change the way we produce and share knowledge and also introducing new agents in the knowledge management field, machines with increasing information process capabilities.

If, as we mentioned at the beginning of this paragraph, knowledge is a strategic resource, firms have to deal with this revolution and to use the new potentiality offered by technology to sustain their competitive advantage. Although there is great emphasis on Industry 4.0 in the media and in the consulting world, it is unclear how and when firms will adopt those new technologies. More importantly, it is still questionable with what KM perspective those technologies will be used by firms. Are the firms investing in Industry 4.0 in order to automatize and extract knowledge or they prefer to increase the communication and relations among workers? Are firms focusing on more tacit or explicit forms of knowledge? How autonomous are those machines and how they are changing decision-making?

In order to answer those questions, we conducted quantitative and qualitative research on Italian manufacturing firms. We decided to focus on manufacturing because this industry is at the cusp of a great transformation led by those new technologies. We selected Italy because it is the second-largest manufacturing country in Europe and it is mainly based on low/medium-tech productions that expose Italian firms to the aggressive competitiveness not only by low-cost countries, but also from more developed ones that are becoming more flexible and innovative in their production with the help of such new technologies. To understand how Italian firms are dealing with Industry 4.0, we decided to focus on the best performing firms that we thought to have the higher probability of using those technologies compared to other firms.

Before analyzing the result of our research, it is useful to take a deeper look at what are Industry 4.0 technologies and how they promise to transform manufacturing and KM within the firm.

2 Manufacturing and Industry 4.0

2.1 Managing Knowledge to Support Manufacturing

It is difficult to draw a line and define when this revolution took place. One good starting point is “How to (Make) Almost Anything” the title of a famous engineering class taught by Prof. Neil Gershenfeld at MIT. The class was specifically designed for applying the potential of digital technologies to the physical world. As Neil Gershenfeld (2012) affirms: “A new digital revolution is coming, this time in fabrication. It draws on the same insights that led to the earlier digitizations of communication and computation, but now what is being programmed is the physical world rather than the virtual one. Digital fabrication will allow individuals to design and produce tangible objects on demand, wherever and whenever they need them. Widespread access to these technologies will challenge traditional models of business, foreign aid, and education.” (p. 43) CNC machines, 3D printers, and the distribution of cheap sensors are the protagonist of a remarkable transformation of a physical object into digital information or bits and back from bits to atoms. “Atoms become the new bits,” as Chris Anderson (2010) put it, and it is possible to shape objects following the rules of the digital while overcoming the limitations of traditional manufacturing. For example, 3D printing can produce shapes that are impossible to obtain with the traditional techniques of subtracting manufacturing (milling machines).

But that revolution is more profound. Gershenfeld admonishes that the very nature of this technological transformation is based on quantity and quality of the information available: “The revolution is not additive versus subtractive manufacturing; it is the ability to turn data into things and things into data” (p. 44). More information means more precision, efficiency, and a decreasing cost of manufacturing and, at the same time, more flexibility thanks to the use of this information for producing an increased variety of products. Indeed, this revolution aims at solving one of the most important trade-offs in traditional manufacturing: volume vs. personalization, or between quantity vs. quality. With existing technology, mass production needs product standardization and economy of scale, while customization is economically possible in low volume and at the expense of a high cost of production. Ideally, that revolution could lead to a future of makers (Anderson, 2010) that can self-produce customized products—based on their needs—at a fraction of the cost of today. From this perspective, the manufacturing industry is no more necessary in increasing the autonomy of the users in (auto) making the products. The focus of attention moves from industry to individuals that can now own the means of production (i.e., 3D printing) and access the required knowledge for making products via online communities of users (Anderson, 2012). We could define that as the American approach to that technological revolution.

In Europe, that technological revolution took the name of Industry 4.0 a term coined in Germany (Kagermann, Helbig, Hellinger, & Wahlster, 2013; Lasi et al., 2014) as part of a public initiative for understanding the impacts of automation in manufacturing. As the largest manufacturing country in Europe, Germany was interested in maintaining its leadership in the industry applying the potential of digital technologies. Instead of conceiving a future without manufacturing production, Germans worked on the idea of transforming the manufacturing process thanks to the new possibility offered by digital technologies and its integration with traditional machines. The starting point of the German approach is based on the concept of cyber-physical systems that aims at managing the interconnections between physical assets and computational capabilities (Lee, Bagheri, & Kao, 2015). The new availability of cheap digital sensors that can be distributed in the manufacturing process and the possibility of connecting isolated machines to a computer network increase the quantity and quality of data and information available for the firm (Wang, Törngren, & Onori, 2015). Thanks to the extensive use of connected machines and the increasing amount of data, the factory itself can become smarter, able—*at least theoretically*—to self-organize production based on continuous feedback (Wang, Wan, Zhang, Li, & Zhang, 2016).

Although there are several possible definitions of Industry 4.0, the literature on engineering and manufacturing tried to identify the main technologies that compose Industry 4.0. Based on an extensive literature review, Alcacer and Cruz-Machado (2019) consider the following technologies under the umbrella of Industry 4.0: *the Industrial Internet of Things* (sensors and connected machines), *Cloud Computing* (distributed platform for accessing information and computation), *Big Data (*storage

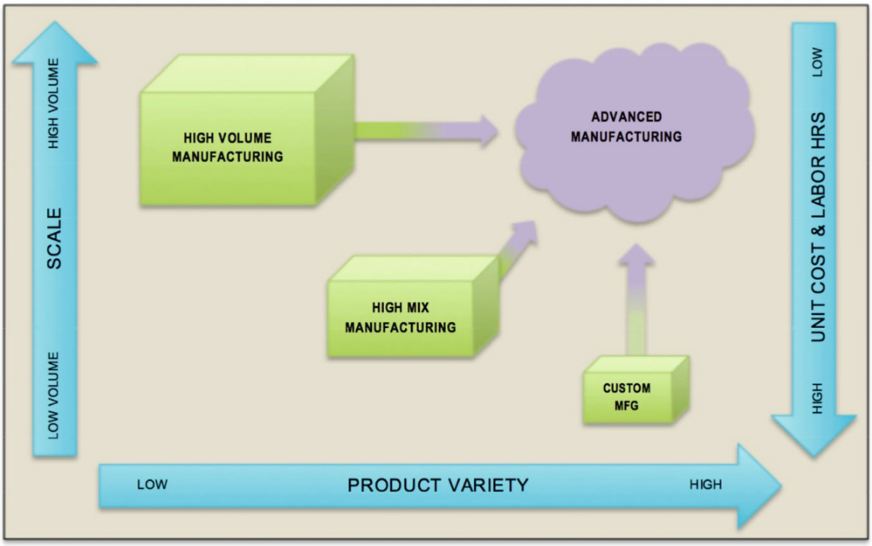


Fig. 1 Shifting trade-offs with advanced manufacturing: scale, product variety, and unit costs. Source: Sturgeon, Fredriksson, and Korka (2017)

of increasing amount of data on manufacturing processes), *Simulation* (the possibility to anticipate the results of a manufacturing process through specialized software), *Augmented Reality* (the possibility to help the operator on the line via enriched information mixed with the perception of the real situation), *Additive Manufacturing* (i.e., 3D printers), *Horizontal and Vertical Integration Systems* (integration of different technologies within different areas of the firm—horizontal—or in the supply chain—vertical), *Autonomous Robots* (robots that can take decisions and can cooperate among them with limited human supervision), and *Cybersecurity* (mechanism to protect data and computation systems from external aggressions). To those technologies we could also add the increased availability of *artificial intelligence* (AI) solutions that based on the data gathered could define a new course of action and taking decisions with limited human control (Fry, 2018). The list of technologies has also been identified within specific policies developed in many countries (i.e., Germany, Italy) to financially support firms' technological investments in selected directions.

The objective of Industry 4.0 is to respond to the increasing request for personalized products coming from the consumers. In this context, smart manufacturing is synonymous for flexible and agile manufacturing that can respond more quickly and precisely to the market. The technological revolution is opening a new scenario of advanced manufacturing where custom products are feasible at decreasing cost (see Fig. 1). The anticipated and never achieved so far *mass customization* (Pine II, 1993) seems finally at hand. The technology and its application at the factory level seem mature enough to make mass customization real. From the perspective of Industry 4.0, the factory is the epicenter of the revolution where the potential of technology can be fully deployed. The factory is where the strategic knowledge is produced and stored.

Although they have differences, both the American and the European (German) take on technological revolution have something in common: the increasing demand of knowledge that is needed in manufacturing. We could say that beyond being a technological revolution it is also a cognitive one, in the sense that new knowledge and understanding are needed. There are at least three main areas where we expect that *knowledge* will expand.

The first one is *knowledge* of the *product*. Sensors, digital machines, computer networks, databases, software, etc. are producing an increasing amount of data and information available about how and when a product is used by the consumer. In this perspective, the rise of smart products (IoT) can open a new domain for a better understanding of the needs of the consumers. Porter and Heppelmann (2014) sustain that the diffusion of smart products could also modify the structure of value chains and the rules of competition. The consumer is not just the end user of the product but could be the new starting point of the production and could be involved in the definition of the product through online collaboration or co-produce the product herself (Anderson, 2012). The knowledge developed by the customer in her own experience could be useful for defining new business models centered on the consumer (Bogers, Hadar, & Bilberg, 2016).

The knowledge of the product means also a better understanding of the production processes. Although it is questionable that more data can be translated into knowledge per se, the possibility to gather information about the product itself and the machines used in the factory could help the operator to increase their knowledge and to have new sources for problem-solving and improving the production process. For example, the possibility of adding a sensor to a traditional milling machine could give to the operator and the plant manager a better understanding of the defects of production and this may lead to new maintenance practices or a new organization of production. This is even more true if we consider the complexity of existing value chains where the production is fragmented among several firms specialized in the specific phase of production. This is particularly relevant in the context of small and medium-sized enterprises (SMEs) and of clusters where a high division of labor exists among localized firms and innovation is tightly coupled with supplier–buyer interaction in the value chain (Chiarvesio, Di Maria, & Micelli, 2004).

The second one is *knowledge* of the *technology*. Although several of the technologies that are part of the Industry 4.0 are not new, their combination is something that is not well established (Alcacer & Cruz-Machado, 2019). The power of digital technologies (sensors, database, software) combined with more flexible machines (robots, additive manufacturing) is a new paradigm that is literally in the making. Specific knowledge on the single technological domain is probably abundant, but how those technologies interact and could be something new that has to be perfected. Best practices on how to mix and match those technologies are still under development and it will be a learning-by-doing experience. At the moment there is still a lot of confusion on when, how, and where to apply those technologies. The recent failure of Adidas in developing their project of a highly automatized and digitalized factory called *Speedfactory* is indicative of technological systems that are not mature. In particular, according to what has emerged in the media, the robotic factory was able just to produce a limited number of models, which mainly consisted of running shoes with a knit upper while it was unable to produce leather ones. "It's a different kind of joining process behind it where we just don't have a solution yet,"[2] said Ulrich Steindorf, senior director of manufacturing at Adidas. Just because a specific technological solution is available, it does not mean that it could be applied to a specific production process. There is a lot of dark spots to explore within the technological framework of Industry 4.0. Dead ends and best practices are not well known yet.

The third one is *knowledge* of the *management* of the firm. We refer to the combination between the new technological features and new opportunities to be discovered. As happened in the previous industrial revolutions, the introduction of new technologies implied a new way of organizing both the production and the definition of the product. It took several years after the invention and diffusion of electricity before an entrepreneur such as Henry Ford developed an organizational model based on the assembly line and large scale of production in order to take full advantage of that technological innovation. Besides, Ford had to identify a new market opportunity: a car that was targeted to the mass instead of small niches of affluent consumers. That concept was something completely new for the time.

Technology needs to meet strategy to express its full potential. If the analogy with the second industrial revolution holds, human creativity in the form of firms' strategy is still important to implement Industry 4.0. Several authors affirm that firms adopt the new technologies because they expect to achieve some specific results in the areas of manufacturing as of marketing to improve their competitiveness (Bharadwaj, El Sawy, Pavlou, & Venkatraman, 2013; Kane, Palmer, Phillips, Kiron, & Buckley, 2015). From this perspective, the adoption requires new knowledge that depends on the business purposes firms aim to achieve. Recent research shows that firms chose to adopt Industry 4.0 technologies for specific strategic motivations such as the improvement of efficiency (Bonfanti, Del Giudice, & Papa, 2018) and productivity (Yao & Lin, 2016) and the reorganization of manufacturing activities, with the opportunity to have them locally (Müller, Kiel, & Voigt, 2018). Other main drivers of adoption relate to the achieving of market and marketing benefits (Coreynen, Matthyssens, & Van Bockhaven, 2017), such as the improvement of customer service as the product variety (Leeflang, Verhoef, Dahlström, & Freundt, 2014).

[2]The digital magazine *Quarz* reported the words of Ulreich Steindorf https://qz.com/1746152/adidas-is-shutting-down-its-speedfactories-in-germany-and-the-us/

2.2 From Data to AI to Enhanced Learning

In May 2017, *The Economist* dedicated its cover to the big tech giants such as Apple, Google, Facebook, Microsoft Tesla, and Uber and their dominance of the digital market. The title of the cover story was symbolically: "The world's most valuable resource is no longer oil, but data".[3] Being the article focused on the monopolist power of such tech giants, data were considered at the base of the success of those companies. In other words, data are the new scarce resource; the one who has access to it will dominate the market. Since 2017, this metaphor becomes very popular and was used by several opinion leaders, like Jaron Lanier,[4] to highlight the potential negative consequences of the use of data by tech giants.

Besides those critical notes on privacy and monopoly, "data as oil" was extensively used in the large consultancy firms to advise companies to invest in data management to take advantage of the potential of AI. Indeed, the leap forward that AI did last year is remarkable. In the field of voice recognition, image recognition, and language translation, the progress of AI is tangible and has led to the deployment of very powerful service that is at our fingertips. For example, you can easily translate a text written in a foreign language by simply pointing the camera of the smartphone over the text. Even more significant are the performances of IBM Watson and Alpha Go of Google that outperformed their human counterpart at games like Chess or Go and at the TV quiz *Jeopardy*. Those results are the outputs of a powerful combination of new algorithm techniques based on deep learning and the availability of big data, giant accumulation of data produced by users in the digital platform like social media, credit card transactions, medical information, etc..

If data is the oil, AI is the modern refinery able to distill knowledge out of the raw but valuable material. Several technology vendors marketed the (almost) unlimited potential of the application of AI for solving big human problems like cancer or the development of new solutions for fighting climate change. That trust on the potential benefit of the application of AI entered also in the consultancy world that is sponsoring the development of AI initiatives among manufacturing and service firms. Although several authors (Tegmark, 2017; Zuboff, 2019) warned about the potential threats that the extensive use of the AI could have for our society, it is beyond the scope of this chapter to analyze those possible negative consequences in detail.

The debate of the potential of AI in elaborating data and producing knowledge is not new and goes back to the 1980s and 1990s at the time of the application of the so-called expert systems (Davenport, 2019). Technology is now more powerful and there is greater availability of data but, as Davenport (2019) admonishes, the question remains the same: how to make AI solutions at work at the firm level.

---

[3]The original article could be reached at this link https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data

[4]The Privacy Project was developed by Jerome Lanier for the *New York Times* https://www.nytimes.com/interactive/2019/09/23/opinion/data-privacy-jaron-lanier.html

Most of the solutions now available are conceived not for tailored applications in the firm but for more general purposes. As Davenport reported, many projects of AI are facing hard times when they are used in real business processes.

The literature on KM (Pauleen, 2017; Pauleen & Wang, 2017) warned that gathering bigger data does not necessarily lead to more knowledge because knowledge is the outcome of sense-making and human judgment. As we saw in the Introduction, the old problem of tacit and explicit knowledge seems to come back when we try to apply AI and big data into practice. Probably, the oil metaphor is misleading. The fact the data are relatively abundant, although not distributed evenly, does not turn necessarily into better solutions as several negative case studies demonstrated. In her book *Hello World: Being Human in the Age of Algorithms*, Hannah Fry (2018) reported many problematic cases in the use of AI such as Steve Talley's, an ordinary American citizen mistaken by FBI facial recognition software for a dangerous bank robber. Steve Talley was brutally arrested, suffered several injuries (some serious), and spent 2 months in a maximum-security prison and it took more than a year to be rehabilitated. Another example are AI applications that are used daily in American courts to decide the amount of punishment based on the probability of recidivism. It is always the popular jury that decides but hardly contradicts the algorithm's response. The result is that black defendants are more likely to remain in jail because they are considered at greater risk of recidivism. The problem here is related to the data on which the algorithm is based, which is biased by the fact that historically in the USA blacks are more arrested than whites. That disproportion in the starting data is reflected in a higher probability in the calculation of the recidivism potential.

As the philosopher Luciano Floridi pointed out (2016), we have too much trust in the intelligence of AI and, on the contrary, we should think that AI is rather a divorce between intelligence and agency. Floridi's take on this is that AI machines dramatically increased their capability of an action in the real world, but this is happening without much contextual intelligence. They can do some tasks, but those tasks need to be very well defined although the system is not able to adjust to the variations that the real context of use can have. In other words, complexity needs to be reduced to let AI thrive and this is not always possible.

Instead of considering AI as a substitution for human intelligence, we should consider AI as an important tool for sustaining learning at the level of individuals and organizations. From this perspective, AI can complement human intelligence and can give us different points of view on events and on decisions to take. They can multiply alternatives and help us to take better decisions. Humans and algorithms can live together, helping each other. When this is happening, the results are remarkable. As Fry (2018) reports, one of the most convincing example of mutual learning and collaboration is on the judgment of cancer cells. AI helps pathologists by reducing the number of suspicious areas to be examined and leaving the final decision to doctors. As Fry says, "The algorithm never gets tired and the pathologist is rarely wrong. The man-machine collaboration in this case leads to an incredible level of accuracy of 99.5%!"

Taking into account this complex and yet to be defined scenario of KM, we aim at exploring how Industry 4.0 technologies are shaping KM in manufacturing firms, the motivations of adoption, impacts in terms of product and process innovation, and knowledge creation within the competitive framework of the firm.

3 Empirical Analysis: Methodology and Results

3.1 Methodology

To reach the research purposes, the study focuses on medium and large Italian companies named *Champions* according to the economic and financial performance criteria of selection defined by *ItalyPost*—Italian Study Centre (Zovico, 2018). In particular, from a population of 14,632 companies between 20 and 120 million euros in turnover 500 were identified that meet, in addition to the turnover range, the following requirements: (1) CAGR (compound annual growth rate) 2010–2016 higher than 7%; (2) EBITDA average of the last 3 years greater than or equal to 10%; (3) debt ratio lower than or equal to 80%; (4) net debt/EBITDA average of the last 3 years lower than or equal to 80%; (5) number of employees greater than 20; and (6) a positive net income 2016. In this way the analysis focuses on a sample of medium and large firms usually engaged in the knowledge creation and management processes for the success of business (McAadam & Reird, 2001) with high performance that may assure no financial constraints that may negatively affect the adoption of new technologies (Kamble, Gunasekaran, & Dhone, 2019).

3.2 Measures

For the research objectives, we adopted a mixed method with quantitative and qualitative analyses. For the quantitative analysis, we carried out a survey submitting a structured questionnaire through computer-assisted web interview (CAWI) methodology (appropriate for contacting a large sample) to entrepreneurs, chief operations officers, or managers in charge of manufacturing and technological processes. The survey was carried out in the period October 2018–March 2019. The questionnaire aimed at assessing some of the enabling technologies that shape the fourth industrial revolution (Tortorella and Fettermann, 2018), specifically (1) autonomous robots, (2) additive manufacturing, (3) big data, (4) cloud, (5) artificial intelligence, (6) augmented reality, and (7) IoT and intelligent products. In addition, we also evaluated the use of some digital technologies typically by artisans in Italy for the deployment of a 3D digital model (Bonfanti et al., 2018), such as laser cutting and 3D scanner. Through a yes-no dichotomous measure, we asked respondents if firms have adopted or not each one of the selected technologies investigated. The choice of these types of technologies is in line with the Italian Ministry of Economic

Development regulation that, in 2016, delimited the scope of Industry 4.0 to the new technologies enabling the advanced manufacturing systems and the cyber-physical system (see Agostini & Filippini, 2019).

In addition to firm descriptive characteristics and the evaluation of Industry 4.0 and ICT endowment, the questionnaire assessed other strategic variables such as the motivations of adoption and the impact of new technologies on business results, on product performance, and on working skills and methods. According to recent literature (Ancarani, Di Mauro, & Mascali, 2019; Dalenogare et al., 2018; Müller et al., 2018; Schneider, 2018; Stentoft & Rajkumar, 2019; Whysall, Owtram, & Brittain, 2019), we considered the most common drivers of adoption as well as the benefits of the new digital technologies to evaluate the variable before mentioned. Specifically the motivations of adoption as well as the impact in terms of business results refer to (1) efficiency and productivity, (2) product diversification and customization, (3) new marketing opportunities, (4) international competitiveness, (5) reshoring and backshoring of production activities, (6) customer service, (7) respond to market requests (customer and standard industry), and (8) the aspect of environmental sustainability. The motivations of adoption were measured with a 5-point Likert scale (from 1 = *not at all* to 5 = *very much*). Instead, the impact of Industry 4.0 technologies on business was measured through a dichotomous variable (*yes*-*no*).

The impact on terms of product use and development refers to (1) the development of product-related services, (2) the role of customer in design and production processes, and (3) the control over product use and the distribution process. Finally, with respect to the working changes related to Industry 4.0, we assessed the modifications in terms of working methods and specifically about the relationships among the different business areas (production and others principally) and with suppliers as well as the creation of new knowledge for both product and production improvements. Impacts on product and on working changes were assessed through a 5-point Likert scale ranging from 1 (*not at all*) to 5 (*very much*).

To analyze the importance of all variables with respect to the Industry 4.0 strategy and explore the relationship with knowledge management, we transformed the Likert variables in dichotomous variables coding with 1 the highest values of Likert scale, which are 4 and 5, and considering 0 all the other three values, which are 1, 2, and 3.

3.3 Sample Descriptive

Through the survey on the 500 *Champions* companies, we were able to collect 75 questionnaires (15% of the population). Table 1 reports the description of the sample. Firstly, *Champions* are international companies characterized by a high export rate (60.5%), but with production activities and suppliers rooted locally (same company region and/or Italy). They focus on customized/customizable

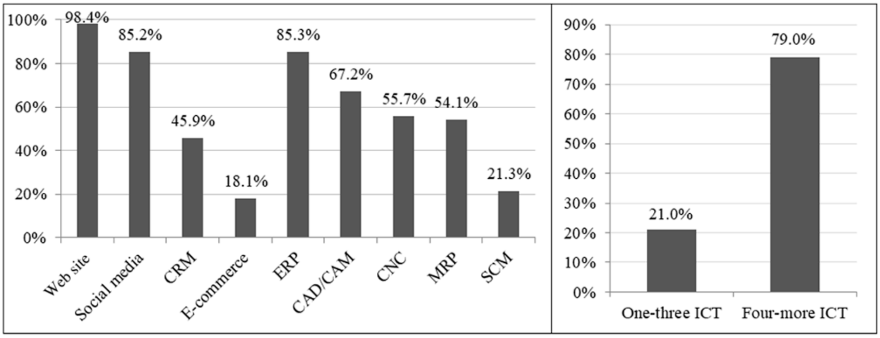
Table 1 Descriptive statistics

Turnover 2017 (average; euros)	59.1 million
Employees 2017 (average)	
Total	138.4
Production	75.6
R&D	9.5
Marketing	3.7
Export 2017 (average; % on turnover)	60.5% (*first export country: 26.7%*)
R&D expenditure 2017 (average; % on turnover)	6.4%
Market	
Business-to-business	64%
Business-to-consumer	36%
Production output	
Standard products	42.8%
Bespoke products	27.5%
Customized products	29.7%
Production activities location	
Same company region	62.7%
Italy	22.4%
Abroad	14.9%
Suppliers' location	
Same company region	31.8%
Italy	45.3%
Abroad	22.9%
Competitive factors	
Product quality	31.1%
Product innovation	27.9%
Production flexibility	16.4%
Customer service	11.5%
Production efficiency	4.9%
Design	1.6%

$N = 75$

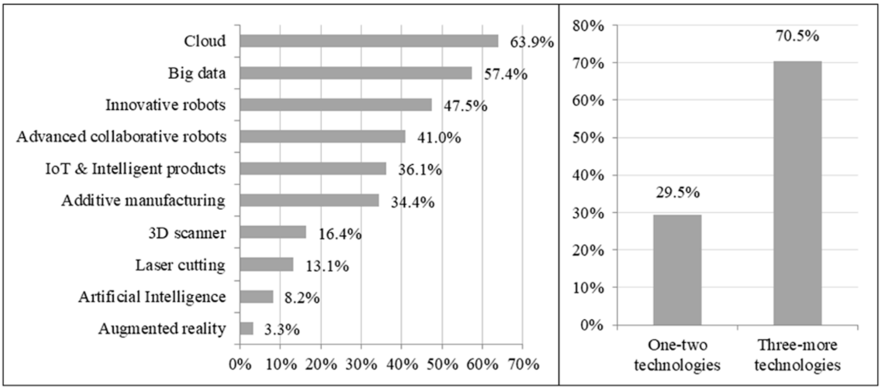
products for the larger part of production output, aiming mainly for product quality and innovation and production flexibility as competitive factors.

As far as the technology endowment is concerned, both referred to the ICT as to the Industry 4.0. Figs. 2 and 3 present interesting results. Firstly, Fig. 2 highlights that companies show a good ICT endowment especially as regards the technologies for the business and processes management (like ERP, CAD/CAM). The web environment is restricted to website and social media as not all firms use e-commerce as a selling platform. Moreover, Fig. 2 shows that *Champions* are technological companies as the 79% of the sample already use at least four (median) ICTs.



N = 75

Fig. 2 ICT endowment



N = 61

Fig. 3 Industry 4.0 adoption

Secondly, as far as the Industry 4.0 technologies are concerned, 81.3% (61 on 75) of the sample adopted at least one of the new technologies investigated. Figure 3 shows that *Champions* adopted two main sets of technologies: the technologies enabling the data management (Cloud, Big data, and IoT) and those technologies affecting the production processes (innovative and collaborative robots and additive manufacturing), marginally the rest of other technologies. In addition, Fig. 3 shows also the intensity of investment in Industry 4.0 technologies. Results stress that Industry 4.0 is not a "single technology adoption" strategy but a technological "system" that needs more technologies as already found in the literature (Dalmarco, Ramalho, Barros, & Soares, 2019; Frank, Dalenogare, & Ayala, 2019). The most part of sample (70.5%) adopted at least three (median) technologies.

3.4 Industry 4.0 and KM in Top Performers: Survey Results

To evaluate the role and the value of Industry 4.0 for KM process of companies with the survey, we aimed to assess some strategic variables in order to define the relationship between Industry 4.0 and KM. In particular, Table 2 shows the motivation of adoptions and the impacts of new technologies on business listed in terms of importance.

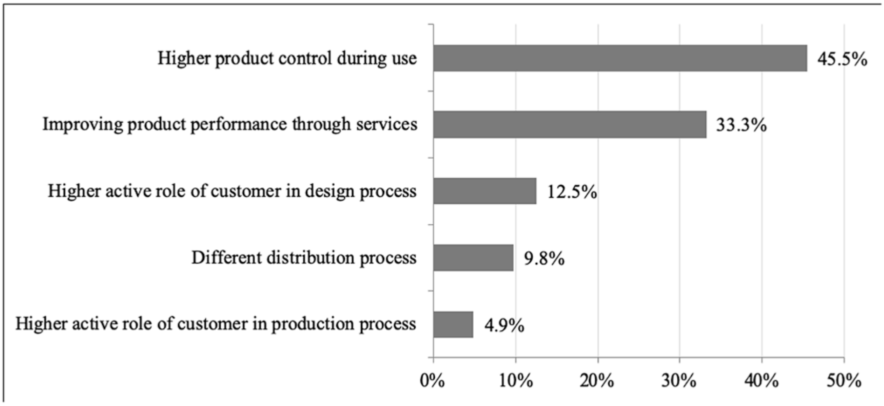
In addition to the production efficiency (73.5%), which represents one of the first and most important antecedents of Industry 4.0 implementation (Kiel, Arnold, & Voigt, 2017), the other most relevant motivation of adoption refers to broader goals: creating new knowledge through market data and interactions with customers and other business partners (Smith, Collins, & Clark, 2005). In particular, *Champions* adopt the new technologies to improve customer service (74.4%), face the international competitiveness (72.3%), and try to exploit new marketing opportunities (50.0%), in terms of new market and new products development. Effectively, through Industry 4.0 technologies companies achieved improvements in the production (efficiency and productivity, respectively, 76.5% and 67.7%) and market (customer service and international competitiveness, respectively, 67.7% and 56.9%) sphere.

To explore the relationship between Industry 4.0 and KM, we also examined the impacts of new technologies on product and on working method/skills. Figure 4 shows how the new technologies affect the product offered by companies. Firstly, *Champions* use the new technologies to get higher control over product use (45.5%). In this way, they can get the data useful to improve production and marketing

Table 2 Motivations of adoption and impacts on business

Motivations of adoption	Frequency (%)	Impacts of I4.0 technologies	Frequency (%)
Improving customer service	74.4	Production costs efficiency	76.5
Production efficiency seeking	73.5	Higher productivity	66.7
Facing international competitiveness	72.3	Improved customer service	66.7
New marketing opportunities	50.0	Keeping international competitiveness	56.9
Improving environmental sustainability	39.0	Increased turnover	43.1
Enhancing product diversification	32.5	Higher product diversification	22.5
Requests from customers	27.5	New markets development	19.6
Maintaining production in Italy	25.6	Improved customized products share	19.6
Standard sector upgrading	20.0	Environmental sustainability	19.6
Imitating competitors	9.8	Relocalization of production activities	3.9
Reshoring-Backshoring	2.7		

N =61



N = 61.

Fig. 4 Impacts of new technologies on product

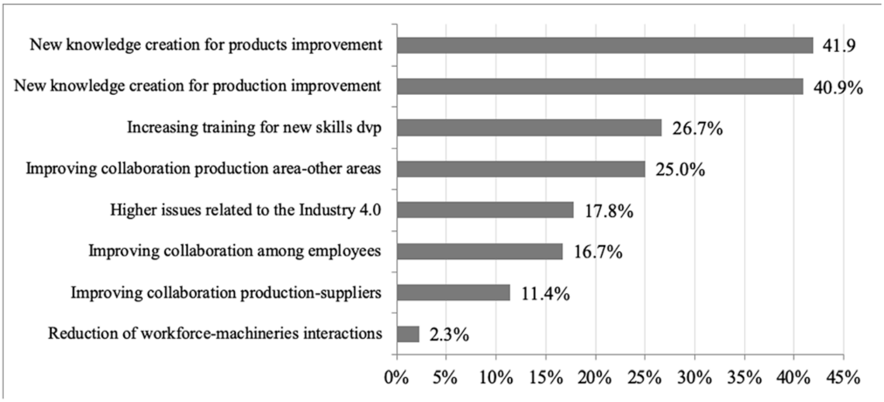
performance. Secondly, they use the new technologies to improve product performance offering new services (33.3%). The collaboration with customers has a marginal value with respect to both the design (12.5%) and the production (4.9%) processes.

The new technologies have also a key role in internal working methods and relationships along value chain, as well as in job skills and competences (Arnold, Kiel, & Voigt, 2016; Nagy et al., 2018). As far as the impacts on production activities are concerned as well as relationships among company departments and with suppliers, Fig. 5 highlights interesting results for the research purposes.

Results reported in Fig. 6 stress the role of knowledge and its value in the Industry 4.0 paradigm. New knowledge creation for both product (41.9%) and production (40.9%) activities improvements is the main output the new technologies use and this depends on data that they are able to generate (Lu & Weng, 2018). The use of new technologies influences also the upgrading of skills and competences (26.7%) and the collaboration among the different business areas (25.0%). It is interesting to see that there is no reduction of human–machine interface (only 2.3%) so that technologies are not substituting completely workforce. Collaboration with suppliers has a marginal role in terms of impact of new technologies (11.4%).

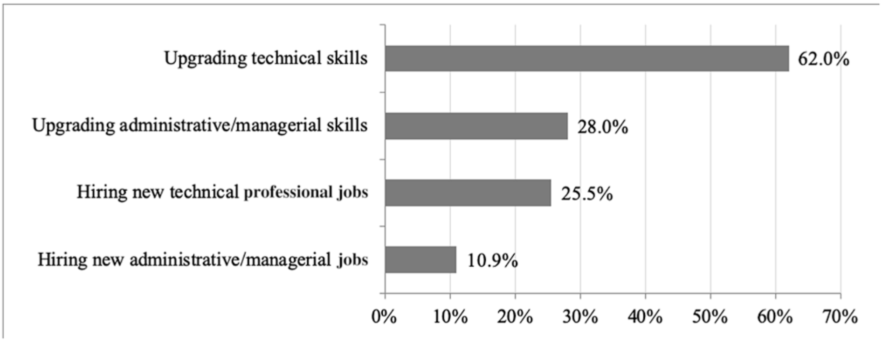
Finally, we focused on skills and competences in terms of needs and changes (Fig. 6). The most important impact on employees' skills and competences refers to the technical area (62.0%), even if also administrative and managerial competences are interested from the Industry 4.0 revolution. These results confirm recent empirical research on the topic (Arnold et al., 2016; Whysall et al., 2019).

In this first exploratory part of the research, in addition to the analysis about Industry 4.0 adoption and its strategic impacts on business process in order to outline how the new technologies link to the KM process, we explored the key role of technologies for knowledge creation described in the theoretical section. Literature has shown that cloud, big data, IoT, and AI represent a group of Industry 4.0



N = 61.

Fig. 5 Impacts of new technologies on internal and external working activities



N = 61.

Fig. 6 Impacts of Industry 4.0 investments on skills and competences

technologies that more than others enable the gathering, storage, and management of data (Tao, Qi, Liu, & Kusiak, 2018; Xu, Frankwick, & Ramirez, 2016). Within our sample, Fig. 3 showed that cloud and big data are the most adopted technologies among those investigated. About 88% (54 on 61) of *Champions* adopted at least one of the four "data-driven technologies." This result stresses the importance of data management for the competitiveness of larger firms that compete at international level. Moreover, only 16.4% (10 on 61) of the sample adopted only such "data-driven" technologies, while most of the *Champions* invest also in other Industry 4.0 technologies. This result confirms the strong integration among the different technologies (Muscio & Ciffolilli, 2019).

As shown in Fig. 3, Cloud is the most adopted technology and big data is the second one. Big data became very important for larger firms because of the necessity to manage and analyze a remarkable amount of data gathered with the new technologies in production as well as in marketing and other business areas (Szalavetz,

Table 3 Correlations among data-driven technologies adopted

	Cloud	Big data	IoT	AI
Cloud	–			
Big data	−0.026	–		
IoT	0.138	0.095	–	
AI	0.224°	0.016	0.273∗	–

$N = 1$; $* \ p < 0.05$; $^{\circ}p < 0.10$

Table 4 Data-driven technologies integration

# Data-driven techs adopted	Cloud	Big data	IoT	AI
One	11 (28.2%)	9 (25.7%)	2 (9.1%)	0 (0.0%)
Two	15 (38.5)	15 (42.9%)	8 (36.4%)	0 (0.0%)
Three	11 (28.2%)	9 (25.7%)	10 (45.5%)	3 (60.0%)
Four	2 (5.1%)	2 (5.7%)	2 (9.1%)	2 (40.0%)
N	39 (63.9%[a])	35 (57.4%[a])	22 (36.1%[a])	5 (8.2%[a])

[a]% on the overall adopters (61)

2019). Moreover, *Champions* show a good IoT adoption rate; instead AI is the less adopted because of its early extensive use for business purposes (Haenlein & Kaplan, 2019). Performing a correlation analysis to explore the relationships among these four technologies adopted and how they correlate, it is interesting to observe (Table 3) that AI is the most correlated technology with the other ones and in particular with IoT (0.273 $p < 0.05$) and Cloud (0.224 $p < 0.10$).

Taking into consideration the adoption rate of these four technologies and the correlation values, it is interesting to see the growing integration of AI with other technologies as well as the role of big data as cross-sectional technology. Table 4 explores the *Champions*' strategies of investments in those four technologies, showing that AI investment is related to at least other two technologies, while IoT is the most integrated technology.

Data show that there is a sort of interdependency among the four data-driven technologies. Specifically, the integration of data-driven technologies, considering the sample adoption rate and the correlation among them, may be represented as shown in Fig. 7.

3.5 Data-Driven Technologies and Knowledge Management in Top Performers: Case Studies

Following the evidence emerged from quantitative analysis previously presented, we carried out a qualitative study aiming at understanding the relationship between Industry 4.0 and KM more deeply. Following recent research on Industry 4.0 (Müller 2019a, 2019b; Szalavetz, 2019; Vanchan, Mulhall, & Bryson, 2018), we focused the qualitative analysis, through a multiple case studies approach (Yin, 2009), on those companies that adopted mainly AI and other data-driven

Fig. 7 Integration among data-driven technologies

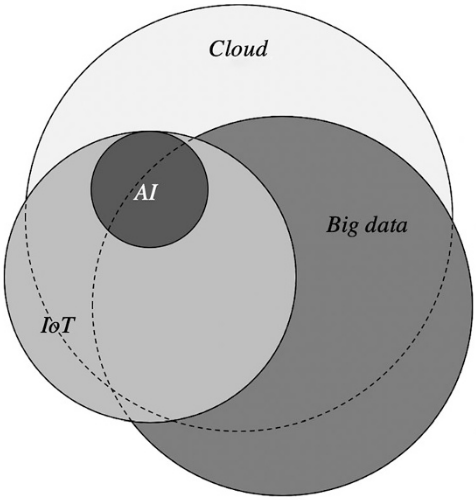


Table 5 *Champions* interviewed

Company	Activity	Industry 4.0 technologies adopted				
		Cloud	Big data	AI	IoT	Other technologies
1	Production of industrial lubricants	x	x	x		Manufacturing smart systems
2	Customized racing cars	x	x		x	• Manufacturing smart systems • Additive manufacturing • Laser cutting • 3D Scanner
3	Business systems solutions and packaging machinery	x	x	x	x	
4	Machinery for testing electronic products	x		x	x	
5	Professional smart kitchen ovens	x	x	x	x	• Manufacturing smart systems • Additive manufacturing • Laser cutting

technologies, in addition to the manufacturing-related Industry 4.0 technologies. We interviewed Chief Operations Officer or R&D managers of selected *Champions* companies, adopting AI solutions. Through the interviews with the COO or R&D managers of the five companies interviewed, we aimed at assessing the impact of new technologies on KM taking into account the use and the impacts on business processes and on workforce.

As Table 5 shows, Cloud is the common technology used by all firms interviewed. Moreover, most of them use data-driven technologies with other manufacturing-related technologies. In this way, we were able to explore the role of data and on knowledge produced by new technologies within both the business and manufacturing processes.

3.6 Results of Qualitative Analysis

Industry 4.0 investments and specifically data-driven technologies are related to KM strategies. We found that AI is mainly used to improve production processes as well as the product use by customers: data acquired—also in relation to IoT—allows the firm creating new knowledge.

> Artificial intelligence is used directly on production plants. It plays a key role on increasing the quality of the process, which transforms into better performance at the production level. . . (#1)

> Artificial Intelligence enables the centralization of operations management on the packaging lines and harmonizes the information coming from different sources in order to transform them from "Raw Data" to "Smart Data" (#3)

> The AI is used to acquire data, analyze them and exploit them in order to take decisions about some autonomous activities. . . For our business the data collected by AI have a very high value.... . .the autonomous system must take the appropriate decisions on the basis of information of AI. . . (#4)

> Artificial Intelligence is mainly used in Business Intelligence area...the oven records and measures data that allow us to make diagnostics and maintenance in a predictive way and creating insights for customers to make the best use of the oven... (#5)

The analysis of interviews highlights the key role of data gathered through AI for the improvement of business processes through statistical machine learning and a consequent process of training and fitting models to data. The opportunity of gathering data through sensors and digitalization helps the firm in making a more in-depth analysis of the productions processes and use of the product. Those data are used by AI in order to find new association and a possible course of action that are validated by the operator or the manager.

In addition to the focus on specific technologies, companies need to reconsider their digital strategy (Davenport & Mahidhar, 2018). In particular, data become new knowledge that companies exploit to advance in operations management and deliver high-quality products on the market. Quality is one of the main competitive factors for companies as *Champions* that have a strong presence on the international markets. In addition to AI, *Champions* consider all the Industry 4.0 technologies very important for new knowledge creation.

> A company must continuously improve its knowledge and this drives us to invest constantly in new technologies (#2)

> The oven has sensors that measure a whole series of things, the aggregate data arrive on Cloud where they are processed and getting insights that we provide to the customers (#5)

> The first technology adopted was IoT. Now we are working with other technologies related to machine learning and deep learning (#5)

The interviews pointed out some interesting insights about how AI and also the other data-driven technologies enable companies to produce data and new knowledge that became very important for the sustaining of competitive advantage. Data and then knowledge allow firms improving the quality of production processes as well as of the product use, with direct consequences for the business growth. Data management, data analysis, and data mining enable knowledge-based decision-making processes (Brettel, Friederichsen, Keller, & Rosenberg, 2014). The new technologies allowed companies to achieve improvements in terms of both production quality and market and sales growth, especially by means of a faster new product development process, time to market response, and new services.

> Artificial intelligence is used directly on production plants. . .increasing the stability, quality and the speed of the process. . .avoiding manual operations. . . (#1)

> . . .the main result related to the use of new technologies is a stronger interest in our new products by our customers and potential customers. . . (#3)

> Among the main results there are the increasing of prototyping and development processes and time to market response. Respect our business model...with the data we can offer additional services..." (#5)

Moreover, the new technologies allowed companies to improve relationships with suppliers and customers. In this way, companies were able to advance their supply chain activities and the customization process, with direct effects on customer satisfaction.

> The introduction of Industry 4.0 technologies has increasingly connected the company with the suppliers, facilitating their quick feedback ... in the co-design process the technology is functional to improve collaboration processes, develop new technical ideas, simulate different scenarios and share technical experiences from different actors of the development process (#2)

> We deliver on the market customized cognitive solutions and smart software characterized by self-learning systems, so customers can exploit the continuous learning process . . . (#4)

> The philosophy of the company is a very strong vertical integration . . . when there is a new idea or a new technology we collaborate with the external environment . . . integrating digital technologies into our processes (#5)

The research also aimed at understanding the relationship between the new technologies and the changes in terms of skills and competences, to consider how tacit and codified processes have to be integrated and the consequences in terms of human resources. The main goal was to verify the role of digital competences that are necessary for the success of Industry 4.0 implementation (Agostini & Filippini, 2019). The new knowledge (technical and managerial) that employees must have to manage data and processes (Butschan, Heidenreich, Weber, & Kraemer, 2019) becomes essential to compete effectively, being the lack of appropriate competences and skilled workforce one of the main barriers for the Industry 4.0 adoption (Horváth & Szabó, 2019). The interviews highlighted the importance of the technology and of the management (see Sect. 2.1)

> Artificial intelligence did not replace the operator but it is mainly a support for their work... Our skills were not sufficient...it was necessary to acquire new competences that we did not have...for the use of AI we were assisted by technology suppliers and external consultants (#1)

> The internal skills for the adoption of Industry 4.0 technologies are fundamental both in the identification phase and in the implementation phase. ... The company is based fundamentally on research and development and innovation is its essence. To improve knowledge the culture of trial and error is promoted through the simulation of real phenomena. Moreover, we are a learning organization that facilitates the dissemination of knowledge and experiences. (#2)

> The main problem in the application of such an advanced technology is the lack of vertical skills to manage it fully ... so we needed of training ... The introduction of AI has certainly not had a negative impact on number of employees ... rather we had to hire and are still hiring new staff with advanced skills related to the AI. Prior investment in the Industry 4.0 allowed the development of a mindset that favours the introduction of more radical innovations as Artificial Intelligence" (#3)

> The new technologies shift the centre of gravity of the skills inside a company ... what the company had to do was create new know-how, guarantee training courses and create all the internal infrastructure to manage these types of projects. ... currently the company is looking for people who can use these innovative technologies ... the workforce, which in the past was 99% mechanical engineers, now consists of approximately the same number of mechanical engineers and other profiles who can exploit the technologies of the future. We talk in general about Data Scientist ... the main goal is to develop the digital competences and the know-how needed to manage the new technologies (#5)

The last verbatim of interviews highlights the key role of new competences for the successful implementation of AI and other Industry 4.0 technologies. In this case, the new knowledge is meant as new competences companies need to have inside if they aim to get the benefits form the implementation of AI and other Industry 4.0 technologies.

More generically, the Industry 4.0 paradigm bases its success on data and knowledge produced by the use of the new technologies. Companies should look for ways to incorporate that knowledge in their products and processes, as well as in a cognitive system able to integrate and share new knowledge created at the wider organizational level. The results of the analysis suggest the need to create a broader and better structured KM system related to this new industrial revolution. Then, this knowledge should be continuously improved and integrated with external partners and customers. The relationship between Industry 4.0 and KM seems, therefore, to be a strategic factor that might affect the competitive advantage of companies, more than what happened with the prior technological waves.

4 General Discussion and Conclusions

Industry 4.0 is a technological revolution that is shaping manufacturing and is changing how firms produce the product and how they interact in the value chain and with the consumer (Schwab, 2017). But as we discussed at the beginning of this chapter, it also a cognitive revolution. New technologies give the opportunity to create, store, and share new knowledge that plays an important role in reinforcing and/or developing firms' competitive advantage (Lu, 2017).

The results of the research show that firms' adoption process is more cautious, incremental, and longer than we could expect. Firms invested in ICT in order to define a sort of base layer of technological infrastructure on which to develop a more sophisticated application. From a KM perspective, firms adopted both an extractive and relational approach. As we saw from the results, firms adopted both ERP and software dedicated to the knowledge extraction as well as on the website, social media, and CRM that are dedicated to communication and interaction within and outside the firm.

The same seems to apply in the case of Industry 4.0. The firms are starting to invest in the more consolidated technologies available like cloud computing and are relatively less attracted by not well-established technology like AR or AI. This approach seems reasonable; firms are still learning how and when to adopt Industry 4.0. Nevertheless, if they have to start, they have to focus on the possibility to gather more data through cloud computing and big data. The main motivation that pushes firms to invest is the need for a better understanding of how the product is used by the consumer and on the production process. If they want to improve their product and the manufacturing process, firms need to have a clearer understanding of what is happening within and outside the factory.

In their process of adoption, firms seem to be driven by their business strategy than by a technological approach. Firms declare to have clearer strategic objectives that they want to reach like improving customer service, increasing production efficiency, and international competitiveness. In terms of KM, firms are interested in knowledge of the product and of the management and less keen on the technology side. As a matter of fact, they discover the need of knowledge of technology once they adopt and is remarkable that almost all the firms that invested in the technology declared the need of improving the technical skills within the company. This distance from the technological knowledge may explain the prudence with which they adopt Industry 4.0 solutions. Firms do not know how to use them properly; therefore, they opt for the ones that are more promising and in line with their strategic objectives. It is not surprising though that the firms that have already invested in several Industry 4.0 technologies are the ones which adopted more sophisticated and complex technologies like AI.

The qualitative analysis underlines the profound cognitive root of Industry 4.0. The firms that adopted AI are aware of both the new possibilities offered by this technology in order to analyze data and to propose a course of action and the importance of the judgment of a knowledgeable operator on the final decision.

This combination requires an increased amount of knowledge of the product and production processes (how could the product and process be improved?), of the management (how the data could be used for the firm?), and of the technology (how does AI work?). As the case studies pointed out, data are important but without the judgment of workers are not that useful. Tacit and explicit knowledge are strictly interconnected even in Industry 4.0 scenario.

References

Agostini, L., & Filippini, R. (2019). Organizational and managerial challenges in the path toward Industry 4.0. *European Journal of Innovation Management, 22*(3), 406–421.

Alavi, M., & Leidner, D. E. (2001). Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS Quarterly, 25*(1), 107–136.

Alcacer, V., & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A literature review on technologies for manufacturing systems. *Engineering, Science and Technology, An International Journal, 22*, 899–919.

Ancarani, A., Di Mauro, C., & Mascali, F. (2019). Backshoring strategy and the adoption of Industry 4.0: Evidence from Europe. *Journal of World Business, 54*(4), 360–371.

Anderson, C. (2010). The next industrial revolution, atoms are the new bit, *Wired*, 01/15/2010.

Anderson, C. (2012). *Makers: The new industrial revolution*. New York: Crown Business.

Arnold, C., Kiel, D., & Voigt, K.-I. (2016). How the industrial internet of things changes business models in different manufacturing industries. *International Journal of Innovation Management, 20*(8). https://doi.org/10.1142/S1363919616400156.

Barney, J. B. (1991). Firm resources and sustained competitive advantage. *Journal of Management, 17*, 99.

Bharadwaj, A., El Sawy, O., Pavlou, P., & Venkatraman, N. (2013). Digital business strategy: Toward a next generation of insights. *MIS Quarterly, 37*(2), 471–482.

Bogers, M., Hadar, R., & Bilberg, A. (2016). Additive manufacturing for consumer-centric business models: Implications for supply chains in consumer goods manufacturing. *Technological Forecasting and Social Change, 102*, 225–239.

Bonfanti, A., Del Giudice, M., & Papa, A. (2018). Italian craft firms between digital manufacturing, open innovation, and servitization. *Journal of the Knowledge Economy, 9*(1), 136–149.

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 perspective. *International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering, 8* (1), 37–44.

Brown, J. S., & Duguid, P. (2000). *The social life of information*. Boston: Harvard Business Review Press. in 2017 the book was published with a new introduction.

Brown, J. S., & Duguid, P. (2001). Knowledge and organization: A social-practice perspective. *Organization Science, 12*(1), 198–213.

Butschan, J., Heidenreich, S., Weber, B., & Kraemer, T. (2019). Tackling hurdles to digital transformation – the role of competencies for successful industrial internet of things (IIoT) implementation. *International Journal of Innovation Management, 23*(4). https://doi.org/10.1142/S1363919619500361.

Chiarvesio, M., Di Maria, E., & Micelli, S. (2004). From local networks of SMEs to virtual districts: Evidence from recent trends in Italy. *Research Policy, 33*(10), 1509–1528.

Coreynen, W., Matthyssens, P., & Van Bockhaven, W. (2017). Boosting servitization through digitization: Pathways and dynamic resource configurations for manufacturers. *Industrial Marketing Management, 60*, 42–53.

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018, July). The expected contribution of industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, *204*, 383–394. Elsevier B.V.

Dalmarco, G., Ramalho, F. R., Barros, A. C., & Soares, A. L. (2019). Providing industry 4.0 technologies: The case of a production technology cluster. *Journal of High Technology Management Research*. https://doi.org/10.1016/j.hitech.2019.100355.

Davenport, T. H. (2019). *The AI advantage. How to put the artificial intelligence revolution to work*. The MIT Press: Cambridge, MA.

Davenport, T. H., & Mahidhar, V. (2018). What's your cognitive strategy? *MIT Sloan Management Review, 59*(4), 18–23.

Davenport, T. H., & Prusak, L. (1998). *Working knowledge*. Boston: Harvard Business School Press.

Drucker, P. (1995). *"The post-capitalist executive," managing in a time of great change*. New York: Penguin.

Floridi, L. (2016). *The fourth revolution: How the Infosphere is reshaping human reality*. Oxford: Oxford University Press.

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics, 210*, 15–26.

Fry, H. (2018). *Hello world: Being human in the age of algorithms*. New York: W.W. Norton & Company.

Gershenfeld, N. (2012). How to make almost everything. *Foreign Affairs, 91*(6), 43–57.

Haenlein, M., & Kaplan, A. (2019). A brief history of artificial intelligence: On the past, present, and future of artificial intelligence. *California Management Review, 61*(4), 5–14.

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change, 146*, 119–132.

Kagermann, H., Helbig, J., Hellinger, A., & Wahlster, W. (2013). *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry*. Final Report of the Industrie 4.0 Working Group. Forschungsunion.

Kamble, S., Gunasekaran, A., & Dhone, N. C. (2019). Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies. *International Journal of Production Research*. doi:https://doi.org/10.1080/00207543.2019.1630772.

Kane, G. C., Palmer, D., Phillips, A. N., Kiron, D., & Buckley, N. (2015). Strategy, not technology, drives digital transformation, becoming a digitally mature enterprise. *MIT Sloan Management Review*. http://sloanreview.mit.edu/projects/strategy-drives-digital-transformation.

Kiel, D., Arnold, C., & Voigt, K.-I. (2017). The influence of the industrial internet of things on business models of established manufacturing companies – A business level perspective. *Technovation, 68*, 4–19.

Kogut, B., & Zander, U. (1992). Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science, 3*, 383–398.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering, 6*(4), 239–242.

Lee, J., Bagheri, B., & Kao, H. (2015). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. *Manufacturing Letters, 3*, 18–23.

Leeflang, P. S., Verhoef, P. C., Dahlström, P., & Freundt, T. (2014). Challenges and solutions for marketing in a digital era. *European Management Journal., 32*(1), 1–12.

Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration, 6*, 1–10. Elsevier Inc.

Lu, H.-P., & Weng, C.-I. (2018). Smart manufacturing technology, market maturity analysis and technology roadmap in the computer and electronic product manufacturing industry. *Technological Forecasting and Social Change, 133*, 85–94.

McAadam, R., & Reird, R. (2001). SME and large organisation perception of knowledge management: Comparisons and contrasts. *Journal of Knowledge Management, 5*(3), 231–241.
Müller, J. M. (2019a). Antecedents to digital platform usage in industry 4.0 by established manufacturers. *Sustainability, 11*, 1121. https://doi.org/10.3390/su11041121.
Müller, J. M. (2019b). Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users. *Journal of Manufacturing Technology Management*. https://doi.org/10.1108/JMTM-01-2018-0008.
Müller, J. M., Kiel, D., & Voigt, K.-I. (2018). What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability, 10*, 247. https://doi.org/10.3390/su10010247.
Muscio, A., & 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*. https://doi.org/10.1080/10438599.2019.1597413.
Nagy, J., Oláh, J., Erdei, E., Máté, D., & Popp, J. (2018). The role and impact of industry 4.0 and the internet of things on the business strategy of the value chain-the case of Hungary. *Sustainability (Switzerland), 10*(10). https://doi.org/10.3390/su10103491
Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. Oxford: Oxford University Press.
Orr, J. (1996). *Talking about machines. An ethnography of a modern job*. ILR/Cornell University Press.
Pauleen, D. J. (2017). Davenport and Prusak on KM and big data/analytics: Interview with David J. Pauleen. *Journal of Knowledge Management, 21*(1), 7–11.
Pauleen, D. J., & Wang, W. Y. C. (2017). Does big data mean big knowledge? KM perspectives on big data and analytics. *Journal of Knowledge Management, 1*, 1–6.
Pine, B. J., II. (1993). *Mass customization. The new frontier in business competition*. Boston: Harvard Business Review Press.
Polanyi, M. (1966). *The tacit dimension*. Garden City, NY: Doubleday.
Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review, 92*(11), 64–88.
Schneider, P. (2018). Managerial challenges of industry 4.0: An empirically backed research agenda for a nascent field. *Review of Managerial Science, 12*(3), 803–848.
Schwab, K. (2017). *The fourth industrial revolution*. New York: Crown.
Smith, K. G., Collins, C. J., & Clark, K. D. (2005). Existing knowledge, knowledge creation capability, and the rate of new product introduction in high-technology firms. *Academy of Management Journal, 48*(2), 346–357.
Spender, J. C. (1996). making knowledge the basis of a dynamic theory of the firm. *Strategic Management Journal, 17*(special issues), 45–62.
Stentoft, J., & Rajkumar, C. (2019). The relevance of industry 4.0 and its relationship with moving manufacturing out, back and staying at home. *International Journal of Production Research*. doi. https://doi.org/10.1080/00207543.2019.1660823.
Sturgeon, J. S., Fredriksson, T., & Korka, D. (2017). *The 'new' digital economy and development*. UNCTD technical notes on ICT for development n.8.
Szalavetz, A. (2019). Industry 4.0 and capability development in manufacturing subsidiaries. *Technological Forecasting and Social Change, 145*, 384–395.
Tao, F., Qi, Q., Liu, A., & Kusiak, A. (2018). Data-driven smart manufacturing. *Journal of Manufacturing Systems, 48*(C), 157–169.
Tegmark, M. (2017). *Life 3.0: Being human in the age of artificial intelligence*. Knopf.
Tortorella, G. L., & Fettermann, D. (2018). Implementation of industry 4.0 and lean production in brazilian manufacturing companies. *International Journal of Production Research, 56*(8), 2975–2987. Taylor & Francis.
Vanchan, V., Mulhall, R., & Bryson, J. (2018). Repatriation or reshoring of manufacturing to the U.S. and UK: Dynamics and global production networks or from here to there and back again. *Growth and Change, 49*(1), 97–121.

Wang, L., Törngren, M., & Onori, M. (2015). Current status and advancement of cyber-physical systems in manufacturing. *Journal of Manufacturing Systems, 37*(2), 517–527.

Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C. (2016). Towards smart factory for industry 4.0: A self-organized multi-agent systems with big data based feedback and coordination. *Computer Networks, 101*, 158–168.

Whysall, Z., Owtram, M., & Brittain, S. (2019). The new talent management challenges of industry 4.0. *Journal of Management Development, 38*(2), 118–129.

Xu, Z., Frankwick, G. L., & Ramirez, E. (2016). Effects of big data analytics and traditional marketing analytics on new product success: A knowledge fusion perspective. *Journal of Business Research, 69*(5), 1562–1566.

Yao, X., & Lin, Y. (2016). Emerging manufacturing paradigm shifts for the incoming industrial revolution. *The International Journal of Advanced Manufacturing Technology, 85*(5–8), 1665–1676.

Yin, R. K. (2009). *Case study research: Design and methods*. Sage: Thousand Oaks, CA.

Zovico, F. (2018). *Nuove imprese. Chi sono i Champions che competono con le global companies*. Egea: Milan.

Zuboff, S. (2019). *The age of surveillance capitalism: The fight for a human future at the new frontier of power*. New York: PublicAffairs.