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MECHANISMS TO BOOST SUPPLY CHAIN RESPONSIVENESS: THE NEXUS BETWEEN INFORMATION TECHNOLOGIES AND SUPPLY CHAIN STRATEGIES

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I dedicate this

thesis to my family,

for their love and support.

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AGRADECIMENTOS

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ABSTRACT

The business landscape has changed substantially over recent decades and become increasingly complex and volatile. Therefore, in order to boost their supply chain responsiveness companies are keen to adapt their supply chain strategies and integrate information technologies. To shed light on the mechanisms that can be used to enhance supply chain responsiveness, this doctoral thesis aims to identify and understand the role that Industry 4.0 information technologies play in the development of the lean and agile supply chain strategies and examine the implications of the relationships between them for firm performance. Accordingly, this study has first synthesized and classified the research on the integration of information technologies and lean and agile supply chain strategies through two systematic literature reviews. These systematic reviews provide a comprehensive overview of the literature on the field by mapping the existing relationships between the concepts and the main information technology applications associated with lean and agile supply chain goals. Gaps are identified and future lines of research are proposed based on these findings. In the second part of this doctoral thesis, some of the previously identified gaps have been addressed through the development of survey-based studies. In this regard, theoretical frameworks have been developed to investigate the different impacts of specific groups of information technologies on the lean and agile supply chain strategies, as well as the interrelationships between information technologies classified according to their degree of consolidation and between lean and agile supply chain strategies. Furthermore, this thesis also investigates the role of technology uncertainty as an antecedent to the use of information technologies and, to conclude, the overall implications for firm performance. The hypotheses are tested through structural equation analysis using a database of Spanish manufacturing companies. This doctoral thesis raises managerial and academic implications by moving knowledge of the supply chain management field a step forward and guiding manufacturing companies as to the most appropriate processes to achieve superior supply chain responsiveness.

Keywords: Agile supply chain; Information technologies; Industry 4.0; Lean supply chain, Supply chain strategy

RESUMEN

El panorama empresarial ha cambiado sustancialmente en las últimas décadas, volviéndose cada vez más complejo y volátil. En consecuencia, para aumentar la capacidad de respuesta de la cadena de suministro, las empresas están dispuestas a adaptar sus estrategias en este ámbito y a integrar las tecnologías de la información. Con el fin de arrojar luz sobre estos mecanismos que pueden utilizarse para mejorar la capacidad de respuesta de la cadena de suministro, esta tesis doctoral pretende identificar y comprender el papel que desempeñan las tecnologías de la información relacionadas con la Industria 4.0 en el desarrollo de estrategias lean y ágiles de la cadena de suministro. Al mismo tiempo, esta tesis analiza las implicaciones de dichas relaciones para los resultados de la empresa. Con ese propósito, en primer lugar, este estudio ha sintetizado y clasificado la investigación sobre la integración entre las tecnologías de la información y las estrategias lean y ágiles de la cadena de suministro a través de dos revisiones sistemáticas de la literatura. Estas revisiones sistemáticas ofrecen una visión global de la bibliografía sobre el tema, trazando un mapa de las relaciones existentes entre los conceptos y las principales aplicaciones de las tecnologías de la información asociadas a los objetivos de las cadenas de suministro ágiles y lean. A partir de estos resultados, se identifican lagunas y se proponen futuras líneas de investigación. En la segunda parte de la tesis doctoral se han abordado algunas de las lagunas previamente identificadas mediante el desarrollo de estudios empíricos. En este sentido, se han desarrollado marcos teóricos para investigar los diferentes impactos de grupos específicos de tecnologías de la información en las estrategias lean y ágiles de la cadena de suministro, así como la interrelación entre las tecnologías de la información agrupadas en función de su grado de madurez (o consolidación) y entre las estrategias lean y ágil de la cadena de suministro. Además, esta tesis también investiga el papel de la incertidumbre tecnológica como antecedente del uso de las tecnologías de la información y las implicaciones generales para los resultados de las empresas. Las hipótesis se comprueban mediante análisis de ecuaciones estructurales utilizando una base de datos compuesta por empresas manufactureras españolas. Esta tesis doctoral plantea implicaciones directivas y académicas al impulsar el conocimiento en el campo de la gestión de la cadena de suministro y al servir de guía a las empresas manufactureras sobre

los procesos más adecuados para lograr una capacidad de respuesta superior en la cadena de suministro.

Palabras claves: Cadena de suministro ágil; Cadena de suministro lean; Estrategias de cadena de suministro; Industria 4.0; Tecnología de la información.

CONTENTS

List of Acronyms

AI	Artificial Intelligence
AMT	Advanced Manufacturing Technologies
APS	Advanced Planning and Scheduling
AR	Augmented Reality
ASC	Agile Supply Chain
AVE	Average Variance Extracted
BDA	Big Data Analytics
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CATI	Computer-Assisted Telephone Interviewing
CB-SEM	Covariance-Based Structural Equation Modeling
CC	Cloud Computing
CFA	Confirmatory Factor Analysis
CIM	Computer Integrated Manufacturing
CMfg	Cloud Manufacturing
CNAE	Spanish Standard Industrial Classification
CPS	Cyber-Physical Systems
CR	Composite Reliability
DF	Degrees of Freedom
DCV	Dynamic Capabilities View
EDI	Electronic Data Interchange
EFA	Exploratory Factor Analysis
ERP	Enterprise Resource Planning
HTMT	Heterotrait–Monotrait
I4.0	Industry 4.0
IDT	Information and Digital Technology
IoT	Internet of Things
IT	Information Technology
JCI	Journal Citation Indicator
JCR	Journal Citations Reports
JIF	Journal Impact Factor
JIT	Just in Time
KPI	Key Performance Indicator
LM	Lean Management
LSC	Lean Supply Chain
MRP	Material Requirement Planning
NNFI	Non-Normed Fit Index
OP	Operational Performance
RBV	Resource-Based View
RFID	Radio-Frequency Identification
RL	Research Line

RMSEA	Root Mean Square Error of Approximation
ROT	Resource Orchestration Theory
RQ	Research Question
SABI	Iberian Balance Sheet Analysis System
SC	Supply Chain
SCM	Supply Chain Management
SEM	Structural Equation Modeling
SJR	SCImago Journal Rank
SLR	Systematic Literature Review
SMEs	Small and Medium Enterprises
SOA	Service Oriented Architecture
TLC	Technology Life Cycle
TQM	Total Quality Management
TU	Technology Uncertainty
VR	Virtual Reality
VSM	Value Stream Mapping
WOS	Web of Science

CHAPTER 1.

Introduction

CHAPTER 1

1 Introduction

This doctoral thesis seeks to identify and understand the role played by information technologies in the pursuit of supply chain responsiveness through the development of lean and agile supply chain strategies. This thesis also investigates how this connection impacts firm performance.

This introduction presents the content of the doctoral thesis from an integrated perspective. For this, the introduction section is structured into six main parts. First, the background provides an overview of the key concepts. Second, the reasons for conducting this doctoral thesis, the proposed research questions and the objectives are set out. Third, the theoretical lenses are presented. The fourth section describes the research methodologies. Next, the overall structure of this thesis is presented, and finally, a complete list of the documents derived from this thesis is provided.

1.1 Research Background

This section aims to provide an insight into the main objects and define the scope of the investigation. Thus, first, it gives the definitions of supply chain responsiveness and the lean and agile supply chain strategies followed by an overview of the information technologies and Industry 4.0 concepts. Lastly, it outlines the existing literature on the association between the key concepts.

1.1.1 Supply chain responsiveness and lean and agile supply chain strategies

Supply chain responsiveness refers to the supply chain's ability to cooperatively respond to environmental changes (Qrunfleh & Tarafdar, 2013; Wu et al., 2006) and can be approached from a twofold perspective: a) as an improvement in supply chain flexibility, and b) as an improvement in supply chain agility (Moyano-Fuentes et al., 2016; Shekarian et al., 2020). Supply chain flexibility can, therefore, be defined as an operational capability that helps organizations to efficiently change internally and/or across their key partners in response to internal and external uncertainties through the effective integration of supply

chain relationships (Fayezi et al., 2017). Meanwhile, supply chain agility is a strategic capability that helps organizations quickly detect and respond to changes in the business environment (Fayezi et al., 2017). Thus, flexibility is related to adaptability and versatility, while agility focuses more on speed (Swafford et al., 2008).

Two supply chain strategies play a key role in developing these capabilities: the lean supply chain (LSC) strategy (to achieve efficiency and flexibility) and the agile supply chain (ASC) strategy (to achieve agility) (Qrunfleh & Tarafdar, 2013). These two approaches, lean and agile, have evolved from the intra-organizational level (Naylor et al., 1999; Womack et al., 1990) to the supply chain level to serve as a mechanism to integrate all partners and tackle challenges such as increased complexity (Goldsby et al., 2006; Marodin et al., 2017).

The LSC strategy aims to improve quality and reduce costs by minimizing sources of waste such as overproduction, defects, and inventory to meet customer needs (Lamming, 1996; Moyano-Fuentes et al., 2019). Implementing lean practices across the supply chain is considered a complex and challenging process that requires close relations between suppliers and customers and ensures optimal coordination of the supply chain flows (Moyano-Fuentes et al., 2019).

On the other hand, the ASC strategy aims to respond quickly to customer demand and meet the dynamic business environment in the short term (Christopher, 2000). The implementation of agile practices across the supply chain also requires appropriate information-sharing among partners and close collaboration to fulfill demand (Qrunfleh & Tarafdar, 2014).

Although the lean and agile approaches have common objectives and multiple studies state that they are complementary strategies, another stream of literature has often addressed the two approaches as mutually exclusive paradigms (Calatayud et al., 2019; Goldsby et al., 2006). In addition, both strategies can be influenced by multiple factors that can generate different impacts on their deployment (Qrunfleh & Tarafdar, 2014). These questions will be further addressed in the following chapters of this doctoral thesis.

1.1.2 Information technologies and Industry 4.0

In this doctoral thesis, the concept of Information Technologies (ITs) (also referred to as IDTs, Information and Digital Technologies) refers to a wide group of technologies

that can support supply chain processes, including information systems in general, communication technologies, and digital technologies (Ghobakhloo, 2020; Núñez-Merino et al., 2020; Zhang et al., 2011). However, while certain technologies are in the advanced or mature stages of their life cycle (Taylor & Taylor, 2012), others are only beginning to be adopted (Wang et al., 2014) and are thus emerging technologies that have the potential to bring about disruptive changes in the business scenario (Queiroz et al., 2021).

The unprecedented advancement of ITs has ushered in the Fourth Industrial Revolution, better known as Industry 4.0 (I4.0) (Kagermann et al., 2013). The concept of I4.0 was introduced at the 2011 Hannover Fair in Germany and refers to a new industrial paradigm based on principles such as vertical and horizontal integration, virtualization, real-time capability, decentralization, service orientation, and modularity interoperability, as well as a number of ITs that can be used to deploy these principles (Ghobakhloo, 2018; Kagermann et al., 2013).

Two approaches can be found to I4.0 ITs in the literature: the first considers that this phenomenon only includes emerging ITs such as Big Data Analytics (BDA), blockchain, and the Internet of Things (IoT), among others (Culot et al., 2020), while the other maintains that I4.0 comprises a wide-ranging group of mature and emerging ITs that are applied jointly and intensively to industry to enable the digitalization and automatization of the entire value chain (Frank et al., 2019; Kagermann & Wahlster, 2022; Núñez-Merino et al., 2020). This doctoral thesis follows this second stream to provide a holistic overview of the topic (Dalenogare et al., 2018; Frank et al., 2019; Ghobakhloo, 2020; Núñez-Merino et al., 2020).

Table 1.1 describes ITs that are considered relevant in the field of I4.0 (Frank et al., 2019; Ghobakhloo, 2018; Núñez-Merino et al., 2020) and that will appear throughout this thesis: IoT, BDA, cloud computing, additive manufacturing, advanced robotics, augmented reality, virtual reality, artificial intelligence, radio frequency technology, blockchain, enterprise resource planning, advanced manufacturing technologies, web 2.0 technologies, and e-business technologies.

Table 1.1. Information Technologies

I4.0 ITs	Description	References
Internet of Things (IoT)	A network of physical objects that are digitally connected to sense, monitor, and interact within a company and between the company and its supply chain.	(Ben-daya et al., 2019; Koh et al., 2019)
Big Data Analytics (BDA)	Technological solutions that enable a high variety and volume of data to be managed and analyzed.	(Frank et al., 2019; Gunasekaran et al., 2017)
Cloud Computing (CC)	CC enables IT software and hardware resources to be shared over the internet, thus allowing information to be easily stored and remotely accessed by diverse actors.	(Hofmann & Rüsch, 2017; Maqueira et al., 2019)
Additive Manufacturing (AM)	AM or 3D printing represents the set of technologies used to develop three-dimensional objects from digital design models layer by layer under computer control.	(Ghadge et al., 2018)
Artificial Intelligence (AI)	The simulation of human intelligence processes by machines.	(Strandhagen et al., 2017)
Advanced Robotics	Robots that are capable of performing tasks with a high level of complexity and minimal human interaction.	(Pagliosa et al., 2021)
Radio-frequency technology (RFID)	RFID is a form of wireless communication that allows the storage and retrieval of data through electromagnetic waves to identify tags attached to objects.	(Powell & Skjelstad, 2012)
Blockchain	A distributed ledger database for recording transactions in a network in a shared and immutable way.	(Longo et al., 2019)
Augmented Reality (AR)	Technological solutions that create an enhanced version of reality by superimposing virtual objects on the real world.	(Ardito et al., 2019)
Virtual Reality (VR)	Technology that enables the design, simulation, and evaluation of environments in 3D.	(Kerin & Pham, 2019)
Web 2.0 technologies	Technologies that include a range of web tools (such as blogs and collaborative websites) that enable knowledge to be created, shared and updated within the company and between business partners.	(Bruque et al., 2015)
Enterprise Resource Planning (ERP)	Software systems for managing operations and production processes.	(Almahamid & Hourani, 2015)
Advanced Manufacturing Technologies (AMT)	Advanced manufacturing refers to the technological advancements that firms can adopt to improve the manufacture of a firm's products and/or its processes.	(Ardito et al., 2019)
E-business technologies	E-business technology focuses on IT resources adopted by firms to exchange information with suppliers and customers online	(Almahamid & Hourani, 2015; Bruque et al., 2015)

Note(s): This list does not cover all existing technologies in the field of Industry 4.0; however, it includes ITs previously studied in the field of lean and agile strategies, as well as other relevant ITs that will be analyzed in this doctoral thesis.

Some of the ITs presented in Table 1.1 such as ERP, advanced manufacturing technologies, web 2.0 technologies, e-business technologies, and RFID are in a more mature stage of the life cycle (Núñez-Merino et al., 2020; Taylor & Taylor, 2012). However, others can be considered more emerging, and it is possible to distinguish a specific group of technologies known as the I4.0 base technologies (Bag et al., 2021; Frank et al., 2019; Narayanamurthy and Tortorella, 2021). This group (Frank et al., 2019) includes cloud computing (Maqueira et al., 2019), BDA technologies (Gunasekaran et al., 2017), and IoT (Ben-daya et al., 2019) technologies. These base technologies are recognized as

the foundation resources for the transition to I4.0 (Frank et al., 2019). Taken together, the I4.0 base technologies enable data collection, storage, processing, analysis, and data sharing processes to be carried out connectedly and intelligently (Kamble et al., 2019; Tortorella & Fettermann, 2018).

Based on the above, the aforementioned ITs are presented in Figure 1.1. The inner ring is divided into two groups according to the degree of maturity of the technologies. In the middle ring, the I4.0 base technologies are differentiated from the other technologies, and all the ITs are listed in the outer ring.

Figure 1.1. IT classification

Source: Own elaboration.

1.1.3 The relationship between information technologies and the lean and agile supply chain strategies

There is a broad consensus among researchers on the relevant role that ITs play in the management of internal and external operations processes (Wu et al., 2006; Zhang et al., 2016). The use of IT helps firms to achieve upstream and downstream supply chain integration, as well as to adapt to the business environment (Zhang et al., 2016). Furthermore, when combined with other complementary resources and capabilities, ITs are

a mechanism to increase supply chain responsiveness and gain a competitive advantage (Novais et al., 2020; Powell & Dent-Micallef, 1997). In addition, there has been a growing interest in integrating ITs and supply chain strategies (Qrunfleh & Tarafdar, 2014).

In this respect, even though in the past lean principles were adopted without using IT (Moyano-Fuentes et al., 2012), the development of IT solutions to improve lean practices has attracted the interest of scholars and practitioners (Núñez-Merino et al., 2020; Pagliosa et al., 2021; Reyes et al., 2021). A number of studies have also looked into the role that IT plays in increasing supply chain agility (Christopher, 2000; DeGroote & Marx, 2013; Mandal, 2018). In this sense, while some studies find a positive association between IT and the LSC and ASC strategies (Qrunfleh et al., 2012; Swafford et al., 2008), others do not show a direct and positive link (Bi et al., 2013; Chiarini & Vagnoni, 2017; Gorane & Kant, 2017). Thus, the prior research is fragmented and provides some conflicting findings in connection with the integration of IT and the LSC and ASC approaches (Chiarini & Vagnoni, 2017; Ding et al., 2012; Raji et al., 2021a).

1.2 Motivation and research questions

Supply chains currently operate in a highly competitive, complex, and volatile business scenario. In this context, supply chains are subjected to pressures to reduce product development cycles, operate with high levels of quality, and reduce costs to meet customer requirements, i.e., improve supply chain responsiveness by providing the right product at the right time and price (Calatayud et al., 2019; Fadaki et al., 2020). Thus, supply chain strategies that seek to improve supply chain responsiveness and meet customer demand efficiently and effectively, such as lean and agile, have become even more relevant (Srinivasan et al., 2020).

More recently, the I4.0 phenomenon has also received the attention of researchers and managers due to its potential to improve or streamline the management of firms and supply chain processes (Núñez-Merino et al., 2022). Although the use of IT for enhancing customer-supplier relationships and supporting key processes, including procurement, warehousing, and transportation (Zhang et al., 2016) precedes the I4.0 concept, factors such as the increased availability and reduced costs of some technologies are inducing many supply chains to make intensive use of some mature and emerging ITs to meet customers' needs more efficiently and quickly (Yang et al., 2021).

However, the previous literature has pointed out that merely investing in IT does not guarantee an improvement in supply chain responsiveness or firm performance (Powell & Dent-Micallef, 1997; Wu et al., 2006). IT investments need to be aligned with the company and supply chain strategies (Qrunfleh et al., 2012), otherwise, they risk making unnecessary investments without achieving the planned results.

Furthermore, the literature on the integration of IT and the LSC and ASC strategies is dispersed and yields some inconclusive results (Raji et al., 2021a). In addition, as mentioned before, there is a very wide variety of ITs. On the one hand, some traditional ITs are inherent components of the concepts of flexibility and agility in the supply chain since they contribute to the acquisition of physical and management capabilities (Zhang et al., 2016). This antecedent effect manifests itself both directly and indirectly through different supply chain capabilities (Swafford et al., 2008). On the other hand, it is suggested that the use of emerging ITs can lead to deeper changes in supply chain management such as blurring the lines between the physical and digital worlds (Calatayud et al., 2019). Thus, mature ITs could play a very different role from emerging ITs in providing leanness or agility in the supply chain.

Additionally, the integration of mature and emerging ITs is a challenge for companies and their supply chains. Yet, it is essential to integrate emerging ITs and existing (mature) technologies to be able to successfully participate at the I4.0 level (Ghobakhloo, 2020; Kagermann et al., 2013; Yan et al., 2014) as, for example, the functions of mature ITs could be enhanced by emerging ITs.

Other specific gaps are related to the mechanisms or strategies such as LSC and ASC that can be used by focal firms to increase supply chain responsiveness and the relationship between these strategies (Shekarian et al., 2020). In the past, studies have addressed these two strategies as opposing paradigms (Goldsby et al., 2006; Yusuf & Adeleye, 2002). However, an increasing number of companies and supply chains are seeking to simultaneously achieve objectives related to cost efficiency and short-term responsiveness (Fadaki et al., 2020). Be this as it may, the relationship between the two strategies remains unclear and needs further understanding (Calatayud et al., 2019; Raji et al., 2021a).

Lastly, the previous literature highlights a lack of studies on the role played by environmental factors, which could influence the relationship between IT and the LSC and

ASC approaches (Buer et al., 2018; Garcia-Buendia et al., 2021; Queiroz et al., 2018) and the need to identify the consequences for firm performance (Garcia-Buendia et al., 2021; Raji et al., 2021b). Technology uncertainty is a major environmental factor in this respect, especially in the context of the fourth industrial revolution, where firms are witnessing rapid and significant changes in technology (Srinivasan et al., 2020). This technology turbulence results in shortened innovation cycles and rapid changes in product specifications and manufacturing processes (Xiao et al., 2019). Accordingly, it is crucial to adopt a holistic perspective to examine antecedents such as technology uncertainty and the implications of the relationship between different bundles of IT and the two supply chain strategies in order to shed some light on the mechanisms that can translate into improved business performance.

Therefore, this doctoral thesis aims to address these gaps by driving forward the knowledge on the interrelationships between different groups of information technologies, LSC strategy, ASC strategy, contextual factors, and the implications for performance.

Based on the above, this doctoral thesis seeks to answer four specific Research Questions (RQs) and achieve some specific objectives, which are presented below:

RQ1. What has been investigated to date on the relationships between ITs and the LSC and ASC strategies and what are the key findings and remaining challenges?

The following specific objectives derive from this question:

Objective 1.1: To identify and provide an overview and novel classification of the existing literature.

Objective 1.2: To discuss the main findings and propose future research directions based on the identified gaps.

RQ2. What effect do ITs have on the implementation of the LSC and ASC strategies depending on their degree of consolidation or their life cycle?

In this case, we seek to achieve the following specific objectives:

Objective 2.1: To empirically analyze the relationship between mature and emerging ITs.

Objective 2.2: To identify and compare the impact of mature and emerging ITs on the implementation of the LSC and ASC supply chain strategies.

Objective 2.3: To empirically analyze the relationship between the LSC strategy and the ASC strategy in the presence of mature and emerging ITs.

RQ3. What role do I4.0 base technologies play in the implementation of the LSC and ASC strategies?

The following specific objectives derive from this question:

Objective 3.1: To empirically study the effect of I4.0 base technologies on the LSC and ASC strategies.

Objective 3.2: To empirically analyze the relationship between the LSC and ASC strategies in an I4.0 setting.

Objective 3.3: To identify and analyze the effects of I4.0 base technologies, LSC, and ASC on business operational performance.

RQ4. In the context of technological uncertainty, what impact do I4.0 ITs have on the LSC and ASC strategies?

The following specific objectives that must be achieved to answer this question are:

Objective 4.1: To analyze the influence of technological uncertainty on I4.0 ITs.

Objective 4.2: To identify from the supply chain perspective the effects of the most representative and promising I4.0 ITs on the implementation of the LSC and ASC strategies.

Objective 4.3: To empirically analyze the relationship between the LSC strategy and the ASC strategy in an I4.0 setting and under technological uncertainty.

Objective 4.4: To analyze the effects of LSC and ASC on operational performance.

1.3 Theoretical lenses: Dynamic Capabilities View and Resource Orchestration Theory

Two theoretical approaches were used in different chapters of this doctoral thesis to guide and support the theoretical propositions: Dynamic Capabilities View (DCV) and Resource Orchestration Theory (ROT) (Sirmon et al., 2011; Teece, 2007). Both approaches attempt to clarify the role of organizational or supply chain capabilities in explaining business performance. DCV and ROT are theories that complement the resource-based view (RBV) (Sirmon et al., 2011; Teece, 2007). The RBV suggests that firms can create a

competitive advantage by assembling resources that are valuable, rare, inimitable, and non-substitutable (Barney, 1991). While the RBV emphasizes the selection of appropriate resources, DCV and ROT help to explain the processes by which competitive advantage is developed and maintained over time (Hitt et al., 2016).

Specifically, the DCV focuses on dynamism in the competitive environment and how an organization or group of organizations can operationalize their mix of resources to generate capabilities and sustain a competitive advantage (Helfat & Winter, 2011; Teece, 2007). Dynamic capabilities are the capabilities that enable a firm to match or even trigger market changes (Helfat & Winter, 2011). In this regard, supply chain dynamic capabilities reflect the ability to adjust the supply chain to tackle changing markets (Hong et al., 2018). Thus, the DCV is a useful framework to understand the relationships between resources, capabilities, and performance at the supply chain level (Hitt et al., 2016).

According to ROT, the most important factor for building a competitive advantage is the ability of managers to leverage a firm's set of resources and bundle these to generate synergistic effects (Sirmon et al., 2011). The role of managers in orchestrating resources to achieve a competitive advantage can be compared to how an orchestra conductor orchestrates the instruments (Liu et al., 2016; Rojo-Gallego-Burin et al., 2020). Therefore, ROT focuses on the managerial initiatives that operationalize a set of resources to generate capabilities (Chirico et al., 2011; Sirmon et al., 2011). At the supply chain level, integrating and leveraging the firm's and its partners' capabilities is also relevant and even more challenging (Hitt, 2016).

Therefore, in the framework of this thesis, ROT and DCV are especially helpful for understanding the orchestration of company and supply chain partners' IT resources and supply chain management approaches to build new capabilities for improving firm performance.

1.4 Research Methodology

This thesis is based on the positivist paradigm and two overarching methodologies have been employed to achieve the defined objectives: the systematic literature review and survey-based research. There is an exploratory component in the first approach since it establishes the context of the topic and delimits the subject through inductive reasoning to identify patterns in the previous scientific literature (Hair et al., 2005; Karlsson, 2009). The second method consists of a quantitative approach that follows deductive reasoning by

testing hypotheses to expand existing knowledge in the area of interest (Karlsson, 2009). The following sections present a brief overview of the methods employed in this doctoral thesis.

1.4.1 Systematic literature review

A systematic literature review methodology was employed to answer the first research question and achieve its two specific objectives (Denyer & Tranfield, 2009; Durach et al., 2017; Thomé et al., 2016; Tranfield et al., 2003). An SLR seeks to create the bases for the development of a research field by synthesizing the existing knowledge and uncovering future research areas (Denyer & Tranfield, 2009; Tranfield et al., 2003). This methodology consists of the application of a replicable, scientific, and transparent process to minimize bias. The review process was carried out following the five stages proposed by Denyer and Tranfield (2009):

(i) *Formulation of the research question(s):* The first step of the SLR is to define a research question that will guide the entire review process. The research question must delimit the study's scope and purpose. Therefore, the key concepts must be clearly defined.

(ii) *Identification of studies:* To identify the relevant studies, this stage includes the selection of the databases (WoS, Scopus, and EBSCOhost) that will be used for locating the studies and the definition of the search strings.

(iii) *Selection and evaluation of studies:* In this stage, researchers should select and adhere to a set of inclusion and exclusion criteria to guarantee the relevance and alignment of the studies with the SLR's research question.

(iv) *Analysis and synthesis:* The fourth stage involves extracting and storing relevant information about each selected study. The end goal is to make associations between the studies and topics.

(v) *Reporting of results and discussion:* The final stage consists of the presentation of the main findings by reporting a descriptive analysis and a thematic analysis.

To ensure that the study can be replicated, all the stages of the SLR (including for example, keywords, and inclusion and exclusion criteria) should be reported in detail. Therefore, following the best practices for conducting systematic literature reviews (Thomé et al., 2016), PRISMA (preferred reporting items for systematic reviews and meta-analysis)

flowcharts were created to illustrate the different phases of the SLR (see Figures 2.2 and 3.2).

1.4.2 Survey-based research

Taking as the starting point the knowledge obtained from the two literature reviews, a confirmatory (or explanatory) survey-based approach was adopted to answer research questions 2, 3, and 4.

The survey-based approach is a prominent research method that has been used to study unstructured organizational problems in operations management (Malhotra & Grover, 1998; van der Vaart & van Donk, 2008). Karlsson (2009) suggests that survey-based research for explanatory purposes is relevant when knowledge of a topic is not too underdeveloped and concepts can be properly defined since a pre-existing conceptual framework is required. Data gathering is primarily conducted to test the concepts established concerning the phenomenon and the connections between the concepts. Furthermore, if properly conducted, the results of a sample can be extrapolated to the population, which is a significant strength of this research method (Karlsson, 2009).

The primary empirical data were collected from Spanish manufacturing firms through a questionnaire developed in the framework of a Spanish Ministry of Science and Innovation-funded research project. The questionnaire is the best data-gathering strategy for this type of explanatory investigation since it offers access to large amounts of information and the application of statistical techniques (Karlsson, 2009). The data gathering method consisted of a telephone survey using a computerized system (Computer Aided Telephone Interviewing, CATI) and a web-based questionnaire.

The questionnaire was addressed to a population of 2,660 Spanish industrial companies with more than 50 workers belonging to sectors that occupy an intermediate position in their supply chain, obtained from the Iberian Balance Sheet Analysis System (SABI) database. A total of 285 questionnaires were returned with 256 complete responses, which represents a response rate of 9.7%. This response rate is similar to that of other works with comparable objectives published in high-impact journals (Qrunfleh & Tarafdar, 2013; Rojo et al., 2016). The sample covers a variety of manufacturing sectors, and the distribution of companies among sectors in the sample is similar to the distribution in the population, which implies that the sample is representative of the population and appropriate for covering the objectives and guaranteeing the reliability of the results.

Specifically, the covariance-based structural equation model was used to test the research hypotheses. Structural equation modeling (SEM) is a technique used to specify, estimate, and evaluate models of linear relationships among a set of observed and unobserved variables. It is a multivariate statistical technique that combines multiple regression, factor analysis, and variance and/or covariance analysis, and accounts for measurement error in the estimation process. SEM enables to confirm (or reject) hypotheses by assessing the extent to which a proposed explanatory model can reproduce the covariance matrix for a sample dataset (Hair et al., 2009). Thus, the main objective of SEM is to contrast theoretical reasoning with empirical data (Shah & Goldstein, 2006).

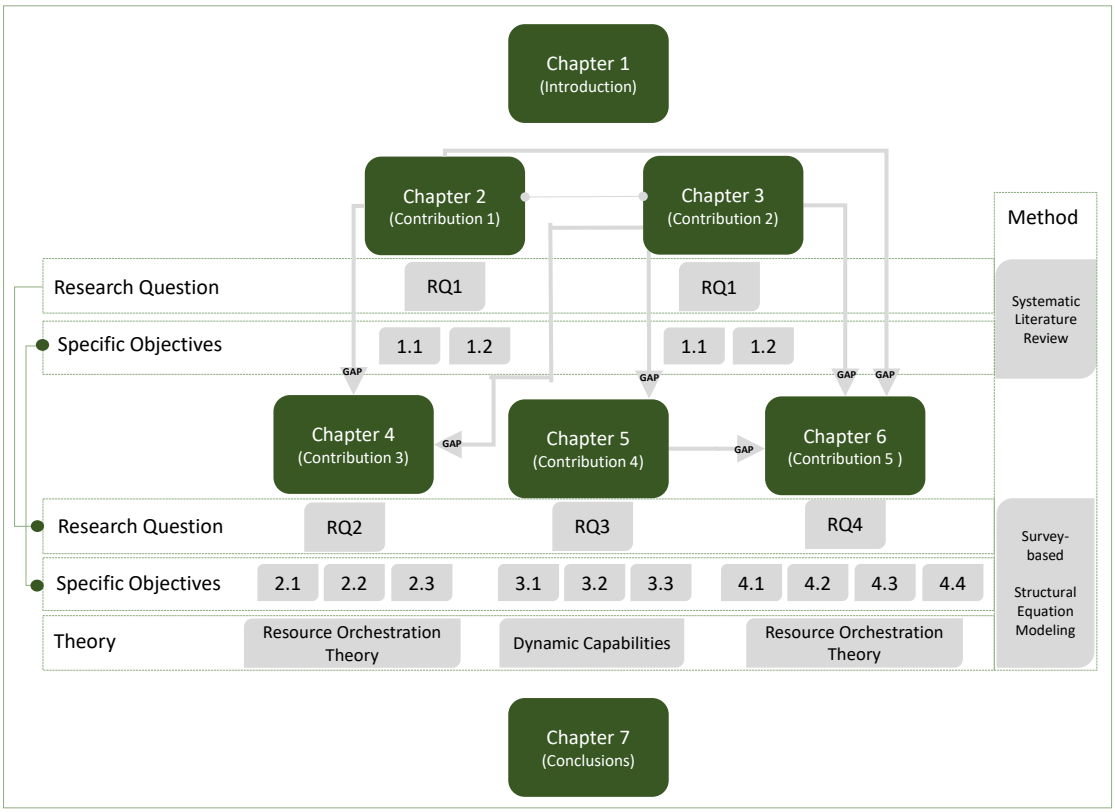
Structural equation models consist of two elements: a structural model and a measurement model. The first estimates the relationships between the constructs (i.e., variables that are not directly observable or measurable). The second estimates the relationships between the indicator variables (i.e., observed variables) and the constructs, which allows the contribution that each indicator makes to the scale to be assessed (Hair et al., 2009).

Other details regarding the questionnaire design and items and the different statistical procedures are explained in the corresponding chapters.

1.5 Thesis structure

This doctoral thesis is presented as a compendium of papers and is composed of seven main chapters. Chapter 1 presents the introductory section, which includes the general framework of the research followed in this thesis. Chapters 2, 3, 4, 5, and 6 provide the original results of the research conducted in this thesis. Finally, Chapter 7 concludes this work with a summary of the research contributions and a presentation of the general implications for theory and practitioners, limitations, and future research directions. Figure 1.2 shows how this thesis is structured, including the chapters, research questions, specific objectives, methodologies, theoretical approaches, and the relationships between the gaps detected in the chapters.

Figure 1.2. Thesis structure map



More specifically, Chapters 2 and 3 of this thesis have contributed to answering the first research question (RQ1). Chapter 2 corresponds to the article titled "Understanding the relationships between information technology and lean and agile supply chain strategies: a systematic literature review", published in 2022 in the journal *Annals of Operations Research*. In this paper, a systematic literature review is carried out that focuses on the existing survey-based research on IT and LSC/ASC. This paper highlights that the research on LSC and ASC has used different conceptualizations of IT and that, in some cases, these conceptualizations have different effects on business outcomes. The article provides an original classification of the literature that considers the studied relationships between ITs and LSC and ASC according to different parameters: (i) types of interaction between the concepts; (ii) IT conceptualization (resource or capability), and (iii) the level of analysis of IT (measured as an aggregate or a specific type of technology).

The third chapter corresponds to the article "The link between information and digital technologies of Industry 4.0 and agile supply chain: Mapping current research and establishing new research avenues". The article was published in the journal *Computers & Industrial Engineering* in 2022. This research complements the second chapter by focusing

on the entire set of articles that have been published on the topic of I4.0 ITs and ASC. Addressing solely the agile supply chain strategy was motivated by the fact that a systematic review of I4.0 ITs and the LSC strategy had only recently been published (Núñez-Merino et al., 2020). Therefore, in this chapter, the adoption of a systematic literature review enables the research to be classified into research lines according to the degree of consolidation of the various technologies. The study shows how ITs can support the ASC by improving its abilities to sense and respond to market changes and customer demands, and an ASC model enabled by I4.0 ITs is proposed.

The fourth chapter, titled "Lean and agile supply chain strategies: the role of mature and emerging information technologies", corresponds to the article published in *The International Journal of Logistics Management* in 2022 and covers the second research question (RQ2). This article is drawn from resource orchestration, and by using structural equation modeling the study investigates the relationships between mature and emerging ITs and the LSC and ASC strategies.

Chapter five corresponds to the article "Implications of using Industry 4.0 base technologies for lean and agile supply chain strategies and performance". This work was developed in the context of an international stay at the Nova University Lisbon (Portugal) in 2022 under the supervision of Prof. Helena Carvalho. This article is under review in the *International Journal of Production Economics*. The chapter addresses the third research question (RQ3) by developing an empirical study based on structural equation modeling. The study focuses on a specific group of technologies known as I4.0 base technologies (cloud computing, IoT, and BDA) to delve into the understanding of the relationships between I4.0 ITs, the LSC and ASC strategies, and operational performance.

The sixth chapter, titled "The link between technology uncertainty and Industry 4.0 technologies: consequences for agile and lean supply chain strategies and performance", represents the last contribution of this thesis. This paper was developed within the framework of an international research stay at the University of Melbourne (Australia) in 2022, with the support of Prof. Guilherme Tortorella. The article, which has been submitted to the International Journal of Operations and Production Management and is currently under review, covers the fourth research question (RQ4). Although this paper continually draws on the resource orchestration theory to develop the relationship between I4.0 ITs and supply chain strategies, this chapter delves into the role of context, specifically, the role

played by technological uncertainty in the adoption of I4.0 ITs, and the integration of these technologies with lean and agile supply chain strategies.

1.6 List of papers and communications

In addition to the main contributions that will be presented in chapters two to six of this thesis, the undertaken research work has resulted in the elaboration of other documents. This section includes the complete list of papers and communications related to this doctoral thesis. These include 5 publications in International Journals indexed in the Journal Citations Reports (JCR) or Journal Citation Indicator (JCI), 2 papers under review in International Journals indexed in the Journal Citations Reports (JCR), 7 works (preliminary versions of articles that were submitted to conferences to receive feedback) presented at National and International Conferences related to Management or Operations Management, and one conference poster.

Furthermore, activities related to the dissemination of the research were also carried out through participation in activities such as talks for high-school students held during the University of Jaen's "Science Week" (Semana de la Ciencia, 2020, 2022) and the delivery of a master class (*How can Industry 4.0 technologies increase supply chain agility?*) as part of the Master of Industrial Engineering course at the University of Melbourne.

- *Articles:*

Oliveira-Dias, D., Moyano-Fuentes, J. and Maqueira-Marín, J.M. (2022). "Understanding the relationships between information technology and lean and agile supply chain strategies: a systematic literature review". *Annals of Operations Research*, Vol. 312, 973–1005. (JCR – Q2)

Oliveira-Dias, D., Maqueira-Marín, J. M. and Moyano-Fuentes, J. (2022). "The link between information and digital technologies of industry 4.0 and agile supply chain: Mapping current research and establishing new research avenues". *Computers & Industrial Engineering*, Vol. 167, 108000. (JCR - Q1)

Oliveira-Dias, D., Maqueira-Marín, J. M. and Moyano-Fuentes, J. (2022). "Lean and agile supply chain strategies: the role of Mature and Emerging Information Technologies". *International Journal of Logistics Management*, Vol. 33, No. 5, 221–243. (JCR – Q2)

Maqueira Marín, J. M., **Oliveira-Dias, D**., Jafari Navimipour, N., Gardas, B., and Unal, M. (2022). "Cloud computing and human resource management: systematic literature review and future research agenda." Kybernetes, Vol. 51, No. 6, 2172-2191. (JCR - Q3)

Oliveira-Dias, D., García-Buendía, N., Maqueira-Marín, J.M. and Moyano-Fuentes, J. (2021), "Information technologies and lean and agile supply chain strategies: a bibliometric study through science mapping." *International Journal of Business Environment*, Vol. 12, No. 4, 338-363. (JCI - Q3)

- *Articles under review*:

Oliveira-Dias, D., Maqueira-Marín, J. M., Moyano-Fuentes, J. and Carvalho H. "Implications of using Industry 4.0 base technologies for lean and agile supply chains and performance". Under review at the *International Journal of Production Economics*. (JCR - Q1)

Oliveira-Dias, D., Moyano-Fuentes, J., Maqueira-Marín, J. M. and Tortorella G. "The link between technology uncertainty and Industry 4.0 technologies: consequences for agile and lean supply chain strategies and performance". Under review at the *International Journal of Operations and Production Management.* (JCR – Q1).

- *National and International Conference communications:*

García-Buendía, N., **Oliveira-Dias, D**., Maqueira-Marín, J.M. and Moyano-Fuentes, J. (2020) "Information technologies and lean and agile supply chain strategies: a science mapping-based bibliometric study", *VI Encuentro Internacional de Especialización para la Investigación en Economía y Empresa*. Jaén, Spain (online).

Oliveira-Dias, D., Maqueira-Marín, J. M. and Moyano-Fuentes, J. (2021) "Estrategias de cadena de suministro lean y ágil y tecnologías de la información: interrelaciones y efectos sobre los resultados empresariales", *XXX International ACEDE Conference*. Cartagena, Spain (online).

Oliveira-Dias, D., Maqueira-Marín, J. M. and Moyano-Fuentes, J. (2021) "Lean and agile supply chain strategies: the role of Mature and Emerging Information Technologies", *EurOMA 2021 Conference*. Berlin, Germany (online).

Oliveira-Dias, D., Maqueira-Marín, J. M., Moyano-Fuentes, J. and Carvalho, H. (2022) "Implications of using Industry 4.0 base technologies for performance and lean and agile supply chain capabilities", *22nd International Working Seminar on Production Economics*. Innsbruck, Austria (online).

Oliveira-Dias, D., Maqueira-Marín, J. M. and Moyano-Fuentes, J. (2022). "Developing lean and agile supply chain capabilities: exploring the effects of mature and latest technologies", *XXXI International ACEDE Conference*. Barcelona, Spain. **Best Paper Award**, Operations and Technology Management section.

Oliveira-Dias, D., Moyano-Fuentes, J., Maqueira-Marín, J.M. and Tortorella, G. (2022). "El papel de la incertidumbre tecnológica y las tecnologías de la industria 4.0: implicaciones para las cadenas de suministro ágiles y lean", *VII Encuentro Internacional de Especialización para la Investigación en Economía y Empresa*. Málaga, Spain. **Best Paper Award**, Operations Management section.

Oliveira-Dias, D., Moyano-Fuentes, J., Maqueira-Marín, J.M. and Tortorella, G. (2023). "Integrating Industry 4.0 Technologies into Lean and Agile Paradigms: The Role of Technology Uncertainty", *13th POMS-HK International Conference*, Hong Kong (S.A.R), China.

- *Conference posters:*

Oliveira-Dias, D., Moyano-Fuentes, J. and Maqueira-Marín, J.M. (2019). "Impact of Information Technology on Supply Chain Agility: a literature review and future directions". *Jornada de Jóvenes Investigadores de la Universidad de Jaén 2019*, Jaén, Spain.

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CHAPTER 2 .

Understanding the relationships between information technology and lean and agile supply chain strategies: a systematic literature review

CHAPTER 2

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CHAPTER 2

Understanding the relationships between information technology and lean and agile supply chain strategies: a systematic literature review

- **Abstract:**

This study analyzes the relationships studied in the literature between Information Technologies (IT) and two supply chain strategies that have similar mechanisms of action: Lean Supply Chain (LSC) and Agile Supply Chain (ASC). The purpose is to identify and understand the role that IT plays in the two strategies depending on the way that it is conceptualized, and whether this is transferred to performance. The Systematic Literature Review is the methodology used to locate articles, select and analyze their content. In general terms, research to date shows a positive association between IT and these two supply chain strategies and that this association improves business results. However, the study shows that research into LSC and ASC has used different conceptualizations of IT and, in some cases, these conceptualizations can have different effects on the study's outcomes. This paper proposes directions for future research and theoretical development are suggested.

- **Keywords:**

Information technologies · Lean supply chain · Agile supply chain · Systematic Literature Review.

CHAPTER 3 .

The link between information and digital technologies of industry 4.0 and agile supply chain: Mapping current research and establishing new research avenues

CHAPTER 3

Paper information:

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CHAPTER 3

The link between information and digital technologies of industry 4.0 and agile supply chain: Mapping current research and establishing new research avenues

- **Abstract:**

The use of Industry 4.0 (I4.0) Information and Digital Technologies (IDT) has given rise to new opportunities and challenges for designing and managing agile supply chains. Therefore, this study aims to investigate the role and implications of IDT of I4.0 for the Agile Supply Chain (ASC) strategy through a systematic literature review of 123 identified papers. The literature has been classified into three research lines based on the Technology Life Cycle: (1) Mature IDT of I4.0 and ASC; (2) Emerging IDT of I4.0 and ASC, and (3) A generic approach to the role and implications of IDT of I4.0 and ASC. This categorization gives an in-depth analysis of the relationship be- tween the IDT of I4.0 and Agile Supply Chain and helps to clarify the way that the research has evolved. Among other findings, the results show that there is a prominent relationship between different types of IDT of I4.0 and ASC. These technologies can support the ASC by improving abilities to sense and respond to market changes and customer demands. The paper also discusses the gaps found in the literature, presents an ASC 4.0 model enabled by IDT of I4.0, and proposes new opportunities for future research.

- **Keywords:**

Agile Supply Chain; Industry 4.0; Information and Digital Technologies; Supply Chain Agility; Supply Chain Agility 4.0 model.

CHAPTER 4.

Lean and agile supply chain strategies: the role of mature and emerging information technologies

CHAPTER 4

Paper information:

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CHAPTER 4

Lean and agile supply chain strategies: the role of mature and emerging information technologies

- **Abstract:**

Purpose – The significant changes that supply chains (SCs) are undergoing and the emergence of disruptive technologies have led to a growing effort to integrate novel and mature technologies into existing SC strategies. Thus, this study investigates the relationships between mature information technologies (ITs), emerging IT and the lean supply chain (LSC) and agile supply chain (ASC) strategies.
Design/methodology/approach – An empirical study based on structural equation modeling of survey data from 256 Spanish focal companies has been conducted to test six hypotheses.
Findings – Drawing on resource orchestration, our results point to mature IT use being an enabler of both LSC and ASC strategy implementation. The results also show an LSC mediating effect on the relationship between mature IT and ASC when SCs follow both strategies. Also, the implementation of emerging IT requires a process of consolidation over time to be genuinely useful as a facilitating mechanism for developing both the lean and agile strategies along the SC. In this sense, a suitable mix needs to be orchestrated between emerging and mature IT.
Originality/value – This study sheds light on the relevance of the mature IT and emerging IT in the context of two SC strategies (lean/agile) and provides practical and theoretical implications.

- **Keywords:**

Lean supply chain; Agile supply chain; Mature information technology; Emerging information technology.

CHAPTER 5.

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

CHAPTER 5

Paper information:

Oliveira-Dias, D. de, Maqueira-Marin, J.M., Moyano-Fuentes, J. and Carvalho, H. (2023), "Implications of using Industry 4.0 base technologies for lean and agile supply chains and performance", *International Journal of Production Economics*, Vol. 262, p. 108916.

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CHAPTER 5

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

- **Abstract:**

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

- **Keywords:**

Lean supply chain; Agile Supply Chain; Industry 4.0 technologies; Dynamic Capabilities.

CHAPTER 6.

The link between technology uncertainty and Industry 4.0 technologies: consequences for agile and lean supply chain strategies and performance

CHAPTER 6

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- **Title:** The link between technology uncertainty and Industry 4.0 technologies: consequences for agile and lean supply chain strategies and performance.
- **Authors:** Diéssica de Oliveira-Dias, Juan Manuel Maqueira-Marín, José Moyano-Fuentes, Guilherme Tortorella.
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CHAPTER 6

The link between technology uncertainty and Industry 4.0 technologies: consequences for agile and lean supply chain strategies and performance

- **Abstract:**

Purpose - This paper investigates the impact of Industry 4.0 (I4.0) technologies on the agile and lean supply chain strategies in the context of technological uncertainty and examines the effect of both of these supply chain strategies on firm operational performance.
Design/methodology/approach - Survey data were gathered from 256 focal manufacturing companies in Spain using a structured questionnaire. Covariance-based structural equation modeling (CBSEM) is used to test the conceptual model. Bootstrapped analysis is applied to test for mediation effects.
Findings - Underpinned by the Resource Orchestration Theory, the results indicate that technology uncertainty has a strong association with I4.0 technology use. Furthermore, the use of I4.0 technologies facilitates the implementation of the lean supply chain strategy; however, they do not directly influence the implementation of the agile supply chain strategy. We also identified a mediation effect of the lean supply chain strategy on the relationship between I4.0 technology use and the agile supply chain strategy and of the agile supply chain on the relationship between the lean supply chain strategy and focal firm operational performance.

- **Keywords:**

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

CHAPTER 7.

Conclusions

CHAPTER 7

7 Conclusions

The main objective of this doctoral thesis was to identify and understand the role played by information technologies in the pursuit of supply chain responsiveness based on the development of lean and agile supply chain strategies. The thesis also investigated how these antecedents impact firm performance. Accordingly, this study has synthesized and classified the research on the integration between ITs and the LSC/ASC fields through two systematic literature reviews and, based on the gaps identified in the previous studies, has empirically analyzed different antecedents and implications of LSC/ASC implementation through three survey-based studies.

7.1 Main contributions

The responses to the four specific research questions and the most relevant conclusions reached in each of the chapters are summarized below. The main contributions are also summarized in Figure 7.1.

7.1.2 Research Question 1

The first research question (RQ1) "What has been investigated to date on the relationships between ITs and the LSC and ASC strategies and what are the key findings and remaining challenges?" can be answered based on the findings in Chapters 2 and 3. Chapter 2 analyzed the key aspects of the existing literature on the relationships between IT and lean and agile supply chain strategies. For this, a systematic review was undertaken of 59 survey-based papers addressing the IT-LSC/ASC relationship. In Chapter 2, results show that the relationships between IT and LSC/ASC can be direct, indirect, or complementary and that different conceptualizations of IT (as a resource or capability) can have different effects on business outcomes. In this regard, there is no general agreement on the way that IT and LSC interact, although the effect of IT on ASC is positive and direct in most of the papers. However, the direct effect occurs mainly when IT is considered as a capability. This chapter also highlights other aspects of the literature, such as the theories that have been used in the field and how IT is measured in each paper (i.e., different types

of IT or generic approaches). Furthermore, a framework for future research was developed based on the findings of the study. The following main gaps and challenges for future research identified in this chapter can be highlighted, among others: the use of consolidated theoretical perspectives in the field; investigation of the role of emerging technologies linked to Industry 4.0 in the context of LSC and ASC strategies; and a better understanding of the IT indirect effects on LSC/ASC and their implications for environmental, social, or sustainable business performance.

This first study only focused on survey-based research, which, in general, allows the analysis of the most mature literature in a field (Danese et al., 2018; Karlsson, 2009). This approach made it possible to determine how the studied concepts are related to each other. However, during the systematic literature review process, it was verified that a considerable group of articles had adopted other methodological approaches (conceptual, simulation, qualitative approaches, etc.). In addition, the literature on I4.0 ITs and LSC was found to have only recently been reviewed and systematized (Núñez-Merino et al., 2020). Therefore, as a complement to these previous studies, a second literature review was performed that included papers that had used any kind of methodology in order to provide a comprehensive overview of the roles and applications of I4.0 ITs in the context of the ASC strategy.

In this respect, in Chapter 3, the link between I4.0 ITs and ASC was explored through a systematic review of 123 papers. The papers were grouped into two main research lines according to the technology's degree of consolidation (mature or emerging) and a third research line was formulated to include papers in which technology had been studied as a generic approach. This study highlights that both mature and emerging ITs can support the ASC strategy by increasing the speed of physical, information, financial, and service flows and enhancing the abilities to sense and respond to market changes and customer demand. However, the adoption of emerging ITs poses multiple challenges and could even lead to negative effects.

Furthermore, from the literature review, a framework for an ASC 4.0 model was proposed. The model contains the main I4.0 IT applications found in the literature, shows their relationships with each supply chain flow (physical, information, financial, and service), and also assembles indicators related to the supply chain flows and sense and

response abilities. These indicators serve as a tool to assess the supply chain's performance and steer it toward an ASC 4.0 model.

In Chapter 3, findings also reveal lines for future research based on the research gaps detected in the reviewed literature. Some of the future research lines discussed were as follows: the study of the relationship between mature and emerging ITs, i.e., how they can complement or undermine each other and what the consequences are for supply chain agility; the role of some emerging I4.0 ITs that have hardly (or not) been addressed in the previous literature such as virtual or augmented reality, advanced and collaborative robots, additive manufacturing, blockchain, and cybersecurity; the joint effect of relevant I4.0 ITs such as IoT, cloud computing, and BDA (Frank et al., 2019); the challenges, synergies, or trade-offs related to the link between the Circular Economy, I4.0 ITs, and ASC. The following chapters investigate some of these issues.

7.1.2 Research Question 2

Based on the main findings in Chapter 4, the second research question (RQ2), "What effect do ITs have on the implementation of the LSC and ASC strategies depending on their degree of consolidation or their life cycle?", can be answered. In this chapter, an empirical study was conducted in which six hypotheses were tested. This study covers some of the gaps detected in Chapters 2 and 3 by analyzing the role played by some ITs that have not been previously explored in the LSC/ASC literature, studying the relationship between mature and emerging ITs, and using the Resource Orchestration Theory as a theoretical framework.

First, the study confirms that there is a positive relationship between mature and emerging ITs. This finding is particularly relevant in a scenario where many companies are moving toward an I4.0 stage in which integration between existing and new ITs is essential. As such, following Resource Orchestration Theory arguments, the chapter's results highlight that supply chain managers need to orchestrate a suitable mix between mature and emerging IT to support both the LSC and ASC strategies.

Second, mature IT has been shown to have a positive impact on LSC and ASC implementation. However, the effect of emerging ITs on the LSC strategy has been confirmed to be negative, while on the ASC it is non-significant. The negative effect of

emerging IT on LSC strategy can be explained by the fact that these ITs can generate variability, which requires further adjustments during their implementation and follow-up.

Third, the results revealed that previously implementing LSC facilitates the implementation of the ASC strategy and that LSC mediates the relationship between mature IT and ASC. The mediation effect means that mature IT can directly improve LSC, while the effect of mature IT on ASC is indirect when the SC follows both strategies.

Thus, two scenarios can be distinguished: in the first scenario, when a supply chain is only pursuing the ASC strategy, the support of mature ITs will enhance agility. This study has acknowledged that the included mature ITs play a key role in the integration/speed of supply chain flows. In the second scenario, where the development of both the LSC strategy and the ASC strategy is being pursued, the results show that a proper orchestration of IT-related resources can enhance the LSC strategy, which will, in turn, support the implementation of the ASC strategy. Therefore, while mature ITs can directly increase supply chain leanness, supply chain agility will be achieved by intensifying the LSC strategy.

7.1.3 Research Question 3

Chapter 5 answered the third research question (RQ3), “What role do I4.0 base technologies play in the implementation of LSC and ASC strategies?” Given that the range of emerging technologies includes ITs with very different characteristics, this paper contributes to expanding the knowledge on I4.0 and LSC/ASC integration by focusing on the specific role of I4.0 base technologies (cloud computing, BDA, IoT). This is a response to a specific gap identified in Chapter 3.

The results show that I4.0 base technologies can enhance the implementation of the LSC strategy. In relation to this, this study provides different examples of the integration between the I4.0 base technologies and the LSC strategy to enhance processes such as information sharing, detection of disruptions, demand forecasting, and the management of inventory levels.

However, this article does not confirm the direct relationship between I4.0 base technologies and the implementation of the ASC strategy. Following the DCV, this chapter suggests that I4.0 base technologies need to be integrated with other supply chain resources/capabilities to build supply chain agility. In this chapter, the development of the

LSC strategy has also been found to influence the ASC implementation, which ultimately leads to the enhancement of the focal firm's operational performance. Lastly, the use of I4.0 base technologies was shown not to directly imply an improvement in operational performance.

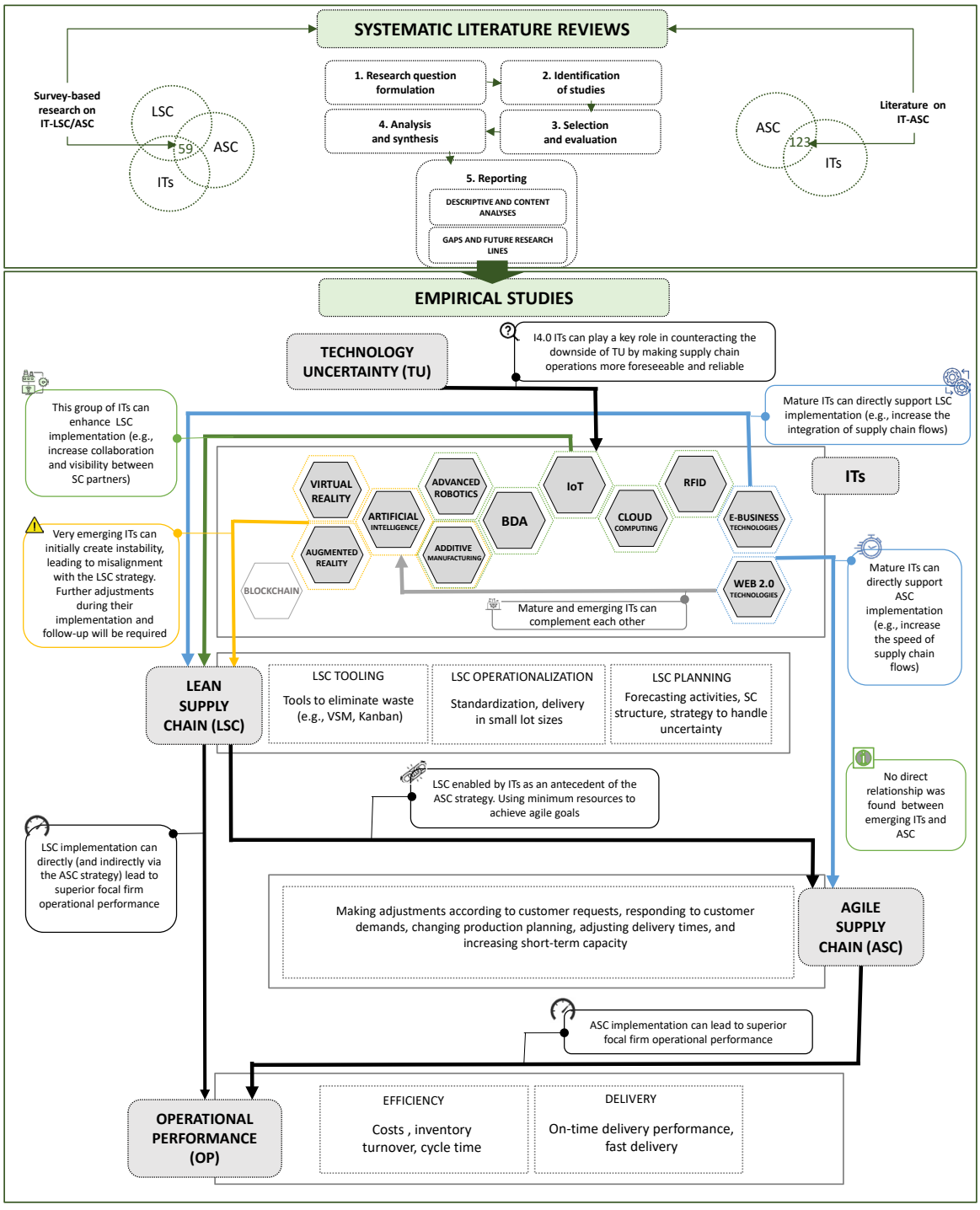
7.1.4 Research Question 4

The main findings in Chapter 6 enable to answer the fourth research question (RQ4), "In the context of technological uncertainty, what impact do I4.0 ITs have on the LSC and ASC strategies?". This study arose out of gaps detected in Chapters 2, 3, and 5, and also as a response to calls for further studies on the role of environmental factors and the association between I4.0 technologies and supply chain strategies (Buer et al., 2018; Garcia-Buendia et al., 2021; Raji et al., 2021a).

Findings indicate that firms are more inclined to use I4.0 technologies under technological uncertainty. The study highlights that the surveyed groups of I4.0 technologies have the potential to facilitate collaboration between SC partners and increase visibility. Therefore, in line with Resource Orchestration Theory arguments (Sirmon et al., 2011), the orchestration of resources across the supply chain enabled by I4.0 technologies will play a key role in counteracting the downside of uncertainty by making supply chain operations more foreseeable and reliable.

Furthermore, as in the case of the use of I4.0 base technologies, this more comprehensive group of ITs also has a direct and positive impact on LSC implementation but not on ASC implementation. On the one hand, the study highlights different ways in which I4.0 technologies could leverage the effect of the LSC strategy. For example, by reducing sources of waste such as unnecessary transportation of materials or overstocking. On the other hand, although not fully expected, the non-significant impact of the I4.0 technologies on the ASC is in line with previous studies (Liu et al., 2013; Swafford et al., 2008) that indicate that the use of ITs does not directly increase supply chain agility. Instead, ITs will support the enhancement of other supply chain capabilities. In this respect, this study provides evidence that an LSC enabled by I4.0 technologies will support the deployment of the ASC strategy. Finally, this chapter shows that the focal firm's operational performance can be increased directly through the ASC strategy and indirectly through the LSC strategy.

Figure 7.1. Summary of main contributions



7.2 Theoretical implications

Different approaches and theories have been used in this Ph.D. thesis to reveal and understand the mechanisms that drive supply chain responsiveness in an Industry 4.0 context. At the theoretical level, the systematic literature review studies (Chapter 2 and Chapter 3) present a comprehensive overview of the literature on the field, which creates

the basis for further research developments. By synthesizing and analyzing the existing knowledge, researchers can easily identify the main topics that have been addressed on the relationship between I4.0 technologies and the LSC/ASC strategies. Researchers can find a detailed description of future research directions in each of the systematic literature review-based studies. These represent an advance on the previous literature, which had focused on other supply chain strategies or strategic aspects such as resilience and sustainability (Birkel & Müller, 2021; Spieske & Birkel, 2021) or lean/agile approaches at the internal level (Buer et al., 2018; Gunasekaran et al., 2019), and also complement other related reviews (Garcia-Buendia et al., 2021; Núñez-Merino et al., 2020; Reyes et al., 2021).

Furthermore, in the empirical studies (Chapters 4, 5, and 6) the dynamic capabilities view and ROT have been employed as theoretical frameworks to gain an understanding of the studied phenomena. More specifically, through the lenses of the DCV and the ROT, the use of different groups of ITs (mature ITs, I4.0 base technologies, and smart manufacturing and warehouse technologies) has been confirmed to enhance LSC implementation by improving different LSC dimensions. These dimensions can be linked to different capabilities such as sensing sources of waste in the supply chain, seizing and enabling the operationalization of the LSC strategy, and supporting the reconfiguration of internal and external resources. However, one specific group of emerging information technologies has been shown to have a negative impact on the LSC strategy. Therefore, taken together the results show that while supply chains can indeed improve their lean capabilities through the support of I4.0 technologies, some emerging ITs can initially create instability and lead to misalignment with the LSC strategy. Thus, the technology life cycle may be an explanatory factor for the different results found. Previous empirical studies had not paid any particular attention to the role of some emerging ITs in the implementation of the lean strategy at the supply chain level (Núñez-Merino et al., 2020). Moreover, the previous literature has either considered the isolated impact of some ITs or adopted a broadly generic approach (e.g., Dubey et al., 2019; García-Alcaraz et al., 2017; Shahin et al., 2016). So, this study is positioned at an intermediate point and focuses on some specific groups of ITs. These findings, therefore, shed light on the distinctive roles played by different bundles of ITs.

This doctoral thesis also sheds light on the relationship between mature and emerging ITs. Previous studies have highlighted that the transition to an I4.0 stage would

require the proper integration of ITs at different technology life cycle stages (Kagermann et al., 2013; Maqueira et al., 2019). In this sense, there was a call for further understanding of this integration (Ghobakhloo, 2018; Maqueira et al., 2019) and, in this regard, this study has revealed that the use of mature ITs and the experience derived from their use can serve as the basis for implementing newer technologies.

Furthermore, in line with DCV arguments, it has been found that the use of ITs by itself does not increase focal firm operational performance. This finding is in line with previous studies, which suggest that to provide better performance, ITs should be embedded and used with complementary resources and capabilities (Novais et al., 2020; T. C. Powell & Dent-Micallef, 1997), as the lean and agile capabilities addressed in the framework of this doctoral thesis are. Yet, an opposing view exists on whether I4.0 technologies directly improve firm performance (Anosike et al., 2021; Dalenogare et al., 2018).

Additionally, as an important theoretical contribution, this Ph.D. thesis advances the discussion about the relationship between LSC and the ASC strategy. Previous studies had addressed the relevance of this relationship (Fadaki et al., 2020) but this link had not been empirically tested. Therefore, this doctoral thesis empirically sets out the two strategies as complementary approaches with LSC considered an antecedent of ASC. The findings empirically support the arguments of Eltawy & Gallear (2017) and Calatayud et al. (2019) and extend the findings of Ghobakhloo & Azar (2018) to the supply chain level. I4.0 technologies can play a relevant role by bridging some of the gaps or conflicting characteristics between the two approaches detected in previous studies (Carvalho et al., 2011; Qrunfleh & Tarafdar, 2014). In addition, given the claim that an ASC must maintain a certain buffer capacity and higher inventory levels than those pursued with the LSC strategy (Qrunfleh & Tarafdar, 2014; Raji et al., 2021a), the findings of this thesis point to the fact that I4.0 base technologies have the potential to improve the forecasting capability and increase supply chain visibility, which leads to greater compatibility between the two strategies. For example, on the one hand, I4.0 technologies could increase LSC's ability to sense, anticipate, and adapt to environmental changes. Thus, in situations of higher uncertainty, LSCs could increase inventory levels to meet demand if necessary. On the other hand, given the increased supply chain visibility, in less volatile environments ASCs could reduce the need for buffer capacity to a certain extent.

7.3 Managerial implications

This Ph.D. thesis also offers implications for managers. The results support companies keen to integrate I4.0 technologies into their supply chains and combine them with the LSC and/or ASC strategy First, different bundles of ITs are seen to have different effects on each of the supply chain strategies. Therefore, a homogeneous effect is not observed. Mature ITs have a direct and positive impact on the LSC strategy, and either a direct or indirect effect on the ASC strategy (depending on the presence or absence of the LSC strategy). On the other hand, very emerging ITs (e.g., virtual and augmented reality, artificial intelligence) have been observed to negatively impact LSC implementation. However, other technologies that can also be considered to be emerging, as is the case of the I4.0 base technologies (e.g., IoT, cloud computing, BDA), but with a higher level of adoption in the industry, do have a positive impact on the LSC strategy.

In contrast, the ASC strategy is not directly affected by the use of emerging ITs. Therefore, managers should be aware of the range of effects that can be produced by emerging ITs and should balance the use of mature and emerging ITs, depending on the effect that they want to achieve. However, they should be aware that emerging ITs do not directly affect ASC but that to increase supply chain agility, they can foster the development of capabilities related to the LSC strategy.

Furthermore, the study provides useful insights for managers in connection with the relationship between the LSC and ASC strategies and its implication for firm operational performance. It has been demonstrated that in an I4.0 context, the development of the LSC strategy facilitates ASC strategy implementation, which ultimately leads to superior operational performance. Lastly, some practical implications specific to the topic of the chapter have been established in each case.

7.4 Limitations and future research directions

Although this doctoral thesis yields a range of insightful advances for literature and practice, this study has some limitations that must be acknowledged.

First, the Systematic Literature Review studies (Chapters 2 and 3) have some inherent limitations. For example, the selection of the search string and the inclusion and exclusion criteria could result in the exclusion of some publications. However, this can be considered a minor limitation since three relevant databases (WoS, Scopus, and EbscoHost)

(Durach et al., 2017; Thomé et al., 2016) were used to identify the documents. In addition, the keywords included in the search strings were carefully selected by various researchers taking into account the previous literature. Another limitation lies in the subjectivity of the classifications carried out in each paper. A group of researchers was involved during all the SLR stages to reduce the impact of this limitation (Thomé et al., 2016). In addition, it is worth mentioning that some emerging ITs that have not been addressed in the reviewed literature (such as quantum computing and supply chain cybersecurity-related technologies) have gained relevance lately. Future studies are therefore encouraged to cover these new developments and their impact on supply chain management. Moreover, while some of the gaps indicated in Chapters 2 and 3 have been covered by the empirical studies, others remain unexplored.

Second, some limitations can also be highlighted regarding the empirical studies (Chapters 4, 5, and 6). The database only consisted of Spanish manufacturing companies, which limits the generalization of the results. Thus, a future research opportunity would be to analyze samples from similar sectors in different countries for comparative and empirical validation. In addition, bearing in mind that data collection took place in 2018 and that I4.0 is a dynamic trend, future research should analyze whether any changes can be identified in the aftermath of the COVID-19 disruptions and include the new solutions and developments that the I4.0 evolution could generate.

Furthermore, since the relationship between I4.0 technologies and ASC has been shown to be indirect, it would be interesting to analyze the role of other environmental and structural factors that could affect the relationship between I4.0 technologies and supply chain agility. For example, future studies could study the role of the supply chain's structural and dynamic complexity (Ateş et al., 2022), i.e., investigate whether such characteristics as the number of suppliers, their characteristics, and reliability, and the stability of the supply chain relationships can influence the role of I4.0 technologies.

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