The lean supply chain management response to technology uncertainty: consequences for operational performance and competitiveness

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Abstract

Purpose – This study aims to analyze the lean supply chain management (LSCM) strategy's role as a mechanism to address technology uncertainty and provide organizations with competitive advantage.

Design/methodology/approach – An empirical study was conducted of 276 Spanish focal firms in industrial sectors that occupy an intermediate position in the supply chain to investigate the influence of technology uncertainty on LSCM implementation and the latter's effect on operational performance and competitiveness. A covariance-based structural equation model (CB-SEM) was used to test three hypotheses.

Findings – Technological uncertainty encourages progress in the implementation of lean throughout the supply chain and so is a mechanism that not only brings stability to the focal company but also improves its performance and puts it in a better competitive position.

Practical implications – Managers are suggested to consider the strategic integration with supply chain partners and the establishment of long-term relationships based on trust and commitment advocated by LSCM to enhance organizations' capabilities and effectively and flexibly respond to technological changes.

Originality/value – This study focuses on the effects of environmental uncertainty on the supply chain. The past literature has focused on the behavior of individual firms to deal with uncertainty, but this work shifts the level of analysis to the supply chain. Therefore, the strategic change to deal with what is happening in the environment is now switched to the supply chain level.

Keywords Lean supply chain management, Technology uncertainty, Operational performance, Competitiveness, Structural equation model

Paper type Research paper

1. Introduction

In recent decades, scholars' and managers' interest in selecting the most appropriate supply chain management (SCM) strategy has increased due to its potential to improve firm performance and enable the achievement of competitive advantage (Zimmermann *et al.*, 2020).

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Technological change and, specifically, the emergence and fast development of Industry 4.0 (I4.0) have revolutionized the traditional idea of competition, and further emphasized the SCM strategy's role in achieving a better competitive position.

Technology uncertainty (TU) refers to the extent of technology development change and unpredictability in an industry (Chen and Paulraj, 2004; Vasconcelos and Ramirez, 2011) and involves significant challenges to manufacturers, as rapid changes in product and/or process standards and specifications can disrupt the smooth flow of materials in extended supply chains (Xiao *et al.*, 2019). TU could motivate the choice of a supply chain (SC) strategy able to mitigate the effects of this type of uncertainty. An SC strategy that seeks long-term collaboration with SC members, such as lean supply chain management (LSCM), could be a mechanism or driver that buffers the effects of TU by sharing the required resources and capabilities among SC members. TU and variability are highly topical, and while previous studies exist that address the impact of mature and emergent I4.0-related practices and technologies on LM (Ghobakhloo and Azar, 2018; Kamble *et al.*, 2020; Wei *et al.*, 2022), to date, none has studied how the perception of this transformation in the industry can affect the management of an SC as a whole. Rapid and unpredictable changes in production and information technologies, a high obsolescence rate and the difficulty to remain competitive without technology upgrades, that is, TU, could motivate the choice of an SC strategy that provides the required efficiency and flexibility.

The previous literature has found a series of drivers and enablers of lean management (LM) implementation throughout the SC. Qi *et al.* (2011) stated that cost leadership strategy leads to LSCM irrespective of the level of uncertainty, while Zimmermann *et al.* (2020) explored the role of SC complexity/dynamism and product characteristics in LSCM implementation. Yildiz Çankaya (2020) investigated strategic sourcing's role in developing a lean SC. More recently, Moyano-Fuentes *et al.* (2021) focused on internal lean implementation as a driver of LSCM, and Maqueira *et al.* (2021) studied internal lean implementation as an antecedent to flexibility in the SC. Thus, various aspects have been assessed as potential drivers of LSCM implementation. However, the role of the current context characterized by technological change and uncertainty in which most manufacturing organizations and SCs operate nowadays remains unknown, which is detrimental to their ability to choose an appropriate SC strategy.

A suitable SC strategy can provide the right ingredients for success in an increasingly competitive environment. So, growing demands to accomplish higher delivery reliability, greater flexibility, better quality and lower costs from an SC perspective while remaining competitive in the market can be addressed through an SC strategy that pursues efficient and flexible processes (Ding *et al.*, 2021). One such strategy is LSCM, which enables waste elimination, cost reductions, quality improvement and increased flexibility across the SC (Swenseth and Olson, 2016; Womack and Jones, 1996). LSCM has emerged as a way to improve competitiveness by enhancing efficiency and flexibility at all stages of the SC (Moyano-Fuentes *et al.*, 2019).

Although several studies have described the successful implementation of LSCM and reported positive results, extending lean principles along the SC is not a simple process as several aspects must be managed (Tortorella *et al.*, 2018a). Indeed, until recently, no rigorous and validated measure of LSCM existed in the literature (Moyano-Fuentes *et al.*, 2019), showing that this multidimensional concept still requires further attention. The identification of effective drivers and suitable environments for LSCM implementation is essential for making organizations' and SCs' efforts more successful (Moyano-Fuentes *et al.*, 2021; Tortorella *et al.*, 2017). Particularly, the failure to fully understand the potential benefits of adopting LSCM for performance and competitiveness in some contexts has resulted in inadequate LSCM implementations (Jasti and Kodali, 2015) and undesired outcomes (Swenseth and Olson, 2016).

Additionally, although some performance outcomes of LSCM implementation have already been addressed empirically (Moyano-Fuentes *et al.*, 2021; Tortorella *et al.*, 2017; Yildiz Çankaya, 2020), the inclusion of the particular context in which the SC operates may provide additional insights. As previous research states, the context can drive the selection of the most appropriate competitive strategy and its performance outcomes (Qi *et al.*, 2011). Meanwhile, some authors have emphasized the need to further explore the performance outcomes of LSCM implementation (Garcia-Buendia *et al.*, 2021; Moyano-Fuentes *et al.*, 2021; Prajogo *et al.*, 2016) as a way to empirically verify the strategy's potential consequences and disseminate its advantages to academia and practice. Empirical studies have frequently investigated LSCM's impact on different aspects of performance (Marodin *et al.*, 2017a; Moyano-Fuentes *et al.*, 2021; Tortorella *et al.*, 2017; Tortorella *et al.*, 2018b) without analyzing whether these results really contribute to competitive advantage, which would be the focal firm's ultimate goal.

Therefore, two research questions (RQ) must be answered: (RQ1) How TU of the industry can influence the implementation of an SC strategy such as LSCM? and (RQ2) What is the impact of the LSCM implementation on operational performance (OP) and the consequent firm competitiveness in this context? For this, we draw on the combined use of contingency theory (CT) and the relational view of resource-based theory (RBT). CT is used to explain the choice of an SC strategy to remain competitive in light of the particular characteristics of the environment as TU of the industry, while the relational view supports the benefits from sharing resources and capabilities with the SC members for the achievement of better performance and competitive advantage as pursued by LSCM. Regarding the methodology used, our empirical analysis was conducted on a sample of 276 Spanish focal firms in industrial sectors that occupy an intermediate position in the SC. The proposed hypotheses were tested using a covariance-based structural equation model (CB-SEM).

The motivation for this work is providing a better understanding on the role of TU of the industry in the implementation of the LSCM strategy in the quest to remain competitive. Since TU affects all competitors in the manufacturing industry, organizations should seek to adopt mechanisms to mitigate its impact by pursuing an SC strategy that can reduce the sources of variability while improving their flexibility and efficiency.

Our paper is organized as follows. Section 2 describes the theoretical framework and arguments leading to the research hypotheses. Section 3 includes a description of the population, sample and methods used in the empirical analysis. Section 4 presents the analysis of the results, while a discussion is presented in Section 5. Finally, Section 6 gives the main conclusions, the study's implications and limitations, and some directions for further research.

2. Theoretical background and research hypotheses

2.1 Theoretical background

Industry in general, and the manufacturing industry in particular, are currently immersed in a significant technological transformation that involves every organization with major effects along the entire SC (Ghobakhloo, 2020). In recent years, SCs have become more complex for several reasons, including the uncertainty that surrounds them and the behavior of the stakeholders in the SC (Ateş and Memiş, 2021; Serdarasan, 2013).

CT emphasizes the alignment of an organization's structure, processes and practices to respond to internal and external aspects of uncertainty (Perdana *et al.*, 2019). Following CT, contextual variables can determine the implementation of management practices and strategies (Hall *et al.*, 1968). The alignment of performance priorities with the environment where the SC operates is essential (Garrido-Vega *et al.*, 2021). In the SC context, environmental uncertainty has been identified as a contingency factor that can determine interorganizational relationships (Zhao *et al.*, 2018) and is considered a critical driver of SCM in some studies (Chen and Paulraj, 2004; Gligor *et al.*, 2016; Wong *et al.*, 2011; Zimmermann *et al.*, 2020).

The source of environmental uncertainty (Chen and Paulraj, 2004; Zimmermann *et al.*, 2020) that is receiving the most attention in the current context of technological change in most industries is TU. TU refers to an industry being characterized by rapid and unpredictable changes in production and information technologies, a high obsolescence rate and the need to keep abreast of technology changes to remain competitive (Chen and Paulraj, 2004) and has been considered an important contingent factor capable of enhancing SC collaboration (Coronado Mondragon and Coronado Mondragon, 2018), SC innovation (Bhatti *et al.*, 2022) and SC integration (Yang and Zhao, 2016). Therefore, according to CT, an industry impacted by increasing TU could be expected to leverage the implementation of an SC strategy such as LSCM, which advocates long-term collaboration with chain partners as a means to secure the resources and/or capabilities needed to overcome or mitigate its impact.

Meanwhile, RBT states that an effectively leveraged combination of rare, valuable and inimitable resources enables organizations to achieve sustainable competitive advantage (Barney, 1991; Grant, 1991). Further, the relational view of RBT focuses on the network as the unit of analysis instead of individual firms (Dyer and Singh, 1998), so obtaining a competitive advantage depends on both the focal firm's and its SC members' resources. This theoretical framework emphasizes the relevance of SC collaboration and cooperation as intangible resources to achieve competitive advantage (Prajogo *et al.*, 2016; Srinivasan *et al.*, 2020), which leads to improved integration with suppliers (Iyer *et al.*, 2019; Xiao *et al.*, 2019), enhanced responsiveness to customers (Gligor *et al.*, 2016; Srinivasan *et al.*, 2020) and better buyer and supplier firm performance (Alshahrani *et al.*, 2018; Rezaei *et al.*, 2018).

Previous research states that the key to implementing LSCM is that all SC members adopt LM internally and advance in its implementation to connect and synchronize all the flows through their internal lean systems (Moyano-Fuentes *et al.*, 2021) to produce the inimitable combination of their resources. Therefore, according to the relational view of RBT, collaborative SC relationships such as those pursued by LSCM to extend the LM principles among SC members may produce wide-ranging improvements to OP that could increase firm competitiveness. This theoretical framework has recently been used to explain resource complementarity in LM application at the SC level (Iyer *et al.*, 2019; Moyano-Fuentes *et al.*, 2021; Yildiz Çankaya, 2020).

In this context, the present study analyzes TU's influence on LSCM implementation and its performance outcomes and the contribution that the latter make to higher firm competitiveness. Our proposed hypotheses on the abovementioned relationships are based on CT and the relational view of RBT.

2.2 Research hypotheses

2.2.1 TU of the industry and LSCM implementation. According to CT, environmental uncertainty is a key driving force of SCM (Qi *et al.*, 2011; Zhao *et al.*, 2018; Zimmermann *et al.*, 2020). In the context of intense technological change characterized by the digital transformation of the SC, organizations are changing how they operate and compete to be successful and secure competitive advantage (Chai *et al.*, 2019). Particularly, the inability to accurately predict general technological developments and keep abreast of changes in product or service standards and specifications in their industry are challenges for organizations striving to improve their competitiveness (Xiao *et al.*, 2019).

TU introduces variability at the SC level, which leads to the search for a strategy for its mitigation or reduction (Yang and Zhao, 2016). Firms with high TU need to build good coordination capabilities and suitable cooperation structures to make their response to technology changes more efficient (Yang *et al.*, 2016). The role of SC collaboration is especially relevant in this context, so the management of stakeholder relationships could have important strategic implications for the implementation of new management practices (Kim and Choi, 2018) and the adoption of new technologies (Maqueira-Marín *et al.*, 2017).

The SC variability and uncertainty caused by rapid and unpredictable changes in technology could be moderated by adopting LM principles and practices (Novais *et al.*, 2020) that require committed and cooperative ties with SC members. LSCM implementation enables to forge long-term relationships based on mutual trust and commitment, frequent information-sharing and win-win relationships with strategic SC partners (Bortolotti *et al.*, 2016; Moyano-Fuentes *et al.*, 2021). Organizations operating in industries with higher TU might have a greater need for effective and quality SC relationships based on cooperation, adaptation and trust, so this context can encourage the extension of LM throughout the SC.

Particularly, a higher level of production technology change could trigger the use of LSCM tools and practices such as value stream mapping (VSM) to identify and eliminate waste, and the more efficient and effective extension of process and product standardization among SC members (Seth *et al.*, 2017). Moreover, rapidly changing technology and a high obsolescence rate could be successfully addressed with the high stock turnover, minimum inventory and small lot size deliveries pursued by LSCM (Bevilacqua *et al.*, 2017). The need to keep abreast of rapid and unpredictable changes in technology to remain competitive could lead SC members to use LSCM techniques such as pull flow, setup time reductions and long-term forecasting of customer demands to be able to respond efficiently and flexibly to any circumstance (Eltawy and Gallear, 2017; Pearce *et al.*, 2018).

Following this reasoning, the effect of a context characterized by TU leads to an increase in the LSCM implementation level. We, therefore, hypothesize that:

H1. A higher level of TU in the industry leads to a higher level of LSCM implementation.

2.2.2 LSCM implementation and OP. The relevance of the LSCM-performance relationship has been broadly addressed by previous research (Garcia-Buendia *et al.*, 2021) since LSCM has several implications for firm and SC performance. According to the relational view of RBT, firm performance is the result of the valuable and difficult-to-imitate combination of both its internal and external SC resources (Barney, 1991), which emphasizes the role of SC relationships in achieving better performance. In line with this theoretical framework, the collaborative and integrative relationships with SC partners pursued by LSCM implementation can lead to OP improvements in a wide range of areas (Moyano-Fuentes *et al.*, 2021; Yildiz Çankaya, 2020).

LSCM aims to improve OP by integrating resources to share information, coordinate processes and activities and implement a continuous improvement process along the SC (Mollenkopf *et al.*, 2010). The purpose is to respond to competitive pressures for higher flexibility, greater delivery reliability, lower costs and better quality. At the internal level, LM has recently been found to contribute to flexibility and delivery performance (Maqueira *et al.*, 2021; Novais *et al.*, 2020), financial and market performance (Agyabeng-Mensah *et al.*, 2020; Elking *et al.*, 2017) and quality (Shah and Naghi Ganji, 2017), among others. Extending LM along the SC can improve economic and productivity performance (Zimmermann *et al.*, 2020), financial performance (Qi *et al.*, 2017), efficiency (Moyano-Fuentes *et al.*, 2021), supply chain performance (Tortorella *et al.*, 2017; Tortorella *et al.*, 2018b), operational performance (Inman and Green, 2018; Iyer *et al.*, 2019) and competitive performance (Yildiz Çankaya, 2020).

However, previous findings regarding potential outcomes have not been wholly conclusive. Danese *et al.* (2012) stated that firms should devote their efforts to just-in-time production to improve efficiency and just-in-time supply to enhance delivery performance. Tortorella *et al.* (2018a, b) found that customer-supplier relationships in an LSCM context could lead to conflicting delivery, lead time and cost outcomes, while Qamar *et al.* (2018) revealed that some firms that adopt lean attain low flexibility levels. These inconclusive results reflect the need for clarification due to their important implications for the practical decision to implement and develop an LSCM. Although the previous empirical evidence has contributed to identifying the positive impact of LSCM implementation on efficiency (Moyano-Fuentes *et al.*, 2021), additional studies are required on its impact on OP measures to advance the knowledge of the benefits of LSCM implementation (Garcia-Buendia *et al.*, 2021).

Particularly, the use of LM tools such as VSM to identify and remove waste along the SC is expected to eliminate non-value-added activities and reduce waiting times, which positively affects firm cycle time and on-time delivery (Nikolaeva, 2018; Seth *et al.*, 2017). Pull flow, Kanban system and setup time reduction could also improve delivery and cycle times, and flexibility (Pinho and Mendes, 2017; Takeda Berger *et al.*, 2018). Additionally, implementing lean-driven process and product standardization as a common practice in the SC could lead to higher quality (Sangwa and Sangwan, 2018) and volume flexibility (Soni and Kodali, 2016). Therefore, extending LM principles along the SC may produce wide-ranging improvements to focal firm OP in terms of cycle time, quality, delivery and flexibility compared to the competition.

The following hypothesis is proposed based on the preceding arguments:

H2. A higher level of LSCM implementation leads to a higher level of focal firm OP.

2.2.3 OP and firm competitiveness. The relational view of RBT states that the unique valuable combination of internal and external resources can lead to the achievement of competitive advantage. Since environmental uncertainty increases the need to obtain access to critical resources and develop competitive advantages (Park *et al.*, 2002), the effective integration of the SC agents is a key factor in achieving the improvements needed to remain competitive (Ragatz *et al.*, 2002). Their ability to manage interorganizational processes is the distinctive competitive capability of some firms in dynamic markets (Stock and Tatikonda, 2008).

It has been argued that firms that master LM tend to dominate high quality and efficiency, greater flexibility to changes in product and volume and shorter lead times as elements of competitiveness (Mefford, 2011). Thus, some authors suggest that SC members should focus on implementing lean techniques to further enhance their OP and competitiveness (Karakadılar and Hicks, 2015). In contexts of TU, SMEs can leverage their information technology resources by implementing digitized lean manufacturing systems that improve their OP and provide them with greater competitiveness (Ghobakhloo and Fathi, 2019). Also in these contexts, the use of new practices such as e-commerce is growing, and organizations that strengthen their SCs by improving their reverse logistics obtain better OP and become more competitive (Saruchera and Asante-Darko, 2021). The use of big data in manufacturing improves both OP and firm's competitiveness (Yiu *et al.*, 2021). In contexts where TU is present, the use of digital manufacturing technologies has a strong impact on OP (flexibility, design, delivery and quality) and is changing the way in which companies increase their competitiveness based on manufacturing (Gillani *et al.*, 2020).

Particularly, as a reduction in the order cycle time leads to a reduction in SC response time and directly influences the customer satisfaction level, it can be considered a major source of competitive advantage (Christopher, 1999). Quality is considered a main driver of competitiveness as it represents a product's or a service's ability to consistently meet customers' expectations (Gillani *et al.*, 2020; Sánchez-Santiago *et al.*, 2012). Delivery reliability in terms of time has been found to provide competitive advantages for the buyer firm in the context of superior relationships with SC members (Gillani *et al.*, 2020; Saruchera and Asante-Darko, 2021; Yang and Zhao, 2016). There is also a general consensus that flexibility in the SC contributes to firm competitiveness (AL-Shboul *et al.*, 2017; Gillani *et al.*, 2020).

The ability to respond rapidly, adequately and flexibly to market demands in the digital world may be a source of competitiveness (Ghobakhloo and Fathi, 2019; Saruchera and Asante-Darko, 2021; Srinivasan *et al.*, 2020; Yiu *et al.*, 2021). Therefore, enhanced OP is expected to be achieved by extending LM along the SC to enable firms to excel in a competitive environment. Accordingly, we hypothesize that:

H3. A higher level of focal firm OP leads to a better competitive position of the firm in its industry.

Figure 1 presents the theoretical research model.

3. Methodology

3.1 Population, sample and data collection

This study has focused on focal enterprises in industrial sectors in a single country, Spain. The selection criteria for the population were (1) organizations located in a single country –Spain– to reduce the effect of cultural, legal and socioeconomic differences; (2) organizations with at least 50 employees to ensure that they had managers responsible for the SC and resources and capabilities focused on managing their SC; and (3) focal firms in an intermediate position in the SC in different industrial sectors, that is, following the approach of van der Vaart *et al.* (2012), sectors near either end of the SC (up/downstream) were not considered, for example, related to raw materials and their transformation, transportation and services. Data for the study population were taken from the SABI (Iberian Balance Sheet Analysis System) database, and the population was classified into sectors based on the CNAE (National Classification of Economic Activities) catalog.

Responses were collected via a questionnaire that included items and scales drawn from the literature related to TU, LSCM implementation, OP and competitiveness. Data collection was done using a computer-assisted telephone interviewing (CATI) system and a backup web questionnaire for nonresponding interviewees to complete the survey. This was considered the most suitable data collection method as it allows access to large data sets and the use of statistical techniques (Saunders *et al.*, 2009). The CATI system affords interviewers access to an information system and the computerized management of the entire process, with data saved in real time and increased availability and efficiency (Hair *et al.*, 2018). Three interviewers specifically trained for this purpose and aware of the objectives and background of the study performed the data gathering supervised by the authors.

Five internationally recognized SCM researchers with at least 10 years of experience in publishing their work in high-impact journals in Web of Science tested the draft version of the survey to guarantee its content validity. Next, five SC managers with more than 5 years of experience and from different industrial focal firms conducted a pilot study to ensure that item definitions were clear and easy to understand, thus minimizing response bias and confirming the quality and validity of the survey instrument (Saunders *et al.*, 2009). Questionnaires were targeted at the most informed respondents for the specific topic of the survey, that is, SC managers, operations managers and logistics managers, who were specifically asked to give answers on the SC practices and strategies adopted, SC environment and performance.

Fieldwork was conducted from January 30 to July 20, 2018. The study population was 2,650 Spanish focal manufacturing enterprises with questionnaires completed by respondents from a total of 276 firms (10.4% response rate). The sample size was judged to be

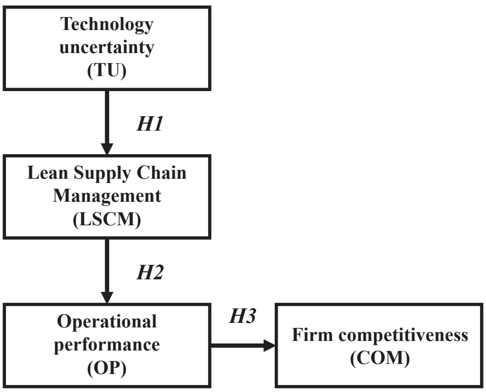

Figure 1.
Theoretical research model

appropriate and not jeopardize the reliability of the results. Firm distribution among the different sectors was similar in the population and the sample (see Table 1). There was no evidence of response bias when comparing the firms' numbers of employees and annual sales or gross operating profit of respondents and nonrespondents, and no specific patterns were found in the reasons for refusing to participate. Also, there were no significant differences between the first and last responses to the questionnaire variables, ruling out any late response bias. These analyses confirmed that the sample was randomly gathered and statistically representative of the population.

3.2 Variables and constructs

Three multi-item constructs were identified for consideration in this study: technology uncertainty (TU), lean supply chain management (LSCM) implementation and focal firm operational performance (OP). A single variable measured firm competitiveness in the sector (COM). All the items were measured on a five-point Likert scale.

Technology uncertainty (TU): a reflective first-order construct formed of the four items proposed by Chen and Paulraj (2004) and measured in terms of the complexity and dynamism of the technological context in which the SC operates. Respondents were asked to indicate their level of agreement with statements related to (1) the industry's rapid change in technology, (2) their ability to remain competitive in this challenging context, (3) obsolescence rate and (4) unpredictable production technology, from "1-totally disagree" to "5-totally agree". These items measured the degree to which technological change can produce an air of uncertainty in SC activities and operations and have previously been used in SCM research (Xiao *et al.*, 2019; Zhao *et al.*, 2018).

Lean supply chain management (LSCM): a reflective second-order construct taken from Moyano-Fuentes *et al.* (2019) as a validated instrument that included three different dimensions –first-order construct– related to LSCM implementation: (1) tools to eliminate waste in the SC (LSCM_T) such as VSM, pull flow and Kanban systems; (2) operationalization (LSCM_O), including minimum inventory, product and process standardization; and (3) strategic planning (LSCM_P) through long-term forecasting of customer demand, and queues and buffers to protect subprocesses. The items were measured using perceptual scales from "1-totally disagree" to "5-totally agree". This second-order construct has previously been used to empirically assess LM implementation along the SC (Moyano-Fuentes *et al.*, 2021).

Table 1.
Sample, population distribution and response rate by sector

Industry	Firms in population		Firms in sample		Response rate
Food products and tobacco	543	20.5%	47	17.0%	8.7%
Chemical and pharmaceutical products	422	15.9%	48	17.4%	11.4%
Manufacture of metal products	322	12.2%	43	15.6%	13.4%
Manufacture of machinery and equipment	275	10.4%	34	12.3%	12.4%
Motor vehicles	273	10.3%	23	8.3%	8.4%
Meat industry	158	6.0%	7	2.5%	4.4%
Electrical machinery and materials	141	5.3%	14	5.1%	9.9%
Manufacture of beverages	106	4.0%	7	2.5%	6.6%
Furniture industry	82	3.1%	8	2.9%	9.8%
Informatics, electronics and optics products	81	3.1%	13	4.7%	16.0%
Manufacture of other transport material	77	2.9%	12	4.3%	15.6%
Shoes and leather	63	2.4%	5	1.8%	7.9%
Other manufacturing industries	60	2.3%	9	3.3%	15.0%
Fabrics and textile	47	1.8%	6	2.2%	12.8%
Total	*2,650*	*100%*	*276*	*100%*	*10.4%*

Operational performance (OP): a reflective first-order construct designed to include operational outcomes and measured in terms of (1) cycle time, (2) quality conformance (to specifications), (3) on-time delivery and (4) volume flexibility. The selection of these items to represent the firm's OP was adapted from Bortolotti *et al.* (2015) and Danese *et al.* (2012). Respondents were asked to give their opinion of their firm's OP compared to their competitors, with values ranging from "1-poor, low" to "5-much better than average".

Lastly, *firm competitiveness* (COM) was operationalized as a single variable (one item) based on Rojo *et al.* (2016) to measure business competitiveness compared to competitors. Respondents were asked to indicate the percentage of ideal or optimal performance that they felt that their firm was achieving compared to industry competition from "1-minimum" to "5-maximum".

Table 2 shows the survey items for each factor (see Appendix for further details).

3.3 Construct validation

Content validity of the constructs was ensured by the selection of variables and constructs based on the existing literature and previously validated measures, and the evaluation of the pretest and pilot study by internationally recognized SCM researchers to check item clarity and legibility to increase the accuracy of the responses. An exploratory factor analysis (EFA) was conducted on all the considered items in SPSS to assess scale unidimensionality and reliability. Table 3 reports the EFA results (columns 3 and 4). The EFA results were satisfactory since eigenvalues were above 1, standardized factor loads were above 0.5 and there was significant explained variance for each extracted factor and high values for chi-squared/degrees of freedom in Bartlett's sphericity test ($p < 0.05$). Reliability was tested with Cronbach's alpha, with scores of 0.6 considered acceptable (Nunnally and Bernstein, 1967). Cronbach's alpha coefficients for the scales were compared with correlations between scale

Construct	Variable	Code	Source
Technology uncertainty (TU)	Our industry is characterized by rapidly changing technology	TU1	Chen and Paulraj (2004)
	If we do not keep up with changes in technology, it will be difficult for us to remain competitive	TU2	
	The rate of process obsolescence is high in our industry	TU3	
	The production technology changes frequently and sufficiently	TU4	
Lean supply chain management (LSCM)	Value stream mapping is used to identify and eliminate waste throughout our supply chain	LSCM1	Moyano-Fuentes *et al.* (2019)
	Our supply chain uses lean manufacturing techniques (such as pull flow, Kanban systems and setup time reduction)	LSCM2	
	Our supply chain generates high stock turnover and minimizes inventory	LSCM3	
	Process and product standardization is a common practice in our supply chain	LSCM4	
	Our supply chain delivers in small lot sizes	LSCM5	
	Our supply chain does long-term forecasting of customer demands and only focuses on the current market segments	LSCM6	
	In our supply chain, the strategy for handling uncertainty consists of using queues and buffers to protect sub-processes	LSCM7	
	Our supply chain structure seldom changes	LSCM8	
Operational performance (OP)	Cycle time (from raw materials to delivery)	OP1	Bortolotti *et al.* (2015), Danese *et al.* (2012)
	Quality conformance	OP2	
	On-time delivery	OP3	
	Volume flexibility	OP4	

Table 2. Survey items and primary factors

Table 3.
Exploratory and confirmatory factor analysis results

Factor		Variable	EFA Standardized factor loading	EFA goodness of fit	CFA Standardized factor loading	R^2
TU		TU1	0.862	KMO = 0.771	0.858	0.737
		TU2	0.750	$\chi^2 = 324.22$	0.642	0.413
		TU3	0.732	*df = 6*	0.603	0.364
		TU4	0.791	*sig. = 0.000*	0.695	0.482
				% EV = 61.671		
LSCM	*LSCM_T*	LSCM1	0.817	KMO = 0.701	0.651	0.423
		LSCM2	0.827	$\chi^2 = 332.38$	0.872	0.760
	LSCM_O	LSCM3	0.782	*df = 28*	0.569	0.324
		LSCM4	0.756	*sig. = 0.000*	0.686	0.470
	LSCM_P	LSCM5*	0.629	*% EV* = 60.941	n/a	n/a
		LSCM6	0.589		0.720	0.519
		LSCM7	0.617		0.529	0.280
		LSCM8*	0.664		n/a	n/a
OP		OP1	0.770	KMO = 0.777	0.666	0.443
		OP2	0.737	$\chi^2 = 275.99$	0.620	0.385
		OP3	0.811	*df = 6*	0.754	0.568
		OP4	0.769	*sig. = 0.000*	0.679	0.460
				% EV = 59.639		

Note(s): (*) indicates that the item was excluded from the CFA as the factor loading was <0.5

items to check the constructs' divergent validity (Anand and Ward, 2009), which was confirmed by the coefficients for the scales being greater than their correlations with other scales in every case.

Finally, convergent validity was verified by confirmatory factor analysis (CFA) using EQS 6.4 software. A robust maximum likelihood CFA was performed with the specified first-order (TU and OP) and second-order (LSCM) constructs after the normalized estimation of Mardia's test was used for data exploration and confirmed multivariate non-normality. The measurement model satisfied goodness-of-fit indices and convergent validity in terms of item factor loading significance and magnitude (>0.5). Items LSCM5 and LSCM8 – marked with an asterisk (*) – were discarded as their loadings were below 0.5. The final fit of the CFA was highly satisfactory for all factors (Satorra-Bentler scaled χ^2 = 142.024 with 95 degrees of freedom, χ^2/df = 1.495; RMSEA = 0.042; MFI = 0.918; NFI = 0.857; NNFI = 0.932; CFI = 0.946; IFI = 0.948). Table 3 gives the standardized factor loadings and R^2 of the variables (columns 5 and 6).

4. Data analysis and results

The hypotheses were tested using a structural model with the CB-SEM approach. CB-SEM was preferred to variance-based SEM (e.g. partial least squares – PLS) for its parameter accuracy. The results of the structural model showed that our model yielded a good overall fit: Satorra-Bentler scaled χ^2 = 88.222 with 79 degrees of freedom, χ^2/df = 1.117; RMSEA = 0.021; MFI = 0.983; NFI = 0.908; NNFI = 0.986; CFI = 0.989; IFI = 0.989. Figure 2 presents the results of the structural model.

The relationships in *H1*, *H2* and *H3* (p < 0.05) were shown to be significant, giving empirical support to the three hypotheses. The TU-LSCM relationship was supported with a significant positive coefficient of 0.37 (*H1*). This indicates that a higher level of TU leads to a higher level of LSCM implementation. The link between LSCM and firm OP was supported with a coefficient of 0.23 (*H2*), which confirms that a higher level of LSCM implementation

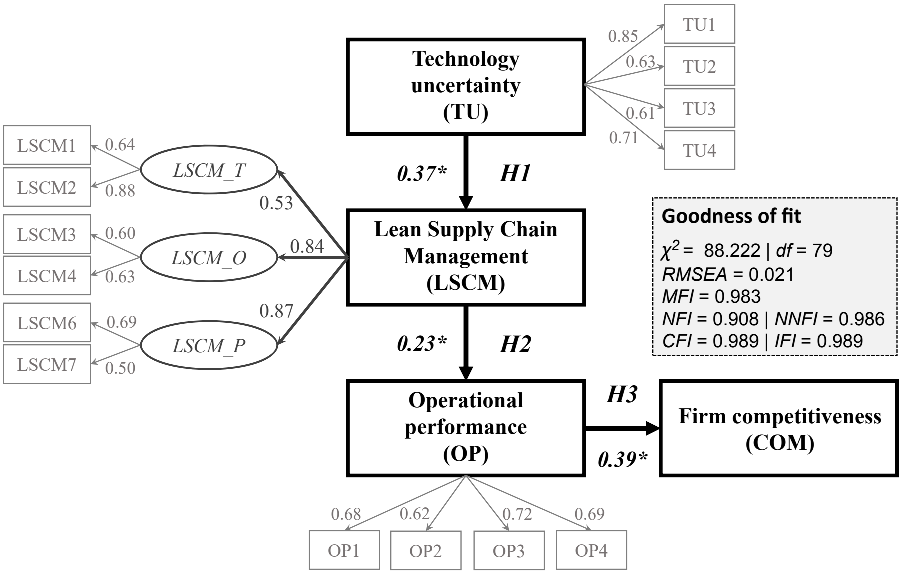

Figure 2.
Structural equation model results

leads to a higher level of focal firm OP. Finally, the OP-firm competitiveness relationship was also supported with a coefficient of 0.39 (*H3*). This finding empirically demonstrates that a higher level of focal firm OP leads to a better competitive position in its industry.

5. Discussion

Our findings confirmed the role of LSCM implementation as a mechanism to address TU and improve business competitiveness. Indeed, contextual aspects such as an industry characterized by rapid technological changes, the need for technology upgrades to remain competitive, a high technological obsolescence rate and changeable production technology act as external drivers in the implementation of an SC strategy capable of mitigating the effects of uncertainty by intensifying long-term collaboration with chain partners, such as LSCM. Stronger long-term collaboration with customers and suppliers would provide the necessary resources and capabilities to address the uncertainty arising from technological changes and achieve the objectives of flexibility and efficiency advocated by LSCM. In turn, progress in LSCM implementation brings positive consequences in terms of the focal firm's cycle time, quality, on-time delivery and volume flexibility – improvements that put the focal firm in a better competitive position in its sector.

Regarding *H1*, LSCM implementation is a reaction mechanism that seeks stability and efficiency to address TU in the industry (*H1* is supported). In this sense, this work builds on a broad stream of research focused on providing the elements that can drive the extension of LM practices along the SC, such as internal LM adoption (Maqueira *et al.*, 2021; Moyano-Fuentes *et al.*, 2021), SC collaboration (Iyer *et al.*, 2019; Srinivasan *et al.*, 2020), operations strategy selection (Qi *et al.*, 2011) and strategic sourcing (Yildiz Çankaya, 2020). Interestingly, these results contrast with some findings in the extant literature that state that LSCM adoption is preferred in environments with low complexity and dynamism (Swenseth and Olson, 2016; Zimmermann *et al.*, 2020), which shows that LM is extended throughout the SC to address chain-level TU. These findings highlight the importance of the collaborative relationships pursued by LSCM to address TU (Moyano-Fuentes *et al.*, 2019).

These results support previous findings on TU's role in developing integrative practices with SC members (Ragatz *et al.*, 2002; Saruchera and Asante-Darko, 2021), its impact on external technology integration processes (Stock and Tatikonda, 2008) and its power to strengthen upstream/downstream involvement for green product innovation (Zhao *et al.*, 2018). This work also complements Maqueira-Marín *et al.* (2017), Saruchera and Asante-Darko (2021) and Srinivasan *et al.* (2020), who found that technological turbulence can enhance collaboration with SC partners, and Lee *et al.* (2009), who stated that TU can drive strategic purchasing, specific investments and supplier alliances. Moreover, it extends previous works on TU's role in driving SC-level competitive strategy selection (Parnell, 2018).

The results of this work are particularly useful for industries characterized by significant changes in production- and process-level technologies such as manufacturing-related technologies. Indeed, the breathtaking change experienced by these industries prompted by the adoption of emerging I4.0 technologies requires the implementation of an SC strategy to mitigate the sources of variability that they introduce (Bosman *et al.*, 2020; Ding *et al.*, 2021) and to achieve the efficiency and flexibility needed to remain competitive. Additionally, this study's findings are all the more relevant in the context of the crisis triggered by the Covid-19 pandemic followed by the war in Ukraine, which have introduced new sources of variability into SCs that must be addressed. Particularly, the global shortage of semiconductor chips is an ongoing international crisis in which demand exceeds supply, with serious consequences for firm performance in terms of cost, flexibility, delivery and competitiveness (Ramani *et al.*, 2022). These external sources of variability, coupled with those arising from frequent technological changes, emphasize the need for collaboration and integration across the SC and exacerbate the need to advance the LSCM strategy to achieve or maintain competitive advantage.

Regarding *H2*, LSCM implementation has a positive effect on focal firm OP (*H2* is supported). This effect provides insights into how implementing LM practices throughout the SC can lead to better performance. Our results empirically demonstrate the benefits of LSCM and thus clarify the inconclusive findings in the literature. This study has revealed that implementing LSCM in the context of TU can enhance cycle time, quality, on-time delivery and volume flexibility. These insights enrich previous works that have found performance improvements in terms of delivery times, inventory levels and quality (Inman and Green, 2018; Iyer *et al.*, 2019); lead time, cost, inventory, quality, delivery service level (Tortorella *et al.*, 2017); inventory and quality (Marodin *et al.*, 2017b); price, delivery, quality, responsiveness and service support (Yildiz Çankaya, 2020); efficiency (Moyano-Fuentes *et al.*, 2021); return on investment, market share, sales growth (Qi *et al.*, 2017; Zimmermann *et al.*, 2020); and profits and labor productivity (Zimmermann *et al.*, 2020). Moreover, the comprehensive instrument used to measure LSCM implementation in this study can solve some problems with other measurement scales detected in the previous literature.

Regarding *H3*, a better competitive position can be accomplished due to OP improvements derived from LM implementation along the SC (*H3* is supported). These results are in line with previous literature findings and show that, in contexts of TU, firms that reorganize their manufacturing systems with supplier involvement improve their OP and become more competitive (Ghobakhloo and Fathi, 2019; Gillani *et al.*, 2020). Thus, by implementing digitized lean manufacturing systems in small and medium-sized enterprises that integrate suppliers (Ghobakhloo and Fathi, 2019), reorganizing reverse logistics in e-commerce activities (Saruchera and Asante-Darko, 2021) and extending to the SC new technologies such as big data, whose use is somewhat uncertain in manufacturing (Yiu *et al.*, 2021), firms' OP is improved and they become more competitive (Ghobakhloo and Fathi, 2019; Gillani *et al.*, 2020; Saruchera and Asante-Darko, 2021; Yiu *et al.*, 2021). Moreover, focal firms' manufacturing activities are now clearly contingent on the design of complex and increasingly global SCs, and manufacturing firms no longer compete on an individual but on an SC basis

(Christopher, 1999). As indicated above, this has led to SC disruptions due to the Covid-19 pandemic and the Russia–Ukraine war, with only firms with very powerful, well-designed and flexible SCs (LSCM) capable of outperforming their competitors.

6. Conclusions

This study investigates TU's role in LSCM implementation and the latter's effect on OP and, consequently, on firm competitiveness. Our findings reveal that TU positively affects LSCM implementation. Moreover, LSCM implementation has a positive effect on focal firm OP, which, in turn, leads to firm competitiveness. LSCM is, therefore, a competitive instrument to address ongoing technological challenges and provide better OP and a better competitive position.

6.1 Theoretical implications

From an academic perspective, our study delves into the drivers that advance the application of lean principles and practices throughout the SC, especially in uncertain contexts. This is in line with CT, which emphasizes that alignment with the SC's operating environment is crucial to remaining competitive. Our results also provide additional insights into the effects of TU as a driving force in the SC context. Our findings reveal that the reaction to uncertainty should not be isolated at the firm level but should occur at the SC level, thus stressing the role of long-term relationships with chain partners.

This work also contributes to emphasizing and specifying LSCM's likely improvements to OP and its essential role in achieving competitive advantage. Our results agree with the arguments used in the relational view of RBT since implementing a particular SC strategy aimed at reducing variability and inefficiency along the SC can produce performance improvements and greater competitiveness in the context of technological change. Therefore, this study clarifies the inconclusive findings on LSCM performance and provides some additional understanding of LSCM's role in improving a firm's performance and its competitive position.

6.2 Practical implications

From a practical perspective, our findings indicate that LSCM implementation is advisable to provide the efficiency and flexibility needed in a context characterized by technological change and variability. Managers are, therefore, advised to consider extending LM upstream and downstream in the SC to address TU. Strategic integration with SC partners and the establishment of long-term relationships based on trust and commitment advocated by LSCM can enhance manufacturing organizations' capabilities to respond effectively and flexibly to technological changes. The previous research argues that the adoption of I4.0 information and digital technologies can have relevant implications in an LSCM context (Núñez-Merino *et al.*, 2020), so we advance by demonstrating that the TU produced by this new paradigm is capable of driving LSCM implementation in a variety of industrial sectors.

Practitioners are recommended to strategically analyze the environment in which their organizations and SC operate since the choice of the right SC strategy can determine the firm's competitiveness in the current circumstances. The response to TU should not be firm level but SC level, to provide the flexibility and efficiency required in these situations. SC managers must be aware that, to improve their performance and be competitive in times of TU, they must achieve flexible supply chains, such as those shaped by LSCM.

Our results can be extended to other developed countries where the technological transition of the industrial and manufacturing sector is making similar progress, thanks to the adoption of I4.0 practices and technologies. The practical implications can also be extended to developing countries since their perception of technological uncertainty could be similar even if the practices or technologies in question are less developed or less advanced. Managers should be wary of advancing LSCM implementation in circumstances such as the current context, where technological changes are combined with unexpected and disruptive changes due to Covid-19 and war, which can only be addressed with an effective supply chain strategy.

6.3 Limitations and future research

Lastly, some limitations to this research and several future research directions can be indicated. The use of the focal firm perspective to assess LSCM could be seen as a minor limitation, as the focal firm is generally understood to have an overview of the chain. Cross-sectional data from a single country have been used, which potentially limits the generalizability of the results as the complexity and uncertainty derived from new technology adoption and digital transformation may be addressed differently in different countries, depending on their level of technological development, and also by sectors with different technology intensities. Nevertheless, the firms participating in this study belong to industries with different degrees of technological intensity, so the TU construct reflects their perceptions of these changes in their particular sectors. Moreover, the variables used to define TU are markedly manufacturing in type and oriented toward describing the type of uncertainty in the manufacturing industry. Therefore, our results are generalizable to any manufacturing firm with similar characteristics, although it would be interesting to extend the scope of the analysis to other countries and nonindustrial sectors such as healthcare, education, hospitality and public administration to provide a fuller perspective of how TU can influence the implementation of some specific SC strategies.

Finally, scholars are encouraged to investigate the role of contextual factors such as the competitive intensity of the industry and supply and demand uncertainty in LSCM implementation and performance. The current global crisis regarding the pandemic, the semiconductor shortage and the Russo–Ukrainian war provides fertile ground for analyzing the influence of supply, demand and TU on the adoption of the most suitable SC strategy to achieve competitiveness. Indeed, the results might be different if the proposed hypotheses were tested today as our data were collected in 2018. Since this study focuses on OP, researchers could extend this analysis to include financial measures. The deployment of mature and emergent technologies in a context characterized by TU could also be addressed.

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Appendix
Survey items and description

Technology uncertainty (TU)

Please rate your degree of agreement with the following aspects regarding the degree of technology uncertainty on the following scale: 1 = totally disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = totally agree.

TU1. Our industry is characterized by rapidly changing technology.

TU2. It will be difficult for us to remain competitive if we do not stay abreast of changes in technology.

TU3. The process obsolescence rate is high in our industry.

TU4. Production technology changes frequently and sufficiently.

Lean supply chain management implementation (LSCM)

Please rate the degree to which you agree with the following statements on lean at the supply chain management level on the following scale: 1 = totally disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = totally agree.

LSCM1. Value stream mapping is used to identify and eliminate waste throughout our supply chain.

LSCM2. Our supply chain uses lean manufacturing techniques (such as pull flow, Kanban systems and setup time reduction).

LSCM3. Our supply chain generates high stock turnover and minimizes inventory.

LSCM4. Process and product standardization are common practices in our supply chain.

LSCM5. Our supply chain delivers in small lot sizes.

LSCM6. Our supply chain does long-term forecasting of customer demand and only focuses on the current market segments.

LSCM7. The strategy for handling uncertainty in our supply chain consists of using queues and buffers to protect subprocesses.

LSCM8. Our supply chain structure seldom changes.

Operational performance (OP)

Please indicate where your company stands on the following operational performance indicators compared to your competitors on the following scale: 1 = much worse than the competition; 2 = worse than the competition; 3 = the same as the competition; 4 = better than the competition; 5 = much better than the competition.

OP1. Cycle time (from raw materials to delivery).

OP2. Quality conformance.

OP3. On-time delivery.

OP4. Volume flexibility.

Firm competitiveness (COM)

Compared to your competitors, what percentage of optimal or ideal business results do you think your company is achieving in your industry on a scale of 1–5, where 1 = the minimum compared to the competition and 5 = the maximum compared to the competition?

COM. Company performance compared to competitors.

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