

# The adoption of Industry 4.0 technologies in SMEs: results of an international study

Industry 4.0  
technologies  
in SMEs

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## Abstract

**Purpose** – The purpose of this paper is to investigate whether the financial resources invested in advanced manufacturing technologies (AMTs) and social capital (SC), in terms of the set of internal and external relationships a firm holds, have a positive effect on the adoption of Industry 4.0 (I4.0) technologies. Furthermore, it tests whether the organizational context strengthens these relationships.

**Design/methodology/approach** – The authors used regression models to analyze data collected through an international survey carried out within the scope of a European project involving six Central European regions.

**Findings** – Results show that small- and medium-sized enterprises (SMEs) having stronger internal and external SC have a higher propensity to adopt I4.0 technologies, and both management support and absorptive capacity (AC) strengthen these relationships, whereas investments in AMTs within the manufacturing area and internal SC have a positive association with the intensity of I4.0 adoption. However, in presence of a high level of management support and AC, the relationship between external SC and I4.0 adoption becomes positive and significant. Management support also moderates the impact that investments in AMTs in the manufacturing area and internal SC have on the intensity of adoption of I4.0 technologies.

**Originality/value** – This paper is one of the first to investigate the context of SMEs that, having fewer resources, face some difficulties in exploiting the potential of I4.0 revolution. Moreover, it adopts a broad perspective on the factors that facilitate the adoption of I4.0.

**Keywords** SMEs, Advanced manufacturing technologies, Social capital, Industry 4.0, Digital technologies

**Paper type** Research paper

## 1. Introduction

Companies worldwide are currently being reshaped by the new industrial revolution – the fourth – also known as Industry 4.0 (I4.0), where traditional manufacturing and production methods are in the throes of a digital transformation. The concept of I4.0 was initially introduced in Germany in 2011 (Lu, 2017), referring to the integration of physical objects, human actors, intelligent machines, production lines and processes across organizational boundaries, with the aim of realizing a system in which all the processes are integrated and information is shared in real time (Hozdić, 2015).

The emergence of I4.0 is deeply rooted in the third industrial revolution which is characterized by rapid developments in information technology (IT), electronics and digitalization, where advanced manufacturing technologies (AMTs) are at its core. AMTs are computer-assisted technologies used by industrial companies to produce their products. They can be described as computer-assisted technologies used to control and monitor manufacturing activities, bringing greater flexibility, shorter production cycles, faster responses to changing market demands, better control and accuracy of production processes (Caputo *et al.*, 2016). Literature (Durão *et al.*, 2017) shows that the adoption of AMTs in connected environments triggers the fourth industrial revolution because it

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allows the receipt of different information from various sources and the production of few items in a reduced time. Therefore, the shift to the fourth industrial revolution seems to be enabled by a factory that has already passed through the challenges of the third industrial revolution, since AMTs can facilitate the adoption of cyber-physical systems (CPS), “defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities” (Lee *et al.*, 2015), that are at the core of I4.0.

On such basis, exploiting the potential of I4.0 is challenging, particularly for small- and medium-sized enterprises (SMEs), as it requires significant investments in technologies. However, this is not enough because also IT competences, a strategic vision of the top management and an organizational context ready to support the transformation process and receive the benefits led by these technologies need to be considered (Balasingham, 2016). Looking at the SME context, after 2011, on one the hand, they have experienced a decline in the availability of resources due to the economic crisis and the banking credit crunch. On the other hand, the increased pervasiveness of the I4.0 revolution, which allows the improvement of manufacturing processes and the development of smart products, has amplified the dynamism and the complexity of SME market and technological environment (Neirotti *et al.*, 2017), increasing their competitive pressures, altering market equilibria and changing industry structure.

For these reasons, nowadays governments are developing some policies and measures to support firms in their digitalization path both financially through funds and structurally through institutional actions at the system level meant at fostering the relationship between the company and the external actors (such as intermediaries, universities and innovative firms) as well as training programs. These policies are also addressed to SMEs that, having fewer resources, face some difficulties in exploiting the potential of I4.0 revolution. Recently, SMEs, thanks also to these policies promoted by governments, have been making some investments in AMTs and, to this purpose, they have established a set of relationships with external partners, not only suppliers and customers, but also technology providers and innovative organizations. However, the literature partially ignores the effects that these actions undertaken by SMEs may have on the real adoption of I4.0 technologies. Furthermore, there are not so straightforward insights on the role that the organizational context plays in favoring the adoption of I4.0 technologies in SMEs (Tortorella and Fettermann, 2017).

To bridge these gaps, the aim of this paper is twofold: the former is to understand whether the financial resources SMEs have invested in AMTs and their set of internal and external relationships (that could be referred to by recalling the concept of social capital (SC) Hitt and Duane, 2002) have a positive effect in the adoption of I4.0 technologies; the latter is to test whether the organizational context strengthens the relationship between the financial resources and SC and the adoption of I4.0 technologies in the context of SMEs. To this end, we carried out an international survey addressed at a sample of SMEs to test our set of hypotheses.

The remainder of the paper is organized as follows: a literature overview on the antecedents of the adoption of I4.0 technologies and moderators are presented, followed by the methodology and data analysis; finally, results are discussed with academic and practical implications.

## 2. Literature review and hypotheses

Increased flexibility in manufacturing, mass customization, smart products, better quality and improved productivity are among the most cited benefits that can be reaped by the new digital industrial revolution that is characterized by the merger of digital and physical workflows. At the heart of I4.0, there are CPS where the internet and supporting

technologies (e.g. embedded systems) serve as pillars to integrate physical objects, human actors, intelligent machines, production lines and processes across organizational boundaries to form a new kind of intelligent, networked and agile value chain.

I4.0 is enabled by the application of AMTs “to bring new values and services for customers and the organization itself” (Khan and Turowski, 2016, p. 16). In particular, AMTs, intended as a cluster of technologies hardware based (e.g. computer numerical control, flexible manufacturing systems and industrial robots) and software based (e.g. computer-aided design, bar coding automatic identification), linked through advanced computing technology, are an important antecedent of I4.0. Indeed, there are few studies (e.g. Maghazei and Netland, 2017) prompting that AMTs should be implemented to exploit the potential of I4.0 revolution successfully. It seems that “an automated production system of people, machines and tools for the planning and control of the production process” (Maghazei and Netland, 2017, p. 136) is an important antecedent of I4.0; just to make an example, Internet of Things (IoT) integrates “advanced manufacturing technology and modern management technology to realize the dynamic perception, intelligent processing and optimal control of manufacturing system” (Huang *et al.*, 2017). Put in other words, the key element that characterizes this new industrial revolution is the change in the manufacturing systems allowed by the integration of information and communication technologies (ICTs), IoT and machines in CPS (Dalenogare *et al.*, 2018).

Consequently, to exploit the advantages of I4.0 entirely, companies need to invest in equipment, ICTs and AMTs. A huge amount of investments, which are supposed to reach €140bn annually in Europe until 2020, is required to embrace the fourth industrial revolution (Davies, 2015). These financial efforts can be particularly overwhelming for SMEs that often do not have the resources required to pursue these investments; the recent contribution by Moeuf *et al.* (2018) shows that carrying out I4.0 projects in SMEs is still a cost-driven initiative and the business transformation advantages are still not demonstrated. Lately, some studies (Sommer, 2015) have outlined that SMEs need more support by institutions in comparison to larger companies, since they are less skilled in coping with the financial, technological and staffing challenges. For example, industries with high production volumes can exploit the benefits of economies of scale and, thus, they are more willing to face larger initial investments to implement I4.0 processes (Deloitte, 2015).

These results have been confirmed also by The Digital Business Readiness study from 2015 that draws the conclusion that many enterprises are lacking resources to promote digital change internally. Along this vein, Davies (2015) outlines that one of the factors that negatively affects the success of digitalization is related to the lack of financial resources. The general conclusion achieved by the Federal Ministry of Education and Research (2016) is that, whereas the digital transformation is particularly beneficial for SMEs, large investments to reap the rewards of I4.0 are needed. In particular, as previously outlined, it seems that some investments in AMTs should be realized to create the right context that can both facilitate the adoption of CPS and to achieve all the benefits of I4.0 revolution. Based on these insights, the first hypothesis is formulated:

- H1.* The financial resources invested in AMTs will be positively associated with SME adoption of I4.0 technologies.

The full digital integration and automation of manufacturing processes, embracing the vertical and horizontal dimensions, require that employees have a broader process scope and, to understand the relations between the processes and information flows, they should cooperate with external actors, finding appropriate solutions for particular problems (Erol *et al.*, 2016). Put in other words, the availability of information along the value chain and the computational systems with their increasing connectivity and capabilities increasingly call for new cross-domain collaborations (Wang *et al.*, 2015). In particular, in the context of SMEs, collaboration is

an imperative: “connecting with partners, achieving autonomous processes, synchronizing flows and customising products,” as showed by Moeuf *et al.* (2018), are becoming part of the strategy of SMEs since they often lack investments in internal R&D activities and in capabilities to manage complex computer solutions.

In this context, also the advent of IoT technology, which allows the creation of new business models (Szozda, 2017) where values are created within a network of units, contributes to shift the focus from the single company to the whole ecosystem, so that all involved parties along the supply chain improve their processes to maximize benefits for the end customers (Atzori *et al.*, 2010). On the same line, to exploit the potential of 3D printing technologies fully, an integration along supply chain is recommended since it allows lowering the costs, improving the ability of mass customization and reducing the inventory (Chan *et al.*, 2018).

Nevertheless, the new industrial revolution calls for collaboration not only with suppliers and distributors, but also with technology and infrastructure providers such as telecoms and internet service providers (Davies, 2015). As a recent report of McKinsey&Company (2016) outlines, companies seem to show uncertainty and a lack of knowledge related to both whether I4.0 applications are to be made internally and/or externally, as well as about suitable providers. Furthermore, I4.0 is affecting the relationship with technology providers, moving from a single-provider model to a set of integrated technology providers. To manage this new context successfully, manufacturers need a well-developed portfolio of potential providers and a strong partner management approach (McKinsey&Company, 2016). It seems clear that to take advantage of the potential of I4.0 technologies employees, who are embedded in a social context, need some soft skills related to the ability “to communicate, cooperate and to establish social connections and structures with other individuals and organizations” (Erol *et al.*, 2016, p. 14), beyond technical skills. In particular, employees are asked to collaborate not only with external actors, but also with colleagues within the boundaries of their own company, where there is no place for the traditional barriers that have separated the various internal functions so far. Cooperation between experts from operations (who have the technical domain knowledge), experts from IT (who hold the knowledge on advanced analytics and the company’s IT architecture and infrastructure), and experts from business (who know how to link investments to a clear business case) and managers who set the digital strategy is a fundamental component of an I4.0 strategy execution (McKinsey&Company, 2016). The challenges posed by I4.0 and its complexity require employees, on the one hand, to have an increased propensity toward building and maintaining a network of experts and cooperating with them in finding appropriate solutions for particular problems (Erol *et al.*, 2016). On the other hand, always referring to employees, a recent article points to the capacity of working in teams as well as the social competences as fundamental skills necessary to cope with the fourth industrial revolution successfully (Sousa and Rocha, 2019).

Hence, the fruitful adoption of these technologies requires a social setting where heterogeneous interdisciplinary and inter-organizational teams, with the ability to communicate and interact, are involved. From a socio-technical perspective, recent contributions (Brettel *et al.*, 2014; Dalenogare *et al.*, 2018) outline how the adoption of the I4.0 emerging technologies is not rid of changes, requiring a new organization of work.

All in all, the previous insights support the idea that a firm SC, intended as “the relationship between individuals and organizations that facilitate action and create value” (Hitt and Duane, 2002), both in its internal dimension and external dimension, is a significant antecedent of the adoption of I4.0 technologies. In particular, in this study we adopt the approach by Cuevas-Rodríguez *et al.* (2014, p. 267) stating that “internal SC will refer to the linkages among individuals or groups within the organizations, while external SC will represent the external linkages to other firms and institutions,” which is in line with Hitt and

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Duane (2002) and with the distinction between intrafirm and interfirm relationships by Adler and Kwon (2002). Based on these insights, the following hypotheses are formulated:

*H2a.* Internal SC will be positively associated with SME adoption of I4.0 technologies.

*H2b.* External SC will be positively associated with SME adoption of I4.0 technologies.

Top management is in charge of providing the company future direction, nurturing its values and beliefs, and giving the firm a sense of identity (Hart, 1992); not only managers spearhead the company, but they also guide employees' behavior. Past research has proved that management support is fundamental in the adoption of the new technologies (e.g. Premkumar and Roberts, 1999), in the success of the innovative projects (Young and Jordan, 2008) and in the integration of technologies into business processes, which in turn facilitates the adoption and usage of cloud computing tools (Ooi *et al.*, 2018). The last consideration suggests what previous literature (Ragu-Nathan *et al.*, 2004; Tarofder *et al.*, 2010) has already demonstrated, that is that management support is crucial in favoring information system adoption and usage. Furthermore, Muninger *et al.* (2019) demonstrate that top managers who pursue digitization of the company also invest in innovation, digital infrastructure and social media.

Once technological investments have been made, managers act as direct facilitators of their successful adoption (Ooi *et al.*, 2018), since they are committed to creating a healthy working environment, sponsoring the importance of these investments through the different functions and pushing employees to become more skillful at using these technologies. Furthermore, the intrafirm and interfirm nature of these investments, that often require collaboration among different departments, as well as along the supply chain, makes the role of managers even more important. Indeed, they act as facilitators of social processes, bringing down the "sky-high vision of I4.0 to the shop floor" (Erol *et al.*, 2016, p. 15); they promote a climate of collaboration, pushing employees to put themselves in the shoes of collaborators from other departments. Evolving digital technologies allows new ways to collect and analyze data, which might contribute to improve company's performance, but to achieve this result managers need to change their decision-making culture and to increase the degree of collaboration in the decision-making process (Frisk and Bannister, 2017).

Nevertheless, the successful adoption of I4.0 technologies often calls for a trustful cooperation not only within the boundary of the company, but also with external actors. This is the case for example of the new customer-oriented business models based on innovative hybrid products and service solutions (Arnold *et al.*, 2016) or a network oriented business model where "the horizontal and vertical integration of the value chain and the related interoperability expand firms' traditional boundaries due to the organization and the stakeholders' network" (Ibarra *et al.*, 2018, p. 7). The adoption of these new business models requires the capability of partnering with external actors, and it can only be achieved by involving the top management who is in charge of coordinating and operationalizing interdisciplinary communication between intra- and inter-firm departments and stakeholders (Kiel *et al.*, 2017). Literature (Saber *et al.*, 2019) has also demonstrated that top management support is fundamental in the successful implementation of any supply chain practices, which is the organizational prerequisite for the adoption of digital technologies: for example, lack of management commitment in the supply chain would impede the introduction of blockchain technology which requires investing in new hardware and software for information collection as well as new roles, responsibilities and expertise.

Based on these insights, we formulate the following hypotheses, where management support acts as a moderator between our independent variables (the financial resources and SC) and I4.0 adoption:

*H3.* Management support strengthens the relationship between financial resources invested in AMTs and SME adoption of I4.0 technologies.

*H4a.* Management support strengthens the relationship between internal SC and SME adoption of I4.0 technologies.

*H4b.* Management support strengthens the relationship between external SC and SME adoption of I4.0 technologies.

Absorptive capacity (AC) has been defined as the capability that enables firms to effectively capture, transform, integrate and use the internal and external knowledge to improve their competitive position (Cohen and Levinthal, 1990; Zahra and George, 2002). AC is nurtured by the prior company's knowledge and by the effectiveness of its organizational communication processes, at the point that Liao *et al.* (2010) sustain that "firms with higher AC are more likely to succeed in implementing new technologies because they have more related experiences or have a more effective communications infrastructure."

This seems particularly important for SMEs that, despite they recur to external relationships due to the lack of internal resources, regularly struggle with making purposively good use of them (Agostini and Nosella, 2019).

Furthermore, the adoption of a new technology often poses significant challenges and barriers to firms, since it requires changes in the organizational processes and communication, asking for employees' ability to collaborate (Ooi *et al.*, 2018). Indeed, the literature (Schilling, 1998; Park *et al.*, 2007) shows not only that the collaboration among employees and with external actors favors a successful adoption of new technology, but also that through AC firms expand their knowledge and skill base, improving their ability to facilitate technology and manufacturing practices adoption.

Just to make some examples, Lin (2014) states that a firm AC is expected to increase the likelihood and extent of e-supply chain management adoption and Tu *et al.* (2006) show that AC is expected to favor the level of time-based manufacturing practices adoption. Finally, Liao *et al.* (2010) state that a firm AC positively influences the use of new manufacturing and technology practices, such as modularity and system integration.

Summing up, we could hypothesize that companies with a higher ability to capture and use external knowledge can exploit at maximum the potential of their collaborations and their effect on technology adoption. In other words, the extent to which a firm can transform and use external knowledge caught by different sources depends on its level of AC; taking value from this knowledge is fundamental in the process of adoption of new technologies, where companies, and in particular SMEs, do not have all the required competences in house. However, a firm AC, is not merely directed to external partners, but it also embraces a firm ability to process different types of knowledge internally, supporting companies in improving the flow of internal and external knowledge (Xiong and Bharadwaj, 2011). Indeed, the successful adoption of the new digital technologies needs employees who are skilled at working together and sharing knowledge and this effect might be potentiated if they are also able to integrate their internal knowledge with the valuable external one.

Therefore, based on these insights, the subsequent hypotheses are formulated:

*H5a.* AC strengthens the relationship between internal SC and SME adoption of I4.0 technologies.

*H5b.* AC strengthens the relationship between external SC and SME adoption of I4.0 technologies.

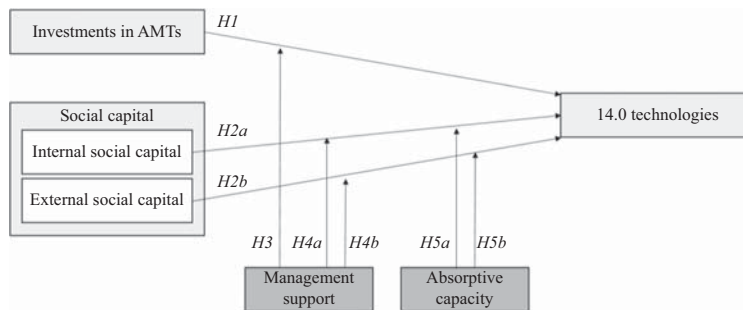
Figure 1 depicts the theoretical model that will be tested.

### 3. Methodology

#### 3.1 Statistical procedure

Two statistical analyses were conducted: the former utilized logistic regression and assessed the variables associated with whether or not firms adopted I4.0 technologies.

**Figure 1.**  
The research model



The latter utilized OLS regression and assessed the variables associated with the intensity of adoption of I4.0 technologies. This allows evaluating the variables associated with the adoption of at least one I4.0 technology, usually interpreted in terms of the probability that an event will occur (i.e. to adopt I4.0 technologies), compared to the adoption of multiple I4.0 technologies, following the approach used by previous authors (e.g. Dickson and Weaver, 2011).

To test for the moderating effect of AC and management support, we adopted the group comparison approach. According to the value assumed by the moderating variable, the sample was divided into two groups, namely, the “high group,” in which firms register a level of the moderating variables (i.e. AC and management support) above the mean value, and the “low group” in which firms register a level of the moderating variables below the mean value. Two separate regression analyses were then conducted in the groups; subsequently, the statistical difference between the regression coefficients associated to each independent variable was tested by means of the Chow test which is a statistical and econometric test of whether the coefficients in two linear regressions on different data sets are equal (Chow, 1960).

### 3.2 Sampling and data collection

I4.0 has been studied much more in the domain of large firms than in SMEs; however, due to their resource constraints and other peculiarities, issues regarding investments and SC are particularly relevant for SMEs, at the backbone of European economy, and thus they become a perfect context of study (e.g. Moeuf *et al.*, 2018). Moreover, Central European regions, despite heterogeneous in geographical terms as well as in economic and social term, are facing similar challenges, among which smart manufacturing is one of the priorities to which the European Union is dedicating specific development programmes[1]. On such basis, to test the hypotheses, an international survey has been carried out within the scope of a European project called InnoPeer AVM, involving six Central European regions, namely, Emilia Romagna (Italy), Lower Silesia (Poland), South Bavaria (Germany), Upper Austria (Austria), Veneto (Italy) and Western Transdanubia (Hungary). The overall aim of the project is to understand the dynamics of I4.0 in the manufacturing sector in SMEs of the involved regions and support the development of I4.0 capabilities of SMEs. These regions represent excellence within a number of manufacturing sectors, namely, metallurgy, electric and electronics, machinery and vehicles.

Accordingly, a purposive sampling technique was adopted to identify our potential respondents. First, companies needed to have a turnover between €2 and 50m. Second, the companies of the sample had to belong to one of the following manufacturing industry (according to NACE Rev.2 classification): 25. Manufacture of fabricated metal products,

except machinery and equipment; 26. Manufacture of computer, electronic and optical products; 27. Manufacture of electrical equipment; 28. Manufacture of machinery and equipment n.e.c. (not explicitly covered); 29. Manufacture of motor vehicles, trailers and semi-trailers; 30. Manufacture of other transport equipment. Finally, they needed to have the headquarter located in one of the investigated regions.

An e-mail containing the description of the project and the link to the online survey was sent to firms respecting these criteria; after two reminders, we finally obtained a total number of 163 complete answers. Data were collected between January and February 2018.

### 3.3 Measures and operationalisation

In our survey, we used already validated scales, measured on the basis of a five-point Likert scale.

To measure the firm adoption of I4.0 technologies (I4.0), we identified the inter-related I4.0 technologies, as suggested by the Italian Ministry of Economic Development (2016), following the approach found in the recent article by Tortorella and Fettermann (2018). We asked firms the level of adoption of each technology ranging from “Not adopted” to “Fully adopted,” and then, after carrying out the factor analysis, we calculated the mean value of the level of adoption of all the technologies. A “dummification” of this variable was made to perform the logistic regression: for each technology, we substitute with 0 answers 1 and 2, and with 1 answers 3, 4 and 5. Then, if values of all technologies summed to zero, we attributed 0 to the new variable (I4.0\_Y/N), otherwise we attributed 1, which means that the firm adopted at least one technology.

For investments (INV), we used the scale indicated by Boyer and Pagell (2000) and we asked firms the amount of investments the firm made in a number of AMTs, ranging from “No investments” to “Heavy investments,” in the previous three years. As Table I shows, the factor analysis distinguishes two factors, i.e. one referred to manufacturing activities (INV\_MAN) and another one to the design activities (INV\_DES), in accordance with Boyer and Pagell (2000).

SC has a twofold dimension, i.e. internal and external. For internal SC (INT\_SC), we adopted the three-item scale used by Subramaniam and Youndt (2005) that reflects the value embedded in the interactions among employees (Nahapiet and Ghoshal, 1998) and concerns the quality of such relationships in terms of employees’ knowledge exchange habits, propensity to collaborate and work in groups (Yang and Lin, 2009). For external SC (EXT\_SC), we asked firms the extent they collaborate with a number of external sources for innovation (i.e. other firms, intermediaries, universities/research centers, consultants, ICT providers), ranging from a very low to a very high level, following Landry *et al.* (2002).

As far as the moderating variables are concerned, the three-item scale for AC is taken from Hsu and Fang (2009) and it represents the firm’s ability to search, identify and utilize external knowledge. Then, the scale for management support (MNG\_SUPP) is based on Lin *et al.* (2016) and represents the level of willingness of senior staff to support and encourage the adoption of I4.0 technologies.

We also controlled for firm size, operationalized as the logarithm of the number of employees and for R&D expenses (e.g. Hambrick *et al.*, 2015; Yanadori and Cui, 2013). This also allows considering the issue of endogeneity, as suggested by previous research (e.g. Ebbes *et al.*, 2017; Hult *et al.*, 2018).

Table I exhibits the details of the constructs and associated measurement items together with the results of the confirmatory factor analysis (CFA) that was performed using SPSS. In particular, we carried out separate CFAs for the dependent, independent and moderating variables (see different colors in Table I), in line with the approach used in previous studies (e.g. Jansen *et al.*, 2006).



Items	Description	Standard loading	Cronbach's $\alpha$
I4.0	Please, rate your present level of adoption of each of the following I4.0 technologies		
I4.0_IOT	Internet of Things	0.763	0.812
I4.0_CLOUD	Cloud computing	0.592	
I4.0_CYBER	Cybersecurity	0.616	
I4.0_BIGDATA	Big data and analytics	0.672	
I4.0_AMS	Advances manufacturing solutions	0.665	
I4.0_AUGM	Augmented reality	0.693	
I4.0_ADDIT	Additive manufacturing	0.624	
I4.0_SIMUL	Simulation tools	0.659	
INV	Please, rate the amount of investments your manufacturing plant has in the following activities		
INV_CAD	Computer-aided design	0.961	0.809
INV_CAE	Computer-aided engineering	0.887	
INV_CAP	Computer-aided process planning	0.582	
INV_CAM	Computer-aided manufacturing	0.700	0.890
INV_ROBOT	Robotics	0.662	
INV_CONTR_SYST	Real-time process control systems	0.881	
INV_GT	Group technology	0.624	
INV_FMS	Flexible manufacturing systems	0.652	
INV_CNC	Computerized numerical control machines	0.660	
INV_MAT_HANDL	Automated material handling systems	0.719	
INV_ENV_CONTR	Environmental control systems	0.932	
INV_BAR_CODE	Bar coding automatic identification	0.758	
INT_SC	Please, rate the level at which		
INT_SC_PROBL	Your employees are skilled at collaborating with each other to diagnose and solve problems	0.914	0.912
INT_SC_LEARN	Your employees share information and learn from one another	0.917	
INT_SC_IDEAS	Your employees interact and exchange ideas with people from different areas of the company	0.935	
EXT_SC	Please, rate the extent you collaborate with each of these external sources for innovation		
EXT_SC_FIRM	Other firms	0.816	0.838
EXT_SC_INTERM	Intermediaries	0.797	
EXT_SC_UNIV	Universities/research centers	0.603	
EXT_SC_CONSUL	Consultants	0.806	
EXT_SC_ICT	ICT providers	0.826	
AC	Please, rate the level at which		
AC_SEARCH	Your employees have the capability to search for external information and knowledge	0.890	0.893
AC_IDENT	Your employees can identify the usefulness of external information and knowledge	0.949	
AC_USE	Your employees can effectively and flexibly utilize extant or newly acquired knowledge	0.882	
MAN_SUPP	Please, rate the level at which		
MAN_SUPP_FIN	Senior staffs provide highly support, such as HR and financial resources, to I4.0 technology	0.959	0.915
MAN_SUPP_ENC	Senior staffs encourage employees to apply I4.0 technology	0.861	

**Table I.**  
Results of the CFA

We evaluated content, construct, convergent and discriminant validity of the measurement scales. According to Bollen (1989), while content validity is assessed conceptually, construct, convergent and discriminant validity must be evaluated both empirically and theoretically. Construct validity was assessed in terms of significance of factor loadings and magnitude of factor loadings (Mahapatra *et al.*, 2012). An analysis of the loadings indicated that all

standardized loadings were greater than 0.5 and highly significant, thus showing convergent validity. We further tested for discriminant validity by calculating the correlation among the constructs. Due to some high values in the correlations, we also calculated the variance inflation factor (VIF) that resulted all lower than three, a part from AC whose VIF is 3.03, thus confirming multicollinearity is not a concern.

In addition, Cronbach's  $\alpha$  of the identified constructs is definitely above the threshold value of 0.6 suggested by Nunally (1978) for all constructs, therefore confirming convergent validity. Table II presents some descriptive statistics of independent variables, whereas correlations are shown in Table III.

To test for common method bias, i.e. variance that is attributed to the measurement method rather than the constructs of interest (MacKenzie and Podsakoff, 2012), we performed two analyses, one during the design and administration of the survey and one *post hoc*. First, we selected respondents who have the necessary experience to answer, we tried to motivate them to answer accurately by explaining why the questions were important; moreover, we assured respondent confidentiality, which should prevent respondents to modify their answers based on outside expectations, and we minimized the length and repetitiveness of the questionnaire as much as possible (MacKenzie and Podsakoff, 2012). In addition, following the approach of many previous studies (e.g. Vaccaro *et al.*, 2012; Dibrell *et al.*, 2008; Bharadwaj and Menon, 2000), we carried out the Harman's one-factor test to check whether a single factor can be extracted and account for most of the variance in the variables included in our study, which would confirm the presence of common method bias (Podsakoff and Organ, 1986; Harman, 1967). To this purpose, we conducted a principal component analysis of all the items employed in the study forcing the number of factors to one and the explained variance is 33.4 percent, thus showing that common method bias is not a thread in our database.

**Table II.**  
Descriptive statistics

	Mean	SD
I4.0	2.26	0.81
INV_MAN	2.26	0.94
INV_DES	2.56	1.06
INT_SC	3.34	0.92
EXT_SC	2.83	0.95
AC	3.22	0.88
MNG_SUPP	3.34	1.09

**Table III.**  
Correlations

	I4.0_Y/N	I4.0	INV_MAN	INV_DES	INT_SC	EXT_SC	AC	MNG_SUPP	R&D	Firm size	VIF
I4.0_Y/N	1.000										
I4.0	0.924	1.000									
INV_MAN	0.340	0.385	1.000								2.43
INV_DES	0.338	0.404	0.711	1.000							2.22
INT_SC	0.426	0.470	0.244	0.325	1.000						2.51
EXT_SC	0.347	0.379	0.511	0.477	0.432	1.000					1.92
AC	0.445	0.473	0.264	0.302	0.767	0.576	1.000				3.03
MNG_SUPP	0.335	0.373	0.400	0.304	0.393	0.493	0.475	1.000			1.52
R&D	0.265	0.266	0.066	0.144	0.167	0.163	0.234	0.151	1.000		1.14
Firm size	0.067	0.138	0.268	0.286	-0.007	0.177	0.018	-0.054	0.213	1.000	1.21

#### 4. Data analysis and results

The results of the first part of the analyses are presented in Table IV. Results of the logistic regression, investigating the impact of investments and SC on the probability to adopt I4.0 technologies, show that both internal and external SC enhance the likelihood that SMEs adopt I4.0 technologies, whereas investments in AMTs do not have a significant impact. Results of the OLS regression, investigating the impact of investments and SC on the intensity of adoption of I4.0 technologies, indicate that only one of the two components of the amount of investments in AMTs is significantly associated to the level of adoption of I4.0 technologies, i.e. the one associated to investments in manufacturing. Instead, investments in design are not statistically significant. As far as SC is concerned, higher levels of internal SC are likely to lead to higher levels of I4.0 adoption, whereas external SC does not seem to have a significant impact. Therefore, *H1*, *H2a* and *H2b* are only partially supported.

Regarding moderation, on the one hand, results of the logistic regression exhibited in Table V demonstrate that management support positively moderates the impact internal and external SC have on the probability to adopt I4.0 technologies. Indeed, internal and external SC have a positive influence on the probability to adopt I4.0 technologies only in the “high” group, i.e. those SMEs that register high levels of management support. Instead, investments in manufacturing and design remain not significant either in the “high” or “low” group. On the other hand, the OLS regression indicates a significant impact of

	Logistic regression (dep. var. I4.0_Y/N)		OLS regression (dep. var. I4.0)	
	Odds ratio	<i>p</i> -value	Estimates	<i>p</i> -value
INV_DES	1.432	0.331	0.056	0.459
INV_MAN	1.156	0.746	0.181	0.040**
INT_SC	1.696	0.050**	0.298	0.000***
EXT_SC	2.159	0.016**	0.034	0.630
Firm size	0.876	0.762	0.023	0.799
R&D expenses	2.046	0.019**	0.155	0.011**
(pseudo) <i>R</i> <sup>2</sup>	(0.28)		0.32	
Adj. <i>R</i> <sup>2</sup>	-		0.29	
No. of observations	163		163	

**Notes:** \*\*,\*\*\*Significant at 5 and 1 percent level, respectively

**Table IV.**  
Results of the  
regression analysis

	Logistic regression (dep. var. I4.0_Y/N)			OLS regression (dep. var. I4.0)		
	High	Low	Chow test	High	Low	Chow test
INV_DES	0.971 (0.163)	0.008 (0.987)	<i>p</i> = 0.076*	-0.021 (0.852)	0.102 (0.352)	<i>p</i> = 0.135
INV_MAN	0.626 (0.479)	0.045 (0.942)	<i>p</i> = 0.089*	0.227* (0.090)	0.214 (0.135)	<i>p</i> = 0.058*
INT_SC	1.039** (0.017)	-0.108 (0.817)	<i>p</i> = 0.008***	0.362*** (0.003)	0.209** (0.050)	<i>p</i> = 0.035***
EXT_SC	1.131** (0.043)	0.225 (0.629)	<i>p</i> = 0.007***	0.236** (0.028)	-0.071 (0.543)	<i>p</i> = 0.009***
Firm size	-0.545 (0.396)	0.277 (0.681)		-0.026 (0.132)	0.076 (0.140)	
R&D expenses	1.018** (0.038)	0.582 (0.235)		0.186** (0.088)	0.105 (0.085)	
(pseudo) <i>R</i> <sup>2</sup>	(0.41)	(0.12)		0.24	0.19	
Adj. <i>R</i> <sup>2</sup>	-	-		0.20	0.14	
No. of observations	79	68		79	68	

**Notes:** \*\*,\*\*\*Significant at 10, 5 and 1 percent level, respectively

**Table V.**  
Results of the  
regression analysis  
with moderators –  
management support

investments in manufacturing, internal SC and external SC only in the “high” group, thus making management support a moderator of such relationships. Instead, the impact investments in design have on the I4.0 adoption that remains not significant independently from the intervention of the moderator. The results of the Chow test further support all these evidences. Therefore, *H3* is partially supported, whereas *H4a* and *H4b* are supported.

As far as AC is concerned, as Table VI shows, it plays the role of moderator both in the logistic and OLS regression, thus meaning that the impact that internal SC and external SC have on the likelihood to adopt I4.0 and the intensity of adoption of I4.0 technologies is significant only in the “high” group. Again, the Chow test further confirms these results. Hence, *H5a* and *H5b* are supported. In particular, the relationship between external SC and the intensity of I4.0 adoption becomes significant only in the presence of the moderator.

Concerning control variables, we tested the models with and without the control variables. Firm size is not statistically significant in any model, whereas R&D expenses are significant in all the analyses, but without influencing the impact that the independent variables have on the dependent ones. This supports the view that financial investments play a relevant role in the ability of the firm to adopt I4.0 technologies.

## 5. Discussion and conclusions

### 5.1 Discussion of results

The purposes of this paper were, first, to investigate whether investments SMEs made for developing AMTs and SC are positively associated to their ability to adopt I4.0 technologies, and, second, to understand whether the organizational context plays a moderation role in these relationships. The rationale behind this study lays in the fact that while, on the one side, SMEs are pushed toward making investments in AMTs and adapt their organizational context to adopt I4.0 successfully, on the other side, there is no empirical evidence supporting the effectiveness of these factors in I4.0 adoption. Moreover, the role of the organizational context in the path toward I4.0 is still disregarded, as some recent studies on the topic explicitly point out (e.g. Sena *et al.*, 2019).

Results show that SMEs having stronger internal and external SC have a higher propensity to adopt I4.0 technologies, and both management support and AC reinforce these relationships, whereas investments in AMTs within the manufacturing area and internal SC have a positive association with the intensity of I4.0 adoption. However, in presence of a high level of management support and AC, the relationship between external SC and I4.0 adoption becomes positive and significant. Management support also moderates the impact that investments in AMTs in the manufacturing area and internal SC have on the intensity of adoption of I4.0 technologies. Contrarily, AMTs investments in the design area seem to

**Table VI.**  
Results of the regression analysis with moderators – absorptive capacity

	Logistic regression (dep. var. I4.0_Y/N)		Chow test	Linear regression (dep. var. I4.0)		Chow test
	High	Low		High	Low	
INT_SC	0.843** (0.015)	-0.703 (0.357)	$p = 0.005^{***}$	0.362*** (0.003)	0.157** (0.036)	$p = 0.022^{**}$
EXT_SC	1.554** (0.027)	0.225 (0.29)	$p = 0.017^{**}$	0.236** (0.028)	0.108 (0.241)	$p = 0.016^{**}$
Firm size	0.334 (0.549)	-1.161 (0.181)		-0.108 (0.121)	0.172 (0.110)	
R&D expenses	0.736** (0.044)	1.017 (0.175)		0.209** (0.086)	0.068 (0.090)	
(pseudo) $R^2$	(0.24)	(0.19)		0.24	0.20	
Adj. $R^2$	-	-		0.20	0.17	
No. of observations	79	68		79	84	

**Notes:** \*\*\*\*\*Significant at 5 and 1 percent level

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have no significant impact either on the propensity to adopt I4.0 technologies or the intensity of I4.0 adoption, with or without the effect of the moderator.

Overall, our findings highlight that SC, both internal and external, seems to be the element that could activate the adoption of I4.0 technologies, but then investments in AMTs within the manufacturing area and sustenance of internal SC are required to enhance the intensity of adoption.

This is in line with recent contributions (Brettel *et al.*, 2014; Dalenogare *et al.*, 2018; Akhtar *et al.*, 2019) stressing the need of a new organization of work to support the changes I4.0 technologies imply, first of all related to collaboration being an imperative in the context of SMEs (Moeuf *et al.*, 2018): for example a recent work of Akhtar *et al.* (2019) has demonstrated how the use of cross functional teams' skills positively affects big data driven actions. Here SC has a twofold perspective: internal, maintaining the view that the capacity of working in teams and leveraging the social context they live in may contribute to cope with the fourth industrial revolution successfully (Sousa and Rocha, 2019; Erol *et al.*, 2016), and external, sustaining previous results that working with a variety of external actors may help in finding appropriate solutions for particular problems posed by I4.0 (Erol *et al.*, 2016; Davies, 2015). To this regard, what we add to previous results is the difference between how SC can trigger the path toward I4.0 and how it can nurture its development over time. Indeed, results of this study show that a strong external SC increases the likelihood that an SME adopts I4.0 technologies, maybe related to their positive inclination toward integration outside the boundaries of the firm, which is the main principle of the fourth industrial revolution. Instead, for external SC to impact on the intensity of adoption of I4.0 technologies, a high level of management support and AC are necessary. As regards the moderating role of AC, SMEs may not possess all required knowledge to implement I4.0, which calls for external expertise. However, there is the need to have someone within the firm who is able to search for the knowledge the firms misses, understand and internalize this external knowledge and exploit it successfully to make a purposively good use of it. At the same time, also having the support and encouragement of managers is likely to push employees to exploit external knowledge to adopt I4.0 technologies, supporting the evidences of some previous studies (e.g. Gunasekaran *et al.*, 2017; Lin *et al.*, 2018) that, in the context of big data, have highlighted the role of top managers in orchestrating resources and building capabilities. Therefore, we predict that a strong external SC in terms of a culture of openness and integration can trigger I4.0 implementation, whereas a strong external SC in terms of the content of external knowledge can lead to an increased intensity of implementation only if top management facilitates this process and people within the firm have the ability to exploit this knowledge.

Overall, it is interesting to notice that, beyond technologies, integration seems to be at the basis of I4.0. Beyond this reasoning on external SC, internal SC exhibits a strong association with both the probability to adopt I4.0 technologies and the intensity of adoption. This suggests that a revolution inside SMEs is taking place, in the sense that those firms that have adopted I4.0 at higher levels have prepared an internal context able to cooperate, share ideas and different backgrounds in an attempt to offer solutions to complex problems and address multifaceted issues. SME managers confirm that the first transformation within the I4.0 domain is the integration of internal systems and processes, which is strongly supported by the possibility to put together different competences and integrate different languages.

Our study confirms that top management has a fundamental role in supporting such a changing scenario, because it is in charge of coordinating intra- and inter-firm communication among different actors (Saber *et al.*, 2019; Kiel *et al.*, 2017). Within this context, investing in AMTs in the manufacturing area seems to be key to increase the intensity of adoption of I4.0, according with Maghazei and Netland (2017), which is also in

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line with Davies (2015) stating that the lack of financial resources could limit the success of digitalization, overall for SMEs.

We can posit that these results concerning investments may be because the fourth industrial revolution is still in its infancy, overall for SMEs that face more obstacles with respect to large firms due to poorly formalized processes, less sophisticated IT infrastructure and fewer economic capabilities (Dassisti *et al.*, 2017). These results were discussed also with some SME managers who have confirmed that SMEs have started mainly from advances in the manufacturing processes with the purpose to make processes more efficient and, consequently, reduce costs. SME managers agree upon the fact that there is still some reluctance in integrating systems since the design phase with suppliers, because they may not be ready for such technologies; therefore, this can be the rationale for the lack of significance of the relationship between investments in AMTs with the design area and the adoption of I4.0 technologies.

Actually, overall results confirm the standpoint that being willing to invest in AMTs is fundamental to nurture the path toward I4.0. However, beyond that, an essential prerequisite to the adoption of I4.0 technologies is the understanding and contribution of the organization at all levels to avoid isolated applications in favor of an integrated approach creating the organizational readiness for I4.0 (Müller *et al.*, 2018), in terms of SC, management support and AC.

### *5.2 Implications and future research*

Based on the reasoning above, this paper significantly contributes to both theory and practice. From a theoretical perspective, it provides support to the assumption that AMTs are essential to increase the intensity of I4.0 adoption, thus suggesting the need to further investigate the balance between investments and benefits or return on investments in the I4.0 domain. Moreover, it enlarges the domain of I4.0 from the technological focus to a wider scope that encompasses the whole organization, thus opening new paths for research in this area. To this regard, I4.0 is far from being only a technological issue, because the object of this transformation is the whole firm, following the vein of some recent research in this field (e.g. Agostini and Filippini, 2019; Sena *et al.*, 2019). Always related to the organizational context, this study highlights the importance of integrating an internal with an external perspective to investigate such phenomenon by looking within but also outside the firm boundaries. Furthermore, it addresses the specific context of SMEs, laying the basis for a deeper understanding of the dynamics behind the path toward I4.0 for SMEs, which is still under-investigated. Studying the different dynamics between SMEs and large firms could reveal interesting insights. Finally, it introduces the difference between the probability to adopt I4.0 technologies and the intensity of adoption, which could tell us more as far as antecedents of I4.0 are concerned.

From an empirical standpoint, this study offers SME managers some practical recommendations concerning the relevance of investing in SC prior to start the path toward I4.0 to lay solid bases to step from the third to the fourth industrial revolution. In particular, SME managers, who often have a direct contact with employees, need to be aware that their role could be vital to give a push and incentive toward I4.0 if they are able to motivate their staff to face complex matters as those posed by I4.0. This could be done by providing them with resources with a specific purpose and by disseminating knowledge and potential advantages, thanks to I4.0. The key point might be represented by making employees feel active part of the changing environment, thus avoiding the reluctance toward change based on their fear to be replaced by technologies. Along the same line, the capabilities of employees to share ideas and solve problems together, as well as to understand and absorb I4.0-related knowledge from the outside are key elements managers should nurture within their firms. As for the efforts governments are lavishing to sustain SMEs in their

digitalization path, the results of the study seem to support their relevance in terms of technological as well as managerial and organizational initiatives. However, beyond that, managers should also be aware that SMEs require investing in advanced technologies to go through the path toward I4.0 and fully exploit its potential, because external financial support is not likely to sustain such a long path.

Obviously, this preliminary study calls for replication, also because the dynamics of the I4.0 revolution are likely to be very fast and change rapidly, therefore also conditions surrounding it could change as swiftly.

Future studies could investigate in depth how SMEs might exploit investments in the design area to adopt I4.0 technologies. Along the same line, there could be other variables supporting the path toward I4.0 in the SME context, as for example employees' technological or soft skills. To this regard, according with the recent study of Dubey *et al* (2019) about the adoption of big data predictive analytics, integrating the perspective of the resources with those offered by the institutional theory can reveal interesting insights. More specifically, institutional pressures, represented by normative, mimetic and coercive mechanisms, might positively affect the adoption of I4.0 technologies. Finally, endogeneity deserves further investigation in future studies.

#### Note

1. For further information, please visit: [www.interreg-central.eu/Content.Node/discover/programme.html](http://www.interreg-central.eu/Content.Node/discover/programme.html) (accessed in February 2019).

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### Further reading

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