Supply chain 4.0 ambidexterity and lean supply chain management: interrelationships and effect on the focal firm's operational performance

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Abstract

Purpose – The purpose of this paper is twofold: firstly, to provide a measurement instrument for supply chain 4.0 ambidexterity by applying the theoretical perspective of ambidexterity to advance Industry 4.0; secondly, to empirically analyse how supply chain 4.0 ambidexterity and lean supply chain management contribute to enhancing the focal firm's operational performance.

Design/methodology/approach – Empirical results are obtained through analysis of survey data from a sample of 209 Spanish focal firms in industrial sectors in an intermediate position in the supply chain. Structural equation modelling was performed to test the three proposed hypotheses.

Findings – Drawing on resource orchestration theory and the relational resource-based view, this study empirically demonstrates the full mediating role of lean supply chain management in the relationship between supply chain 4.0 ambidexterity and the focal firm's operational performance.

Originality/value – Although recent research has highlighted the pertinence of applying inter-organisational ambidexterity to foster Industry 4.0 (Hofmann *et al.*, 2019), to the best of the authors' knowledge, this is one of the first studies to apply this theoretical framework to explain the transition to supply chain 4.0. In addition, to date, to the best of the authors' knowledge, no study exists that has developed a measurement scale and used this concept in an empirical analysis to advance theory development.

Keywords Supply chain 4.0 ambidexterity, Operational performance, Lean supply chain management, Industry 4.0 technologies, Resource orchestration theory

Paper type Research paper

1. Introduction

The transition towards the adoption of Industry 4.0 technologies is essential for supply chains to survive in dynamic and hypercompetitive environments (Ghadge *et al.*, 2020). In digital transition, traditional and emerging information technology (IT) are used together to obtain the advantages that they provide, thanks to internet technologies and the connectivity that these technologies enable (Ghobakhloo, 2018, 2019). Many Industry 4.0 technologies are nascent (Núñez-Merino *et al.*, 2020; Oliveira-Dias *et al.*, 2022a), so the effects of their use are still unclear. This is why companies that venture to use these emerging technologies – big data, cloud computing, the Internet of Things (IoT), artificial intelligence (AI) and virtual and augmented reality (VR and AR), among others – in their supply chains do so for exploration. The adoption of these emerging technologies is not an "all or nothing" matter. On the contrary, companies present different degrees of implementation of such technologies in their supply chains as they are exploring these novel technologies. Taken all the above together, digital transition involves the exploration of emerging technologies and the exploitation of existing mature technologies.

Along these lines, the literature has highlighted the pertinence of applying the theoretical lens of inter-organisational ambidexterity to advance Industry 4.0 and supply chain management (SCM) development (Hofmann *et al.*, 2019). The assumption is that under ambidexterity firms capable of managing both exploratory and exploitative activities will be the most successful (Tushman and O'Reilly, 1996). Specifically, an ambidextrous SC 4.0 is defined as the ability of companies to:

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Supply Chain Management: An International Journal
28/7 (2023) 112–128
Emerald Publishing Limited [ISSN 1359-8546]
[DOI 10.1108/SCM-05-2023-0274]

Funding: The authors acknowledge the financial support of Spanish Ministry of Science, Innovation and Universities (Research Project PID2019-106577GB-I00 by MCIN/AEI/10.13039/501100011033).

Received 31 May 2023
Revised 21 September 2023
1 November 2023
Accepted 2 November 2023

> Simultaneously exploit current SCM capabilities and resources along the supply chain – supply chain 4.0 exploitation – as well as explore new technological opportunities coming along with Industry 4.0 components – supply chain 4.0 exploitation – and manage the tensions arising from pursuing both (Hofmann *et al.*, 2019, p. 950).

This definition reconciles the need to combine the technology strategy with the supply chain strategy (Frederico *et al.*, 2020) and highlights the importance of achieving a balance between supply chain 4.0 (SC4.0) exploration and exploitation in managerial practice. Given the emerging nature of novel I4.0 technologies (Oliveira-Dias *et al.*, 2022a), their implementation at the supply chain level involves search, taking risks, experimentation, discovery and innovation by companies, activities that the literature includes under the label of exploration (Azadegan and Dooley, 2010; March, 1991). We, therefore, posit that companies explore emerging I4.0 technologies through their implementation. As such, this work extends the line of reasoning of studies such as Rintala *et al.* (2022), which propose that exploration in a supply chain context can be achieved by investing in new technologies. For its part, SC4.0 exploitation refers to the level at which an organisation exploits its current supply chain competencies and mature I4.0 technologies, among other supply chain resources.

Recent studies underline the need for further research on an ambidextrous perspective of SCM 4.0 (Benzidia *et al.*, 2021; Hofmann *et al.*, 2019). This study is among the first to respond to this need for research by proposing a measurement scale for SC4.0 ambidexterity. Ambidextrous SC4.0 highlights the need that organisations have to achieve a balance between their ability to exploit their existing supply chain competencies and technologies and explore others that are only now emerging. So, this study contributes an empirical measure to address the concept of SC4.0 ambidexterity.

However, the mere acquisition of technology does not lead to an improvement in performance and must be supported by a continuous improvement mindset (Tortorella *et al.*, 2019a) and firms' resources and capabilities such as the firm's management system (Powell and Dent-Micallef, 1997). This study proposes that lean supply chain management (LSCM) is a management system that complements the use of technologies in the supply chain. LSCM consists of the deployment of lean practices along the supply chain (Moyano-Fuentes *et al.*, 2019). To obtain a competitive advantage, it must be coupled with the use of ITs in the supply chain and management systems. In this way, we contribute to a stream of literature that recognises the need to study how Industry 4.0 is integrated with other management approaches (Tortorella *et al.*, 2017). The current literature on this relationship has demonstrated the complementarity of LSCM and digitalisation (Núñez-Merino *et al.*, 2020; Oliveira-Dias *et al.*, 2022b). Despite the interest sparked in the scientific community, the need still exists for empirical studies to clarify the mechanisms with which LSCM adoption supports Industry 4.0 and that consider a broader variety of technologies and sectors in their analyses (Núñez-Merino *et al.*, 2020; Tortorella *et al.*, 2019a). The present work intends to cover this gap by analysing LSCM implementation as a mechanism that enables to benefit from both exploring and exploiting SC4.0 resources and capabilities. This paper examines whether the effect of resource investment – SC4.0 ambidexterity – on performance – operational performance – is mediated by managerial actions – LSCM, which is a key part of resource orchestration theory – ROT (Miao *et al.*, 2018). Our model is grounded in ROT (Hitt *et al.*, 2016; Sirmon *et al.*, 2007) as a theoretical framework that can help supply chain managers to foresee the combination of explored and exploited SC4.0 resources and capabilities that generate a competitive advantage. ROT can be especially helpful for understanding how LSCM needs a particular set of SC4.0 resources and capabilities to improve operational performance. Our model is also based on the relational resource-based view (RRBV; Arya and Lin, 2007) to support the relationship between LSCM and operational performance, as this theoretical framework asserts that capabilities at the supply chain level contribute to greater performance.

A study of this type is especially important for supply chain managers and researchers. The main goal is to provide a measurement scale for SC4.0 ambidexterity and study how its impact on the focal firm's operational performance is mediated by LSCM. This work contributes to furthering research on Industry 4.0 and SCM.

This paper is organised as follows: Section 2 presents key concepts and summarises the theoretical framework. Section 3 sets out the hypothesis development. Sections 4 and 5 include the methodology and an analysis of the empirical findings. Section 6 contains a discussion of the results, and Section 7 presents the conclusions, the implications for supply chain theory and managers, limitations and future research lines.

2. Theoretical framework

2.1 Resource orchestration theory and the relational resource-based view

ROT is a theoretical lens that combines an extended resource-based view and dynamic capabilities theory, and in doing so overcomes the limitations of both (Sirmon *et al.*, 2011). Neither of these last two theoretical frameworks identifies how resources and capabilities can be developed in firms (Rojo *et al.*, 2020a) or which combination of resources enable to achieve competitive advantage (Liu *et al.*, 2016). ROT covers this gap by emphasising the key character of managers as orchestra conductors who identify, bundle and leverage resources to build new resources that, *per se*, do not create competitive advantage (Helfat *et al.*, 2007; Sirmon *et al.*, 2007). Bundling resources implies their integration to form capabilities and leveraging them involves putting firm capabilities into practice to achieve competitive advantage for the firm (Sirmon *et al.*, 2011). If capabilities are difficult to imitate, it is even more difficult to imitate how they are coordinated and synchronised (Hitt *et al.*, 2016). ROT (Helfat *et al.*, 2007; Sirmon *et al.*, 2007, 2011) can be used to propose that the implementation of lean along the supply chain depends on the ability of the focal firm's managers to explore and exploit supply chain resources to advance the implementation of SC4.0 in the pursuit of better coordination and integration. Under this perspective, managers play the role of orchestra conductors by structuring and bundling different resources – internal as well as external – through the supply chain (Wong *et al.*, 2018). Structuring involves acquiring – purchasing resources; accumulating – internal development of resources; and divesting – assessment of existing resources (Sirmon *et al.*, 2007, 2011). Bundling includes stabilising – incrementally improving existing

Supply Chain Management: An International Journal
Volume 28 · Number 7 · 2023 · 112–128

resources; enriching – developing existing capabilities; and pioneering – creating new capabilities (Sirmon *et al.*, 2007, 2011).

For its part, RRBV is also a recent extension of resources-based theory (Lavie, 2006; Prajogo *et al.*, 2016) that integrates the basic principles of resource-based theory and relational network theory. It analyses inter-organisational relationships to explain how cooperation and collaboration between members of a network of firms obtain a competitive advantage when sharing resources. It proposes that the established relationships are extremely difficult to imitate and represent competitive advantage (Lavie, 2006). This theoretical framework has been used to analyse resource complementarity when implementing lean at a SC level (Iyer *et al.*, 2019; Moyano-Fuentes *et al.*, 2021; Yildiz Çankaya, 2020, among others). This is why, following the line of reasoning of the recent study by Garcia-Buendia *et al.* (2023), this theoretical lens is used to explain how the exchange of resources and capabilities between supply chain members enabled by implementing lean at the supply chain level can translate into better performance and the achievement of competitive advantage. In addition, this theoretical framework maintains that there are capabilities at a supply chain level, i.e. supply chain integration, that contribute to better performance. Based on this, we also conclude that lean at the supply chain level generates capabilities – i.e. supply chain integration – that ultimately improve operational performance.

2.2 Supply chain 4.0 ambidexterity: resource structuring for lean supply chain management

Recent studies highlight the role that ambidexterity plays under the supply chain and Industry 4.0 perspective. We find studies that adopt the perspective of ambidexterity to analyse the positive effects of the adoption of Industry 4.0 technologies, e.g. additive manufacturing and blockchain technology (Belhadi *et al.*, 2022b; Benzidia *et al.*, 2021) and others that have found that supply chain ambidexterity reinforces SC4.0 maturity (Alamshah and Yunus, 2022). The study by Belhadi *et al.* (2022a) supports a positive relationship between Industry 4.0 adoption and ambidexterity at the internal level. In addition, the studies by Gastaldi *et al.* (2018, 2022) draw attention to the role that digital transformation plays in reinforcing organisational capabilities and, thus, facilitating the achievement of ambidexterity at the organisational level. In this work, we go one step further by operationalising the definition of SC4.0 ambidexterity proposed by Hofmann *et al.* (2019) with the addition of a new measure.

We have broken down the definition of SC4.0 ambidexterity into two clearly differentiated elements, SC4.0 exploration and exploitation. SC4.0 exploration refers to the degree of use in the supply chain of Industry 4.0 technologies such as Industry 4.0 base technologies – cloud computing, big data and IoT – and smart working and manufacturing technologies – AI, AR and VR (Frank *et al.*, 2019). This conceptualisation extends the line of reasoning of studies such as Rintala *et al.* (2022), which propose that exploration in a supply chain context can be achieved by investing in new technologies. SC4.0 exploitation refers to the degree of exploitation of current supply chain capabilities and resources along the supply chain. Mature Industry 4.0 technologies are included as internal resources. This concept involves reducing redundancies in existing processes, leveraging and improving existing technologies and developing stronger competencies in existing supply chain processes. Therefore, SC4.0 exploitation focuses on clearly-defined, short-term, measurable targets: reliability, risk reduction and the overall efficiency of supply chains (Partanen *et al.*, 2020). The operationalisation of SC4.0 ambidexterity follows the line of reasoning of a stream of literature that posits that under Industry 4.0 we find both emerging and more traditional technologies (Núñez-Merino *et al.*, 2020). We conceive SC4.0 ambidexterity as the firm's ability to explore SC4.0 resources while exploiting its current resources, i.e. mature technologies, as the manager's ability to integrate and reconfigure both the firm's and the SC4.0 partners' resources to obtain new resources and capabilities through exploration and exploitation in a fashion akin to a conductor conducting an orchestra.

2.3 Lean supply chain management implementation: orchestration of supply chain resources

Lean supply chain is a set of organisations directly linked by upstream and downstream flows of goods, services, information and finances that work together to reduce cost and waste by efficiently and effectively pulling what is required to meet the needs of individual customers (Vitasek *et al.*, 2005). LSCM consists of applying lean principles inter-organisationally at the supply chain level.

The implementation of LSCM has recently sparked the interest of the scientific community and has been linked to improvements in organisational efficiency (Tortorella *et al.*, 2017) and SC4.0 digitalisation (Núñez-Merino *et al.*, 2020). Regarding the impact of LSCM implementation on the focal firm's operational performance, there is still an ongoing debate in the literature as recent systematic literature review studies show (Oliveira-Dias *et al.*, 2022b). In fact, there is a branch of literature that presents contradictory results when analysing the relationship between LSCM and operational performance (Danese *et al.*, 2012; Qamar *et al.*, 2018; Tortorella *et al.*, 2018a, 2018b), which indicates a potential negative relationship between the two. However, Garcia-Buendia *et al.* (2023) found that LSCM has a positive impact on operational performance and plays an essential role in achieving competitive advantage. We contribute to clarifying this debate by adopting a global perspective when analysing LSCM. Likewise, there is a stream of that explores the role of ambidexterity in the context of Industry 4.0 and lean at the analytical level of the organisation (Dixit *et al.*, 2022; Vilkas *et al.*, 2023). Specifically, it has been found that ambidextrous innovation capabilities play a full mediating role in the relationship between lean manufacturing and Industry 4.0 adoption (Dixit *et al.*, 2022) and that the organisational ambidexterity perspective can be adopted when analysing the interrelationship between lean and agile capabilities (Vilkas *et al.*, 2023). We contribute to this line of research by analysing how Industry 4.0 and ambidexterity contribute to the implementation of LSCM. Our work differs from previous studies in that it is aimed at the analytical level of the supply chain and seeks to clarify how to implement LSCM, a stream of research that still needs further study (Garcia-Buendia *et al.*, 2021). For this, we use ROT as a theoretical lens. As a result, LSCM can be envisaged as the orchestration of supply chain resources and partners to achieve LSCM implementation.

3. Hypotheses development

3.1 The effect of supply chain 4.0 ambidexterity on lean supply chain management implementation

SC4.0 exploration involves the employment of Industry 4.0 technologies such as cloud computing, big data, IoT, VR, AR and AI. We follow a stream of literature that supports complementarity between Industry 4.0 technologies and LSCM (Núñez-Merino *et al.*, 2020; Oliveira-Dias *et al.*, 2022b; Rossini *et al.*, 2019). Along these lines, recent studies have found that improvement at the supply chain level is gained through the coupled implementation of SC4.0 exploration and LSCM practices (Tortorella *et al.*, 2019a). LSCM involves greater coordination and management of physical, information and financial flows between the various agents involved (Moyano-Fuentes *et al.*, 2019) and can be facilitated by structuring Industry 4.0 technologies (Sharma and Kulkarni, 2016).

This relationship can be analysed by isolating each technology that is susceptible to being selected. In general terms, the greatest support effect of Industry 4.0 technologies on LSCM has been found when IoT, big data and cloud computing are chosen, three of the six technologies that we analyse in our study. Firstly, cloud computing advantages are in line with LSCM objectives, i.e. lower costs and better resource exploitation, (Núñez-Merino *et al.*, 2020). Cloud computing also allows a greater integration of physical, information and financial supply chain flows (Novais *et al.*, 2019) leading to greater company's efficiency. Meanwhile, physical integration reinforces just-in-time (JIT) deliveries (Novais *et al.*, 2020). Information integration allows real-time process monitoring and decision-making (Rosin *et al.*, 2019), reducing or even preventing the bullwhip effect (Hofmann and Rüsch, 2017; Xu *et al.*, 2018). In addition, it can enable collaboration across the LSC due to the use of more modern communication tools (Ciano *et al.*, 2020; Hofmann and Rüsch, 2017; Sanders *et al.*, 2016; Xu *et al.*, 2018).

The literature has pointed towards the role big data plays in enabling communication between automated systems and the LSCM approach to achieve efficiency and in LSCM visualisation and metrics analysis (Núñez-Merino *et al.*, 2020). This technology increases the efficiency of the decision system (Roy and Roy, 2019). It also contributes to waste elimination by identifying the historical sources of waste (Rosin *et al.*, 2019).

IoT is important for LSCM, as it brings product visibility and information integration (Xu *et al.*, 2018). IoT facilitates real-time information sharing and, thus, enhances supply chain collaboration (Tiwari, 2020), agility and flexibility. In addition, this technology facilitates on-time product delivery, transport route optimisation and if it is implemented in article labelling, it controls and smartly dispatches orders following an improved pull system that is very useful for JIT suppliers – e-kanban (Sanders *et al.*, 2016). The study by Ciano *et al.* (2020) shows that IoT reduces set-up time and the implementation of a quality practice using information technologies prevents any errors (Poka-Yoke 4.0).

VR applied to LSCM enables complex processes to be learned with different agents involved (Li *et al.*, 2018). Likewise, the study by Rauch *et al.* (2016) points to the specific use of VR to achieve a lean-accelerated time-to-market with fewer product development costs. Along these lines, the study by Tortorella *et al.* (2020) demonstrates the influence that this technology has on lean value stream design. The study by Rosin *et al.* (2019) states that it has the potential to identify production problems by simulating a production system and to optimise the production system as well as to provide visual data.

AR can influence the principle of continuous improvement by helping to picture value stream mapping (VSM) and value chain mapping to stabilise and standardise the processes and the visual data supply (Rosin *et al.*, 2019).

Finally, the literature has pointed to the role that AI plays in decision-making to meet LSCM objectives (Liu *et al.*, 2013), such as waste reduction. This technology can be applied to improve JIT deliveries (Güner *et al.*, 2012) and analyse traffic information to enable order location and the management of load status in transport (Hofmann and Rüsch, 2017). In addition, it can also help to eliminate waste by reducing any unnecessary transportation (Rosin *et al.*, 2019).

Once we have isolated each technology, we are able to evaluate their joint effects. It is remarkable that most of technologies drive greater coordination, collaboration (Rosin *et al.*, 2019; Tiwari, 2020) and integration in the supply chain, features that are intrinsically linked to LSCM implementation (Moyano-Fuentes *et al.*, 2021). In fact, technologies such as cloud computing applied in a supply chain context generate new capabilities such as supply chain integration "by enabling the company to identify, capture, store and manage information both internally and externally and provide additional capabilities to manage physical, information and financial flows" (Novais *et al.*, 2020, p. 639). Structuring – the investment decision – would help to implement LSCM and achieve its objectives as Industry 4.0 technologies could be used to integrate the supply chain.

However, ITs cannot create competitive advantage *per se*, as the studies by De Powell and Dent-Micallef (1997) and Tortorella *et al.* (2019a) show. As ROT suggests, simply making an investment in technology is not enough to achieve success. Firms may invest in Industry 4.0 technologies, but investment levels are easy to copy and do not meet the criteria for resources that generate advantages (Sramek *et al.*, 2015). Specifically, implementing SC4.0 exploration on:

> Ill-structured processes can jeopardise performance. In this sense, while Industry 4.0 adoption – measured by the degree of implementation of Industry 4.0 technologies – can change the nature of LSCM by leading companies to superior levels of excellence, it may also raise the need for a more mature continuous improvement mindset within organisations to avoid the illusion of achieving higher performance levels through the simple acquisition of technology and not by actually changing managerial habits and practices (Tortorella *et al.*, 2019a, p. 309).

Therefore, the link between SC4.0 exploration and LSCM implementation is dependent on managers' decisions to invest in one or another technology and combine them with SC4.0 exploitation as it put into practice a continuous improvement mindset. In terms of ROT, SC4.0 exploitation represents the structuring and bundling of current supply chain resources and capabilities. SC4.0 exploitation is measured as the managerial effort to reduce duplicities – structuring – and to leverage and improve mature Industry 4.0 technologies and supply chain competences – structuring and bundling. As the implementation of LSCM entails improving quality and a continuous improvement process at the supply chain level, this can be achieved through structuring and bundling current supply chain resources and capabilities – SC4.0 exploitation (Moyano-Fuentes *et al.*, 2019). In addition, the search for overall supply chain efficiency is the main goal of SC4.0 exploitation, which is in line with LSCM's continuous focus on eliminating inefficiencies (Partanen *et al.*, 2020). Combining IT with other resources and capabilities – SC4.0 exploitation – could also generate other capabilities – i.e. supply chain integration (Novais *et al.*, 2020) – that go hand in hand with LSCM (Ahmed *et al.*, 2019). In sum, SC4.0 exploration should thus be complemented with SC4.0 exploitation to prompt supply chain members to feel the need to cooperate and integrate through the supply chain to find a strategy – LSCM – that gives them a competitive advantage. Finally, we have to bear in mind that combining SC4.0 exploration and exploitation could be hard to imitate by competitors due to their complementarity. We extend the line of reasoning of Hitt *et al.* (2016) by proposing that LSCM activities require some particular resources and capabilities: SC4.0 exploration and SC4.0 exploitation. When managing the exploration and exploitation strategies, an ambidextrous perspective of SC4.0 mitigates the risk of over-reliance on one or the other to advance the implementation of LSCM (Ojha *et al.*, 2018).

Based on the above, we concur with Taylor and Helfat (2009, p. 719), who state that "without the ambidexterity required to link the new with the old, the end result may be a technological advance that fails to meet market needs"; managers can advance LSCM implementation by orchestrating the resources inherent in SC4.0 ambidexterity and bundling them into greater supply chain integration and coordination to reduce waste. So, both SC4.0 exploration and exploitation are needed to implement LSCM.

As a result, we propose the following hypothesis:

H1. Supply chain 4.0 ambidexterity has a direct positive effect on lean supply chain management implementation.

3.2 Lean supply chain management and focal firm's operational performance

We propose that LSCM implementation leads to an improvement in a focal firm's operational performance that includes reductions in cost, inventory turnover and cycle time. There is an ongoing debate around the proposed relationship, as several authors have found contradictory results (Danese *et al.*, 2012; Oliveira-Dias *et al.*, 2022b). This debate can be explained by the different and incomplete approaches used to measure LSCM. We follow the research stream that has found a positive relationship between the adoption of LSCM practices and an operational performance improvement (Chu *et al.*, 2021; Moyano-Fuentes *et al.*, 2019; Tortorella *et al.*, 2019b). We follow a global perspective when analysing LSCM, as in the study by Moyano-Fuentes *et al.* (2021).

The systematic literature reviews conducted by Núñez-Merino *et al.* (2020) and Oliveira-Dias *et al.* (2022b) highlight that several authors have demonstrated the association between LSCM and the focal firm's operational performance at the internal and the supply chain levels. Specifically, the study by Moyano-Fuentes *et al.* (2021) maintains that the main goal of LSCM is to improve the focal firm's operational performance, specifically, its product delivery results, as it integrates resources to share information, coordinates processes and activities along the supply chain and puts into practice a continuous improvement process throughout the supply chain. The study by Carvalho *et al.* (2017) maintains that lean techniques deliver cost reductions and efficiency.

Lean supply chain tooling contributes to waste reduction which, in turn, delivers cost reductions and improves efficiency (Danese *et al.*, 2012; Garcia-Buendia *et al.*, 2021). The study by Wee and Wu (2009) found that deploying VSM, the basic LSCM tool, along the SC, goes hand in hand with cost and lead time reductions. Reduction in lead time leads to efficiency (Sharma *et al.*, 2021). Also, the study by Ruiz-Benitez *et al.* (2019) identified eight LSCM practices that reduced costs. The use of lean manufacturing techniques such as Kanban cards and pull flow systems contributes to cost reduction (Rossini and Portioli-Staudacher, 2016). Similarly, reducing the inventory level is linked to inventory cost reduction (Hooshang, 2010).

Lean supply chain operationalisation and, specifically, process and product standardisation reduce variability which can translate into cost reductions (Moyano-Fuentes *et al.*, 2021). For their part, Apte and Goh (2004) maintain that reductions in variability in conjunction with LSCM practices minimise cycle time and contribute to an increase in efficiency.

Finally, lean supply chain planning can enhance the focal firm's efficiency by reducing manufacturing cost, accelerating stock turnover and minimising cycle time, as it implies long-term customer demand forecasting and a focus on the current market segment (Apte and Goh, 2004; Qrunfleh and Tarafdar, 2013). Reductions in customer demand and production lead time uncertainty and variability can be obtained by using queues as buffers to protect sub-processes along the supply chain (Moyano-Fuentes *et al.*, 2021). Therefore, we propose verifying the following hypothesis:

H2. The higher the level of lean supply chain management implementation, the better the focal firm's operational performance.

3.3 Mediating effect of lean supply chain management implementation in the supply chain 4.0 ambidexterity–focal firm's operational performance relationship: leveraging capabilities for focal firm's operational performance

Drawing on ROT (Sirmon *et al.*, 2011) and the RRBV (Arya and Lin, 2007), this study proposes that SC4.0 ambidexterity influences the focal firm's operational performance through the implementation of LSCM.

LSCM implementation could act as the mechanism that leverages the abilities to explore and exploit inherent in SC4.0 ambidexterity (Sirmon *et al.*, 2011) and the integration capability that they generate. ROT studies the "resources-something happens-performance" relationship (Sramek *et al.*, 2015, p. 247).

In our case, "something happens" refers to how LSCM effectively manages and integrates SC4.0 exploration and exploitation jointly across the supply chain. Specifically, the leveraging mechanism is put into action. Leveraging capabilities includes mobilising, coordinating and deploying (Sirmon *et al.*, 2007). On the one hand, mobilising and coordinating implies the integration of resources into an effective capability configuration; on the other, deploying is the effective use of capability configurations (Helfat *et al.*, 2007). LSCM may play an important role in resource orchestration, as managers will prepare the focal company to generate value from SC4.0 ambidexterity. In turn, SC4.0 ambidexterity provides the mobilising vision to use internal and external supply chain resources (Zeng and Khan, 2019) to achieve supply chain integration and to deploy this capability – supply chain integration. Along these lines, the main goal of LSCM is the integration of resources to "share information and coordinate processes and activities along the supply chain" (Moyano-Fuentes *et al.*, 2021, p. 67). Following Miao *et al.* (2018, p. 136):

> A central tenet of the resource orchestration theory is that the effect of resource investment on firm performance is mediated by managerial actions in selecting, combining, and leveraging complementary resources which often entails gaining access to needed resources from partner firms to exploit opportunities.

In this context, LSCM allows the focal firm to tap into external supply chain resources as it engenders supply chain collaboration, cooperation and integration to reduce waste and costs (Iyer *et al.*, 2019). The theoretical framework of the RRBV (Arya and Lin, 2007) can be used to explain the complementary role LSCM plays in improving the focal firm's operational performance (Moyano-Fuentes *et al.*, 2021). As the study by Arya and Lin (2007) asserts, inter-organisational linkages drive access to partner resources. When resources spread beyond the focal firm's boundaries, managers can integrate them into inter-organisational routines and operational processes (Miao *et al.*, 2018) to enable the flow of the resources needed to build new capabilities and exploit those that already exist (Aslam *et al.*, 2020). We follow the line of reasoning of the RRBV by proposing that both internal and external supply chain resources drive firm performance (Arya and Lin, 2007).

Past empirical evidence shows that LSCM implementation and a related construct, supply chain flexibility – as LSCM offers flexibility to the supply chain – have a mediating effect to explain the focal firm's efficiency (Maqueira *et al.*, 2021; Moyano-Fuentes *et al.*, 2021). Likewise, some studies have found a link between Industry 4.0 technologies and efficiency through intra- and inter-organisational processes (Núñez-Merino *et al.*, 2020; Pfohl *et al.*, 2016 in Núñez-Merino *et al.*, 2020; Oliveira-Dias *et al.*, 2022b). Consequently, the exploration of emerging Industry 4.0 technologies and the exploitation of internal supply chain resources (as are Industry 4.0 mature technologies, among others) become more valuable when integrated with supply chain partners' resources through LSCM due to the synergies gained from their integration. The leveraging strategy – LSCM – is even hard to imitate as lean management creates valuable, rare, inimitable and non-substitutable capabilities (Agyabeng-Mensah *et al.*, 2020). It is through the supply chain that the integration of supply chain partners' resources and capabilities drives greater efficiency and effectiveness to the focal firm (Hitt *et al.*, 2016; Novais *et al.*, 2019). An isolated firm does not obtain the same level of operational performance that it does when it belongs to a lean supply chain, thanks to its access to a greater variety of resources and, in the final instance, the orchestration of collective capabilities. As Arya and Lin (2007, p. 718) state "resources sharing entities" obtain greater operational performance than "atomistic profit-seeking firms". Therefore, the combination of SC4.0 ambidexterity – resources and capabilities – and LSCM – managerial acumen (Liu *et al.*, 2016) – results in the focal firm's superior operational performance and explains why similar investments by two different focal firms in Industry 4.0 technologies and the exploitation of internal supply chain resources can lead to different outcomes.

In other words, LSCM provides a distinct value proposition to supply chain partners supported by SC4.0 ambidexterity. The value comes from cost reduction, turnover and cycle time. Also, following the relational point of view, LSCM has already been verified to play a mediating role in lean's impact on the focal firm's internal level efficiency (Moyano-Fuentes *et al.*, 2021). Taken together, we propose the following hypothesis:

H3. Lean supply chain management implementation has a mediating effect between supply chain 4.0 ambidexterity and the focal firm's operational performance.

Figure 1 shows the proposed theoretical model.

4. Methodology

4.1 Population, questionnaire and data gathering

Data were collected using a computerised system (computer-aided telephone interview [CATI]). In CATI, the contact details of potential respondents are randomly displayed to interviewers. This method allows appointments to be made with respondents and their responses to be saved in real time (Hair *et al.*, 2009). Interviewers were specifically trained to collect the data for this research. In addition, a supervisor randomly listened to interviewers to control the way that surveys were being collected. Authors also controlled the quality of the interviews on the first day of work. In the middle of the data collection period, a web questionnaire was used to obtain answers from non-responding interviewees. The questionnaire was tested by a panel of five internationally recognised supply chain management researchers to ensure content validity. Subsequently, a pilot study was conducted with five heads of supply chain management to guarantee the comprehensiveness of the item definitions in the sample.

To minimise common bias, the survey was directed at two firm informants, the head of supply chain management, logistics or operations management in some areas – SC4.0 exploitation, LSCM and focal firm operational performance – and the head of information systems management in others – SC4.0 exploration (Podsakoff *et al.*, 2003). The study population was composed of 2,650 Spanish medium-size focal manufacturing companies taken from the SABI (Iberian Balance Sheet Analysis System) database, which provides economic and financial information about 2,900,000 Spanish companies based on their balance sheets. Researchers can conduct searches of the database using a selection of the

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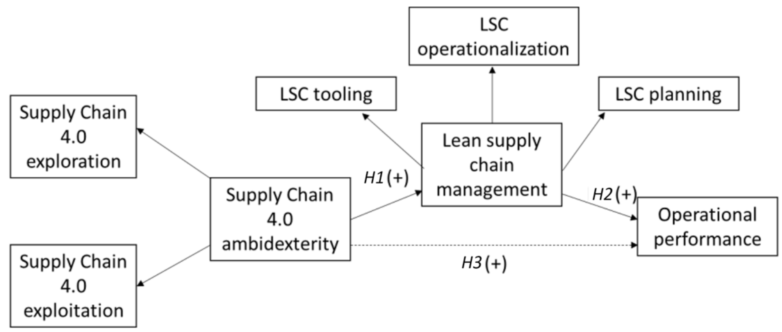
Figure 1 Theoretical model



Source: Authors' own work

variables that they find interesting with the results allowing their analysis. We focus on the focal firm as a unit of analysis because it has a wider vision of what happens upstream and downstream in the supply chain. The questionnaires were administered from January to July 2018. During this period, we were able to analyse the transition of supply chains to Industry 4.0. We gathered 209 valid responses (7.88% response rate), which is similar to some earlier works published on related topics (Green *et al.*, 2019: 4.82%; Jin *et al.*, 2014: 3.3%; Vijayasarathy, 2010: 7.5%).

We compared respondents with non-respondents and found no evidence of response bias. Similarly, we found no significant differences in annual sales, number of employees, gross operating profit and population in the sample using the mean difference test. Finally, the first 40 and last 40 responses were compared, and no significant differences ($\alpha = 0.05$) were found for any of the variables in the questionnaire, demonstrating that there was no late response bias. In summary, the data and analysis show that the sample used was randomly obtained and statistically representative of the population. Table 1 gives the sample and population distribution. It is interesting to highlight that the first three sectors represent 52.15% of the population and 48.56% of the sample, respectively, which shows that the sample is representative of the population. In the majority of cases, respondents are the head of SCM, logistics or operations management and the head of IT.

Table 1 Sample and population distribution

Sector	No. and percentage of companies in sample		No. and percentage of companies in population	
	Frequency	%	Frequency	%
Food products and tobacco	38	18.18	543	20.49
Chemicals and pharmaceutical	37	17.70	422	15.92
Manufacture of metal products	34	16.27	322	12.15
Manufacture of machinery and equipment	23	11.00	275	10.38
Motor vehicles	18	8.61	273	10.30
Informatics, electronics and optics products	11	5.26	81	3.06
Manufacture of other transport material	10	4.78	77	2.91
Electrical machinery and materials	8	3.83	141	5.32
Other manufacturing industries	7	3.35	60	2.26
Fabrics and textile	6	2.87	47	1.77
Manufacture of beverages	5	2.40	106	4.00
Meat industry	5	2.39	158	5.96
Furniture industry	4	1.91	82	3.06
Shoes and leather	3	1.44	63	2.38
Total	209	100	2,650	100

Source: Authors' own work

4.2 Variables

4.2.1 Supply chain 4.0 ambidexterity

This multidimensional third-order reflective construct is broken down into two dimensions, SC4.0 exploration and exploitation. The first dimension, SC4.0 exploration, is a reflective construct composed of eight items divided into three factors:

1. cloud computing – core base technologies;
2. complementary base technologies – big data and IoT; and
3. smart working and manufacturing technologies – AI, VR and AR.

Respondents were asked to gauge the degree of implementation of each technology in their firms on a 5-point Likert scale (1 = not implemented; 3 = implemented to some extent; 5 = fully implemented). Factors were created following the study by Frank *et al.* (2019) that classifies Industry 4.0 technologies. The second dimension, SC4.0 exploitation, is a reflective construct adapted from the study by Kristal *et al.* (2010) composed of four items related to the degree of exploitation of supply chain competences. Two items focus on reducing operational redundancies and developing stronger competences on existing processes and the other two on leveraging and improving mature Industry 4.0 technologies. Respondents were asked to indicate their degree of agreement with a series of statements on SC4.0 exploitation on a 5-point Likert scale (1 = totally disagree; 3 = neither agree nor disagree; 5 = totally agree).

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4.2.2 Implementation of lean supply chain management

LSCM implementation is a second-order reflective construct composed of eight items taken from the study by Moyano-Fuentes *et al.* (2019). Three dimensions measure this construct:

1 tools to eliminate waste in the SC;
2 LSC operationalisation; and
3 LSC planning.

One item of LSC operationalisation (LSCM5) and one item of LSC planning (LSCM8) were removed after exploratory factor analysis, as can be seen in Table 2 and the explanation in Section 5. Informants indicated their degree of agreement with a series of statements on LSCM on a 5-point Likert scale (1 = totally disagree; 3 = neither agree nor disagree; 5 = totally agree) (Moyano-Fuentes *et al.*, 2019, 2021).

4.2.3 Operational performance

Operational performance is a one-dimensional reflective construct composed of three items related to the focal firm's operational performance: unit cost of manufacturing, inventory turnover, and cycle time (Danese *et al.*, 2012; Moyano-Fuentes *et al.*, 2021). Informants were asked to compare their operational performance indicators with competitors' on a 5-point Likert scale (1 = poor, low; 3 = average or equal; 5 = much better than average) (Danese *et al.*, 2012).

4.3 Common method and multicollinearity issues

Common method bias was minimised by using two respondents per firm – one of the managers was in charge of the supply chain and the other had responsibilities in the area of technologies and IT systems – and was subsequently tested using Harman's single-factor test (Podsakoff *et al.*, 2003). All the variables in the exploratory factor analysis were loaded with the number of factors constrained to 1. As the first component accounts for under 23% of all variables, common method variance does not present a serious problem in our sample. We tested for potential multicollinearity by calculating the variance inflation factor (VIF) values (Hair *et al.*, 2009). The VIF values are lower than the cut-off value of 5. Therefore, multicollinearity is not a concern in this study.

4.4 Data analysis: factorial analysis and structural equation model

Covariance-based structural equation modelling (CB-SEM) with EQS 6.4 software was chosen to test the hypotheses in this study. SEM requires the evaluation of the measurement model. Following the factorial analysis methodology, which includes exploratory and confirmatory analysis, we identified and evaluated the measurement model. The standardised load values of the scale items were verified to be above 0.5 (Kaplan, 2000). After conducting exploratory and confirmatory factor analysis (CFA) with SPSS software (v. 25) and EQS 6.4 software, respectively, covariance analysis was conducted to verify the effects and relations between the structural model variables (Hair *et al.*, 2009). In addition, we evaluated the fit of the model to study model data accuracy. To guarantee robust results, the PROCESS macro for SPSS was used to perform an additional mediation analysis following the Preacher and Hayes (2008) bootstrapping procedure, which estimates the significance of the indirect effect. Bootstrapping provides a sampling distribution of the indirect effect to obtain confidence intervals (CIs) by resampling with replacement. CIs that do not include zero give empirical evidence of significant indirect effects (Shrout and Bolger, 2002). After all these steps, we analysed the results to draw conclusions regarding hypothesis acceptance or rejection. The following section includes the details of the data analysis conducted in this study, specifically, an evaluation of the measurement and structural model and testing to confirm the hypothesised relationships.

5. Analysis and results

5.1 Measurement model

The use of almost all the previously proposed and validated measurement scales and the questionnaire pretested by a panel of internationally recognised SCM researchers ensured content validity. One first-order factor was used to measure the focal firm's operational performance, one second-order factor to measure LSCM and one third-order factor was used to measure SC4.0 ambidexterity. We performed an exploratory factor analysis to assess scale unidimensionality and reliability analysis. Scale unidimensionality was confirmed as we obtained eigenvalues higher than the unit, standardised factor loads greater than 0.5 except for one item of LSC operationalisation (LSCM5) and one item of LSC planning (LSCM8), significant explained variance for each extracted factor and high values for chi-square/degrees of freedom in Bartlett's sphericity test ($p < 0.05$). We tested reliability using Cronbach's alpha. We considered scores of 0.6 or higher adequate as this figure is widely accepted in the literature (Nunnally and Bernstein, 1994) and in line with recent papers published in the SCM field (Jafari *et al.*, 2022; Kauppi and Luzzini, 2022). The Composite Reliability Index was used as an additional measure of reliability. Composite reliability for core base technologies (0.923), complementary base technologies (0.87), smart working and manufacturing technologies (0.93), SC4.0 exploitation (0.879), lean supply chain tooling (0.88), lean supply chain operationalisation (0.829), lean supply chain planning (0.792) and operational performance (0.804) all exceeded the criterion of 0.7, which indicates reliability. Table 2 gives the exploratory factor analysis results and a description of observable variables. As standardised loading factors were below the 0.5 threshold, items indicated with an asterisk (*) were removed after exploratory factor analysis and reliability analysis. Figure 2 gives the final measurement model.

In the measurement model, factor loadings above 0.5 denote content convergent validity (Bagozzi and Yi, 1988), which was also evaluated using average variance extracted – obtained through exploratory factor analysis with SPSS – following Fornell and Larcker (1981). The average variance extracted for core base technologies (0.8009), complementary base technologies (0.7691), smart manufacturing and working technologies (0.8169), SC4.0 exploitation (0.646), lean supply chain tooling (0.785), lean supply chain operationalisation (0.7073), lean supply chain planning (0.6561) and the focal firm's operational performance (0.5781) all exceeded the criterion of 0.5. Content discriminant validity is assumed to exist if the squared average variance extracted for each construct – obtained through exploratory factor analysis with SPSS – exceeds its shared variance (correlation). This was found to be the case in all combinations of paired constructs,

Table 2 Exploratory and confirmatory factor analysis

Factor	Variable	Standardised factor loading (CFA)	Standardised factor loading (EFA)	Cronbach's alpha	Bartlett's test	Explained variance (%)
Supply chain 4.0 exploration						
Core base technologies (cloud computing)	CLOUD1. Infrastructure as a Service, IaaS	0.78	0.867	0.818	$\chi^2 = 329.537$	80.098
	CLOUD2. Software as a Service, SaaS	0.883	0.919		df = 3	
	CLOUD3. Platform as a Service, PaaS	0.856	0.898		Sig = 0.000	
Complementary base technologies	CBT1. Big data	0.726	0.877		$\chi^2 = 70.911$	76.956
	CBT2. Internet of Things	0.743	0.877		df = 1	
					Sig = 0.000	
Smart working and manufacturing	SW1. Virtual reality	0.867	0.91		$\chi^2 = 356.406$	81.691
	SW2. Augmented reality	0.896	0.92		df = 3	
	SW3. Artificial intelligence	0.794	0.881		Sig = 0.000	
Supply chain 4.0 exploitation	SCE1. To stay competitive, our supply chain managers focus on reducing operational redundancies in our existing processes	0.583	0.724	0.816	$\chi^2 = 297.531$ df = 6 Sig = 0.000	64.609
	SCE2. Leveraging of our current supply chain technologies is important to our firm's strategy	0.66	0.782			
	SCE3. To stay competitive, our supply chain managers focus on improving our existing technologies	0.82	0.846			
	SCE4. Our managers focus on developing stronger competencies in our existing supply chain processes	0.838	0.856			
Lean supply chain management						
Lean supply chain tooling	LSCM1. Value stream mapping is used to identify and eliminate waste throughout our supply chain	0.683	0.886	0.67	$\chi^2 = 80.627$ df = 1 Sig = 0.000	78.427
	LSCM2. Our supply chain uses lean manufacturing techniques (such as pull flow, Kanban Systems and setup time reduction)	0.832	0.886			
Lean supply chain Operationalisation	LSCM3. Our supply chain generates high stock turnover and minimises inventory	0.614	0.841		$\chi^2 = 39.037$ df = 1	70.751
	LSCM4. Process and product standardisation is a common practice in our supply chain	0.676	0.841		Sig = 0.000	
	LSCM5. Our supply chain delivers in small lot sizes*		*			
Lean supply chain planning	LSCM6. Our supply chain does long-term forecasting of customer demand and only focuses on the current market segments	0.661	0.81		$\chi^2 = 21.158$ df = 1 Sig = 0.000	65.603
	LSCM7. In our supply chain, the strategy for handling uncertainty consists of using queues and buffers to protect sub-processes	0.472	0.81			
	LSCM8. Our supply chain structure seldom changes*		*			
Operational performance	OP1. Unit cost of manufacturing	0.537	0.728	0.635	$\chi^2 = 76.095$	57.799
	OP2. Inventory turnover (OP2)	0.655	0.781		df = 3	
	OP3. Cycle time (from raw materials to delivery)	0.627	0.771		Sig = 0.000	

Note: *Items removed after confirmatory factor and reliability analyses
Source: Authors' own work

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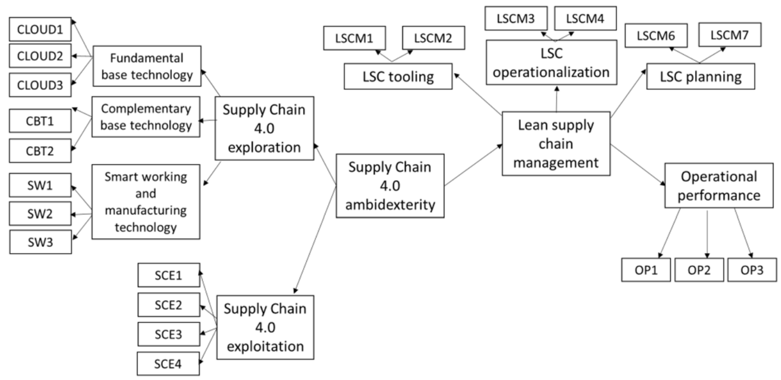
Figure 2 Measurement model



Source: Authors' own work

thus providing evidence of discriminant validity for all scales (see Table 3).

CFA using CB-SEM was used to evaluate all the factors in the final measurement model (see Table 2) and to demonstrate the multidimensionality and goodness-of-fit of the two second-order constructs proposed in the study (SC4.0 exploration and LSCM implementation) and the third-order construct (SC4.0 ambidexterity). Both the final measurement model and the second- and third-order factors showed acceptable fit indicators.

5.2 Structural equation model

CB-SEM was used to analyse the structural model (see Figure 3). Firstly, model stability must be analysed. The number of parameters in this model is 40. As a result, the ratio between the number of subjects and parameters is above 5:1, which confirms model stability according to Kline (1998). The model's goodness-of-fit must be studied taking into account the indicators and the recommended values presented in Hair *et al.* (2009). With regard to the model's absolute fit, RMSEA (0.056) and GFI (0.886) indicate the model's good overall fit. It is also necessary to ensure that the model has a good incremental fit. In the proposed model, all the indicators were well above the minimum threshold (AGFI = 0.854; NFI = 0.792; NNFI = 0.886; CFI = 0.903; IFI = 0.905). The final aspect to be studied is the proposed model's parsimony. The value of the normed chi-square (1.67) is within the accepted limits. In sum, the model revealed an acceptable goodness of fit, thus supporting model stability and in line with previous literature about supply chain (Chiou *et al.*, 2011; Kumar *et al.*, 2020; Lin and Lin, 2019; Oliveira-Dias *et al.*, 2023; Siddh *et al.*, 2021).

The results of the analysis are consistent with the proposed hypotheses, which are therefore confirmed. All relationships are significant. We find that SC4.0 ambidexterity explains greater implementation of LSCM. Its path coefficient is 0.719 ($p < 0.001$). *H1* is thus supported and explains 51.8% of the variance in LSCM. Therefore, the simultaneous pursuit of SC4.0 exploration and exploitation enables the implementation of LSCM. LSCM had a significant impact on operational performance with a path coefficient of 0.46 ($p < 0.001$). *H2* is thus accepted and explains 21.2% of the variance in operational performance. This result helps to close an ongoing debate in the literature on the relationship between LSCM and operational performance (Garcia-Buendia *et al.*, 2021).

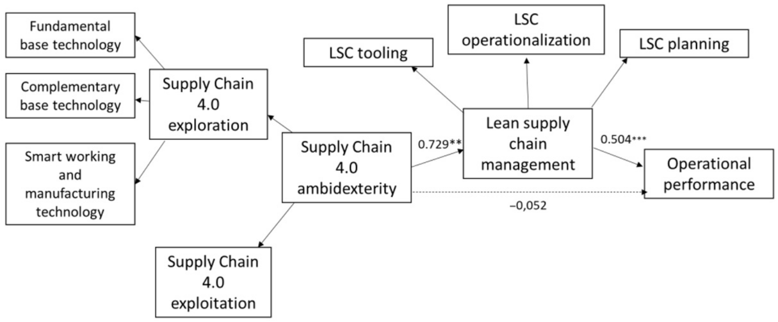
We followed Rhee *et al.* (2010) in performing decomposition of effects, disaggregating the total effect of an independent variable on a dependent variable into its indirect and direct effects. The presence of a significant indirect effect indicates that a substantial part of the relationship between the dependent and independent variable is explained through the

Table 3 Mean, standard deviation, correlation matrix and squared root of AVE

Research constructs	Mean	SD	1	2	3	4	5	6	7	8
1. CLOUD	2.49	1.29	*0.8949*							
2. CBT	2.24	1.21	0.501**	*0.877*						
3. SW	1.23	0.59	0.285**	0.296**	*0.9038*					
4. SCE	3.8	0.68	0.158**	0.197**	0.027	*0.8038*				
5. LSCT	2.28	1.2	0.266**	0.25**	0.157*	0.266**	*0.886*			
6. LSCOP	3.43	0.93	0.195**	0.165*	−0.053	0.271**	0.288**	*0.841*		
7. LSCP	2.82	0.99	0.157*	0.175*	0.039	0.418**	0.237**	0.365**	*0.81*	
8. OP	3.43	0.6	0.018	−0.023	−0.019	0.174**	0.066	0.268**	0.13	*0.7603*

Notes: ** $p < 0.01$; * $p < 0.05$; CLOUD = cloud computing; CBT = complementary base technologies; SW = smart working and manufacturing technologies; SCE = supply chain 4.0 exploitation; LSCT = lean supply chain tooling; LSCOP = lean supply chain operationalisation; LSCP = lean supply chain planning; OP = operational performance; SD = standard deviation; diagonal = AVE square root
Source: Authors' own work

Figure 3 Structural model



RMSEA	GFI	AGFI	NFI	NNFI	CFI	IFI	X^2	df	X^2/df
0.057	0.886	0.854	0.792	0.886	0.903	0.905	300.27	180	1.67

Notes: ***$p < 0.001$; **$p < 0.05$
Source: Authors' own work

mediating variable. Estimation of the indirect effects allowed us to verify *H3*. The results show that operational performance is positively influenced by SC4.0 ambidexterity through LSCM ($\lambda = 0.367$, $t = 2.341$). This means that LSCM plays an important role in explaining the relationship between SC4.0 ambidexterity and operational performance. To analyse the total mediating effect of LSCM, we examined the direct relationship of the SC4.0 ambidexterity variable with operational performance. The result ($\lambda = -0.052$) reveals a non-significant relationship, indicating that the relationship of SC4.0 ambidexterity with operational performance occurs entirely through LSCM, which exercises a full mediating effect. In other words, LSCM implementation is a prerequisite for achieving the simultaneous SC4.0 exploration and exploitation that, in turn, generates operational performance benefits.

Moreover, we conducted bootstrapping analysis to assess the indirect effects of LSCM on the SC4.0 ambidexterity–focal firm's operational performance relationship. After conducting 10,000 bootstrap replicates, the effect size of LSCM was calculated as 0.0948 with 95% bias-corrected CIs [0.0391, 0.1672]. According to this analysis, the association between SC4.0 ambidexterity and operational performance is positively mediated by LSCM and is significant because the bias-corrected CIs did not include zero.

6. Discussion of results

We applied ROT and the RRBV to empirically test the relationship between SC4.0 ambidexterity, LSCM and the focal firm's operational performance. Firstly, the results show that SC4.0 ambidexterity has a significant positive effect on LSCM implementation. This positive effect indicates that achieving an optimal balance between supply chain exploration and exploitation activities in the transition to SC4.0 enables the implementation of LSCM, as it drives the spread of lean principles, practices and techniques along the SC. This finding is especially important as, for the very first time, we have provided and tested a variable – SC4.0 ambidexterity – previously proposed by Hofmann *et al.* (2019).

We relate both exploration and exploitation to LSCM implementation. As Ojha *et al.* (2018) assert "Exploration practices [in the supply chain context] yield new knowledge and ideas, but only after the ideas are exploited (selected, implemented, produced) can they create value" (p. 79). In other words, to avoid sub-optimal supply chain processes linked to an excessive focus on exploitation or a lack of stability due to an excessive focus on SC4.0 exploration, firms must combine the exploitation of their current capabilities with the creation of new capabilities throughout their transition to SC4.0. We demonstrated that when the exploration and exploitation of resources inherent in SC4.0 ambidexterity are used to implement LSCM, the orchestrating process is hard to understand and, consequently, imitate by competitors due to the accumulative effect that the one (SC ambidexterity) has on the other (LSCM implementation), thus creating the conditions for collaboration, coordination and integration that are characteristic of LSCM and achieving competitive advantage. This result is consistent with the previous literature on operations management, which has provided evidence of the benefits of ambidexterity in this area (Kristal *et al.*, 2010; Rojo *et al.*, 2020a) and of the complementarity of Industry 4.0 technologies and LSCM (Núñez-Merino *et al.*, 2020; Oliveira-Dias *et al.*, 2022b). This study also contributes to extending a stream of research that analyses the interplay between Industry 4.0 and ambidexterity to create value in the supply chain (Belhadi *et al.*, 2022a) and extends the analysis of the interrelationships between Industry 4.0, lean management and ambidexterity to the supply chain level. To the best of the authors' knowledge, only a limited number of recent studies have analysed the link between the variables Industry 4.0, lean management and ambidexterity at the organisational level (Dixit *et al.*, 2022; Vilkas *et al.*, 2023). In sum, our results show that LSCM implementation requires support from SC4.0 ambidexterity to achieve the required levels of supply chain coordination and integration and, as a result, to meet the objectives pursued with this management system. This is consistent with the study by Tortorella *et al.* (2017), which asserts that LSCM demands a different business model as performance improvement is gained through cooperation given that a collaborative environment is compulsory to obtain a lean supply chain. Furthermore, our results demonstrate the assertion of Hitt *et al.* (2016) as we have confirmed that LSCM activities require particular resources and capabilities, i.e. SC4.0 ambidexterity. As such, we follow the line of reasoning of Yao and Zhu (2012), who argue that "alignment between IT and SC processes can help firms improve their operations" (p. 1047).

Secondly, LSCM implementation is found to improve the focal firm's operational performance. This is consistent with the previous literature (Garcia-Buendia *et al.*, 2021; Maqueira *et al.*, 2021; Moyano-Fuentes *et al.*, 2021; Tortorella *et al.*, 2019b) but our result is still relevant as we provide evidence of this relationship in a wide variety of sectors in supply chains and technologies in the transition to SC4.0.

Thirdly, in line with ROT, our results indicate that the effect of SC4.0 ambidexterity on the focal firm's operational performance is indirect via LSCM. This result supports the idea of the mediating role of LSCM in focal firm efficiency, as found in the study by Moyano-Fuentes *et al.* (2021). This result may be useful to explain the mixed findings on the IT – performance relationship in the literature. This finding is also in line with the RRBV (Arya and Lin, 2007) as the access to external resources provided by LSCM via cooperation and the reduction of costs and waste can complement the firm's internal resources and drive sustainable competitive advantage, thus improving operational performance. This finding extends a stream of literature that posits the need for complementary resources for collaboration to implement LSCM to enhance operational performance (Moyano-Fuentes *et al.*, 2021). We demonstrate that unless supply chain partners work in a collaborative relationship – LSCM – SC4.0 ambidexterity will not succeed. On the other hand, exploring emerging Industry 4.0 technologies and exploiting internal supply chain resources and capabilities and mature technologies on their own do not create the focal firm's higher operational performance. This result is in line with the findings of Moyano-Fuentes *et al.* (2021), as we demonstrate that competitive advantage is only created when internal and external resources are combined.

7. Conclusions

Firstly, as far as the authors know, this study is one of the first attempts at providing a measurement instrument for SC4.0 ambidexterity. Secondly, this work is one of the few that delves further into the antecedents to LSCM implementation, i.e. SC4.0 ambidexterity. Thirdly, we extend the previous findings that have identified LSCM implementation as a driver of focal firm performance. Fourthly, this work demonstrates the full mediating effect of LSCM in the relationship between SC 4.0 ambidexterity and the focal firm's operational performance. Fifthly, it joins other research in supporting the ability of the RRBV and ROT to explain SCM phenomena, in general, and LSCM, in particular (Minguela-Rata *et al.*, 2023; Oliveira-Dias *et al.*, 2023, among others). These findings have several implications for academia and practitioners.

7.1 Implications for supply chain theory

This work's first contribution to theory is to introduce the concept of SC4.0 ambidexterity and propose a measurement scale. In doing so, this study responds to the recent research call in the literature to apply the theoretical lens of organisational ambidexterity to the transition to SC4.0 (Hofmann *et al.*, 2019). This study is pioneering in that it demonstrates the validity of a measurement scale that analyses the transition to SC4.0 from an ambidexterity perspective.

Secondly, drawing on ROT, our findings indicate that structuring and bundling SC4.0 exploration and exploitation supports the implementation of LSCM. This means that managing the tension between these two complementary activities can be beneficial at the supply chain level. This extends the line of reasoning of studies such as Dixit *et al.* (2022) and Vilkas *et al.* (2023), which study the relationship between ambidexterity and lean at the supply chain's internal level. Following the line of reasoning of Rintala *et al.* (2022), SC4.0 exploration and exploitation can both help organisations meet different supply chain members' expectations and translate SC4.0 resources into LSCM implementation.

The results contribute to advancing the literature on the antecedents to LSCM implementation and shed light on how SC4.0 resources should be combined and managed to achieve a lean SC. In addition, our findings advance the literature by clarifying the impact that SC4.0 exploration can exert on the implementation of LSCM when combined with SC4.0 exploitation. As we mentioned previously, the benefits of adopting emerging technologies are not particularly well-known compared to those of much more mature technologies. This is why companies that explore emerging technologies through their implementation can gain a competitive advantage over their competitors as these technologies help them to cooperate and integrate with their supply chain members and, thus, facilitate the spread of lean practices at the supply chain level.

Thirdly, we deepen the knowledge of how implementing LM practices along the supply chain contributes to the focal firm's operational performance. In doing so, this study contributes to resolving the debate around the benefits of implementing LSCM. This study demonstrates that implementing LSCM in the context of I4.0 adoption could help to reduce cycle time, the unit cost of manufacturing and inventory turnover. In other words, when supply chain managers implement lean practices to, among other things, reduce waste along the supply chain and increase value for customers, they also contribute to enhancing the focal firm's operational performance. In addition, the measurement instrument used to assess LSCM implementation can contribute to solving problems found with other measurement scales in the previous literature. The instrument that we used was validated by a panel of international experts (Moyano-Fuentes *et al.*, 2019), as no measurement instrument previously existed that had been sufficiently accepted at the international level. Furthermore, it has been used empirically in recently published research papers (Garcia-Buendia *et al.*, 2023; Oliveira-Dias *et al.*, 2023).

Fourthly, the main contribution of this study is to provide empirical evidence of the full mediating role of LSCM in the relationship between SC 4.0 ambidexterity and the focal firm's operational performance. This means that the combination or bundling of explored and exploited SC4.0 resources (I4.0 and mature technologies, among others) produces a synergistic effect capable of supporting LSCM implementation, which, in turn, improves the focal firm's operational performance. This result is explained through the theoretical lenses of ROT and the RRBV, which support the need for the combined use of all the supply chain members' resources for SC4.0 ambidexterity to have a multiplier effect on operational performance via LSCM. Therefore, supply chain managers do not only need to structure and bundle the explored and exploited resources inherent in SC4.0 ambidexterity but also the capabilities generated by their combination (i.e. supply chain integration) must also be leveraged through LSCM implementation. This finding is in line with the study by Erboz *et al.* (2021), which proposes that the implementation of I4.0 technologies requires a higher-order integrative capability, and previous works that maintain that investment in ITs *per se* does not improve performance (Tortorella *et al.*, 2019a) and that they need to be combined with other focal firm resources and capabilities (Minguela-Rata *et al.*, 2023). It is worth highlighting that this work contributes to extending a research stream that demands clarification of how I4.0 technologies can be integrated with supply chain processes and existing managerial approaches, e.g. LSCM (Tortorella *et al.*, 2019a). What is more, this study springs the lid on the "resources-something happens-performance" black box relationship (Sramek *et al.*, 2015, p. 247): SC 4.0 ambidexterity-LSCM-operational performance.

Lastly, this work's fifth contribution to theory is that it is one of a small number (Rojo *et al.*, 2020a, 2020b) that apply ROT beyond firm boundaries, from the supply chain perspective, which is a contribution to the development of this line of research. It also adds to another stream of research that uses the RRBV to advance knowledge on SCM.

7.2 Implications for supply chain practice

This study also has some practical implications. Firstly, the proposed scale can be used to measure the real implementation level of SC4.0 ambidexterity and guide its adoption. A focal firm that wants to change from a linear supply chain perspective to a SC4.0 must explore and exploit both the supply chain resources and capabilities inherent in SC4.0 ambidexterity.

Secondly, our findings show that supply chain managers must find the right balance when exploring and exploiting supply chain resources to advance LSCM implementation. Therefore, this study demonstrates that supply chain managers need to have both practices in place to extend lean practices beyond the frontiers of the organisation. As a result, the role of supply chain managers in identifying, selecting, combining and implementing supply chain resources in the transition to SC4.0 is key to supporting the implementation of LSCM. Furthermore, heads of production and supply chain must be aware that when they combine the use of I4.0 technologies with the exploitation of other supply chain resources, they could generate higher order capabilities (i.e. supply chain integration) that help them to spread lean principles and a continuous improvement mindset across their supply chains.

Thirdly, the empirical evidence found for the LSCM-operational performance relationship gives supply chain managers some insights into how to obtain a competitive advantage by pursuing an LSCM strategy.

Fourthly, the indirect link between SC4.0 ambidexterity and focal firm operational performance found in this study can lead practitioners to consider the SC4.0 ambidexterity-LSCM relationship for maximising operational performance. For this, supply chain managers have to recognise that achieving SC4.0 ambidexterity alone is not enough to improve the focal firm's operational performance and that improvement is obtained when LSCM is also implemented. So, supply chain managers should be aware of how important it is for all supply chain members to implement lean at the internal level as a prior step to deploying LSCM and, thus, achieving improvements in the operating results. For this, the focal company needs to provide technical assistance to enable its supply chain's members to, first, implement lean internally. They should then achieve SC4.0 ambidexterity as a second step to nurture the collaborative conditions for implementing LSCM. For this to happen, it is essential for supply chain managers in an I4.0 adoption context to actively seek to orchestrate their own resources and those of their supply chain members to support the deployment of LSCM, as this management system helps them to create synergies between internal and external supply chain resources and tap into operational benefits. Therefore, extending LM along the supply chain is the key to benefitting from SC4.0 ambidexterity, as it provides supply chain managers with the flexibility and efficiency required under an ambidextrous mindset.

7.3 Limitations and future research lines

This research has some limitations that must be highlighted. Respondents were located in Spain. As a result, answers might be conditioned by geographical and cultural issues, as companies from different countries with cultural differences may have different tendencies towards exploration or exploitation. However, this also increases the likelihood that they might apply to other geographical areas with similar cultural characteristics to Spain and, consequently, is only a minor limitation. Future studies should analyse the proposed model using a sample composed of different countries to evaluate international supply chains and the presence of any significant differences between the tendencies of exploratory and exploitative companies. Our data is cross-sectional, so this work should be complemented in the future by longitudinal analysis. Likewise, despite our response rate being acceptable and similar to that in other works in the operations management area, it would have been desirable for it to be higher. Also, our measurement scale proposal will only be useful if it is used by other researchers in the future. Furthermore, we used a subjective measure of operational performance, which can lead to a degree of bias, so future studies should use quantitative measures of operational performance from secondary sources to replicate our findings. Future studies should replicate our study when the implementation of emergent Industry 4.0 technologies is more advanced. Another possible research line would be to examine some moderating factors such as IT competence and relational capability in the proposed model, among others. Finally, it would be interesting to have a deep understanding of the relationship between Industry 4.0 adoption and LSCM that considers the mediating role of supply chain ambidexterity. This future research line would contribute to closing the current debate on the Industry 4.0 adoption-LSCM relationship.

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