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The impact of Operations and IT-related Industry 4.0 key technologies on organizational resilience

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ABSTRACT

Industry 4.0 is one of the primary paradigms of the current industrial context. Despite the widespread research on this topic, an analysis of its key technologies' impact on company performance and resilience is not available. Hence, this work proposes a conceptual model for investigating the influences among Industry 4.0 key technologies (IT-related and Operations-related technologies), organizational resilience (in terms of internal and external) and performances in Italian companies. We distinguished company performance, referring to companies' results in the past, from organizational resilience, which investigates future survival chances. Using structural equation modelling, a second-order construct has been used to test the hypothesized relationships. The results show that the implementation level of Industry 4.0 IT-related key technologies positively impacts organizational resilience and perceived performance. These results can assist company managers and decision-makers in increasing organizational resilience by effectively implementing Industry 4.0 technologies.

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1. Introduction

Currently, Industry 4.0 is becoming the primary paradigm of the world industrial context. The concept of Industry 4.0 was initially proposed for developing the German economy in 2011 (Roblek, Meško, and Krapež 2016; Vogel-Heuser and Hess 2016), even though several countries have recently created local programs to improve the development and adoption of Industry 4.0 technologies. Nevertheless, the technologies that today are distinguished as Industry 4.0 (e.g. Industrial Internet of Things (IIoT), Augmented Reality, Cloud Technologies applications, Autonomous Robots, etc.) were developed before the 'RAMI4.0' reference architecture proposed for Industry 4.0 (Kagermann, Wahlster, and Helbig 2013). The new phase of their development is characterized by a great change in the manufacturing systems connectivity due to the integration of ICT, IIoT and machines in Cyber-Physical Systems (CPS) (Kagermann 2015). According to Roblek, Meško, and Krapež (2016), the Industry 4.0 features are not only highly correlated with internet technologies and advanced algorithms, but they also represent industrial processes of value-adding and knowledge management (Antomarioni et al. 2019).

In literature, some works studied the maturity models for the implementation of Industry 4.0 technologies (Lu and Weng 2018; Bordeleau, Mosconi, and de Santa-Eulalia 2020; Stentoft et al. 2020; Wagire et al. 2020), while other works analyzed the impact of these technologies on industrial performance (Chiarini, Belvedere, and Grando 2020; Dalenogare et al. 2018; Zangiacomi et al. 2020). Although most of the studies conducted so far show a substantial improvement in business performance thanks to the implementation of Industry 4.0 key technologies, it should be noted that there are also other aspects to be considered. For instance, Müller, Buliga, and Voigt (2018) highlighted that many SMEs perceive the substantial organizational efforts required to implement Industry 4.0 technologies as challenging. These companies perceive Industry 4.0 as costly in the short-term (high investments in machine parks and IT infrastructure and costs for IT personnel and technical training). In contrast, its expected benefits require time to unfold. Hirsch-Kreinsen (2016) underlined that SMEs tend to avoid technologies with uncertain results, while Faller and Feldmüller (2015) noted that investments as early adopters are often evaded due to the risk of investing in the wrong technologies.

Thus, it is interesting to analyze how Industry 4.0 technologies impact company performance achieved in the recent past – considering aspects like customer satisfaction, order fulfilment, sales trend and number of employees trend (Duarte and Davies 2003) – and their resilience capability, that is, strategy to recover quickly from difficulties and toughness and therefore on its ability to survive in the long term. Indeed, resilience capability, a company's property to handle impending vulnerabilities and potential disruptions, is considered a critical success factor for modern firms (Wieland and Wallenburg 2013; Rajesh and Ravi 2015; Rajesh 2016). Accordingly, in this paper, a conceptual model has been proposed for investigating the influences among the implementation level of the Industry 4.0 key technologies, companies' resilience and company performances. Industry 4.0 key technologies are clustered in two groups, considering their application areas: the first one is close to the IT-technology

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(Internet of Things, Manufacturing Big Data, Cloud Manufacturing, etc.); the second one refers to the Operations Technology environment (Advanced human–machine interface, Advanced automation, Additive Manufacturing, etc.). Instead, company resilience is treated separately, analyzing the external and internal challenges, that is, aspects related to demand and supply dynamics are separated from the company's internal management.

The rest of the paper is structured as follows: after this introduction, in Section 2, a theoretical background has been proposed to identify the Industry 4.0 key technologies and resilience capabilities to be analyzed in the research model. A set of research hypotheses and the research model used for answering these research questions have been defined in Section 3. The methodology followed in this work is detailed in Section 4. Section 5 reports the statistical analysis carried out. In particular, a second-order structural equation modelling has been used. A discussion regarding the results obtained and the conclusion have been developed in Sections 6 and 7, respectively.

2. Theoretical background

Industry 4.0 and resilience paradigms are two widely present concepts in the papers published in recent years. In most papers, these two paradigms are analyzed independently and focus on how their implementation can change companies' business models. For instance, Dalenogare et al. (2018) explored how the adoption of different Industry 4.0 technologies can be related to the expected benefits for the product, operations and side-effects aspects. They used secondary data from a large-scale survey of 27 industrial sectors of the Brazilian industry and highlighted that only some of the Industry 4.0 technologies are considered promising for industrial performance, while others are not. Müller, Buliga, and Voigt (2018) conducted qualitative research on 68 German SMEs from three industries (automotive suppliers, mechanical and plant engineering and ICT companies), analyzing how Industry 4.0 enhances changes to the business models of manufacturing small and medium-sized enterprises (SMEs). Frank, Dalenogare, and Ayala (2019) analyzed the adoption levels of Industry 4.0 technologies and their implication for manufacturing companies performing a survey in 92 manufacturing companies. They showed that Industry 4.0 regards the systemic adoption of front-end technologies in which Smart Manufacturing plays a central role. In contrast, base technologies such as Big Data and Analytics are still low implemented.

All these works agree that Industry 4.0 concepts bring disruptive changes to supply chains, business models and business processes. The main keywords of these changes are interoperability, virtualization, decentralization, real-time capability, service orientation and modularity.

In the following subsections, we will analyze and classify the most important key technologies related to Industry 4.0 and factors that best represent the resilience capabilities of a company. These technologies and factors will then be used in the questionnaire during the survey phase. The objective is to investigate which Industry 4.0 key technologies can increase companies' resilience and company performances.

2.1. Operations and IT-related Industry 4.0 key technologies

As already highlighted in the Section 1, all technologies nowadays distinguished as Industry 4.0 were developed long before the introduction of RAMI4.0. Nevertheless, the Industry 4.0 industrial stage introduced new aspects concerning a strong integration between manufacturing operations systems and information and communication technologies (ICT) (Dalenogare et al. 2018). Vogel-Heuser and Hess (2016) highlighted that the key fundamental principles of Industry 4.0 include data integration, flexible adaptation, intelligent self-organizing, interoperability, manufacturing process, optimization, secure communication and service orientation. These principles aim at reaching different goals. Shafiq et al. (2016) identified some of these goals: to boost mass customization of manufactured products, the automatic and flexible adaptation of the production chain and parts and products tracking; facilitate communication among parts, products, and machines; apply human–machine interaction (HMI) paradigms, achieve IIoT-enabled production optimization in smart factories and provide new types of services and business models of interaction in the value chain.

Different key technologies support the adoption of Industry 4.0 principles in the service and manufacturing sectors. Frank, Dalenogare, and Ayala (2019) divided Industry 4.0 technologies into front-end and base technologies. Front-end technologies consider the four 'smart' dimensions concerned with operational and market needs: Smart Manufacturing, Smart Products, Smart Supply Chain and Smart Working. The '*front-end technologies*' have an end-application purpose for the companies' value chain. The base technologies include technologies that provide connectivity and intelligence for front-end technologies. The '*base technologies*' comprise four elements: Internet of Things, Cloud Services, Big Data and Analytics. This technologies cluster enables the Industry 4.0 principles because base technologies allow front-end technologies to be connected in a completely integrated manufacturing system (Tao et al. 2018b; Wang et al. 2016).

A similar classification of Industry 4.0 key technologies has been proposed by Osservatori.net (2015). This classification links technologies to two groups: one related to Information Technology, represented by the Internet of Things, Manufacturing Big Data and Cloud Manufacturing, and a heterogeneous one related to the Operations Technology layer, represented by advanced Human–Machine Interface, Advanced Automation and Additive Manufacturing. According to this classification, we propose a conceptual framework of Industry 4.0 technologies based on two main clusters in this work. The first one is close to the IT-technology, and it includes the Industrial Internet of Things, Horizontal and Vertical System Integration, Cybersecurity, Big Data Analytics and Cloud Technologies applications. The second one is close to the Operations Technology layer, and it includes Autonomous

Robots, 3D Simulation of product/service development, Additive Manufacturing and Augmented Reality.

2.2. Internal and external organizational resilience factors

Literature shows that company organizational resilience is a multi-disciplinary concept that has been developed across several sectors and disciplines (Andres and Marcucci 2020; Dormady, Roa-Henriquez, and Rose 2019; Sahebjamnia, Torabi, and Mansouri 2018; Bevilacqua et al. 2018; Bevilacqua et al. 2020; Burnard, Bhamra, and Tsinopoulos 2018; Antomarioni et al. 2017). In ecology, Holling (1973) associated 'resilience' with the ability of systems to absorb change, as opposed to 'stability', such as the ability of the latter to return to a state of equilibrium after a temporary disturbance. From a social point of view, Timmerman (1981) was the first to define resilience as 'the measure of a system's capacity, or part of it, to absorb and recover from the occurrence of a dangerous event'. During the last decades, the resilience concept was then adopted by business researchers, which introduced the idea of 'organizational resilience', as the ability to react to and recover from an acute shock or interruption (Herbane 2019). Many studies have been carried out to deepen the research on this topic: Tisch and Galbreath (2018) focused on organizational resilience in climate change, addressing their research to a company's ability to absorb an impact recover from an extreme weather event. Ortiz-de-Mandojana and Bansal (2016) argue that sustainable development can contribute both to short-term outcomes and organizational resilience, defined as 'the firm's ability to sense and correct maladaptive tendencies and cope positively with unexpected situations'. Many studies have contributed to the literature by offering their definitions, contributions and classifications to enrich the descriptive framework of organizational resilience (Korber and McNaughton 2018; Ma, Xiao, and Yin 2018).

Nevertheless, to lay the basis of the present study, it is necessary to create a comprehensive picture by studying organizations from the type of interaction point of view. In literature, these interactions have been divided by categories, depending, for example, on the risk source. Jüttner, Peck, and Christopher (2003) classified the interactions between the SC and environment (external) as environmental risk sources. The interactions among SC's subjects (internal) have been classified as network-related risk sources and organizational risk sources, respectively, if deriving from the inter-partner or intra-partner interactions. A subsequent significant contribution to the literature has been given by Christopher and Peck (2004). Their work also focuses on the categorization of risks along the SC: internal to the firm (i.e. process and control risks), external to the firm but internal to the supply chain network (i.e. demand and supply risks) and external to the network (i.e. environmental). A more recent contribution consists of Birkie, Trucco, and Fernandez Campos (2017) research that lists four groups of capabilities: proactive-internal, proactive-external, reactive-internal and reactive-external. For the aim of the present study and the subsequent survey, which will lay the basis for the structural equation modelling analysis, organizational resilience will be addressed through these two dimensions: Internal and External Resilience.

2.2.1. Internal Resilience

Following the categorization mentioned above, literature shows that many factors can be associated with capabilities strengthening an organization's Internal Resilience. For instance, strong financial liquidity, financial leverage and solvency contributed to a critical development of companies' resilience during the economic crisis of 2008 (Abylaev, Pal, and Torstensson 2014), in comparison to those which did not have such features. An additional element that critically contributed to organizational resilience is product and service diversification since this differentiation strategy offered a critical competitive advantage (Brandon-Jones et al. 2014). Connected to this aspect, Brand Position is a further factor that provides internal resilience (Elbedweihy et al. 2016; Augusto, Godinho, and Torres 2019): in fact, the modelling of the company's offer according to the real needs and preferences of potential customers, brand-loyalty will be developed. Risk Management Culture is the main Internal Resilience factor shared by many researchers (Baldwin 2019; Engemann and Henderson 2014; McManus et al. 2008). It comprehends all of the company's risk management branches: prevention techniques, risk evaluation, reduction of action plans to face sudden disturbances (Bevilacqua et al. 2020). The need for this element emerges from the necessity for formalized risk management procedures within all organizations, for example, business continuity planning (Rezaei Soufi, Torabi, and Sahebjamnia 2019), which often struggle to manage the scale and variety of potential risks.

Moreover, Information Visibility along the organization SC, intended as the ability to track the information about products and processes from the manufacturer to the final client, is a necessary component to create and establish Risk Management culture, and therefore to achieve organizational resilience (Annarelli and Nonino 2016; Pal, Torstensson, and Mattila 2014). Finally, literature shows that human resources' strategic management is a critical condition to develop organizational resilience (Al-Ayed 2019; Branicki, Steyer, and Sullivan-Taylor 2019; Mitsakis 2020; Akgün and Keskin 2014). Indeed, skills building and cross-training among key employees enable organizations to respond effectively to difficult situations (Lengnick-Hall, Beck, and Lengnick-Hall 2011).

2.2.2. External Resilience

For the purposes of this research, External Resilience encompasses the company's ability to assess the risks arising from demand and supply. The former is potential or actual upstream disturbances, while the latter comes from SC's downstream processes (Christopher and Peck 2004). In this regard, literature shows that completion and the growing customers' expectations encourage companies to reach new flexibility levels without sacrificing efficiency and quality. Different authors selected internal resilience factors that can mainly aid the company to achieve these goals: while flexible contract with suppliers, multiple sourcing and distribution strategies, support the organization in reaching a high level of resilience in case of disruption along the SC itself, like material flow interruption or loss of connections and infrastructures (Costa et al. 2019)

3. Hypotheses development

This work aims to help company managers understand what is needed to effectively implement Industry 4.0 technologies in manufacturing companies to increase organizational resilience and performance. Moreover, the study of internal and external resilience capabilities will allow managers to identify the best business model to be adopted. Accordingly, in this paper, we aim at investigating the network of influences among the implementation level of the Industry 4.0 key technologies (IT-related and Operations-related technologies), organizational resilience (in terms of internal and external resilience) and performance in the last two years (customer satisfaction, order fulfilment, sales trend, number of employees trend).

3.1. Relationship between IT-related key technologies and organizational resilience

Implementing IT-related key technologies in the Industry 4.0 field represents a current research trend; their influence on organizational resilience is also supposed in some works. For instance, Xu, Xu, and Li (2018) noticed that a smart factory environment could increase its resilience. However, it represents a challenging objective: indeed, the aim of an intelligent factory is creating a multi-disciplinary environment and capitalizing on new technologies, being able to avoid and limiting disruptions (Ivanov and Dolgui 2020). Dalenogare et al. (2018) assert that cloud services support customers in maintaining the control of their remote products, providing relevant benefits in case of disruptions. Indeed, the possibility of accessing data remotely and of storing them on different devices ensures a higher level of availability in case of any malfunctioning. Moreover, as Morisse and Prigge (2017) observed, product traceability due to data integration improves resilience: indeed, the organizations can know almost in real-time where their product parts are and, in case of disturbances in the delivery process, they can quickly react. Other authors (e.g. Bevilacqua et al. 2017; Jeschke et al. 2017) observe that Industry 4.0 IT-technologies can increase resilience, with better efficiency in using production resources smart grids for energy saving. Energy consumption improvement can be achieved through intelligent systems for energy management that schedule intensive production stages in time with favourable electricity rates (Gilchrist 2016; Jeschke et al. 2017).

Industry 4.0 can enable unprecedented customer access to real-time information concerning the exact manufacturing stage of the products ordered and increased connectivity with its customers and suppliers (Raut et al. 2020). However, different SMEs show little enthusiasm towards real-time information sharing, fearing the implications of becoming a 'transparent supplier'. As the shared information could include sensitive data about inventories, bottlenecks and incidents (Meyer, Wortmann, and Szirbik 2011), new ethical, technical and legal approaches are needed in Industry 4.0. These are also required for counteracting cyber criminality, as companies are responsible for their data security and the data security of supply chain partners linked to them (Schuh, Anderi, and Gausemeier 2017).

Although IT solutions' implementation shows many benefits, according to Müller, Buliga, and Voigt (2018), different challenges must be faced across three business model elements: value creation, value offer and value capture. Various reasons are connected to these impressions. While many companies aim to establish an IT-facilitated, automated interconnection with suppliers and customers, they struggle with the resulting uncertainties and complexities, for instance, in case of disturbances. If an interconnected machine malfunctions, it can disrupt the entire production (Ahuett-Garza and Kurfess 2018). Moreover, the high production process transparency will be detrimental to many SMEs (Müller, Buliga, and Voigt 2018).

The last challenge concerns the new skills development in Industry 4.0. Companies should work together with their employees to generate value creation innovations. Some studies (Chryssolouris, Mavrikios, and Mourtzis 2013; Gorecky et al. 2014; Weber 2016) have shown that companies need more substantial employee training, as entirely new skills are required for human intervention in case of machine failure. Furthermore, extant studies reveal that SMEs are likely to become dependent on college-level education due to increasing industry dynamics. In contrast, training and reallocation of manufacturing employees will become more frequent along the value chain (Hirsch-Kreinsen 2016).

As highlighted, the existing literature shows that authors' opinions on the link between Industry 4.0 IT-technologies and organizational resilience are not always unanimous. Since most of the works indicated a positive relationship, hypothesis 1a has been developed:

> **H1**: The implementation level of IT-related Key Technologies has a positive impact on companies' resilience capabilities.

3.2. Relationship between IT-related key technologies and company performance

Several papers have highlighted the relationship between Industry 4.0 IT-technologies and company performance. In particular, different authors have outlined how IT-technologies allow companies to have more support for decision-making in production processes and have more delivery reliability than a rapid reconfiguration of production lines and the possibility of predicting production line breakdowns (Schuh, Anderi, and Gausemeier 2017; Pu et al. 2019).

Advanced analytical tools can analyze data collected from IIoT systems in order to monitor and forecast machinery failures, overloads or any other problems. This approach allows companies to develop predictive maintenance policies that help avoid downtime due to unexpected failures during the production process. It also helps to identify product non-conformities in earlier stages of the production process, increasing quality control and reducing production costs (Tao et al. 2018b), resulting in an overall performance improvement (Raut et al. 2019).

The use of IIoTs for internal traceability can also help to face volatile and competitive markets. Indeed, an optimized inventory control supports recall actions by identifying specific components in batches of finished products, increasing customers' satisfaction level. Internal traceability can also provide support to adaptable systems with flexible lines (Wang et al. 2016), in which machines read product requirements in the sensors embedded in them and carry out the actions to manufacture them. IT-technologies can enhance monitoring capability in production systems and physical products, allowing customers to know the product condition and usage parameters. Products with embedded software connected to Cloud services can be controlled through digital remote interfaces, increasing customers' value (Dalenogare et al. 2018). Firstly, products can have optimization functions, enhancing product performance based on predictive diagnoses that communicate any necessary corrections (Gilchrist 2016; Jeschke et al. 2017). Moreover, product monitoring provides useful information for manufacturers, who can collect this data and identify product usage patterns for market segmentation and new product development. In two different surveys carried out in Brazilian companies, ICT adoption has significantly grown, improving work productivity (Mendonça, Freitas, and de Souza 2008; Tortorella, Giglio, and van Dun 2019).

In contrast with the majority of the studies presenting promising improvement of company performance capitalizing on the benefits brought by IT-technologies, Frank et al. (2016) showed that the investments in software acquisition have not led to good results in terms of market benefits or internal manufacturing process improvement in a large-scale survey of the Brazilian industry. The authors suggest that companies are investing in software acquisition simply to automatize their operational routines instead of seeking advanced ICT tools that could give them a real competitive advantage in innovation development (Frank et al. 2016). The main challenge concerns the high investments in machine parks and IT infrastructure and costs for IT personnel and technical training regarding the value creation. Müller, Buliga, and Voigt (2018) highlight that many companies perceive Industry 4.0 as costly in the short-term, whereas its expected benefits require time to unfold.

Although there is some disagreement over the relationship between Industry 4.0 IT-technologies and company performance, mainly due to the attributional style and success perception level based on the role covered by the respondents (Antomarioni et al. 2020), most of the authors have highlighted a positive relationship between the two variables. Therefore, the following hypothesis is formulated:

> **H2**: The implementation level of IT-related Key Technologies has a positive impact on companies' performance.

3.3. Relationship between Operations-related key technologies and organizational resilience

There is a lack of research developed to assess the impact of Operations-related key technologies on organizational resilience. Indeed, as Ho et al. (2015) noted, the risk management analysis on the manufacturing and process area should be considered a key field for the research. However, according to Xu, Xu, and Li (2018), the implementation of Industry 4.0 technology enables higher reliability levels, thus increasing organizational resilience. Koos, Cully, and Mouret (2013) considered that the spreading of autonomous robots, that is, one of the Operations-related key technologies, has a positive impact on processes' resilience. Indeed, human errors can be limited, as well as better working conditions ensured. Moreover, these autonomous robots can move throughout the operation without human assistance and can avoid harmful situations in order to protect themselves, workers and property (Złotowski, Yogeeswaran, and Bartneck, 2017). More generally, cyber-physical systems enhance the performances of an industry 4.0 organization both in terms of safety, reliability, and resiliency (Lee, Bagheri, and Kao 2015).

Augmented and Virtual Reality implementation during the operators' training phases has proved successful in terms of resilience since it improves the expertise and learning time, thus limiting the occurrence of disruptions (Gorecky et al. 2014). Instead, adopting simulation techniques can support in defining the risk of disruptions or failure modes in advance. Some examples can be found for analyzing the resilience of supply chain structures: for example, Carvalho, Cruz-Machado, and Tavares (2012) propose a mapping framework for the improvement of the supply chain resilience through the identification of instability causes (e.g. extreme climate conditions, accidents) in the perspective of identifying the current state of the analyzed a supply chain and anticipating possible future transitions. Instead, the 3D simulation has been recognized to be useful in the structural field for simulating the infrastructures' resilience (Guidotti et al. 2016); hence, it should be considered in the operations field as well. Simulating the 3D model of a product would allow the anticipation of potential disruptions or criticisms in its usage. Recurring to cyber-physical systems surely supports disruption predictions, considering machines' ability to self-adapt. On the contrary, such implementation cannot be profitable if the data provided by the machines and converted into information are not consistent and reliable: indeed, they would not allow the reliable self-prediction pursued by the cyber-twin (Lee, Bagheri, and Kao 2015).

Due to the information reported in the existing literature, considering the need for depth in this field of research, the following hypothesis is formulated:

> **H3**: The implementation level of operations-related key technologies has a positive impact on companies' resilience capabilities.

3.4. Relationship between Operations-related key technologies and company performance

Among the Industry 4.0 Operations-related key technologies, an important role is played by Additive Manufacturing. Yin, Stecke, and Li (2017) highlighted how this technology accelerates product innovation and assists co-design activities, promoting more customized production since products can be digitally modified before their physical production, reducing processing time, resources and tools needed. The possibility of co-design products with customers will result in highly customized products, increasing the product's perceived value and the company (Weller, Kleer, and Piller 2015). In this sense, customers remain loyal to the company, harbouring benefits in this sense. Additive Manufacturing also promotes the sustainable production, as it only requires one process that generates less waste than traditional manufacturing, resulting in optimal resource usage (Raut et al. 2019). In contrast with other authors, Dalenogare et al. (2018) showed a negative association of this technology with expected operational benefits.

In addition to Additive Manufacturing, Augmented Reality and 3D Simulation of product/service development and production processes are promising technologies in the Industry 4.0 environment. Gorecky et al. (2014) used Virtual Reality in manufacturing maintenance to accelerate workers' training with an immersive simulation of the maintenance routines. Scurati et al. (2018), instead, suggested that Augmented Reality supports workers with interactive and real-time guidance for the necessary steps of the tasks to be done. Tao et al. (2018a) adopted these tools in product development activities to create virtual models of the product, helping to detect flaws during the product usage without needing physical prototypes. Improvements in training, execution guidance and prototyping represent a benefit for company performance since they allow both time and quality efficiency. Despite these essential benefits, Frank, Dalenogare, and Ayala (2019) findings show that Augmented and Virtual Reality is still rarely implemented. The same was reported in other studies that still consider them initial technologies whose potential benefits are always underestimated (Elia, Gnoni, and Lanzilotto 2016).

Autonomous Robots is the last Industry 4.0 Operations-related key technology taken into consideration in the survey. Autonomous Robots can gain information about their environment and work for an extended period without human intervention. These trends towards robotic involvement in industry processes will allow companies to improve productivity and customer experience and gain a competitive advantage (Amigoni, Luperto, and Schiaffonati 2017). However, literature has also highlighted some problems that need to be addressed. Dalenogare et al. (2018), in a survey on Brazilian companies, found that this technology was not significantly associated with the expected benefits because it is in a very early stage of adoption in the Brazilian industry. According to the CNI report (CNI 2016), only around 8% of the industry has adopted these technologies for operations processes. Hence, several industrial sectors may not be aware of their contribution to operations benefits.

Most of the papers in extant literature suggest that Industry 4.0 Operations-related key technologies can offer several benefits to the industry. However, at the same time, some challenges still need to be faced. Therefore, in light of the previous consideration, we hypothesize a positive relationship between Operations-related Key Technologies and the company performance:

> **H4**: The implementation level of Operations-related Key Technologies has a positive impact on companies' perceived performance.

The proposed research model is represented in Figure 1. As many authors have pointed out, the impact of Industry 4.0 technologies may vary depending on the company size. The above assumptions will be analyzed for both Large and SME.

4. Research methodology

4.1. Sample and data collection

The sample addressed for the current study is composed of randomly selected firms operating in all industrial fields of sector C, according to the Statistical Classification of Economic Activities in the European Community (2008). Specifically, 750 randomly selected companies operating in Italy were identified, aiming at horizontally covering the industrial environment from both the sector and turnover point of view. They were contacted via a phone call to

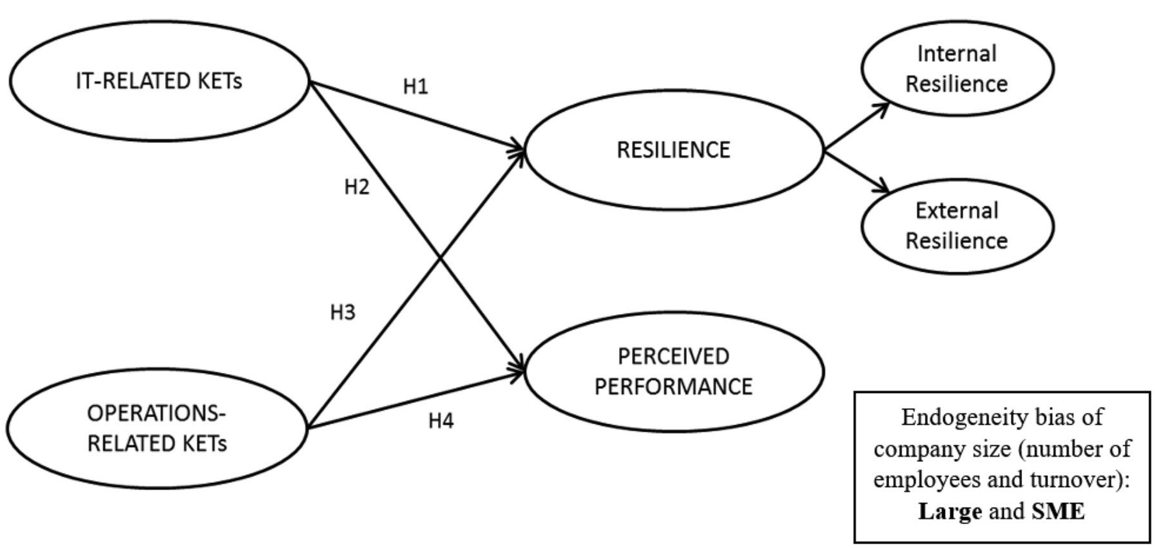

Figure 1. Hypothesized research model.

Table 1. Sample composition in terms of the industrial sector, turnover and company department of the respondent.

Sample characteristic	Description	%
Industrial sector	Food & Beverages Products	8%
	Electrical and Mechanical Machinery and Equipment	31%
	Chemical Products	3%
	Transport Products	10%
	Textile, Leather & Clothes Products	18%
	Pharmaceutical Products	4%
	Furniture	3%
	Rubber and Plastics	2%
	Others	21%
Turnover	Less than 2 million €	15.6%
	Between 2 and 10 million €	23.7%
	Between 10 and 50 million €	15.6%
	More than 50 million €	15.6%
	Not available	21.2%
Department	Production (non-managerial position)	63%
	Marketing & Finance	28%
	Production management	14%
	Top management	11%
	Research and development	10%
	Supply Chain management	9%
	Project Management	8%
	Administration & HR	7%
	Maintenance & Quality control	5%
	IT Management	4%
	Risk Management	3%

obtain the contact information of the person in charge of the supply chain and production management. Firstly, they were asked whether they had already started implementing Industry 4.0 technologies in their company: 221 of the 750 companies were eliminated at this stage since they had not begun an I4.0 journey. The questionnaire was then sent via e-mail to the direct contact obtained during the first call, asking to forward it to the most suitable person for completion; a reminder was delivered two weeks after the first e-mail. One hundred and eighty-six questionnaires were returned, but 26 were incomplete, so the analysis was only conducted on the remaining 160. The response rate was above 20% (21.3% considering only the valid responses). The sample was greater than 100, and if the reliability is assessed, the results can be regarded as satisfying (Malhotra and Grover 1998). However, the possibility of a non-response bias was tested by comparing the responses of early and late respondents: the *t*-test comparison presented non-significant differences in the scored values ($p < .001$). The sample is heterogeneous both in terms of industrial sector, invoices of firms and position covered by the respondent (Table 1).

4.2. Variables and scales

The development of the questionnaire (see Appendix 1) started from the literature review presented in Section 2. It is organized in four sections: PART A opens with general information on the company to contextualize the environment in which each of the interviewed organizations operates, such as the firm's size, industrial sector and respondents' role. In PART B, an assessment of Industry 4.0 Key technologies' implementation level has been required. Specifically, respondents were required an evaluation on a 5-point Likert scale the implementation level of the nine fundamental technologies sustaining the Industry 4.0 paradigm (see Section 2.1). In PART C, the resilience capabilities are investigated from a twofold perspective. Firstly, the internal situation is examined: indeed, respondents are asked to rate on a 5-point Likert scale the INTERNAL RESILIENCE of the company in terms of financial liquidity, project portfolio and risk management, together with its brand image, organizational solutions to enable social relationships (e.g. team working, creative problem solving, soft skills development) and information sharing (see Section 2.2). The second aspect evaluated in this section regards the EXTERNAL RESILIENCE of the organization. Information regarding the relationships among customers, suppliers and the company itself is required (see Section 2.2). In the fourth part, some questions regarding the PERCEIVED PERFORMANCE of the companies are asked. The firms' performance can be evaluated through many measures, depending on the aspects of interest. For instance, economic and financial performances have been assessed through indicators like return on investment, return on assets and sales by several authors (Flynn, Huo, and Zhao 2010; Qi et al. 2017; Wei et al. 2019). Due to the structure of the survey applied to conduct the current study and to the addressee of the questionnaire, it was decided to measure company performance through some quantitative indicators easily discoverable by respondents (variation of sales and employment growth in the last two years) and qualitative indicators (customer loyalty and satisfaction and delivery reliability).

While questions about organizational resilience investigate the possibility of the company's long-term survival, questions about performance take a snapshot of its performance over the past two years.

4.3. Measurement scale

Data collection and analysis were performed using SPSS Amos 20. In particular, considering the organization of the questionnaire and the theoretical contributions analyzed, five latent variables were hypothesized (IT-RELATED KETs, OPERATIONS-RELATED KETs, INTERNAL RESILIENCE, EXTERNAL RESILIENCE, PERFORMANCE). Each construct was tested through a Confirmatory Factor Analysis (CFA) to identify the strength of the relations among latent and observed variables. Specifically, it was found that a second-order construct better represented INTERNAL RESILIENCE and EXTERNAL RESILIENCE. Hence a further latent variable (RESILIENCE) was introduced. A CFA was then carried out to verify whether the model's parameters fitted the recommended thresholds and, obviously, the goodness of the proposed research model. Due to the wide variety of indexes provided by SPSS Amos, only a few were chosen to present the achieved results. Firstly, the relative Chi-Square was selected since it provides a measure of the model fit disentailed from sample dimensions. The Normed Fit Index (NFI) was too sensitive for the sample size: indeed, Mulaik et al. (1989) recognized that for samples smaller than 200 cases, it underestimates the model fit. Hence, the Comparative Fit Index (CFI) was chosen: it is a modified NFI that is not affected by sample size. Also, the Tucker–Lewis Index (TLI) and the Incremental Fit Index (IFI) were reported. The Root Mean Square of Error (RMSEA) was considered as an additional measure of the fitting.

We report the followed rules of thumb: the relative chi-square should be lower than 2, according to Ullman (2001). The CFI, IFI and TLI should be above 0.9, as recommended by Hu and Bentler (1999), and the upper confidence interval of Root Mean Square Error of Approximation (RMSEA) lower than 0.07 (Steiger 2007). Initially, the results achieved by the measurement model were not completely satisfying ($\chi^2(164) = 244.287$; CMIN/df = 1.490; RMSEA = 0.055; CFI = 0.882; TLI = 0.864; IFI = 0.887), so modifications were made, according to the procedure described by Hair et al. (2013). Firstly, standardized regression weights of each item were reviewed to drop the variables whose values resulted lower than 0.5: variables reporting information on the implementation level of the Autonomous Robots (I1), Information systems' integration (I3) and Information sharing (C5) – respectively belonging to OPERATIONS-RELATED KETs, IT-RELATED KETs and INTERNAL RESILIENCE CAPABILITIES – were excluded from the analysis. In addition, Sales variation (P3) and Number of performance variation (P4) were eliminated from the PERFORMANCE construct. The statistical significance ($p < .001$) of each of the remaining variables and relationships was assessed. Then, items with a standardized residual value higher than 2.58 or lower than -2.58 were checked, and all the remaining ones met the recommended values. The internal consistency reliability was tested by determining the Cronbach's alpha (Cronbach 1951): all the factors obtained pretty high values, ranging within 0.699 and 0.898. Moreover, the Composite reliability exceeds the 0.60 threshold as well as the Average Variance Extracted (AVE). Hence, discriminant validity is assessed. After modifications, the measurement model presented a better fit to the observed data ($\chi^2(120) = 133.310$; CMIN/df = 1.111; RMSEA = 0.026; CFI = 0.978; TLI = 0.972; IFI = 0.979).

The common method bias was tested both through the Harman's singularity test and the common latent factor test. The former evaluation showed an AVE by a unique factor loading lower than 30% (28.57%). The latter, instead, returned a common method variance of 3.12%. Hence, we can assume that the measurement model is not affected by any external measure (Podsakoff et al. 2003).

5. Results

In order to provide a descriptive statistic of the observed variables analyzed in the current study, the mean values and standard deviations (SD) is reported in Table 2, grouping them by the corresponding latent variable (i.e. Operations- and IT-related Key Technologies' implementation level, internal and external resilience and company performance).

5.1. Hypothesis testing

In order to test the hypothesis developed in Section 3, a Structural Equation Model was developed. The goodness of the model fit, detailed in Table 3, showed adequate support between data and the final model represented in Figure 1: $\chi^2(103) = 118.343$; CMIN/df = 1.149; RMSEA = 0.031; CFI = 0.973; TLI = 0.965; IFI = 0.975. To decide whether a hypothesis was accepted or rejected, the following rule of thumb was applied. According to Hair et al. (2013), the critical ratio (CR) between the regression weight estimate and its standard error has to be greater than $|1.96|$. Indeed, a CR greater than 1.96 or smaller than -1.96 provides a significance level of .05.

The results show that two out of the four hypothesized paths are significant, presenting consistent positive relations for the paths IT_RELATED_KET → RESILIENCE (H1) and IT_RELATED_KET → PERCEIVED_PERFORMANCE (H2). Hence, it can be noticed how the IT-related key technologies' implementation level positively influences both performance perception, order fulfilment and customer satisfaction, and the resilience capabilities level. Thus, hypotheses H1 and H2 can be accepted. On the contrary, the Operations-related practices' implementation level does not impact either

Table 2. Scales obtained by each key technology, measure of external and internal resilience and company performance.

Latent variables	Variables description	Mean	SD
IT-Related Key Technologies	Horizontal and Vertical System Integration	3.54	1.12
	Industrial Internet of Things	3.66	1.17
	Cybersecurity	3.18	1.33
	Cloud Technologies	3.76	1.18
	Big Data analysis	1.95	1.48
Operations-related Key Technologies	3D simulation of product/service development, and production processes	2.43	1.00
	Autonomous Robots	2.41	1.12
	3D Printing	3.52	1.24
	Augmented Reality	2.39	1.17
Internal Resilience	The company has strong financial liquidity	2.59	1.68
	The company has a diversified projects/products/services portfolio	2.96	1.36
	The company has an established brand position in the market/s in which it operates	3.25	1.20
	The 'risk management culture' is rooted within all levels of the company	3.74	1.06
	There is a free flow of information along the company's Supply Chain	2.69	1.32
	The company promotes organizational solutions such as team working, creative problem solving, soft skills training	3.06	1.30
External Resilience	The company has flexible contracts with suppliers	2.83	1.25
	Regarding the procurement phase, the company adopts multiple sourcing strategies	4.15	0.97
	Regarding the distribution phase, your company adopts distribution solutions using multiple channels	3.56	1.03
Performance	Delivery reliability	3.61	1.17
	Customers' satisfaction level	3.97	1.12
	Sales variation during the previous 2 years	3.32	1.14
	Personnel variation during the previous 2 years	3.29	1.17

resilience capabilities or perceived performance. These results lead to the rejection of H3 and H4.

5.2. Endogeneity bias of company size

According to several authors, the firm's dimension is relevant in influencing the impact level of Industry 4.0 projects. In general, smaller firms are more likely to experience difficulties in innovative activities (Müller, Buliga, and Voigt 2018; Dalenogare et al. 2018). Through an endogeneity bias test, the firm's dimension influence is tested, both in terms of number of employees and turnover. The procedure requires adding control variables useful to understand the study's validity: two extended models are built considering the number of employees and the firms' turnover as control variables. Indeed, endogeneity bias concerns the impossibility to interpret the effect of a predictor on a dependent variable because a variable that simultaneously affects both the predictor and the dependent variable is omitted in the model (Antonakis et al. 2014).

Adding the number of employees and the firms' turnover as control variables has no impact on the verification of the original hypotheses (H1 and H2) and the rejection of the other ones, as reported in Table 4. Moreover, in both cases, the two variables load a positive and significant regression on the IT-related and Operations-related key technologies: this means that the larger the enterprise, the higher the implementation level of the Industry 4.0 IT-related Key Technologies.

6. Discussion

The present study is useful for operation managers and industrial policymakers since they exemplify the relation between two critical business trends: Industry 4.0 and organizational resilience, while also examining the trend of companies' performance. Moreover, this analysis is a key added value for operation managers in light of the uncertainty about the potential benefits of Industry 4.0. Companies that aim to start their digitalization journey towards Industry 4.0 should first understand which technologies are the most powerful in enhancing operational performance and supporting organizational resilience. Our findings suggest that IT-related key technologies have positively influenced past performance and can leverage company resilience in the future. Company managers should consider this result when exploring the advantages of implementing these kinds of technologies compared to the operational ones.

An initial analysis of the results gives a clear picture of broader picture: firstly, it appears that there is the need for more commitment to these new technologies, in a top-down perspective. Indeed, only 30% of the 750 managers initially contacted by phone were familiar with all nine key technologies proposed in the questionnaire. As long as operations managers perceive the benefits of adopting both operations and IT-related key enabling technologies, the transfer of such a perception to the whole personnel will be easier. This aspect can be related to the fact that the higher the commitment is, the higher the attention to the adoption and performance of such technologies and the impact on organizational resilience.

Considering the results obtained from endogeneity bias (Table 4), there is no significant difference between the results for small and medium-sized enterprises and large enterprises, in contrast with the results of other studies such as Müller, Buliga, and Voigt (2018). Indeed, the authors state that most SMEs face major economic obstacles in implementing such practices. This fact highlights that also Italian SMEs are starting to capture the opportunities offered by technologies. In particular, interviews with SMEs have shown that these companies perceive that investments in IT-related technologies can ensure their survival in the long term by becoming more resilient. Small and medium-sized manufacturers must keep up to date with the progress and improvements that Industry 4.0 technology creates. Indeed, today's online buyers will not settle for manufacturers that are lagging.

Table 3. Fit indices.

Latent variable	SFL	SE	CR	p	HP	
IT_RELATED_KET → RESILIENCE	0.277	0.092	3.018	**	ACCEPTED	H1
IT_RELATED_KET → PERFORMANCE	0.331	0.119	2.775	**	ACCEPTED	H2
OPERATIONS_KET → RESILIENCE	0.055	0.077	0.712	.476	REJECTED	H3
OPERATIONS_KET → PERFORMANCE	0.048	0.116	0.416	.677	REJECTED	H4

Note: $\chi^2(103) = 118.343$; CMIN/df = 1.149; RMSEA = 0.031; CFI = 0.973; TLI = 0.965; IFI = 0.975. SFL is the Standardized Factor Loading. SE estimates the standard error of the covariance. CR is the critical ratio obtained by dividing the covariance estimate by its standard error. A value exceeding 1.96 represents a significance level of .05. p is the significant probability.
**Significant probability level of less than .05.

Table 4. Fit indices obtained adding the number of employees and turnover as a control variable.

Control variable	Latent variable	SFL	SE	CR	p	HP	
Number of employees[a]	IT_RELATED_KET → RESILIENCE	0.337	0.093	3.645	**	ACCEPTED	H1
	IT_RELATED_KET → PERFORMANCE	0.364	0.125	2.912	**	ACCEPTED	H2
	OPERATIONS_KET → RESILIENCE	0.093	0.070	1.326	0.185	REJECTED	H3
	OPERATIONS_KET → PERFORMANCE	0.069	0.101	0.689	0.491	REJECTED	H4
Turnover[b]	IT_RELATED_KET → RESILIENCE	0.339	0.090	3.757	**	ACCEPTED	H1
	IT_RELATED_KET → PERFORMANCE	0.362	0.123	2.936	**	ACCEPTED	H2
	OPERATIONS_KET → RESILIENCE	0.105	0.071	1.474	0.140	REJECTED	H3
	OPERATIONS_KET → PERFORMANCE	0.069	0.100	0.684	0.494	REJECTED	H4

[a]Note: $\chi^2(103) = 163.843$; CMIN/df = 1.377; RMSEA = 0.049; CFI = 0.926; TLI = 0.905; IFI = 0.930.
[b]Note: $\chi^2(103) = 155.342$; CMIN/df = 1.305; RMSEA = 0.044; CFI = 0.939; TLI = 0.921; IFI = 0.942.
**Significant probability level of less than .05.

Regarding the specific results obtained through the hypotheses' test, Sections 6.1 and 6.2 will be respectively dedicated to discussing IT- and Operations-related Key Technologies' impact.

6.1. The impact of IT-related key technologies

The analysis results, exemplified in Table 3, show how H1 and H2 hypotheses are verified: IT-related key technologies positively influence both resilience and the perceived level of company performance.

During the survey, companies highlighted that, in recent years, digital solutions played a significant role in solving complex problems. Moreover, several managers highlighted that Horizontal and Vertical Integration, in terms of production, favoured the progressive connection among business units, envisaging the constant communication of their performance state and autonomous dynamic response. Results highlight that this process increases both performance and organizational resilience. Indeed, it offers a significant added value concerning forecasting possible failures or disruptions in the production line. This result is in line with Ivanov, Dolgui, and Sokolov (2019) research, which confirms that the added value in terms of performance is also easily perceived as integrating various systems such as ERP, RFID, sensors and blockchain significantly streamlines operations.

Moreover, technologies such as IIoT have left their mark on companies because the integration of these know-hows has improved production processes traceability and meets the company's needs at a global level. Accordingly, Curado et al. (2019) also point out how implementing IIoT can improve resilience, security, safety and privacy. In fact, this technology becomes critical within environments composed by a large quantity of smart objects producing information and, simultaneously, with the need to acquire the best knowledge to respond to a given situation and actuate decisions quickly. Instead, big data analysis applications report the lowest values in terms of implementation (see Table 2). Such technologies are the more innovative: company managers pointed out that they may not be sufficiently implemented in the current industrial scenario because of a lack of training and awareness of their potentialities.

From a proactive point of view, the tools offered by Cloud technologies, especially when integrated with the Internet of Things, provided important tools for managers to help predict interruptions and foresee circumstances that could seriously degrade system performance. The most important aspect highlighted by companies' managers was the possibility to enable aftersales solutions for monitoring and controlling sold products with embedded sensors, processors, software and connected via internet. This result converges with Ralston and Blackhurst (2020) analysis: they point out that such technologies, embedded in smart systems, can lead to resilience enhancing, by improving performance along the whole SC and allowing firms to tackle unexpected events better. Consequently, technologies such as Cybersecurity, which are the first barricade against the uncertainties derived from these new business models, become fundamental, as this study reveals. In this context, different risk management managers underlined the relationship between Cybersecurity and internal/external resilience, in particular, to counteract the onset of disruption and distortion threats. The first one concerns the over-reliance on fragile connectivity that creates the potential for deliberate internet outages capable of bringing trade to its knees. There is also a heightened risk that ransomware will be used to hijack the Internet of Things. The second one regards the intentional spread of misinformation by bots and automated sources, which causes trust in information integrity. Many other researchers agree with this result in various sectors (Avanzini and Spessa 2019; Lykou, Anagnostopoulou, and Gritzalis 2018; Pescaroli et al. 2018), underlining the key role of Cybersecurity in today's evolving industry. In particular, the study conducted by Annarelli, Nonino, and Palombi (2020) highlights how developing Cybersecurity organizational culture plays a prior role in creating a resilient organization. It can represent a strategic path if paired with fostering in-depth knowledge of these technologies at all managerial levels.

6.2. The impact of Operations-related key technologies

Table 3 also shows how H3 and H4 hypotheses are not verified, indicating no relationship between the adoption of Operations-related key technologies and organizational resilience or company performance.

The first consideration to this result concerns the low implementation level of all four technologies classified under 'Operations' (Autonomous Robots, 3D Simulation, Additive Manufacturing and Virtual Augmented Reality). Table 2, in fact, shows that none of these four technologies, except Additive Manufacturing, has an average level exceeding the score of 2.5. Becue et al. (2020) study diverges from these results: in their work, the researchers demonstrate how the implementation of Digital Twins and Autonomous Robots technologies, among others, can enhance the resilience of a smart manufacturing environment. Nonetheless, it should be pointed out that different managers interviewed during the survey agree that the use of Autonomous Robots in conditions that are incredibly hazardous to the human body can almost zero the risk factor for operators. Another contribution can be found in worker fatigue, which is a critical factor concerning job injuries. At the same time, they agree that an Augmented Reality system could significantly improve employee training, thus improving workers' skills and work safety. Nevertheless, managers still consider their initial technologies, and the implementation can only grow after the consolidation of the internal Smart manufacturing dimension of Industry 4.0.

As for the rejection of hypotheses H3 and H4, several interviewees pointed out that the implementation of simulation systems requires high computing capabilities, necessary for a multitude of tasks: planning, processing, simulation and monitoring of production lines, optimization and analysis of data generated during the product life cycle. Studies by Dalenogare et al. (2018) confirm that the adoption of the Industry 4.0 technologies is anything but self-supported. There are at least three dimensions to consider in the process of digitization towards the 4.0 industry. The first one is the organization dimension of work, which must be rethought regarding introducing these new technologies. The second one is related to the skills and abilities of workers, who must remain updated regarding Industry 4.0 technologies. The third one is related to the external environment since the adoption of new technologies depends on the maturity of the company in which these technologies are implemented. The last dimension addressed is particularly accurate in emerging economies, which face critical barriers related to Industry 4.0 realization.

7. Conclusions

Previous literature research has not analyzed the impact of the Operations and IT-related Industry 4.0 key technologies on companies' resilience and, therefore, on the companies' capabilities to handle vulnerabilities and potential disruptions. This study addresses the research gap by assessing such impact and thus providing proper support in understanding what role key technologies play in improving companies' ability to withstand disruptions and, in general, adapt to unexpected scenarios. This concept has been recently developed and can surely contribute to companies' development to increase their competitiveness. Hence, this paper analyzes the impact of Industry 4.0 key technologies implementation on companies' resilience. To this aim, a representative sample of 160 Italian companies was interviewed, collecting data on the key technologies' implementation level and their resilience capabilities, both considering the internal aspects and the external ones. Besides, the relations between the impact of the key technologies and the perceived performance values are examined. The analysis is carried out using Structural Equation Modelling.

The results highlight that the implementation level of IT-related key technologies has a positive impact on resilience and perceived performance. Hence, implementing such a branch of key technologies can also support the organizations in increasing the resilience level. In this way, the organization can dually benefit from the introduction of IT-related technologies: on the one end, such techniques contribute to increasing the company's competitiveness; on the other end, an improvement in terms of resilience internal and external performance is enabled. The higher the implementation of IT-related key technologies, the better company's perception of order fulfilment and satisfaction. On the contrary, neither the relationships among the operations-related key technology and resilience nor between operations-related key technologies and performance is supported. Indeed, as these technologies are the most innovative, it is fundamental to spread knowledge of them and their implementation before their actual benefits and impacts can be appreciated by company managers.

The research method proposed in this work can engage managers within all organization levels and foster a resilient firm approach. It is necessary to assess technology's potential benefits both from both resilience and performance points of view. Therefore, the present study exemplifies the link between such technologies and resilience, investigating the characteristics of these relationships. By knowing these features, managers possess a key added value in choosing the next strategic paths to maximize both resilience and business performance. In line with the practical implications, the proposed conceptual framework can also guide company managers towards a conscious and successful implementation of 4.0 technologies and, in a parallel manner, an improvement in terms of resilience. Moreover, our study allows company managers to prioritize Industry 4.0 investments, highlighting the value of IT-related technologies rather than operations-related technologies.

Some limitations and future research directions can be highlighted. Firstly, although heterogeneous both from the sector and turnover point of view, the statistical sample used in this study is geographically limited since the results are exclusively from companies located in Italy. In fact, an interesting analysis could consist of conducting further studies among comparable samples, coming from different countries, which could provide important insights on how external factors, for example, legislation, culture or attitude towards changes, may influence the implementation of Industry 4.0 key technologies and their impact on the resilience level. By comparing companies located in different countries; in fact, the same implementation level of Industry 4.0 key technologies could not necessarily lead to the same impact on performance and/or resilience. Due to the fast-changing characteristics of the industrial scenario, further investigation should be carried out to understand the improvement of the Industry 4.0 implementation level and the resulting resilience improvement on the same sample within a middle-term and a long-term time interval.

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No potential conflict of interest was reported by the author(s).

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Appendix 1. Applied survey

- **PART A – GENERAL QUESTIONS**

Company sector

- FOOD & BEVERAGES PRODUCTS
- ELECTRICAL AND MECHANICAL MACHINERY AND EQUIPMENT
- CHEMICAL PRODUCTS
- TRANSPORT PRODUCTS
- TEXTILE, LEATHER & CLOTHES PRODUCTS
- PHARMACEUTICAL PRODUCTS
- FURNITURE
- RUBBER AND PLASTICS
- OTHERS

How many employees does your company have?

- <10
- Between 10 and 50
- Between 50 and 250
- >250
- Don't know/answer

Could you indicate your annual turnover?

- ≤2 M€
- Between 2 m€ and 10 m€
- Between 10 m€ and 50 m€
- >50 M€
- Don't know/answer

What is your role within your company?

- **PART B – IMPLEMENTATION LEVEL OF INDUSTRY 4.0 PRACTICES**

Please indicate the implementation level of the following Industry 4.0 practices in your company:
(Never implemented; Implementation attempted and failed; In use for less than a year; In use in some departments from more than a year; In use in the whole company for more than a year.)
Autonomous Robots
3D Simulation of product/service development and production processes
Horizontal and Vertical System Integration
Industrial Internet of Things
Cybersecurity
Cloud Technologies applications
Additive Manufacturing
Augmented Reality
Big Data Analysis

Notes: please insert a comment to justify the given answers

- **PART C – RESILIENCE CAPABILITIES**

- **PART D – COMPANY PERFORMANCE**

INTERNAL RESILIENCE
Using a 1–5 scale, where 5 stands for 'Definitely agree' and 1 'Not agree', in an objective manner, indicate to what extent the phrases reflect your business reality
The company has strong financial liquidity
The company has diversified projects/products/services portfolio
The company has an established brand position in the market/s in which it operates
The 'risk management culture' is rooted within all levels of the company
There is a free flow of information along the company's Supply Chain
The company promotes organizational solutions such as team working, creative problem solving, soft skills training
The company has flexible contracts with suppliers
Regarding the procurement phase, the company adopts multiple sourcing strategies
Regarding the distribution phase, your company adopts distribution solutions using multiple channels.
EXTERNAL RESILIENCE
Using a 1–5 scale, where 5 stands for 'Definitely agree' and 1 'Not agree', in an objective manner indicate to what extent the phrases reflect your business reality
Political uncertainties (e.g. wars, coups d' état) influence your business
National and international government restrictions (e.g. embargos) influence your company's performance
Macroeconomic trends influence your company's performance
Revolts, demonstrations, terrorist attacks influence your company
Natural disasters (earthquakes, floods, tsunamis, etc.) affect your company's performance
The market/s in which your company operates is/are volatile
The market/s in which your company operates is/are competitive

Variation of sales growth in the last 2 years?

1. □ <–20%
2. □ Between –20% and 0%
3. □ Stable
4. □ Between 0% and 20%
5. □ >20%

Variation of employment growth in the last 2 years?

1. □ <–20%
2. □ Between –20% and 0%
3. □ Stable
4. □ Between 0% and 20%
5. □ >20%

Percentage of delivery reliability?

1. □ Systematical delays or errors
2. □ Less than 20%
3. □ Between 20% and 50%
4. □ Between 50% and 90%
5. □ >90%

According to your experience, how do you consider the customer satisfaction level?

(1) □ Completely unsatisfied
(3) □ Partially satisfied
(5) □ Completely unsatisfied