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Implications of using Industry 4.0 base technologies for lean and agile supply chains and performance

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ABSTRACT

The adoption of Industry 4.0 (I4.0) technologies in recent years has generated conditions for substantial changes in supply chain management. However, research is still ongoing on how I4.0 technologies can be integrated into current supply chain models to improve supply chain capabilities and performance. This work aims to contribute to understanding the relationships between Industry 4.0 technologies and lean and agile supply chain strategies, and identifying the implications for the focal firm's operational performance. In this study, we focus on a specific group of emerging I4.0 technologies known as I4.0 base technologies (i.e., cloud computing, Internet of Things, and Big Data analytics), whose complementary features can enhance the data collection, storage, and sharing, as well as the analysis processes. Drawing on the Dynamic Capabilities Theory, a structural equation model is used to analyze data collected from 256 Spanish focal manufacturing firms. Results indicate that I4.0 base technologies do not have the same effects on lean and agile supply chain strategies. While I4.0 base technologies can make supply chains leaner, they have been found to have no significant direct effect on agile supply chain implementation. Further, findings indicate a direct relationship between the lean and agile approaches and that the latter generates mediation effects between lean and operational performance.

1. Introduction

Supply chains (SCs) are being subjected to countless pressures to adapt to the global business scenario, which is increasingly volatile, uncertain, and complex. While the development of a Lean approach – which focuses on eliminating non-value-added activities - and an Agile approach – which focuses on quickly adapting and responding to customer requirements - throughout the supply chain (SC) is an option for improving SC performance (Srinivasan et al., 2020), the adoption of Industry 4.0 (I4.0) technologies also emerges as a means to increase the SC's competitiveness (Frederico et al., 2020; Kagermann et al., 2013).

According to the previous literature (Ghobakhloo, 2020; Núñez-Merino et al., 2020; Oliveira-Dias et al., 2022a), there are several I4.0 enabling technologies, including some mature and emerging technologies, such as Radio-frequency identification (RFID), additive manufacturing, augmented/virtual reality, Internet of Things (IoT), and Big Data Analytics (BDA). Among the emerging technologies, a specific group of I4.0 technologies is known as I4.0 base technologies, i.e., Cloud Computing (CC), BDA, and IoT technologies (Frank et al., 2019). These technologies are considered critical as they support key processes for developing I4.0 principles and the manufacturing system's integration and connectivity (Frank et al., 2019; Narayanamurthy and Tortorella, 2021).

In this sense, some studies have separately analyzed the effect of some specific I4.0 technologies on Lean Supply Chain (LSC) and Agile Supply Chain (ASC) (Raji et al., 2021a, 2021b). For example, applying a case study approach using a set of technologies, Raji et al. (2021a) found that BDA and IoT have a high positive impact on Lean practices; in contrast, Agile practices are mainly impacted by CC and cyber-physical systems (Raji et al., 2021a). Liu et al. (2018) indicate that CC allows to scale Information Technology (IT) resources to rapidly employ IT applications, which enables a quick response to market changes. According to Reyes et al. (2021), the information generated with BDA enables to carry out a more precise demand forecast and, consequently, reduces the

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waste derived from overproduction. Therefore, the previous research points out that LSC and ASC will be affected by the use of I4.0 base technologies. However, research on the integration between I4.0 technologies and the different SC approaches is still ongoing. The initial efforts have mainly focused on the shop floor level (Tortorella et al., 2021), and the few papers that have considered the SC domain do not analyze the role of base technologies from a more global and strategic perspective point of view.

Furthermore, the previous literature has yielded inconsistent results on the relationship between Lean and Agile SC strategies. While some works consider these to be complementary (e.g., Narasimhan et al., 2006; Oliveira-Dias et al., 2022b; Raji et al., 2021a), others consider Lean and Agile to be mutually exclusive approaches (e.g., Putnik and Putnik, 2012). Therefore, there is a need for empirical studies to clarify the combinations of different resources (I4.0 base technologies) and strategies (Lean and Agile). Furthermore, although some consequences of the Lean and Agile SC strategies for firm operational performance have been addressed in the previous literature (e.g., Blome et al., 2013; Garcia-Buendia et al., 2021), including I4.0 base technologies as antecedents offers complementary perspectives to explain the inconclusive results found. To address these gaps, this work aims to contribute to understanding the effects of Industry 4.0 base technologies on the Lean and Agile SC and the implications for the focal firm's operational performance, i.e., companies that have a global view of the supply chain. Specifically, it intends to answer two research questions.

RQ1. What effect do I4.0 base technologies have on the Lean and Agile SC strategies and the focal firm's operational performance?

RQ2. What effect does the Lean SC strategy have on the Agile SC strategy in an I4.0 setting and what effect do the two strategies have on the focal firm's operational performance?

To answer these research questions, drawing on the Dynamic Capabilities Theory, a structural equation model (SEM) is used to test the hypothesized relationships. The dynamic capabilities perspective (Teece, 2007; Yu et al., 2019) is adopted to discuss the use of I4.0 base technologies and their integration with the Lean and Agile SCs strategies to enhance value creation for the final customer (LSC), increase the ability to quickly respond to customer requirements (ASC), and ultimstely, achieve superior focal firm operational performance. In this regard, SC processes such as the integration of SC flows, the development of competencies through increased collaboration, and the reconfiguration of internal and external resources can be supported by I4.0 base technologies (Enrique et al., 2022; Papanagnou et al., 2022). These processes are essential for the correct deployment of the Lean and Agile strategies (Blome et al., 2013; Oliveira-Dias et al., 2022b; Teece et al., 1997). Our research contributes to shedding light on the set of resources and capabilities deployed by supply chains to effectively integrate I4.0 base technologies into current SC management models to improve firm performance. This issue is extremely relevant since many companies that invest in information and digital technologies fail to achieve the expected results (Attaran, 2020). In addition, implementing SC strategies is a demanding and challenging process that requires mechanisms or drivers to support the implementation process (Moyano-Fuentes et al., 2021; Tortorella et al., 2017). Thus, the empirical results regarding the aforementioned relationships offer insights into which combinations of resources should be deployed to achieve the proposed objectives.

The remainder of the article is structured as follows. Section 2 provides the background and our research hypotheses. Section 3 presents the research method used in the empirical analysis. Section 4 presents the results, while Section 5 includes a discussion of the findings of the data analysis. Finally, conclusions drawn from the study are provided in Section 6.

2. Background and hypothesis development

2.1. Dynamic capabilities, Lean Supply Chain, and Agile Supply Chain

The Dynamic Capabilities View focuses on clarifying how combinations of resources and capabilities can be restructured, developed, and deployed to achieve a competitive advantage in volatile markets (Teece, 2007; Winter, 2003). The concept of dynamic capabilities complements the Resource Based Theory by incorporating the dynamic view of firm capabilities (Teece, 2007; Winter, 2003). Following, Teece (2007), dynamic capabilities can be grouped into three clusters: sensing, seizing and transforming. Sensing capabilities are related to the identification and assessment of new opportunities. The second cluster of capabilities (seizing) refers to the mobilization of internal and external resources to capture value from the identified opportunities. The final cluster (transforming) refers to rearranging resources through continued renewal and reconfiguration to keep the firm aligned with its business environment (Teece, 2012). The dynamic capabilities view has received increasing attention in the operations management field (Eslami et al., 2021; Hitt et al., 2016; Rojo et al., 2018; Wamba et al., 2020). The results indicate that dynamic capabilities could be generated in a focal firm through collaboration with SC partners (Eslami et al., 2021). Thus, the dynamic capabilities view can be used to understand the relationships between resources, capabilities, and performance at the SC level (Hitt et al., 2016).

In line with dynamic capabilities theory, which advocates the ability of firms to continually integrate, build, and reconfigure competencies to sustain business growth (Blome et al., 2013; Teece, 2007), the LSC is characterized by the capabilities of SCs to eliminate non-value-added activities to meet customers' individual needs (Iyer et al., 2019; Lamming, 1996; Srinivasan et al., 2020). Therefore, to create extra value for customers, the Lean strategy focuses on managing variability and reducing costs by using resources more efficiently than traditional systems and working in collaboration with suppliers and customers (Carvalho et al., 2011; Hines et al., 2004; Moyano-Fuentes et al., 2019; Qrunfleh and Tarafdar, 2013). However, implementing Lean along the SC is a complex and challenging process (Moyano-Fuentes et al., 2021; Tortorella et al., 2017). When correctly deployed, the LSC strategy generates a dynamic capability that enhances the SC's ability to improve quality, eliminate waste, and improve competitiveness (Iyer et al., 2019; Srinivasan et al., 2020).

Meanwhile, the ASC refers to the SC's capability to quickly adapt and respond to customer requirements (Wamba and Akter, 2019). To be Agile, the SC needs to develop the ability to scan the environment, anticipate changes, and then use this market knowledge to quickly cope with volatile demand (Gligor et al., 2013; Narasimhan et al., 2006; Qi et al., 2011). Accordingly, deploying this strategy can generate a dynamic capability that enables SCs to respond to business environment changes quickly and effectively (Eckstein et al., 2015; Wamba and Akter, 2019).

Based on the description mentioned above, both SC strategies could enhance firms' performance and ultimately lead to potentially sustainable competitive advantage. Therefore, Lean and Agile SC strategies can generate dynamic capabilities by exploiting existing resources and capabilities and developing new ones (Gutierrez et al., 2022; Srinivasan et al., 2020), which enables firms to achieve superior performance (Blome et al., 2013).

2.2. Industry 4.0 base technologies

The concept of I4.0 - referred to as the Fourth Industrial Revolution (Kagermann et al., 2013) - was introduced in 2011 and advocates the digital transformation of the manufacturing industry through enhanced connectivity between machines, tools, and workers (Kagermann and Wahlster, 2022). The I4.0 concept embraces a variety of principles, such as interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity (Hermann et al., 2015), as well as a range of technologies that can be used to deploy these principles (Kagermann and Wahlster, 2022).

According to the previous literature, there is no absolute consensus on which technologies form part of Industry 4.0 (Culot et al., 2020). On the one hand, one literature stream considers that only emerging technologies such as IoT or BDA should be included in this phenomenon (Culot et al., 2020). On the other hand, a second research approach maintains that a large group of mature and emerging technologies form part of Industry 4.0 that are jointly and intensively applied to industry to achieve efficacy and efficiency (Frank et al., 2019; Ghobakhloo, 2020; Núñez-Merino et al., 2020; Oliveira-Dias et al., 2022a). Following Frank et al. (2019), I4.0 technologies can be classified into two main groups: front-end and base technologies. The first group (front-end technologies) includes a variety of technologies related to advanced manufacturing, product offerings, horizontal integration, and human-machine interaction (Frank et al., 2019). The second group (I4.0 base technologies) includes some specific technologies such as CC, IoT, and BDA (Bag et al., 2021; Frank et al., 2019; Narayanamurthy and Tortorella, 2021). These are considered the core emerging technologies of I4.0 as they support the front-end technologies and provide firms with connectivity and intelligence (Frank et al., 2019). Together, the I4.0 base technologies enable the processes of data collection, storage, process, analysis, and data sharing to be carried out smartly (Kamble et al., 2019; Tortorella and Fettermann, 2018), i.e., they allow these processes to be executed with high accuracy, efficiency, and speed with little or no human intervention (Fay and Kazantsev, 2018; Kamble et al., 2019). The base I4.0 technologies all have different characteristics that complement each other. So, while IoT devices provide real-time data about the characteristics and location of physical objects (Manavalan and Jayakrishna, 2019), BDA includes technological solutions that allow the processing and analysis of structured and unstructured data to support decision-making processes (Choi et al., 2018; Fay and Kazantsev, 2018). This can be complemented by CC facilitating data sharing and analytics thanks to ubiquitous, on-demand network access and the large computing capacity on which BDA can be run, which thus provides a powerful and flexible system for SC integration (Novais et al., 2019). Therefore, drawing upon the dynamic capabilities view (Hitt et al., 2016; Teece, 2007), we focus on the group of I4.0 base technologies since they can be considered the foundational resources in the digitalization of SC processes and the implementation of I4.0.

2.3. Hypothesis development

2.3.1. I4.0 base technologies and LSC

Recent studies have highlighted the positive outcomes of combining Industry 4.0 technologies and Lean practices (Anosike et al., 2021; Ciano et al., 2021; Kamble et al., 2019; Raji et al., 2021a). In this sense, Ghobakhloo and Fathi (2020) found that the alignment between IT resources, Lean strategy, and digitalization can generate a specific dynamic capability that is extremely relevant in the I4.0 era. This dynamic capability refers to the firm's ability to better align and alter its IT resources and generic capabilities to adapt to the inherent uncertainties of the I4.0 context (Ghobakhloo and Fathi, 2020; Winter, 2003).

More specifically, concerning the I4.0 base technologies, the literature found that the use of IoT can lead to improvements in information flow and physical flow, which is reflected in better decision-making, route optimization, and reduced order time (Kamble et al., 2019). IoT improves information sharing between SC partners at the SC level by providing frequent feedback on SC processes (Manavalan and Jayakrishna, 2019). For example, IoT can help to reduce waste by monitoring parameters such as temperature in the perishable food SC (Manavalan and Jayakrishna, 2019) and enabling preventive maintenance practices (Raji et al., 2021a). BDA can be used to sense and evaluate potential disruptions caused, for example, by port congestion or extreme natural events (floods, hurricanes) (Choi et al., 2018).

Further, BDA can help to carry out more accurate demand forecasting and increase sensing competencies (Bag et al., 2022), and as a consequence reduce waste from overproduction (Reyes et al., 2021). The scalable and powerful IT infrastructure provided by CC can also positively impact Lean SC by enabling knowledge-sharing and collaboration across the LSC (Núñez-Merino et al., 2020; Reyes et al., 2021), which is essential not only for exploiting the identified opportunities but also transforming the set of SC resources and capabilities (Bag et al., 2022; Ghobakhloo and Fathi, 2020). In addition, CC can increase the SC's flow efficiency by reducing errors in information systems and increasing SC integration (Maqueira et al., 2019; Novais et al., 2019, 2020). CC also provides the infrastructure on which data generated by IoT devices are managed through BDA. In this regard, CC and IoT devices can be used jointly for tracking and tracing to adjust production and inventory plans according to the JIT philosophy (Reyes et al., 2021). Another example of how I4.0 base technologies could facilitate LSC implementation is the digitalization of traditional *kanban* cards to create e-*kanban* systems (Sanders et al., 2016). The use of I4.0 base technologies makes *kanban* systems more efficient by reducing card losses and triggering automatic replenishment (Kolberg et al., 2017). According to the Dynamic Capabilities View (Teece, 2007; Winter, 2003), these three technologies are closely related and can be considered a cohesive set of resources that can be deployed together to improve the LSC strategy by supporting the integration, development, and reconfiguration of various internal and external competencies (Ghobakhloo and Fathi, 2020; Gutierrez et al., 2022; Teece, 2007). Taking these arguments together, we hypothesize the following.

H1. Industry 4.0 base technologies have a direct and positive influence on LSC implementation.

2.3.2. I4.0 base technologies and ASC

From the dynamic capabilities perspective, the SC management research has shown that information technology resources can be bundled to support the development of dynamic capabilities in the SC (Hitt et al., 2016; Rojo et al., 2018). The previous literature has analyzed separately the effects of CC, BDA, and IoT on ASC implementation. The literature shows that BDA can be used to identify customer trends, track and monitor SC functions to detect atypical events, and anticipate SC changes (Wamba et al., 2020). As a result, BDA solutions can enable the achievement of objectives related to ASC management, such as swiftly sensing market changes (Dubey et al., 2019). BDA can also improve response activities by enabling fast and efficient information handling along the entire SC and supporting demand planning (Alberti-Alhtaybat et al., 2019), thus increasing the ability to fully exploit market opportunities (Bag et al., 2022).

Moreover, in the case of CC, some studies have indicated that this technology impacts SC agility by enabling integration between SC partners and enhancing the speed of information sharing (Novais et al., 2019; Schniederjans et al., 2016). Besides, by using CC, SCs can scale the data computing capacity more easily and quickly (Liu et al., 2018), which allows SCs to continuously adapt and reconfigure their IT resources. Regarding the relationship between IoT and SC agility, some studies have advocated that IoT applications can lead to greater visibility in the SC and thus provide real-time information to make better and faster decisions on procurement and route optimization activities (Ben-daya et al., 2017). In warehousing tasks, IoT can save time spent on scanning and recording data (Yan et al., 2014).

Furthermore, integrating these three technologies provides opportunities to speed up the SC flows, create new knowledge, and support ASC implementation in a turbulent environment. Based on the dynamic capabilities view, I4.0 base technologies can support SC processes related to the integration of supply chain flows, the creation of competencies through increased collaboration, and the reconfiguration of internal and external resources required to implement the ASC strategy, which aims to rapidly tackle market changes (Blome et al., 2013; Teece et al., 1997). Thus, the following hypothesis is formulated based on the above discussion.

H2. I4.0 base technologies have a direct and positive influence on ASC implementation

2.3.3. Lean supply chain and agile supply chain

While the dichotomy of Lean versus Agile has been addressed in the past literature (e.g., Yusuf and Adeleye, 2002), a growing number of studies are advocating a conciliatory vision by highlighting the complementarity between the two paradigms (Fadaki et al., 2020; Sharma et al., 2021). According to Fadaki et al. (2020), most firms follow both the Lean and Agile approaches instead of simply pursuing one of the models, Lean or Agile. Likewise, Iqbal et al. (2020) suggest that Lean and Agile are complementary paradigms that influence performance. Research also supports that high-performing Agile firms adopt Lean manufacturing practices such as Total Quality Management (TQM) and Just In Time (JIT) (Ghobakhloo and Azar, 2018; Inman et al., 2011). Earlier studies have also indicated that Lean thinking is required to develop Agile capabilities using minimum resources (Inman et al., 2011; Narasimhan et al., 2006; Vinodh et al., 2009). Moreover, since LSC implementation focuses on waste reduction and the mitigation of process variability, it builds a basis for flexibility (Abdelilah et al., 2021; Vonderembse et al., 2006). In this regard, previous studies indicate that flexibility is a precursor of SC agility (Swafford et al., 2008) and that SC flexibility and LSC capabilities are very similar (Maqueira et al., 2021). Therefore, according to the dynamic capabilities view, we suggest that ASC implementation can represent a higher-order dynamic capability (Blome et al., 2013; Eckstein et al., 2015) that can be effectively enabled by the capabilities deployed in LSC implementation. In this sense, a Lean SC strategy can be considered an antecedent of ASC and will positively affect the achievement of Agile goals. Based on these arguments, the following hypothesis is formulated.

H3. LSC has a direct and positive influence on ASC implementation in I4.0 environments.

2.3.4. Lean and agile supply chain and operational performance

The primary purpose of implementing the Lean and Agile SC strategies is to improve SC performance. In this study, operational performance represents the firm's efficiency in terms of cost reduction and delivery performance (Danese et al., 2012).

The LSC strategy focuses on reducing costs and non-value-added activities, which requires customer and supplier collaboration (Garcia-Buendia et al., 2021; Qrunfleh and Tarafdar, 2014). It achieves this by adjusting and integrating internal and external resources and following a continuous improvement process along the SC to improve operational performance. In this sense, previous studies (Danese et al., 2012) have found that JIT practices can help to reduce the overall lead time and improve on-time delivery performance. Furthermore, Moyano-Fuentes et al. (2021) indicate that LSC management can improve firm efficiency by decreasing costs and cycle times and improving inventory turnover.

The ASC strategy also creates opportunities for increased operational performance by enhancing cost-effective market responsiveness (Carvalho et al., 2011). Previous studies show that SC Agile capabilities improve customer satisfaction and the firm's operational performance in speed to market (DeGroote and Marx, 2013; Ngai et al., 2011; Swafford et al., 2008). Likewise, Sangari and Razmi (2015) have found that ASC contributes to superior performance and competitiveness. Indeed, ASC implementation generates capabilities that comply with the characteristics of dynamic capabilities (i.e., capabilities that are not tradable, require a long time to develop, involve complex relationships with other resources, etc.) (Blome et al., 2013; Teece et al., 1997), and is, therefore, considered a significant driver of firm performance (Mandal, 2018). Thus, according to the dynamic capabilities view, the implementation of the Lean and Agile SC strategies supported by I4.0 base technologies involves the development and exploitation of various capabilities (Gutierrez et al., 2022; Srinivasan et al., 2020), leading to a high level of performance for the focal firm. The following hypotheses are proposed based on the rationale of the studies mentioned above.

H4. LSC has a direct and positive influence on the focal firm's operational performance

H5. ASC has a direct and positive influence on the focal firm's operational performance

2.3.5. I4.0 base technologies and operational performance

In essence, I4.0 technologies enable the integration of workflows and the automated production of goods and services, allowing faster decision-making, better demand forecasting, and the production of customized products on a large scale (Frank et al., 2019; Hofmann et al., 2019; Kagermann et al., 2013). Consequently, the Industry 4.0 context brings opportunities and benefits such as reducing manufacturing lead times, increased operational efficiency, and the emergence of new business models (Hofmann and Rüsch, 2017).

More specifically, Gunasekaran et al. (2017) found that organizations that have successfully exploited BDA have improved their SC organizational performance. Similarly, Dalenogare et al. (2018) showed that Big Data and the use of sensors for digital automation have a significant link with operational results. Moreover, Anosike et al. (2021) use empirical data to state that improving operational performance is the main motive that leads manufacturing organizations to adopt IoT technologies. Further, Bruque-Cámara et al. (2016) noted a significant link between the level of community CC adoption and operational results since this technology can enhance the interconnection between SC members and allow, for example, information to be shared about product design and composition.

The joint use of I4.0 base technologies provides opportunities for the focal firm to share ideas with suppliers and customers and identify new market opportunities and areas for improvement (Frank et al., 2019; Tortorella et al., 2020). Previous studies indicate that the expected benefits of the use of I4.0 base technologies include greater supplier and customer integration (Bruque-Cámara et al., 2016), improved productivity (Manavalan and Jayakrishna, 2019), lower operating costs, and superior product quality (Raut et al., 2021; Wamba et al., 2020). Accordingly, we hypothesize that.

H6. There is a positive relationship between I4.0 base technologies and the focal firm's operational performance

Fig. 1 presents the hypothesized theoretical model.

3. Method

3.1. Survey design

The research uses a quantitative approach to test the research hypotheses with data collected via a questionnaire. Questionnaire development and refinement were executed in three steps: (1) A detailed

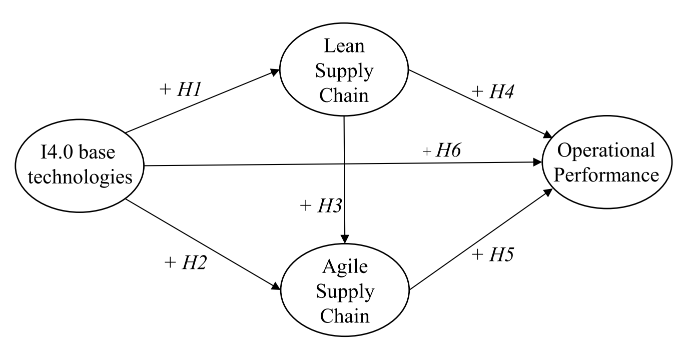

Fig. 1. Theoretical model.

review of the literature was carried out to identify potential measures; (2) A first version of the questionnaire was assessed through pre-tests with five international researchers in Supply Chain Management (SCM) and Information Technology; (3) Pilot surveys were conducted with five SC managers to ensure the meanings and comprehensiveness of all the items. Furthermore, since the data were collected in a non-English-speaking country, the questionnaire and all the scales were translated into Spanish and subsequently back-translated into English.

3.2. Variables

The four key constructs of our theoretical model are latent variables that must be measured indirectly. The measures used in this study were taken from validated items from prior research. Some were refined in line with feedback from five academics (pre-test) and five SC managers (pilot study), which was gathered from the above-mentioned pre-test and pilot studies. These steps ensured that the questionnaire was properly designed to measure the intended constructs. The variables used are described in the following paragraphs and Appendix A includes the list of items used in this study.

Lean Supply Chain strategy: LSC scale was measured using a second-order reflective construct validated in previous studies (Moyano-Fuentes et al., 2019, 2021). The scale was composed of three dimensions (Moyano-Fuentes et al., 2021). The first dimension (2 items) captured the use of tools to eliminate waste in the SC (e.g., VSM and Kanban Systems) (Moyano-Fuentes et al., 2021). The second dimension (3 items) was related to the operationalization of the LSC strategy through processes such as standardization and delivery in small lot sizes (Moyano-Fuentes et al., 2021). The third dimension (3 items) referred to the long-term planning dimension of the LSC strategy, including items related to forecasting activities, the strategy to handle uncertainty, and the SC structure (Moyano-Fuentes et al., 2021). LSC measures were rated on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

Agile Supply Chain strategy: The ASC scale was measured using a first-order reflective construct composed of 5 items adapted from previous studies (Gligor et al., 2013; Qi et al., 2011; Tachizawa and Gimenez, 2010). The measure captured aspects related to the SC's capability to make adjustments according to customer requests and respond to customer demands, and also to the SC's ability to quickly change production planning, increase short-term capacity, and reduce delivery times (Gligor et al., 2013; Qi et al., 2011; Tachizawa and Gimenez, 2010). ASC measures were rated on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

I4.0 Base Technologies: I4.0 base technologies were measured using a first-order reflective construct adapted from the previous literature (Frank et al., 2019; Tortorella and Fettermann, 2018). The construct comprised a set of Industry 4.0 base technologies: BDA, IoT, and CC. The degree of adoption was measured on a 5-point scale ranging from 1 (not implemented) to 5 (fully implemented).

Operational Performance: Focal firm's Operational Performance (OP) was measured using a second-order reflective construct adapted from the previous literature (Danese et al., 2012; Liu et al., 2009) formed of two dimensions: Efficiency (3 items) and Delivery (2 items). For operational performance, we asked the managers to compare their firm's performance with that of their competitors on a 5-point scale (from 1 "poor, low" to 5 "superior").

3.3. Sampling and data gathering

Spanish focal manufacturing firms (≥50 employees) located in intermediate positions in their SCs were established as the object of study. The population framework was obtained from the "Iberian Balance Sheet Analysis System" database. Firms were classified into sectors according to Spain's national classification of economic activities. Only manufacturing sectors were selected, and firms from industrial sectors that did not occupy an intermediate position in the SC (i.e., extractive or mining industries, distribution) and firms that had closed down were excluded, leaving a total of 2650 firms. In addition, the focal firm perspective from the point of the managers' perceptions was adopted to identify an upstream and downstream view of the SC. This approach is in line with previous SC management studies (Novais et al., 2020; van der Vaart et al., 2012).

Data collection was carried out by telephone survey using a Computer-Aided Telephone Interviewing (CATI) method between January 2018 and July 2018. This methodology has been used in previous studies in the SCM field (Maqueira et al., 2019; Rojo et al., 2020). The CATI method allows interviewers access to information systems that randomly display target respondents' contact details and afford computerized management of the entire process. Data gathering was performed by interviewers who received specific training for study purposes and worked an average of 4 h per day throughout the fieldwork period. During the work period, a supervisor was responsible for providing guidance when the interviewees had any specific questions that needed answering. In addition, one of the researchers was on hand to answer any more complex questions by phone and e-mail.

Furthermore, the first calls were personally supervised by the authors of this article. A web questionnaire was also designed for firms that preferred to answer via the web. The questionnaire was divided into two areas (SC management and Information Technology). The first section was addressed to heads of SC, operations management, and logistics, and the second to IT managers. The survey was considered complete only when both respondents had filled out the questionnaire. A total of 285 questionnaires were received (10.8% response rate), with 256 (9.7%) valid questionnaires for the objective of this study. Thus, the data set is a random sample of firms that responded to the survey via phone or web questionnaire. The response rate is similar to previous studies in the SCM and IT fields (Queiroz et al., 2018; Tachizawa and Gimenez, 2010; Tarafdar and Qrunfleh, 2017; Wei et al., 2015). Therefore, the response rate does not jeopardize the reliability of the results.

The firm distribution in the population and the sample according to sector classification is shown in Table 1. As can be observed, there is a proportional distribution of firms among the sectors, indicating that the sample represents the population.

Table 1
Population and sample distribution by sector.

	Population		Sample		Response Rate
Sector	Number	%	Number	%	
Food products and tobacco	543	20.49%	46	17.97%	8.5%
Chemicals and pharmaceutical products	422	15.92%	46	17.97%	10.9%
Manufacture of metals products	322	12.15%	42	16.41%	13.0%
Manufacture of machinery and equipment	275	10.38%	29	11.33%	10.5%
Motor vehicles	273	10.30%	21	8.20%	7.7%
Meat industry	158	5.96%	6	2.34%	3.8%
Electrical machinery and materials	141	5.32%	11	4.30%	7.8%
Manufacture of beverages	106	4.00%	6	2.34%	5.7%
Furniture industry	82	3.09%	7	2.73%	8.5%
Informatics, Electronics and Optics products	81	3.06%	12	4.69%	14.8%
Manufacture of other transport material	77	2.91%	10	3.91%	13.0%
Shoes and Leather	63	2.38%	5	1.95%	7.9%
Other manufacturing industries	60	2.26%	9	3.52%	15.0%
Fabrics and Textile	47	1.77%	6	2.34%	12.8%
Total	**2650**	**100%**	**256**	**100%**	**9.7%**

A variety of steps were taken to analyze the possibility of response bias. First, no significant statistical variations were found in a comparison of the number of employees, gross operating profit, and firms' annual sales from the population and the sample. Further, a random selection of non-respondent firms was contacted via phone to determine whether any patterns justified their refusal to participate. This indicated no specific shared characteristics among the firms that did not participate in the study. In general, response bias is not an issue in our sample. Finally, we compared responses from (40) firms that responded first with (40) responses from late-responding firms. Therefore, the responses from these two groups were shown not to significantly differ ($\alpha = 0.05$) for any of the variables in the questionnaire.

In summary, no evidence of non-response bias was found, and the analysis confirmed that the sample used was representative of the population. Furthermore, with regard to common method bias, we adopted some procedural measures before collecting the data to minimize any bias (Podsakoff et al., 2003). First, we conducted the survey pre-test, and second, we used two respondents in each firm (Podsakoff et al., 2003). In addition, we performed the traditional Harman's single-factor test (Podsakoff et al., 2003). The results of this test showed that the single factor explains nearly 21.40% of the total variance, thus indicating that common method bias is not an issue (Podsakoff et al., 2003).

4. Analysis and results

4.1. Measurement model

Content validity was ensured using measures accepted in the literature (see Appendix A), and by carrying out the above-mentioned expert review and pre-test procedures. Exploratory factor analysis (see Table 2) was performed to test the unidimensionality of the measures and gave satisfactory values for standardized factor loadings (>0.5), for the explained variance and Bartlett's test ($p < 0.05$). The Cronbach's alpha values were also considered adequate (>0.7) (Nunnally and Bernstein, 1994) and confirmed the reliability of each construct.

Divergent validity was assessed by analyzing the Cronbach's α coefficients for the scales (Table 2) and between-item correlations (see Table 3) (Anand and Ward, 2004). Divergent validity was confirmed by the scales' Cronbach's α coefficients, which were higher than the correlation coefficients with other scales in every case.

Further, a confirmatory factor analysis using EQS 6.4 was carried out to confirm the scales' dimensionality and test convergent validity. The multivariate non-normality of data was confirmed by the normalized estimation of Mardia's test, which indicated that the Robust Maximum Likelihood Method was applicable. Then, a factor model with 18 observed variables was designed. Table 4 shows the values obtained with the confirmatory factor analysis.

4.2. Structural equation model

The Robust Maximum Likelihood Method (Satorra, 1993) has been estimated using EQS 6.4 software to test the hypotheses. It has yielded a good overall fit for the baseline structural model (see Fig. 2 for the results). The relationships in H1, H3, and H5 were seen to be significant ($p < 0.05$), while the relationships in H2, H4, and H6 were not significant (see Fig. 1). Therefore, hypotheses H1, H3, and H5 were supported but H2, H4, and H6 were not.

When developing SEM, testing and comparing alternative models is recommended to explore the robustness of the findings (Bollen and Long, 1992; Maqueira et al., 2021; Swafford et al., 2008). Therefore, to further investigate the unexpected results of H2 and H4, two models that individually consider each SC strategy were tested. The aim was to dig deeper into the relationships between I4.0 base technologies, each SC strategy, and operational performance. The comparison of the alternative models with the baseline model allows us to identify the isolated effects of I4.0 base technologies on LSC and operational performance, on the one hand, and on ASC and operational performance, on the other hand, i.e., to visualize the antecedents and consequences of each SC strategy without any interference from the other strategy.

In this regard, an alternative model (Model 1, Fig. 3) was tested that included the relationships between I4.0 base technologies and LSC (H1), between LSC and operational performance (H4), and between I4.0 base technologies and operational performance (H6). The results of this model indicated a good overall fit (Satorra, 1993). In this model (Model 1), H1 and H4 received support with significant factor loadings, although H6 was still not significant.

The second alternative model tested (Model 2, Fig. 3) included only H2, H5, and H6. According to Fig. 3 (Model 2), this model has a worse overall fit than the previous models (RMSEA = 0.061). The direct relationship between I4.0 base technologies and ASC (H2) remains unsupported. A third model was also considered for testing the direct effect of each technology (BDA, IoT, and CC) on ASC. Based on fit criteria, we found that this model had poor goodness of fit (RMSEA = 0.115).

Table 2
Exploratory factor analysis.

Factor			Variable	Standardized factor loading	Cronbach's alpha	Bartlett test	% Explained variance
I4.0 base technologies			IT1	0.837	0.7	$\chi2 = 133.703$ df = 3	61.537
			IT2	0.803		Sig. = 0.000	
			IT3	0.708			
LSC	Tooling		LS1	0.886	0.7	$\chi2 = 270.415$ df = 15	72.466
			LS2	0.839		Sig. = 0.000	
	Operationalization		LS3	0.821			
			LS4	0.768			
			LS5*				
	Planning		LS6	0.684			
			LS7	0.881			
			LS8*				
ASC			AS1	0.629	0.8	$\chi2 = 369.964$ df = 10	54.295
			AS2	0.744		Sig. = 0.000	
			AS3	0.728			
			AS4	0.792			
			AS5	0.780			
Operational Performance		Efficiency	EF1*		0.8	$\chi2 = 305.026$ df = 6	79.690
			EF2	0.900		Sig. = 0.000	
			EF3	0.732			
		Delivery	DE1	0.863			
			DE2	0.918			

Note: *Items excluded after exploratory and reliability analyses.

Table 3
Correlations between scale items.

	IT1	IT2	IT3	LS1	LS2	LS3	LS4	LS6	LS7	AS1	AS2	AS3	AS4	AS5	EF2	EF3	DE1
IT1																	
IT2	0.531**																
IT3	0.398**	0.331**															
LS1	0.202**	0.192**	0.198**														
LS2	0.193**	0.168**	0.162**	0.531**													
LS3	0.073	0.110	0.188**	0.183**	0.263**												
LS4	0.147*	0.096	0.052	0.205**	0.241**	0.380**											
LS6	0.188**	0.118	0.144*	0.129*	0.231**	0.301**	0.343**										
LS7	0.183**	0.097	0.084	0.192**	0.292**	0.184**	0.221**	0.345**									
AS1	0.045	−0.009	0.139*	0.073	0.103	0.230**	0.112	0.174**	0.098								
AS2	0.120	0.081	0.010	0.013	0.085	0.125*	0.080	0.240**	0.056	0.407**							
AS3	0.080	−0.010	0.079	−0.027	0.039	0.147*	0.011	0.106	0.044	0.231**	0.404**						
AS4	0.083	0.026	0.075	−0.028	0.003	0.178**	0.043	0.234**	0.120	0.281**	0.470**	0.612**					
AS5	0.055	−0.006	0.059	−0.002	0.092	0.249**	0.200**	0.259**	0.160*	0.495**	0.454**	0.408**	0.494**				
EF2	0.178**	0.114	0.108	0.136*	0.129*	0.271**	0.249**	0.211**	0.110	0.147*	0.209**	0.100	0.153*	0.180**			
EF3	−0.021	−0.119	−0.055	0.002	0.038	0.066	0.102	0.067	0.003	0.102	0.139*	0.172**	0.102	0.181**	0.453**		
DE1	0.106	−0.053	0.002	−0.068	0.042	0.025	0.154*	0.073	0.112	0.166**	0.204**	0.194**	0.164**	0.253**	0.360**	0.484**	
DE2	−0.008	−0.136*	−0.024	−0.104	−0.040	−0.074	0.074	0.060	0.079	0.167**	0.213**	0.223**	0.233**	0.261**	0.270**	0.380**	0.700**

Table 4
Confirmatory factor analysis.

Factor	Variable/Factor	Standardized factor loading	R^2
I4.0 base technologies	IT1	0.80	0.636
	IT2	0.66	0.437
	IT3	0.51	0.256
LSC	Tooling	0.53	0.279
	Operationalization	0.82	0.669
	Planning	0.91	0.830
Tooling	LS1	0.60	0.365
	LS2	0.88	0.773
Operationalization	LS3	0.61	0.367
	LS4	0.63	0.393
Planning	LS6	0.67	0.448
	LS7	0.52	0.266
ASC	AS1	0.52	0.270
	AS2	0.65	0.426
	AS3	0.65	0.425
	AS4	0.73	0.537
	AS5	0.71	0.510
Operational Performance	Efficiency	0.83	0.690
	Delivery	0.81	0.657
Efficiency	EF2	0.60	0.359
	EF3	0.76	0.573
Delivery	DE1	0.92	0.574
	DE2	0.76	0.853

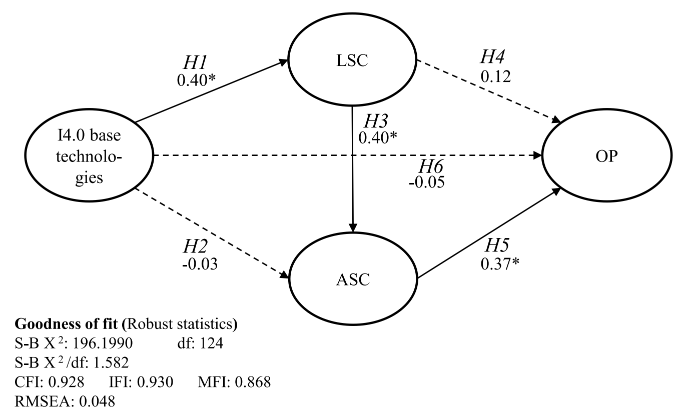

Fig. 2. Baseline structural model: results.

Further, the path coefficient values between each technology and ASC were statistically insignificant. Finally, ANOVA was applied to examine the effects of control variables such as industry type and SC position on the relationships between I4.0 and both SC strategies, and no significant results were found.

Taken together, the results indicate that I4.0 base technologies do not have the same effects on the Lean and Agile SC strategies. While I4.0 base technologies can make SC leaner, no significant direct effect of I4.0 base technologies on ASC was found. Results also show that both of the SC strategies can affect operational performance but under different conditions. Further, findings indicate a direct relationship between LSC and ASC and that ASC generates mediation effects between LSC and operational performance.

5. Discussion

This study has tested six hypotheses to offer an understanding of the impact of I4.0 base technologies on the Lean and Agile SC strategies and focal firm operational performance (RQ_1), and the interaction between the two SC strategies and their impact on the focal firm's operational performance (RQ_2). To answer these questions, we collected data from Spanish focal firms in different industrial sectors that occupy intermediate positions in the SC and analyzed the data using structural equation

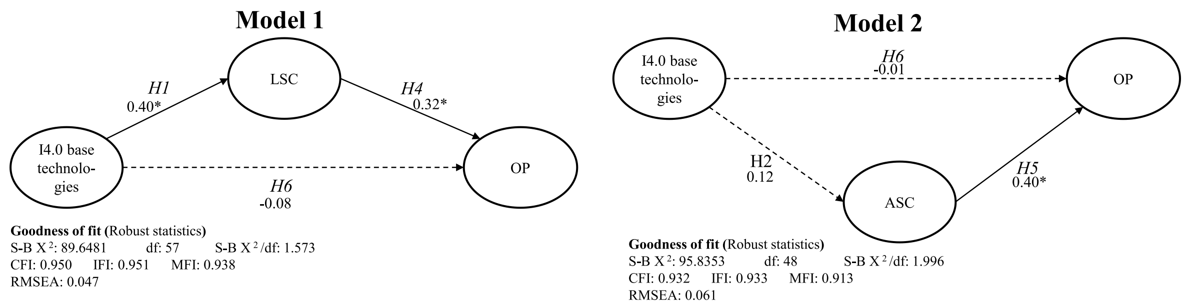

Fig. 3. Alternative models: Model 1 and model 2.

modeling.

Regarding the first research question (RQ_1), our findings show that LSC is directly affected by the use of I4.0 base technologies (H1), while a direct effect on ASC was not found (H2). Thus, using I4.0 base technologies can improve LSC, which is in line with previous studies (Kamble et al., 2019; Núñez-Merino et al., 2020; Raji et al., 2021a). Although the introduction of highly emerging technologies may generate some volatility and uncertainty in the SC (Oliveira-Dias et al., 2022b), the set of I4.0 base technologies can be considered to be already in a more advanced state of development compared to other promising technologies such as virtual/augmented reality or blockchain (Frank et al., 2019; Núñez-Merino et al., 2020). Therefore, our findings suggest that using BDA, IoT, and CC can indeed be compatible with Lean at the SC level. More specifically, according to the dynamic capabilities view, I4.0 base technologies can enhance LSC sensing capabilities by improving the detection of any possible disruptions and sources of waste in the SC. This set of technologies can also improve LSC's ability to seize related capabilities by improving the efficiency of information and physical SC flows, thus enabling a better operationalization of the LSC strategy. Furthermore, I4.0 base technologies can help the focal firm to manage the reconfiguration of internal and external resources by supporting knowledge management and collaboration in the LSC.

Concerning H2, surprisingly, our results do not support the positive and direct relationship between I4.0 base technologies and ASC. Some studies indicate that the effects of information and digital technologies on ASC could be indirect through the development of capabilities such as SC integration, collaboration, and flexibility (Oliveira-Dias et al., 2022c). Therefore, the proper integration of SC chain flows and the willingness to collaborate and share information are essential for improving SC agility (Bi et al., 2013; Liu et al., 2013; Oliveira-Dias et al., 2022a). Another explanation for the limited effect of the I4.0 base technologies on ASC might be these technologies' characteristics. Previous studies highlight that technologies such as cyber-physical systems (Raji et al., 2021a) can have a greater impact on SC agility, which may indicate that while LSC is directly affected by I4.0 base technologies, another group of technologies could have a higher impact on ASC (Oliveira-Dias et al., 2022a). Considering that each I4.0 technology (or group of technologies) has different features, emerging technologies could have very different effects from each other. Therefore, future research should investigate the effect of different bundles of I4.0 technologies on ASC.

Additionally, the effect of I4.0 base technologies on the focal firm's operational performance (H6) has been demonstrated to be non-significant. One explanation for this result can be found in the dynamic capabilities theory perspective, which assumes that information technology use by itself does not improve firm competitiveness but, rather, needs to be combined with other resources such as human and management resources (Novais et al., 2020; Powell and Dent-Micallef, 1997). Therefore, to provide better performance, I4.0 base technologies need to be embedded and used with complementary resources and SC strategies.

Regarding RQ_2, first, our results have demonstrated that LSC positively impacts ASC (H3). In line with the dynamic capabilities view, this result indicates that the ASC strategy is influenced by the implementation of the LSC strategy, which implies the establishment of operating routines to enhance cooperative relationships between partners and linked upstream and downstream SC flows. In light of this, we can postulate that the effects of I4.0 base technologies on ASC may be indirect due to the mediation by LSC. It can be inferred that I4.0 base technologies alone are less effective in directly improving ASC implementation. Instead, SCs will need to implement I4.0 base technologies in conjunction with LSC practices. This finding is in line with the previous research that indicates that leanness is an antecedent of agility (Ghobakhloo and Azar, 2018; Iqbal et al., 2020). Second, our results show that both LSC and ASC can affect focal firm operational performance (H4, H5). However, LSC's impact on the focal firm's operational performance is direct only when ASC strategy is not included in the model. According to the dynamic capabilities view, this means that when SCs pursue the capabilities deployed by both strategies, ASC plays a mediation role between LSC and focal firm operational performance.

6. Conclusions

Our study has explored the interrelationships between I4.0 base technologies, the Lean and Agile SC strategies, and performance. More specifically, we have examined the effect of I4.0 base technologies (CC, BDA, IoT) on the Lean and Agile SC strategies, the influence of one of these strategies on the other, and their effects on operational performance. The survey study was conducted using data from 256 manufacturing firms located in Spain. In summary, using a dynamic capability perspective, the presented findings support a direct effects model in which I4.0 base technologies are enablers of LSC, and LSC, in turn, directly and positively impacts ASC, which ultimately results in higher operational performance. Further, in the absence of ASC, LSC can also improve operational performance (Model 1). This means that ASC's impact on performance is much stronger than the effect of LSC. In other words, agility has a stronger relationship with performance than leanness; however, at the same time, agility is enhanced by leanness.

Taken as a whole, this study provides an in-depth understanding of the mechanisms that build stronger SC capabilities and improve operational performance in the era of the fourth industrial revolution.

6.1. Theoretical implications

This paper addresses some important gaps in the literature such as the role played by I4.0 base technologies in the implementation of SC strategies and the relationship between two primary SC strategies (Lean and Agile) in an I4.0 setting. This study, therefore, complements previous findings (Núñez-Merino et al., 2020; Oliveira-Dias et al., 2022b; Raji et al., 2021a; Reyes et al., 2021) by empirically examining the aforementioned relationships.

Although integration between Lean practices and information technologies is not new, initial efforts have been focused on the shop floor level (Tortorella et al., 2021). So, much remains to be investigated concerning the implementation of the Lean SC strategy and Industry 4.0 technologies in the SC. Thus, on the one hand, this paper contributes to a better understanding of this integration. It demonstrates that the use of CC, BDA, and IoT can improve the connectivity and smartness of LSC in building a strong SC dynamic capability. On the other hand, despite the considerable number of studies that have pointed to the benefits of I4.0 technologies for ASC (Dubey et al., 2019; Wamba et al., 2020), our results do not confirm this direct relationship. However, we have seen that base technologies need to be complemented with other resources to build agility, which is in line with other studies that find an indirect relationship between information technologies and agility or ASC (Samdantsoodol et al., 2017; Schniederjans et al., 2016).

Additionally, this study also provides a fresh perspective on the relationship between LSC and ASC and their consequences for the firm's operational performance. Therefore, based on the dynamic capabilities theory, this study sheds light on the processes behind the development of two SC strategies (Lean and Agile) that generate SC dynamic capabilities and, ultimately, enhance firm performance.

6.2. Practical implications

The results of this study offer managerial guidance to supply chain managers on the value of I4.0 base technologies for supporting the Lean and Agile SC strategies and the effects on focal firm operational performance that can be expected.

Since the use of I4.0 technologies in manufacturing firms is at an initial stage, this study provides guidance on the I4.0 resources and SC strategies integration. It shows that the implementation of a specific group of technologies (i.e. I4.0 base technologies) as a starting point for the transition to I4.0 does not directly imply any improvement in operational performance, but it does have a positive effect on LSC implementation. Thus, the lack of a direct link between I4.0 base technologies and operational performance highlights the importance of considering the I4.0 - Lean relationship for the maximization of operational performance. Therefore, by way of an example, automation achieved with the support of technology must occur in processes that genuinely add value to the customer, i.e., taking into account Lean principles. Additionally, this research provides examples of ways in which the LSC strategy can be enhanced by the use of I4.0 base technologies.

Further, according to our results, SC managers who encourage the development of LSC as an initial step will obtain benefits when it comes to implementing ASC and, ultimately, better operational performance. This result corroborates that leanness and agility are not contradictory objectives in SC management. Indeed, the results demonstrate that LSC is fundamental to achieving ASC in an I4.0 environment. Support from I4.0 base technologies can help bridge the gap between some of the features of LSC and ASC that could be considered conflicting such as buffer capacity and inventory levels (Carvalho et al., 2011; Qrunfleh and Tarafdar, 2014). I4.0 base technologies have the potential to improve forecasting capability and increase supply chain visibility, which can lead to greater compatibility between the two SC strategies. Thus, the leaner an SC is, thanks to the I4.0 base technologies, the more Agile it will be over time, which will boost its performance. This can be seen as, a virtuous circle, where the use of I4.0 base technologies enhances leanness in SC (i.e. LSC), which in turn enhances agility (i.e. ASC) and ultimately leads to better performance; and better results will then allow further investments in technologies that will continue to feed the circle.

6.3. Limitations and future studies

The limitations of this study and future research developments should be considered in the context of the present findings. First, one important limitation of our study is that the data have only been collected from Spanish firms, which limits the generalization of the results. Future studies should consider carrying out similar research in other countries, for example, emerging economies. Another limitation is the time that has elapsed since the data was collected. Although it would have been preferable to use more up-to-date data, other similar studies that analyze the effects of digital technologies have used data from years prior to 2018 (e.g., Gillani et al. (2020) use data from 2014 and Di Maria et al. (2022) from 2017). However, future studies using longitudinal data could analyze the extent to which the adoption of digital technologies has been affected by the COVID-19 pandemic. Third, this study addresses a limited number of technologies and SC strategies. Therefore, future studies should consider the effect of other I4.0 technologies, the complementarity between different bundles of I4.0 technologies with similar features, their impact on LSC and ASC implementation and on other SC strategies such as hybrid approaches, and the resilient and green SC strategies. Future studies should also investigate the specific LSC and ASC-related capabilities that each technology develops and analyze models that link technologies, capabilities, and results.

Further, it is worth highlighting the importance of "small data" for future developments (Bhatia et al., 2022; Wilson and Daugherty, 2020). While CC and IoT devices are becoming more affordable and attainable for small and medium-sized firms, using Big Data can be challenging due to data availability and the associated complexity. These firms could instead leverage Data & Analytics techniques to extract knowledge from small data sets. Finally, future studies could also explore the effects of I4.0 base technologies on some recognized antecedents of SC agility, such as SC flexibility and SC integration, to further understand how SCs can be more Agile.

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Data availability

Data will be made available on request.

Appendix A. Survey items used in this study

Lean Supply Chain - *Moyano-Fuentes et al. (2019)*

To what extent do you agree with the following aspects related to the LSC? (5 point scale, "1 = totally disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = totally agree"):

Tools to eliminate waste in the SC:

LS1 - Value stream mapping is used to identify and eliminate waste throughout our supply chain.

LS2 - Our supply chain uses lean manufacturing techniques (such as pull flow, Kanban systems, and setup time reduction).

LSC operationalization:

LS3 - Our supply chain generates high stock turnover and minimizes inventory

LS4 - Process and product standardization is a common practice in our supply chain.

LSC planning:

LS6 - Our supply chain does long-term forecasting of customer demands and only focuses on the current market segments

LS7 - In our supply chain, the strategy for handling uncertainty consists of using queues and buffers to protect sub-processes

Agile Supply Chain *- Adapted from Gligor et al. (2013), Qi et al. (2011), and Tachizawa and Gimenez (2010)*

To what extent do you agree with the following aspects related to the ASC (5 point scale, "1 = totally disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = totally agree"):

AS1 - Our supply chain can make the adjustments to order specifications requested by our customers.

AS2 - Production planning has the ability to respond quickly to varying customer needs.

AS3 - Our supply chain can increase short-term capacity as needed.

AS4 - Our supply chain can adjust/expedite its delivery lead times.

AS5 – Our supply chain responds to customer demand.

Operational Performance - Adapted from Liu et al. (2009) and Danese et al. (2012)

Please, indicate on a scale of 1–5 your firm's position in the following operational performance indicators compared to your competitors ("1 = poor, low; 2 = below average; 3 = average or the same as the competition; 4 = above average; 5 = much better than average"):

Efficiency

EF2 - Inventory turnover

EF3 - Cycle time (from raw materials to delivery)

Delivery

DE1 - On-time delivery performance

DE2 - Fast delivery

I4.0 base technologies *- Adapted from Tortorella and Fettermann (2018)*

Please indicate the extent to which each of the following technologies has been implemented in your company's supply chain (5 point scale; "1 = not implemented; 2 = poorly implemented; 3 = partially implemented; 4 = highly implemented, 5 = fully implemented").

IT1- Big Data Analytics

IT2 - Internet of Things

IT3 - Cloud Computing

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