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How does the technology environment impact supply chain strategy and operational performance?

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ABSTRACT

Purpose: This paper investigates the relationship between technological uncertainty and the use of Industry 4.0 (I4.0) technologies, and its impact on the implementation of agile and lean supply chain strategies. It also examines the effect of both of these supply chain strategies on focal firm operational performance in terms of efficiency in manufacturing processes and delivery performance.

Design/methodology/approach: Survey data were gathered from 256 focal manufacturing companies in Spain using a structured questionnaire. Covariance-based structural equation modeling (CB-SEM) is used to test the conceptual model.

Findings: Underpinned by the Contingency Theory and the Resource Orchestration Theory, the results indicate that technology uncertainty has a strong association with I4.0 technology use. Furthermore, the use of I4.0 technologies facilitates the implementation of the lean supply chain strategy and the agile supply chain strategy. Focal firm operational performance was also observed to be affected by the two strategies in different ways.

Originality: This study extends the literature on operations management by studying the fit between the external environment and strategy by incorporating an in-between element: the use of I4.0 technologies. This research provides a unique empirical analysis of the role of technology uncertainty and integration between I4.0 technologies and supply chain strategies.

Keywords:

Agile Supply Chain; Lean Supply Chain; Industry 4.0 technologies; Supply Chain strategy; Technology Uncertainty.

Quick Value Overview:

Interesting because: The manufacturing sector has seen rapid technological advancements, yet many companies struggle to realize the expected benefits of Industry 4.0 (I4.0) technologies despite substantial investments. Previous studies emphasize the need for mechanisms to translate technology use into better operational performance. However, most research on aligning I4.0 with Lean Supply Chain (LSC) and Agile Supply Chain (ASC) strategies has focused on pairwise relationships between specific technologies and practices. Our study advances the field by conceptualizing LSC and ASC as comprehensive measures, enhancing the understanding of the relationships between the external technological environment, the internal technological environment, supply chain strategies, and operational performance.

Theoretical value: The study shows that technology uncertainty is directly positively related to the use of I4.0 technologies supporting interrelationships between the external technology environment and the internal technology environment. I4.0 technologies facilitate the implementation of both LSC and ASC strategies. Focal firm operational performance was observed to be affected by the two supply chain strategies in different ways. The outcome of the LSC strategy will be an operational performance gain in terms of efficiency performance. Meanwhile, ASC implementation can significantly increase delivery performance as well as efficiency performance.

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Practical value: In contexts of technological uncertainty, manufacturing companies are more likely to recognize the potential benefits of technologies and increase their deployment at the supply chain level. Thus, managers play a critical role in identifying and leveraging I4.0 technologies to improve operational performance through the implementation of LSC and ASC strategies. Managers who deeply understand I4.0 technologies and their potential can better coordinate their use to achieve lean and agile goals.

1. Introduction

Companies are operating under an ever-changing, complex, and competitive environment, which poses significant challenges to supply chain (SC) management. In recent years, manufacturing sector has witnessed quick and significant changes in technology, leading to shortened innovation cycles and rapid changes in product specifications and processes, and business models (Srinivasan *et al.*, 2020). One of the main factors that contribute to the current highly dynamic scenario is technology uncertainty (Baofeng *et al.*, 2022; Garcia-Buendia *et al.*, 2023). Technology uncertainty can be seen as the rate of technological changes faced by companies in an industry over time (Chen and Paulraj, 2004). This dynamism is reflected in different manufacturing sectors. For example, the automotive industry is undergoing rapid technological changes (e.g., the switch to electric and hydrogen vehicles and autonomous driving) that require increased capabilities from both the focal company and its suppliers. Otherwise, manufacturing companies that are not prepared for or ignore technological developments may risk falling behind (Baofeng *et al.*, 2022; Oh and Rhee, 2008). One well-known case is the Nokia company, which failed to innovate and keep up with technological changes and trends in smartphone design, which resulted in it losing market share to companies such as Apple and Samsung. Accordingly, technology uncertainty has been identified as a key contingency factor in the operations management literature (Garcia-Buendia et al., 2023; Xiao et al., 2019; Xu et al., 2022).

Therefore, to counteract technological turbulence, SCs are expected to make strategic decisions that will provide the necessary capabilities to encourage appropriate responses to environmental changes by increasing efficiency in manufacturing processes and delivering customer orders on time and quickly. SC managers should look for ways to improve the agility and flexibility of the SC, both by tightening relationships with their key suppliers and by investing in cutting-edge technologies. In this context, the advancement of the Industry 4.0 (I4.0) phenomenon (Kagermann *et al*., 2013) and its enabling technologies is bringing new possibilities to the way that SCs can be integrated, coordinated, controlled, and managed (Calatayud *et al*. 2019). In this regard, some studies have stated that the intensive adoption of digital technologies could change the structure of SCs, e.g., by shortening the SC, with consequent potential risks for actors who do not adapt to disruptive changes (Wamba and Queiroz, 2022). Digital technologies can also directly affect SC strategies (Oliveira-Dias *et al.*, 2023). Amazon is an example of how the use of Big Data Analytics enables the implementation of an agile SC strategy locating products in warehouses close to final customers before the latter place an order (Enrique *et al.*, 2022; Oliveira-Dias *et al.*, 2022a).

Previous studies have also highlighted that, despite large investments, many manufacturing companies fail to reap the expected benefits of I4.0 technologies, such as cost reductions or an enhanced service level (Rodríguez-Espíndola *et al.*, 2022). This failure can be traced back to the lack of alignment between the digital strategy implementation and the SC's objectives (Qrunfleh and Tarafdar, 2014). In addition, previous studies indicate the need for intermediate mechanisms to turn technology use into improved operational performance (Oliveira-Dias *et al.*, 2022a). In this respect, the use of I4.0 technologies should be aligned with the SC strategy for better results (Qrunfleh and Tarafdar, 2014; Raji *et al*., 2021a). In this context, the integration of I4.0 technologies and two SC strategies, Lean (mainly related to exploiting

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operational efficiencies and cost reduction applying, for example, lean manufacturing techniques along the SC) (Moyano-Fuentes *et al*., 2019) and Agile (focused on quickly responding to changes in the environment and demand for manufacturing firms) (Christopher, 2000; Qrunfleh and Tarafdar, 2013) have attracted considerable attention (Núñez-Merino *et al*., 2020; Oliveira-Dias *et al*., 2022b). However, recent studies underline the importance of further research on whether and how I4.0 technologies could lead to changes in SC processes, and more specifically, how I4.0 technologies affect Lean Supply Chain (LSC) and Agile Supply Chain (LSC) (Bokhorst *et al.*, 2022; Ciano *et al.*, 2021; Raji *et al.*, 2021a, 2021b).

Thus, this study relies on the lenses of the contingency theory (CT) (Donaldson 2006; Sousa and Voss 2008) and the resource orchestration theory (ROT) (Sirmon *et al*., 2011) to further our understanding of the relationship between the external technological environment (technological uncertainty) and the internal technological environment (use of I4.0 technologies) and its impact on the implementation of SC strategies and operational performance. The contingency perspective argues that organizations have to adapt their strategies and processes to fit their environment to achieve high performance (Donaldson 2006). Thus, scholars have acknowledged that internal and external environmental factors (contingencies) need to be better understood to attain superior performance (Lucianetti *et al.*, 2018; Sousa and Voss, 2008). In this regard, managers play a key role in mapping the firm's environment and structuring and bundling resources to build and leverage capabilities accordingly (Sirmon et al., 2011). This special focus on the role of managers in orchestrating resources has been explained by the ROT framework (Sirmon *et al*., 2011). Accordingly, this study's research question can be specified as:

RQ. What impact does the technological environment have on the development of lean and agile supply chain strategies, and ultimately, what is the impact on operational performance?

So, the technological environment is shaped, on the one hand, by technological uncertainty, which is an external contingency that cannot be directly managed, and on the other, by the use of I4.0 technologies, which are resources that can be actively coordinated by SC managers (Gillani *et al.*, 2020; Lucianetti *et al.*, 2018). I4.0 technologies can be considered operant resources (i.e., they can act on other actors and trigger innovation processes and routines) (Li and Jia, 2018) that enable the integration of knowledge and capabilities along the SC to facilitate the deployment of lean and agile SC strategies.

This study offers three main contributions. First, it adds to the manufacturing literature by conceptualizing the effects of technology uncertainty on the use of I4.0 technologies. Second, with this study, we respond to calls for further empirical research on the integration between I4.0 technologies and the LSC and ASC strategies (Garcia-Buendia *et al.*, 2023; Raji *et al.*, 2021a, 2021b) by conceptualizing LSC and ASC as comprehensive measures. So, this study goes beyond the pairwise relationships between specific technologies and practices. Third, the paper extends the discussion on how LSCs and ASCs perform in terms of efficiency in manufacturing processes and delivery performance (operational performance).

This paper is structured as follows. The theoretical background is introduced in section 2, followed by the hypotheses in section 3. In section 4, we describe the research method. Next, the results are presented in section 5. In section 6, the key theoretical insights and practical implications are discussed. Lastly, the paper ends with some concluding remarks, limitations, and recommendations for future research.

2. *Contingency Theory and Resource Orchestration Theory*

This study draws on the CT (Donaldson, 2006; Sousa and Voss, 2008) and the ROT (Sirmon *et al.*, 2011). The CT indicates that different contexts often have different needs and so require different approaches to operations management (Sousa and Voss, 2008). Thus, the

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contingency perspective is useful for examining the relationships between external contextual factors and internal organizational variables. External factors are beyond the company's control, while internal organizational variables are derived from decisions made by managers to adapt to the environment and achieve specific performance goals (Romero-Silva *et al.*, 2018).

The ROT framework also adds insights to our discussion. ROT integrates arguments provided by the resource-based view (RBV) and dynamic capabilities theory into a single framework and places a special focus on managers' roles in identifying, combining, and deploying resources and capabilities to enable a better fit with the environment and achieve better results. Therefore, ROT emphasizes overlooked elements (e.g., dynamics and managers' role) and enriches the RBV (Sirmon *et al*., 2011). The use of this theory to ground operations and SC management studies has increased in recent years (Hitt *et al*., 2016; Queiroz *et al*., 2022; Minguela-Rata *et al*., 2023). This framework highlights the active role of managers, who play a crucial role as "orchestra conductors". Further, many new technologies are emerging in the I4.0 context that may have very powerful effects but about which not much knowledge exists due to their recency. This is what gives the most proactive managers the opportunity to identify the potential of these resources in their SCs, combine them, and put them into action to create new capabilities to generate competitive advantage (Hitt *et al*, 2016).

3. Hypothesis development

3.1 Technology uncertainty and I4.0 technologies

Following the CT perspective, changes in the environment impact firms and their SC operations (Sousa and Voss, 2008). Inter alia, turbulent environments lead not only to fast innovation cycles and increased availability of technologies but also to increased ambiguity and risk in the firm's business processes (Srinivasan *et al.*, 2020). Thus, according to CT, a firm should adapt its organizational structures and strategy to the uncertain technological environment (Drnevich and West, 2023). In addition, according to the ROT view, maintaining a competitive advantage in uncertain environments requires innovation and the creation of new capabilities through the combination of resources (Sirmon *et al*., 2011). In such conditions, the response to technology uncertainty should no longer be the responsibility of a single company but of all the companies in the SC (Xiao *et al.*, 2019). Therefore, to counteract uncertainty, SC partners seek to enhance information-sharing and improve decision-making, thus making internal SC operations more predictable (Wong *et al.*, 2009).

Consequently, SCs may look for mechanisms to support and improve innovation and coordination between partners to overcome uncertainty (Gillani *et al.*, 2020; Patterson *et al.*, 2003). Accordingly, technology uncertainty can lead to the adoption of innovations for the improvement of processes (Tan, 2023). In this sense, I4.0 technologies allow the improvement of company-level processes and processes associated with the SC. Therefore, SC managers must be proactive toward external changes and exploring new technologies in a changing technological environment so as to avoid market obsolescence, and they must also exploit and orchestrate existing SC resources and capabilities to seek stability and efficiency (Coreynen *et al.*, 2020; Rojo *et al.*, 2020; Xiao *et al.*, 2019). Indeed, higher environmental uncertainty was suggested to be linked to the adoption of SC technologies (Cegielski *et al.*, 2012; Patterson *et al.*, 2003). More specifically, Coreynen *et al*. (2020) have found that companies active in highly technologically turbulent environments are more oriented toward digitalization, in other words, toward the use of technologies.

This paper focuses specifically on the role of the most representative and promising I4.0 technologies from the SC perspective: Internet of Things (IoT), Big Data Analytics (BDA), cloud computing, additive manufacturing, advanced robotics, radio-frequency identification (RFID),

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and blockchain (Koh et al., 2019; Núñez-Merino et al., 2022). Some works (Frank et al., 2019; Tortorella et al., 2020) distinguish IoT, BDA, and cloud computing as "base" technologies of I4.0 since they support other technologies. In contrast, additive manufacturing, advanced robotics, RFID, and blockchain technologies can be classified as smart manufacturing and warehouse technologies (Frank et al., 2019; Ghobakhloo, 2018). In this context, I4.0 base technologies are stated to allow greater visibility, integration, and collaboration between SC members (Frank *et al.*, 2019), while other technologies related to smart manufacturing and warehouse management can bring flexibility and robustness to SC operations (Calatayud *et al*., 2019; Oliveira-Dias *et al*., 2022a).

Therefore, as a contingency factor, technology uncertainty can influence firms' initiatives in the adoption of I4.0 technologies. These technologies can be used to gain insights into shifting market patterns and devising product offerings that align with evolving customer needs (Calatayud *et al.*, 2019; Enrique *et al.*, 2022). Moreover, in the same way that a company faced with technology uncertainty transcends its boundaries to manage its suppliers' resources, according to the ROT perspective (Sirmon *et al*., 2011), SC managers will be more likely to increase the use of I4.0 technologies as manufacturing companies have an increased need to integrate knowledge and skills using technologies as operant resources (Li and Jia, 2018). Based on these arguments, the following is hypothesized:

H1. There is a positive relationship between technology uncertainty and the use of I4.0 technologies.

3.2. I4.0 technologies and Lean and Agile supply chain strategies

With the advent of the fourth industrial revolution, SCs are experiencing a period of technological breakthroughs. In this context, I4.0 technologies have the potential to significantly transform SCs of manufacturing firms by introducing automation, connectivity, and data-driven decision-making (Wamba and Queiroz, 2022). Therefore, to some extent, the use of I4.0 technologies can be seen as a contingency factor that has the potential to transform the implementation of LSC, which has typically been regarded as a low-tech approach (Pagliosa *et al.*, 2021).

Previous studies have investigated integration between lean practices and digital technologies (Bokhorst et al., 2022; Ciano et al., 2021; Raji et al., 2021b; Tortorella et al., 2019). Some authors have presented proposals using specific technologies to address some of the lean manufacturing principles with applications at the internal or SC levels (e.g., Value Stream Mapping (VSM) enabled by RFID, Kanban systems enabled by IoT devices and cloud computing (Shahin *et al.*, 2020)), which allows a broader view of operations management and contributes to the reduction of error rates (Ghobakhloo, 2018).

Moreover, since LSCs pursue low inventory levels and high stock turnover, accurate inventory data are especially important (Buer *et al.*, 2018). Scholars have highlighted the fact that I4.0 technology use can lead to efficient inventory control. In this context, RFID use enables the traceability of material flows and improves the visibility of inventory positions, which enables stock reductions (Núñez-Merino *et al.*, 2020). Additive manufacturing can also potentially impact inventory minimization, since it reduces the transportation of materials and some assembly steps in product development (Raji *et al.*, 2021a).

A further challenge that LSCs face is to make an accurate demand forecast, based on which they can produce only what is necessary and reduce delivery times (Moyano-Fuentes *et al.*, 2021). Previous studies highlight that the use of BDA can improve demand forecast abilities (Choi *et al.*, 2018) by creating predictive models and leading to more efficient production and more responsible use of resources (Núñez-Merino *et al.*, 2020). Another application is reported

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by Dweekat *et al.* (2017), who showed that dairy SCs could use IoT technologies to monitor products' expiration dates on a daily basis and share this information with all SC members.

From the above discussion, it seems that the use of I4.0 base technologies such as cloud computing, BDA, and IoT can increase visibility and improve decision-making of manufacturing firms to adapt more efficiently to the needs of demand. Meanwhile, the use of advanced robotics, RFID, and additive manufacturing is directly related to waste elimination. Moreover, according to the ROT view, SC managers can leverage the SC's resources and capabilities by orchestrating the resources of SC members (Queiroz *et al*., 2022; Minguela-Rata *et al*., 2023). As such, either technology use needs to be extended to the other SC members or all the partners' IT competencies have to be taken full advantage of to enhance new SC capabilities (Novais *et al*., 2020) such as LSC implementation. Thus, managers can leverage LSC processes based on the use of I4.0 technologies that make LSCs more responsive to respond to changes in the external environment. Therefore, we postulate the following hypothesis:

H2: There is a positive relationship between the use of I4.0 technologies and LSC implementation.

The use of I4.0 technologies can also reshape ASC implementation as their use can act as an operant resource, i.e., it can trigger innovation processes (Li and Jia, 2018). Recent studies have highlighted the power of BDA to support accurate demand forecasting and the identification of customer needs, which may enable the customization of products and services accordingly (Choi *et al*., 2018; Oliveira-Dias *et al*., 2022a). At the same time, cloud computing is seen as a tool to support SC integration and accelerate SC flows, thereby increasing agility (Maqueira *et al.*, 2019; Novais *et al.*, 2020). Furthermore, applied together, I4.0 base technologies (cloud computing, BDA, and IoT) can increase SC agility by facilitating information-sharing and collaboration with partners and enhancing decision-making (Choi *et al.*, 2018; Frank *et al.*, 2019).

Additionally, the use of smart manufacturing technologies such as additive manufacturing, RFID, and advanced robotics can increase SC agility by enabling rapid prototyping, real-time information, and the automation of logistics processes (Oliveira-Dias *et al*., 2022a). In general, this group of technologies is aimed at increasing agility to manage market fluctuations by accommodating changes in manufacturing and enabling product customization (Calatayud *et al.*, 2019). In this sense, the Spanish corporation Inditex stands out for its SC agility. The corporation has successfully implemented I4.0 technologies across the SC to increase control over its goods by putting in place an "omnichannel" strategy (Oliveira-Dias *et al.*, 2022a). The company also exploits BDA by gathering and analyzing information from different sources to better understand customer demand and respond quickly.

Thus, through the ROT lens, manufacturing firms' and SCs' sense and response capabilities are an outcome of manager-orchestrated resources, including mechanisms to support and enhance SC visibility, coordination, and speed of response to customer needs (Queiroz *et al.*, 2022; Sirmon *et al.*, 2011). In this sense, I4.0 technologies play an essential role in facilitating the deployment of the ASC strategy. Therefore, we hypothesize the following:

H3: There is a positive relationship between I4.0 technology use and ASC implementation.

3.3. Supply chain strategies and focal firm operational performance

According to the CT view, contextual factors influence the organizational structure of a business unit, and the organizational structure, in turn, impacts the overall performance of a company (Sousa and Voss, 2008). Hence, the way in which an SC is structured influences the firm's performance. Complementarily, ROT also helps to understand the effects of the LSC

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strategy on focal firm operational performance. It should also be borne in mind that implementing the LSC strategy involves more than just bundling some isolated lean practices together and that it is, rather, a global strategy for the SC (Moyano-Fuentes *et al.*, 2021). Thus, its implementation requires SC managers to make enormous resource orchestration efforts (Hitt *et al.*, 2016) designed to integrate SC members to reduce waste along the SC, which will affect focal firm operational performance. In this study, firm operational performance is measured in terms of efficiency in manufacturing processes and delivery performance (Danese *et al*., 2012). As regards efficiency performance, previous studies have highlighted that implementing Lean tools such as VSM along the SC allows the unit cost of manufacturing to decrease by reducing inefficiencies across the SC (Seth *et al*., 2017). Standardization of products and processes can also lead to reductions in costs and cycle times. Likewise, integrated inventory management and pull system can lead to the reduction of inventory-related costs and increase inventory turnover (Srinivasan *et al.*, 2020). In this line, Moyano-Fuentes *et al*. (2021) find that a higher level of LSC implementation is associated with a higher level of firm efficiency.

As regards the impact of LSC on delivery performance, research indicates that LSCs entail close relationships with suppliers and improved coordination of SC flows, which allows improvements in on-time delivery performance (Danese *et al.*, 2012; Oliveira-Dias *et al.*, 2023). In addition, adhering to daily schedules can maintain a smooth and uninterrupted flow of materials across production lines and speed up production activities and delivery times (Raji *et al.*, 2021a).

Therefore, based on the CT view and ROT arguments, we posit that to fit the I4.0 scenario environment, SC managers make efforts to integrate resources and capabilities along the SC and implement the LSC strategy, which can greatly impact the manufacturing focal firm's operational performance. Accordingly, we hypothesize the following:

H4: There is a positive relationship between LSC implementation and the focal firm's operational performance in terms of (H4a) efficiency performance and (H4b) delivery performance.

With regard to the ASC strategy, previous studies frequently associate this strategy with a better capability to sense and respond to market changes quickly and cost-effectively, thus leading to better operational performance (Carvalho *et al*., 2011). Furthermore, according to the previous literature, SC agility can also help an organization reduce its manufacturing costs as the ASC strategy requires increased collaboration and coordination between the focal firm and its partners, which leads to the timely exchange of schedules and inventory levels (Bottani, 2009), and thus reduces the detrimental impacts of the bullwhip effect or costs derived from SC disruptions (Blome *et al.*, 2013).

Regarding, delivery performance, an ASC uses market knowledge to exploit opportunities and quickly launch products by shortening cycle time and delivery time (Naim and Gosling, 2011). Sangari and Razmi (2015) have empirically established that ASC contributes to superior focal firm performance, including on-time delivery. In addition, ASCs provide capabilities for the focal firm to quickly respond to customer needs by modifying orders or speeding up delivery times (Srinivasan *et al*., 2020).

Therefore, better operational performance depends on the integration and orchestration of SC resources that can lead to an increased speed of physical, information, financial, and service SC flows (Oliveira-Dias *et al*., 2022a). Hence, we hypothesize that:

H5: There is a positive relationship between ASC implementation and the focal firm's operational performance in terms of (H5a) efficiency performance and (H5b) delivery performance.

4. Method

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4.1. Survey design and sample

This study follows a quantitative approach using a survey-based instrument to collect pertinent data on the use of Industry 4.0 technologies and the implementation of SC strategies and operational performance, and demographic data from focal firms and their respondents. A survey-based approach allows to test the established concepts concerning a phenomenon and the connections between the concepts, and so better explain a phenomenon (Karlsson, 2009). This approach has been used to address topics related to the present work (Moyano-Fuentes *et al*., 2021; Rojo *et al*., 2016). The questionnaire was developed and refined following three main steps. First, a literature review was carried out to identify pre-tested scales in the previous literature. Most of the answers used a five-point Likert scale. Second, the questionnaire was assessed and improved through pre-tests with five international academics in operations management and information technology. Third, a pilot study was conducted with five head SC managers and five head IT managers to assess the comprehensiveness and readability of the questionnaire. Some of the questions were revised in line with the experts' recommendations in order to improve clarity.

The questionnaire was divided into two main areas: (a) SC management, and (b) information technology. To obtain the most knowledgeable responses, each part of the questionnaire was directed at high-ranking informants in the specific areas ((a) SC, logistics or operations managers, and (b) IT managers).

Concerning the target population, Spanish focal manufacturing companies with at least 50 employees were established as the target of the study. The population was obtained from the Iberian Balance Sheet Analysis System (SABI) database, which includes accounting and financial information on a comprehensive set of (over 2 million) firms operating in Spain. The SABI database has previously been used to compile the population census in earlier empirical studies (Garcia-Buendia *et al.*, 2023; Rojo *et al*. 2016). This study takes the perspective of the focal firm so as to have a global view upstream and downstream of the SC. In addition, to ensure that the selected companies had a broad view of the SC, companies from industrial sectors that did not occupy an intermediate position in the SC were excluded (i.e., extractive or mining industries, distribution). Thus, the selection criteria yielded a population of 2,650 Spanish manufacturing companies.

The survey was conducted by telephone using a computerized system (Computer Aided Telephone Interviewing, CATI). Following ethical standards, the invitation guaranteed the anonymity and confidentiality of the responses. Additionally, respondents were asked to respond on behalf of their companies rather than personally, which reduces social desirability bias (Podsakoff *et al*., 2003). The interviewers were trained by the research team for this specific study. In addition, the researchers were able to audit interviews. This data-gathering method has previously been successfully used in operations and SC research (Sacristán-Díaz *et al.*, 2018). A web questionnaire was also designed for companies that preferred to answer via the web. Data collection took place during the first six months of 2018. A total of 285 questionnaires were received, including 29 incomplete questionnaires that were discarded for the objective of this study. Thus, a total of 256 (9.7%) valid questionnaires were obtained. This response rate is similar to that of other works with comparable objectives published in high-impact journals (Qrunfleh & Tarafdar, 2013; Rojo *et al*., 2016). The sample covers a variety of manufacturing sectors, and the distribution of companies among sectors in the sample is similar to the distribution in the population (see Appendix A). This implies that the sample is representative of the population and appropriate for covering the objectives and guaranteeing the reliability of the results.

4.2. Non-response and common-method bias

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To analyze whether non-response could be an issue in this study, we compared data (gathered from SABI) from previous years on annual sales and the number of employees in the responding companies and the population, and no significant differences were found. In line with the Armstrong and Overton (1977) recommendations, response bias was also tested by comparing early and late responses. Neither the t-tests nor a comparison of the telephone survey and web questionnaire responses revealed any statistically significant differences for any of the variables in the questionnaire.

We sought to mitigate common method bias by following the recommendations proposed by Podsakoff *et al*. (2003). Ex-ante, as the questionnaire was divided into two distinct parts, two knowledgeable informants were used per company, with I4.0-related questions responded by IT managers and the other questions by SC managers. In addition, we varied the order in which the groups of variables appeared in the questionnaires. Ex-post, the marker variable technique was used to control for common method biases by including a variable in the study that was theoretically unrelated to at least one other variable of interest (Chin *et al.*, 2012;). No significant relationship was found between the marker variable (achieving environmental goals collectively) and the constructs in the SEM model. Finally, Harman's single-factor test was conducted to assess common method bias by verifying whether the majority of the variance could be explained by a single factor (Podsakoff *et al.*, 2003). The results showed that the first factor accounted for only 17% of the variance in all cases. Accordingly, we concluded that common method bias is not a significant concern in our data.

4.3. Measures

Content validity is guaranteed as the measures have been derived from prior research on similar topics. All the items used in this study are presented in Appendix B.

Technology uncertainty was measured using a first-order reflective construct to capture the scope of the technological changes taking place in the industry (Chen and Paulraj, 2004). Respondents' agreement/disagreement was scored on a five-point Likert scale (from "strongly agree" to "strongly disagree").

LSC implementation was measured using a validated scale (Moyano-Fuentes *et al*., 2019, 2021). LSC was designed as a second-order reflective construct composed of three dimensions: (1) Tools to eliminate waste in the SC; (2) LSC operationalization (3) LSC planning. Respondents' agreement/disagreement was scored on a five-point Likert scale.

ASC implementation was measured using a first-order reflective construct adapted from previous studies (Gligor *et al.*, 2013; Qi *et al.*, 2011; Tachizawa and Gimenez, 2010). The measure included items related to the capability of the SC to make adjustments, respond to customer demands, quickly change production planning, increase short-term capacity, and speed up delivery times. Respondents' agreement/disagreement was scored on a five-point Likert scale.

I4.0 technologies were measured using a second-order reflective construct adapted from previous studies (Frank *et al.*, 2019; Rossini *et al.*, 2019). A factor analysis identified two dimensions: (1) the first dimension was called I4.0 base technologies (Frank *et al.*, 2019), while (2) the second dimension was called smart manufacturing and warehouse technologies (Ghobakhloo, 2018). Respondents were asked to indicate the extent of I4.0 technology adoption with answers on a Likert scale (from "fully adopted" to "not adopted").

Two reflective constructs were derived from prior studies (Danese *et al.*, 2012; Liu *et al.*, 2009) to measure the focal firm's operational performance: Efficiency and Delivery. Managers were requested to score their firm's efficiency in manufacturing processes and delivery performance compared to the competition's on a Likert scale (from "much higher than average" to "poor, low").

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Control variables: We also considered two control variables to mitigate for potentially omitted variable bias in our main effects and avoid endogeneity (Lu *et al*., 2018). Therefore, to address extraneous effects resulting from firm factors, we considered two characteristics that might affect firm performance: firm size and firm age (Gligor *et al.*, 2015). First, firm size was measured as the log of the number of employees. Firm age was measured by subtracting the year that the firm was founded from the year before the survey was conducted (logarithmic).

5. Data analysis and results

5.1. Measurement model

First, the model's content validity was guaranteed by the questionnaire pre-tests and the use of measures that had previously been validated. Next, scale unidimensionality was assessed through Exploratory Factor Analysis (EFA) in SPSS v.22. The constructs' reliability was assessed using factor loadings and Cronbach's alpha. In addition, Bartlett's test was carried out to check the sampling adequacy. After discarding items with loadings below 0.5, we ran a second exploratory factor analysis that showed that all the factor loadings exceeded 0.5 (see Table I) and provided significantly explained variance for each extracted factor, high values for $\chi 2$/degrees of freedom in Bartlett's sphericity test ($p < 0.05$). Furthermore, as presented in Table I, Cronbach's alpha values were above 0.6, which is considered acceptable (Nunnally and Bernstein, 1994) in line with previous papers in the SC management field (Csiki *et al.* 2023).

Lastly, EQS 6.4 was used to run a confirmatory factor analysis to test discriminant validity, convergent validity, and construct reliability. The Robust Maximum Likelihood Method was used since the level of multivariate kurtosis was significant according to Mardia's test. The robust goodness of fit statistics suggest that the fit of the model is adequate. Standardized factor loads and R^2 for each variable are presented in Table I. All the factor loadings are higher or very close to 0.5, suggesting convergent validity of the theoretical constructs.

--- Insert **Table I** ---

Additionally, Cronbach's alpha and composite reliability (CR) were assessed to ensure the reliability of the scales (see Table II). Cronbach's alpha was considered acceptable in all cases (Nunnally and Bernstein, 1994). The CR values were similarly acceptable in all cases, ranging from 0.66 to 0.86 (Nunnally and Bernstein, 1994). Average variance extracted (AVE) values for the measurement scales were above 0.5, except for ASC and Efficiency. We opted to retain all ASC and Efficiency items as the AVE value was very close to 0.5 and so did not affect content validity (Fornell and Larcker, 1981). Therefore, these values provided evidence of adequate convergent validity (Fornell and Larcker, 1981).

Finally, discriminant validity was confirmed (Fornell and Larcker, 1981) as the AVE square root was higher than the construct correlations in all cases (see Table II).

--- Insert **Table II**---

5.2. Hypothesis testing: results

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Structural equation modeling was used to test the hypothesized model in EQS software version 6.4. Overall goodness of fit indices provided satisfactory values. Figure 1 shows the results of the analysis and the model fit indices.

--- Insert **Figure 1** ---

The results (see Figure 1) show that technology uncertainty has a positive association with I4.0 technologies (.57) at a significance of $p< 0.05$ (95%). Thus, H1 is supported. The results also indicate that the use of I4.0 technologies has a positive effect on LSC implementation (.67) and ASC implementation (.31), so, hypotheses H2 and H3 are also supported. Further, LSC is confirmed to govern and positively influence efficiency performance (.24). However, there is a lack of support for the direct association between LSC and delivery performance. Therefore, H4a is supported but H4b is not. ASC implementation has a positive association with efficiency (.31) and delivery performance (.43); therefore, H5a and H5b are supported. Finally, the control variables, firm size, and firm age have no significant effect on the operational performance dimensions.

5.3. Robustness test

Finally, we checked the robustness of the results. An alternative model was estimated and their global fits were compared (Rojo *et al.*, 2016). The alternative model assumed that I4.0 base technologies directly influence operational performance dimensions, not including the two SC strategies constructs, while keeping the other relationships. A comparison between the fit indices of the baseline and the alternative model shows that the former presents a better fit, thus demonstrating that the baseline model better explains the data.

6. Discussion

This study sheds light on the role that the technological environment plays in the deployment of SC strategies. More specifically, this study explores the effects of technology uncertainty as an external contingency on the use of I4.0 technologies and responds to calls for further studies on the association between I4.0 technologies and the lean/agile SC strategies (Buer *et al.*, 2018; Raji *et al.*, 2021a). Additionally, this study extends the discussion on the impact of these two SC strategies on operational performance.

Our study's findings can be grouped into three main points. First, the paper provides evidence that the firm's perception of technology uncertainty is directly and positively related to the use of I4.0 technologies (H1), which supports interrelationships between the external technology environment and the internal technology environment. This can be explained by the fact that the use of I4.0 technologies can provide tools to enhance collaboration between SC partners and also increase the visibility of the SC, which is essential to counteract uncertainty and maintain a competitive advantage. Moreover, in contexts of technological uncertainty, manufacturing companies may be more likely to be aware of the potential benefits of technologies and choose to increase their level of deployment at the SC level. This finding is in line with the ROT argument that firms should orchestrate different assets beyond the firm itself, i.e., that they should use I4.0 technologies to support processes across the SC to leverage existing capabilities and build new capabilities. In addition, periods of greater technology turbulence usually increase the availability and reduce the costs of technological resources (Lucianetti *et al.*, 2018), which could influence managers' decisions to adopt I4.0 technologies. Hence, this study is aligned with

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previous literature about the link between the external environment and the adoption of SC technologies (Patterson *et al*., 2003; Cegielski *et al*., 2012). However, it takes a steep forward by examining the role of I4.0 and clarifying some aspects that have produced contradictory results in the past. For example, studies such as Wei *et al*. (2015) and Arnold and Voigt (2019) found that environmental uncertainty could be an inhibitor of the use of digital technologies, mainly for companies with greater risk aversion. Therefore, in the light of the ROT theory, our results highlight the role of managers in harnessing the most suitable technologies. Managers with a strong understanding of I4.0 technologies and the potential that they offer can recognize those that are best suited and coordinate their use to attain lean and agile goals.

Second, regarding the interrelationships between I4.0 and the LSC and ASC strategies, we found that the use of I4.0 technologies has a direct and positive relationship with LSC implementation (H2) and ASC implementation (H3). Thus, the results suggest that manufacturing firms can benefit from the use of I4.0 technologies to increase the ability to deal with market changes and improve the efficiency and agility of various SC operations. These outcomes confirm the role of I4.0 technologies as operant resources in the deployment of stronger SC strategies (Raji *et al*., 2021a). On the one hand, the set of I4.0 base technologies has been recognized as a powerful tool to collect and process real-time information, which ensures that SC decisions can be made based on up-to-date, reliable information (Enrique *et al.*, 2022; Frank *et al.*, 2019). On the other hand, when actively coordinated by managers, smart manufacturing and warehouse technologies can simultaneously increase the accuracy and agility of production and logistics processes.

Third, we found some interesting evidence while investigating the role of the LSC and ASC strategies in the focal firm's operational performance in terms of efficiency and delivery performance. Regarding the lean strategy, the results show a direct and positive effect on efficiency performance (H4a) but not on delivery performance (H4b). This provides insights into the different impacts that LSC can have on operational performance. While LSC can directly enhance efficiency performance (Moyano-Fuentes *et al.*, 2021), our findings show that the LSC deployment does not ensure enhanced delivery performance. This result partially contradicts previous studies (Garcia-Buendia *et al.*, 2023; Srinivasan *et al.*, 2020), which point to a positive and significant relationship between LSC and on-time deliveries. However, the literature also finds that faster deliveries are more closely related to ASC than LSC (Raji *et al.*, 2021a). This would explain why no significant result is found when the two dimensions of delivery performance (on-time delivery and faster delivery) are analyzed together. Regarding the agile strategy, the results show a direct and positive effect on efficiency performance (H5a) and delivery performance (H5b). This adds to the literature by providing the ASC's potential to lead to elevated operational performance by responding quickly and cost-effectively to market volatility.

6.1. Theoretical implications

Drawing on the CT and ROT, the theoretical framework in this research provides scholars with new insights into the relationships between the technology environment in general, SC strategies, and focal firm delivery and efficiency performance. Particularly, this study adds to the literature by revealing the SC response to external factors, i.e., technology turbulence. In doing so, it extends and complements previous studies (Garcia-Buendia *et al.*, 2023; Raji et al., 2021a) in the manufacturing realm. For example, Garcia-Buendia et al. (2023) report that technological uncertainty triggers advancements in LSC management. However, they also note that the adoption of I4.0 technologies has significant implications for LSC, yet this aspect has not been empirically analyzed. Addressing this gap, our study offers a holistic view of the most prominent digital technologies for manufacturing companies and conceptualizes LSC and ASC as comprehensive measures. This approach goes beyond the previous literature, which focused on one-to-one relationships between specific technologies and LSC/ASC practices (Raji et al., 2021a, 2021b).

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Additionally, we distinguish between two aspects of operational performance - delivery and efficiency - by treating them as separate constructs. This enables us to explore the individual impacts of LSC and ASC on each aspect of operational performance, providing a nuanced understanding of their effects.

6.2. Managerial implications

Since the number of technological innovations has increased dramatically in recent years and manufacturing companies and their SCs cannot adopt all of these new technologies, structuring, bundling, and leveraging the portfolio of technologies is a key challenge for SC managers (Autry *et al.*, 2010; Sirmon *et al.*, 2011). Therefore, from a managerial perspective, our results show that I4.0 technologies positively affect the development of the LSC strategy and the ASC strategy. I4.0 technologies can be an effective mechanism for deploying lean and agile practices at the SC level and, consequently, enable SCs to become more effective. The outcome of the LSC strategy will be an operational performance gain in terms of efficiency performance. Meanwhile, ASC implementation can significantly increase not only the service level offered to customers in the delivery system but also efficiency performance. Overall, this work shows that managers must carry out a technological vigilance task that allows them, on the one hand, to recognize technological uncertainty as a contingent factor and, on the other hand, to identify new disruptive technologies to deploy in their SCs to achieve a competitive advantage based on the LSC and ASC strategies.

7. Concluding remarks, limitations, and further research

Based on hypothesis testing and supported by CT and ROT, this study offers original contributions to theoretical debates and implications for practitioners. It confirms the positive link between I4.0 and two SC strategies in the context of technological uncertainty in which the role of managers in organizing and coordinating resources is critical for improving operational performance.

This study has some inherent limitations. First, we acknowledge that extrapolation to other contexts may be limited by the study having focused on focal manufacturing companies with at least 50 employees in a single country (Spain). Another limitation is related to the fact that we have focused on a single point in time, during a period when the level of I4.0 maturity in SCs was, in general, low. Future studies should adopt a longitudinal and intercountry approach to investigate the effect of the degree of progress in the adoption and use of I4.0 technologies. Furthermore, future research could also study the role played by small companies (not considered in this study) that participate in the SCs of large companies. These small companies are also receiving pressures to incorporate I4.0 technologies, otherwise they may risk falling behind. In this regard, it would be interesting for public administrations and professional associations to be aware of this threat and facilitate the implementation of these technologies in small companies through financial support, training and technological advice. Moreover, the group of I4.0 technologies that was studied was limited. Although the studied set of technologies can play a relevant role in SCs, future researchers are encouraged to include new I4.0 developments. In addition, the impact on costs has not been included directly but indirectly through efficiency gains. In the future, financial and cost measures should be incorporated to identify the consequences of using Industry 4.0 in the implementation of SC strategies.

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Table I. Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA)

Factor		Variable	EFA				CFA	
			Standardized factor loading	Cronbach's alpha	Bartlett test	% Explained variance	Standardized factor loading	R^2
Technology Uncertainty		TU-1	0.87	0.79	Bartlett $\chi2$= 310.422 df= 6 Sig.= 0.000	62.290	0.88	0.77
		TU-2	0.75				0.65	0.42
		TU-3	0.74				0.61	0.37
		TU-4	0.79				0.72	0.52
I4.0 technologies	I4.0 base technologies	IE-1	0.68	0.71	Bartlett $\chi2$= 264.391 df= 15 Sig.= 0.000	58.927	0.49	0.24
		IE-2	0.84				0.77	0.66
		IE-3	0.79				0.72	0.47
	Smart manufacturing /warehouse technologies	IE-4	0.69				0.47	0.22
		IE-5	0.80				0.77	0.60
		IE-6	0.70				0.53	0.28
		IE-7*						
LSC	Tooling	LS-1	0.88	0.69	Bartlett $\chi2$= 249.484 df= 15 Sig.= 0.000	72.298	0.61	0.38
		LS-2	0.84				0.88	0.78
	Operation-alization	LS-3	0.81				0.59	0.35
		LS-4	0.77				0.64	0.41
		LS-5*						
	Planning	LS-6	0.60				0.67	0.45
		LS-7	0.90				0.50	0.25
		LS-8*						
ASC		AS-1	0.64	0.79	Bartlett $\chi2$= 375.814 df= 10 Sig.= 0.000	54.708	0.50	0.25
		AS-2	0.75				0.65	0.42
		AS-3	0.73				0.68	0.46
		AS-4	0.79				0.76	0.58
		AS-5	0.78				0.68	0.47
Efficiency		OP-1	0.69	0.62	Bartlett $\chi2$= 93.391 df= 3 Sig.= 0.000	57.037	0.48	0.23
		OP-2	0.82				0.84	0.71
		OP-3	0.75				0.53	0.28
Delivery		OP-4	0.93	0.79	Bartlett $\chi2$= 191.911 df=1 Sig.= 0.000	86.433	0.74	0.55
		OP-5	0.93				0.98	0.97

Note: *Items excluded after the first exploratory factor analysis

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Table II. Convergent and discriminant validity results

Research constructs	AVE	CR	α	Mean	SD	Correlation matrix 1	2	3	4	5	6
1. Technology Uncertainty	.52	.81	.80	3.10	.90	*0.721*					
2. I4.0 technologies	.49	.66	.69	2.04	.87	.264**	*0.700*				
3. LSC	.57	.79	.69	3.00	.78	.275**	.267**	*0.755*			
4. ASC	.44	.80	.79	3.86	.70	.170**	.021	.239**	*0.663*		
5. Efficiency	.41	.66	.63	3.44	.68	.145*	.046	.232**	.236**	*0.640*	
6. Delivery	.75	.86	.84	3.91	.81	.027	-.060	.050	.329**	.373**	*0.866*

Notes: The AVE square root can be seen in the main diagonal in italics. *Significant at 0.05; **Significant at 0.01.

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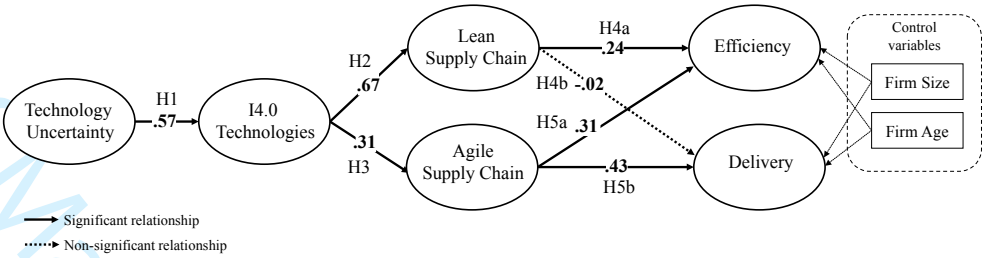
Figure 1. Structural baseline model results



Model	$S-B$ X_2	df	$S-B$ X_2/ df	RMSEA	CFI	IFI	NNFI	RHO
Baseline model	593.0390	336	1.765	0.056	0.843	0.847	0.823	0.869

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APPENDIX A - Population and sample distribution by sector

Sector	Firms in population	%	Firms in sample	%	Response Rate
Food products and tobacco	543	20.49%	46	17.97%	8.5%
Chemical and pharmaceutical products	422	15.92%	46	17.97%	10.9%
Manufacture of metal 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	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	**2,650**	**100%**	**256**	**100%**	**9.7%**

Appendix B – Survey items

Survey items		References
	Technology Uncertainty	Chen and Paulraj (2004)
TU-1	Our industry is characterized by rapidly changing technology.	
TU-2	If we don't keep up with changes in technology, it will be difficult for us to remain competitive.	
TU-3	The rate of process obsolescence is high in our industry.	
TU-4	The production technology changes frequently and sufficiently.	
	I4.0 technologies	Frank *et al.* (2019); Rossini *et al.* (2019)
	Industry 4.0 base technologies:	
IE-1	Cloud Computing	
IE-2	Big Data Analytics	
IE-3	Internet of Things	
	Smart manufacturing and warehouse technologies:	
IE-4	Radio frequency identification	
IE-5	Advanced robotics	
IE-6	Additive manufacturing	
IE-7	Blockchain	
	Lean Supply Chain	Moyano-Fuentes *et al.* (2019); Moyano-Fuentes *et al.* (2021)
	Tools to eliminate waste in the SC:	
LS-1	Value stream mapping is used to identify and eliminate waste throughout our supply chain	
LS-2	Our supply chain uses lean manufacturing techniques (such as pull flow, Kanban systems, and setup time reduction)	
	LSC operationalization:	
LS-3	Our supply chain generates high stock turnover and minimizes inventory	
LS-4	Process and product standardization is a common practice in our supply chain	
LS-5	Our supply chain delivers in small lot sizes	
	LSC planning:	
LS-6	Our supply chain does long-term forecasting of customer demands and only focuses on the current market segments	

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LS-7	In our supply chain, the strategy for handling uncertainty consists of using queues and buffers to protect sub-processes	
LS-8	Our supply chain structure seldom changes	
	Agile Supply Chain	Gligor *et al.* (2013); Qi *et al.* (2011); Tachizawa and Gimenez (2010)
AS-1	Our supply chain can make the adjustments to order specifications requested by our customers	
AS-2	Production planning has the ability to respond quickly to varying customer needs	
AS-3	Our supply chain can increase short-term capacity as needed	
AS-4	Our supply chain can adjust/expedite its delivery lead times	
AS-5	Our supply chain responds to customer demand	
	Operational Performance	Danese *et al.* (2012); Liu *et al.* (2009)
	Efficiency:	
OP-1	Unit cost of manufacturing	
OP-2	Inventory turnover	
OP-3	Cycle time (from raw materials to delivery)	
	Delivery:	
OP-4	On-time delivery performance	
OP-5	Fast delivery	

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