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MURILO ZAMBONI ALVARENGA

THE ROLE OF SUPPLY CHAIN MEMORY FOR SUPPLY CHAIN DISRUPTION MANAGEMENT

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“He wanted to change the world
To make it all worthwhile
So he put his pen to paper
And poured out everything inside”

James Cassells/ Danny Worsnop/ Ben Bruce

ABSTRACT

Several examples demonstrate that disruptions have significant negative impacts on supply chain performance. In this context, the literature on the subject has sought to understand why some supply chains can maintain or recover their operations more quickly and effectively than others in the face of these undesirable events. Despite the advances in the topic in recent years, existing literature lacks studies addressing the role of memory in dealing with disruptive events. The beginning thesis was that memory plays an important role, directly and indirectly, in improving supply chain disruption management. However, absorbing and applying new knowledge (i.e. absorptive capacity) might be necessary to handle non-routine events such as COVID-19, considering some drawbacks that memory can bring to organizational and supply chain processes. Three papers were developed to investigate this topic. The first paper examined if both resilience and robustness are directly impacted by memory and if the relationship between these disruption management capabilities and supply chain performance is moderated by memory using a mixed-methods approach. The second explored the impact of digital technologies on supply chain resilience and robustness, considering the mediating role of memory and the moderating effect of non-routine events like the COVID-19 pandemic. Finally, the third paper investigated the moderating role of absorptive capacity in the relationship between memory and resilience and robustness. The findings contribute disruption management field showing up the role of memory in supply chain disruption management, pointing it as an antecedent, mediator, and moderator of resilience and robustness previous relationships. However, for robustness, the absorption and application of new knowledge are necessary to effectively manage non-routine events and mitigate potential drawbacks associated with memory in organizational and supply chain processes. The results demonstrate to practice the importance of learning from past disruptive events, keeping that knowledge alive, as well as acquire new knowledge in order to deal with it effectively and efficiently in the future.

Keywords: Supply chain disruption management. Supply chain memory. Resilience. Robustness. Digital technologies. Supply chain performance. Survey. Mixed-Methods.

RESUMO

Vários exemplos demonstram que as interrupções têm impactos significativamente negativos no desempenho da cadeia de suprimentos. Nesse sentido, a literatura acerca do tema buscou entender porque algumas cadeias conseguem manter ou recuperar suas operações de forma mais rápida e eficaz do que outras diante desses eventos indesejáveis. Apesar dos avanços no tópico nos últimos anos, a literatura existente carece de estudos que abordem o papel da memória no enfrentamento de eventos disruptivos. A tese aqui discutida é de que a memória desempenha um papel importante, direta e indiretamente, na melhoria da gestão de interrupções nas cadeias de suprimentos. No entanto, a absorção e aplicação de novos conhecimentos podem ser necessárias para lidar com eventos raros, como a COVID-19, considerando algumas desvantagens que a memória pode trazer aos processos organizacionais e da cadeia de suprimentos. Três artigos foram desenvolvidos para investigar esse tema. O primeiro artigo examinou, utilizando uma abordagem de métodos mistos, se tanto a resiliência quanto a robustez são diretamente impactadas pela memória e se a relação entre essas capabilidades de gestão de interrupções e o desempenho da cadeia de suprimentos é moderada pela memória. O segundo explorou o impacto das tecnologias digitais na resiliência e robustez da cadeia de suprimentos, considerando o papel mediador da memória e o efeito moderador de eventos não rotineiros, como a pandemia de COVID-19. Por fim, o terceiro artigo investigou o papel moderador da capacidade absortiva na relação entre memória e resiliência e robustez. As descobertas contribuem para o campo da gestão de interrupções, mostrando o papel da memória no gerenciamento de interrupções na cadeia de suprimentos, apontando-a como antecedente, mediadora e moderadora das relações anteriormente abordadas na literatura. No entanto, para a robustez, a absorção e aplicação de novos conhecimentos são necessárias para gerenciar efetivamente eventos raros. Os resultados demonstram para a prática a importância de se aprender com eventos interruptivos passados, manter essa memória viva, bem como absorver novos conhecimentos a fim de lidar efetivamente e eficientemente com esses eventos no futuro.

Palavras-Chave: Gestão de interrupções na cadeia de suprimentos. Memória da cadeia de suprimentos. Resiliência. Robustez. Tecnologias digitais. Desempenho da cadeia de suprimentos. *Survey*. Métodos Mistos.

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1 GENERAL INTRODUCTION

This chapter aimed to present the research problem, the general research objective, the thesis argument, as well as the papers that comprise the thesis. Furthermore, the objectives and contributions of each article to address the research problem are presented.

1 General introduction

Overview

The existence of great global competition, increasingly larger and more complex supply chains, increased customer expectations, reduced product life cycles, rapid technological innovations, increased outsourcing, and demand volatility make supply chains more vulnerable to disruptions (Birkel & Hartmann, 2020; Quang & Hara, 2017; Zhao et al., 2023). An annual survey applied by the Business Institute of Continuity (Institute, 2023) demonstrated that 65.8% of 288 respondents from 58 countries and 17 sectors experienced at least one disruption in their supply chain over the last 12 months. Throughout this thesis, several examples of those disruptive events will be presented, but, for now, I can mention COVID-19, which has impacted and continues to impact people's lives, organizations, and supply chains, due to its high uncertainty and duration (Craighead et al., 2020; Ivanov, 2021; Ruel & El Baz, 2021).

Given the negative impact these disruptions can have on supply chain performance (Adobor & McMullen, 2018; Quang & Hara, 2017), disruption management capabilities, as the ability to quickly and adequately recover from a disruption (i.e. resilience) (Pettit et al., 2019; Sheffi & Rice Jr., 2005), or the ability to keep operations at an acceptable level even when a disruptive event occurs (i.e. robustness) (Brandon-Jones et al., 2014; Klibi et al., 2010; Kwak et al., 2018), are critical to determining which supply chain will collapse and which will prosper even in this adverse context (Soni et al., 2014). In this sense, both managers and academics are looking for better strategies to deal with them (Brusset & Teller, 2017).

Despite the numerous disruptive events that can affect supply chains, it is also true that in the era of Industry 4.0, current supply chains have now better tools to manage their operations (Huang et al., 2023; Ning et al., 2023; Zhao et al., 2023). For example, Lowe's Companies is developing digital twins to create "smart stores" that adapt and evolve in real-time, providing their customers with what they want at the right time, in the right quantity, and in the right location. (Bernard, 2022). In addition to digital twins, cloud computing, the Internet of Things (IoT), big data analytics, and blockchain are some technologies that can be used by current supply chains to improve their operations, as well as to better deal with disruptive events (Birkel & Hartmann, 2020; Oliveira & Handfield, 2019; Spieske & Birkel, 2021).

Thesis argument

Although several studies have pointed out capabilities that make chains more robust or resilient (Brusset & Teller, 2017; Bühler et al., 2016; Cheng & Lu, 2017; Kumar & Anbanandam, 2019; Kwak et al., 2018; Liu & Lee, 2018), or the positive effects of being resilient and robust on supply chain performance (Altay et al., 2018; Chowdhury et al., 2019; Dubey et al., 2021; Kwak et al., 2018; Wieland & Marcus Wallenburg, 2012), a literature review carried out by the author (Alvarenga et al., 2020), corroborates with previous literature reviews on the subject (Ali et al., 2017; Kochan & Nowicki, 2018), where it is possible to identify that discussions about the knowledge-based view, specifically, the role of the experience, familiarity and knowledge (i.e. memory) (Hult et al., 2004, 2006; Moorman & Miner, 1997) in dealing with disruptions (Adel et al., 2022; Scholten et al., 2019; Singh & Singh, 2019) are underexplored.

Memory is the current knowledge that the organization/chain members have based on past events that can be used in the future (Anand et al., 1998; Foroughi et al., 2020; Walsh & Ungson, 1991). As it will be discussed throughout the thesis, memory allows making more efficient decisions to deal with disruptions based on what has been learned in the past, having a direct positive impact on both resilience and robustness, as a means to improving the impact of new digital technologies on supply chain disruption management capabilities and as a way supply chains can find the best resource configuration to turn resilience and robustness efforts into performance (Alvarenga et al., 2023b, 2023a; Queiroz et al., 2023). Therefore, **the beginning thesis was that memory plays an important role, directly and indirectly, in improving supply chain disruption management. However, during research development, even confirming the beginning thesis, a new question emerged as a complement. That is: although memory is important for improving supply chain disruption management, absorbing and applying new knowledge (i.e. absorptive capacity) might be necessary to handle non-routine events such as COVID-19, considering some drawbacks that memory can bring to organizational and supply chain processes** (Kyriakopoulos & Ruyter, 2004; Moorman & Miner, 1997; Sen et al., 2021).

To investigate the topic, the thesis adopted a three-paper format, each with specific objectives. The first paper (paper one), titled "**Let's talk about bad experiences instead of forgetting them: An empirical study on the importance of memory for supply**

chain disruption management", was published in the International Journal of Production Economics (https://doi.org/10.1016/j.ijpe.2023.108872) on April 12, 2023. This first paper aimed at investigating if both resilience and robustness are directly impacted by memory and if the relationship between these disruption management capabilities and supply chain performance is moderated by memory. As identified in the disruption management literature, there is a need for studies to identify the conditions under which supply chain resilience and robustness significantly contribute to supply chain performance (Chowdhury et al., 2019). This paper bridges this gap by combining contingent resource-based and knowledge-based views, highlighting supply chain memory as a crucial condition for the high efficiency of supply chain resilience and robustness for performance. Furthermore, the paper demonstrates the direct impact of supply chain memory on resilience and robustness, providing empirical examples of how memory can assist in disruption management.

Fresh literature postulates the need for more empirical studies linking digital technologies and disruption management capabilities (Ivanov et al., 2022; Spieske & Birkel, 2021; Xu et al., 2020), as little is known about the mechanisms that act in this relationship. So, the second paper (paper two), titled "**The impact of using digital technologies on supply chain resilience and robustness: the role of memory under the COVID-19 outbreak**", published in Supply Chain Management: An International Journal (https://doi.org/10.1108/SCM-06-2022-0217) on January 17, 2023, aimed at expanding knowledge about the impact of using digital technologies on supply chain resilience and robustness, examining the mediating role of memory. Additionally, it assessed the effectiveness of memory for resilience and robustness in the case of non-routine events, such as the COVID-19 pandemic. The results of the paper provided novel and valuable insights into information processing theory, disruption management theory, and the knowledge-based view lens. The findings revealed the mediating effect of supply chain memory on the relationship between the use of digital technologies and both resilience and robustness. Additionally, the study contributes to theory by demonstrating how contingent factors, such as COVID-19, can influence the effectiveness of knowledge creation, storage, and retrieval through digital technologies in building more resilient and robust supply chains.

Finally, the third paper (paper three), titled "**From crisis to opportunity: combining memory and absorptive capacity to enhance supply chain disruption management**"

was accepted at the ENANPAD 2023 conference and is now submitted to the International Journal of Operations and Production Management, aimed at extending the previous knowledge about the impact of supply chain memory on resilience and robustness. The paper investigated the moderating role of absorptive capacity in the relationship between memory and resilience and robustness. It was developed considering that the first two papers indicated evidence of the need to combine new and old knowledge to deal with disruptions. The study presented novel insights into the role of knowledge in disruption management, showcasing the combined influence of memory and absorptive capacity on supply chain resilience and robustness.

Table 1 summarizes the research's argument, the objectives of each paper, and their main contributions to the literature. The three papers complement each other in presenting the interplay between memory and previous disruption management theory relationships. They were developed using data collected from supply chain managers from various countries. Papers one and two were co-authored with Professor Marcos Paulo Valadares de Oliveira from Universidade Federal do Espírito Santo and Professor Tiago Oliveira from Universidade NOVA de Lisboa - NOVA Information Management School. Paper three also involved the participation of Professor Hélio Zanquetto Filho from Universidade Federal do Espírito Santo.

Following this introduction, each of the papers will be presented, each containing its sections of introduction, theoretical construction of hypotheses, methodology, results, implications for theory and practice, and conclusions. In addition to presenting the three papers, the final chapter of the thesis provides an overall conclusion regarding the research findings and their implications for theory and practice.

Table I. Research objectives

THE ROLE OF SUPPLY CHAIN MEMORY FOR SUPPLY CHAIN DISRUPTION MANAGEMENT			
Thesis argument	**Memory plays an important role, directly and indirectly, in improving supply chain disruption management. However, absorbing and applying new knowledge is necessary to handle non-routine.**		
	1	2	3
Paper	Let's talk about bad experiences instead of forgetting them: An empirical study on the importance of memory for supply chain disruption management	The impact of using digital technologies on supply chain resilience and robustness: the role of memory under the covid-19 outbreak	From crisis to opportunity: combining memory and absorptive capacity to enhance supply chain disruption management
Published	Yes (https://doi.org/10.1016/j.ijpe.2023.108872)	Yes (https://doi.org/10.1108/SCM-06-2022-0217)	No
Aims	Investigate the direct impact of memory on both supply chain resilience and robustness and the moderating effect of memory on the relationship between resilience and robustness with supply chain performance.	Investigate the impact of digital technologies on supply chain resilience and robustness, pointing out supply chain memory as a mediator. Check the role of memory when extremely new disruptive events like the COVID-19 outbreak occur.	Investigate the impact of memory on resilience and robustness, verifying the moderating effect of absorptive capacity.
Methodology	Mixed-Methods	Quantitative	Quantitative
Main theoretical contribution	The paper contributed to the theory by combining the contingent resource-based and knowledge-based views to explain supply chain performance, highlighting supply chain memory as a condition in which supply chain resilience and robustness are highly efficient for it.	This study offers new and valuable insights into information processing theory, disruption management theory and knowledge-based view lens revealing how contingent factors like COVID-19 could influence the effectiveness of knowledge created, stored and retrieved by means of digital technologies in building more resilient and robust supply chains.	Presented new insights into the role of knowledge in disruption management, demonstrating the combined impact of memory and absorptive capacity on supply chain resilience and robustness.
Thesis main conclusion	Supply chain memory serves as an antecedent to supply chain resilience and robustness, moderates the impact of resilience and robustness on performance, and acts as a mediator of the relationship between the use of digital technologies and resilience and robustness. Additionally, for robustness, its effects are impacted by the novelty of the disruption and the ability to acquire, assimilate and apply new knowledge.		

2 PAPER ONE - LET'S TALK ABOUT BAD EXPERIENCES INSTEAD OF FORGETTING THEM: AN EMPIRICAL STUDY ON THE IMPORTANCE OF MEMORY FOR SUPPLY CHAIN DISRUPTION MANAGEMENT

Paper History

Paper one was the first paper developed for the thesis purpose. It was developed when I was at NOVA Information Management School in Lisbon, Portugal as a visiting scholar. It was first submitted to the International Journal of Production Economics in January 2022 and was rejected after review. After improvements, the paper was resubmitted to the same journal in April 2022 and went through one major revision and two minor revisions after the acceptance in April 2023. The last revision required the insertion of a qualitative phase to validate the quantitative results.

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Let's talk about bad experiences instead of forgetting them: An empirical study on the importance of memory for supply chain disruption management

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ABSTRACT

Few studies have been concerned about the role of previous knowledge in supply chain disruption management. Based on the premise that supply chain resilience and robustness impact supply chain performance, this paper aims to expand this knowledge by conceptually and empirically establishing the role of supply chain memory for supply chain disruption management performance. A survey receiving 290 valid responses was conducted with supply chain managers. Quantitative data were analyzed with structural equation modeling. In addition, a mixed-methods approach was conducted to validate and explore the quantitative results. This paper contributes to theory and practice showing that experience, familiarity, and knowledge about dealing with disruptions improve supply chain resilience and robustness efficiency. The moderation effect of memory reveals that high memory leverages the impact of supply chain resilience on supply chain performance. Moreover, it brings important insights into the impact of robustness on supply chain performance since it is conditional to memory levels. The full model was able to explain 37.19% of supply chain performance.

1. Introduction

The supply chain disruption management topic is extremely relevant nowadays (El Baz and Ruel, 2021; Pettit et al., 2019; Xu et al., 2020). Disruption is known as *"unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain"* (Craighead et al., 2007, p. 132) and can derive from intentional, accidental, or random events (Carvalho and Machado, 2007; Sheffi and Rice Jr., 2005). The Covid-19 pandemic (Hudecheck et al., 2020), Hurricane Laura (Kapadia and Fuller, 2021) and Tropical storm Nicole (Garland, 2022) are examples of random events; The Suez Canal block (Stevens, 2021) and Japanese chipmaker Renesas Electronics plant fire (Thomas, 2021) are examples of accidental events; while recent strikes at Cargil-Canada (Fikowski, 2021), Kellog-United States transportation (Casey, 2021), and several strikes in the transportation industry around the globe (Hossaim and Barua, 2021; Koh, 2021; McDonald, 2021) are examples of intentional events. Whatever causes disruptions, these examples demonstrate how risks and uncertainties can be devastating, not only for a single organization but also for multiple supply chain members (Ambulkar et al., 2015). We understand that even planned and anticipated events can lead to disruption without proper management.

In the face of the increase in raw material costs and suppliers demanding upfront payments generated by recent global supply chain disruptions like COVID-19 and the Russia-Ukraine conflict, supply chains were dramatically impacted, causing companies like the cosmetics maker Revlon to file for bankruptcy (Paramasivam et al., 2022). According to Hubs' "Supply chain resilience report 2023", semiconductor shortages, port congestion, and inflation, as well as COVID in China and carbon emission regulations, can potentially leverage disruptions in supply chains around the globe ("Survey: Top Supply Chain Risk of 2023 Is Semiconductor Shortage," 2022). Since most supply chains have to cope with these disruptive events throughout the year (Institute, 2018), their capability to fit with the environment and recover faster and properly from disruption (i.e., resilience) (Pettit et al., 2019; Sheffi and Rice Jr., 2005) or maintain the efficiency of operations even when disruptive events occur (i.e., robustness) (Brandon-Jones et al., 2014; Klibi et al., 2010; Kwak et al., 2018), seems crucial for determining which chains will collapse and which ones will evolve even in this context. Therefore, both managers and academics are looking for better ways to deal with them (Brusset and Teller, 2017).

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The resource-based view (Brusset and Teller, 2017; Bühler et al., 2016; Cheng and Lu, 2017; Kumar and Anbanandam, 2019; Kwak et al., 2018; Liu and Lee, 2018) and dynamic capabilities view (Abeysekara et al., 2019; Altay et al., 2018; Brusset and Teller, 2017; Chowdhury and Quaddus, 2017; Kwak et al., 2018; Singh and Singh, 2019; Yu et al., 2019) are dominant theories in supply chain disruption management quantitative studies. Most literature has focused on the impact of collaboration (Kumar and Anbanandam, 2019; Mandal et al., 2016), flexibility (Brusset and Teller, 2017; Mandal et al., 2016), visibility (Kumar and Anbanandam, 2019; Mandal et al., 2016) and, more recently, supply chain analytics (Dubey et al., 2021; Singh and Singh, 2019; Zouari et al., 2020) on resilience or, specifically, robustness. However, quantitative studies based on the Knowledge-Based view lens (Kwak et al., 2018; Leoni et al., 2022) and supply chain memory, in particular, are underexplored.

Despite its benefits, few studies have been concerned about the role of previous knowledge, i.e., memory, in dealing efficiently with future disruptions (Baghersad et al., 2022; Leoni et al., 2022). Since memory is understood as the accumulated experience of a system (Folke, 2006), it provides the context and sources for a better fit between capabilities and vulnerabilities, being considered a key factor in properly facing environmental challenges (Cegarra-Navarro and Martelo-Landroguez, 2020; Martelo-Landroguez and Cegarra-Navarro, 2014). Learning from past experience is needed to build resilient and robust systems, as well as to improve their impacts on supply chain performance (Pettit et al., 2019; Rankin et al., 2014). For example, the 2011 earthquake and tsunami in Fukushima, Japan, affected Ericsson's normal operations. To deal with this incident, the lessons learned from previous disruptions, like a 2010 warehouse incident, were put into practice (Norrman and Wieland, 2020). The same event made Toyota improve its supply chain visibility (Baghersad et al., 2022). Norrman and Wieland's (2020) study demonstrated that Ericsson's risk management nowadays is partly a result of the learning from its past experience, as well as the ability to formalize, apply and refine what was learned.

Also, regardless of previous studies having already empirically pointed out the impact of both resilience and robustness on supply chain performance (Altay et al., 2018; Chowdhury and Quaddus, 2016, 2017; Chowdhury et al., 2019; Wieland and Marcus Wallenburg, 2012), studies on the conditions in which supply chain resilience and robustness are highly effective to supply chain performance still need development (Chowdhury et al., 2019). Since we are only studying survivors' organizations, risk management practices are expected to be related to performance perception (Denrell, 2003), a bias commonly ignored by the supply chain disruption management field. These gaps lead us to an important research question (RQ):

RQ) Does supply chain memory improve the impact of supply chain resilience and robustness on supply chain performance?

Based on the preceding, this paper's main aim is to expand the knowledge about the impact of both supply chain resilience and robustness on supply chain performance by pointing out the role of supply chain memory. We argue that supply chain memory not only improves supply chain memory and robustness, which leads to a higher supply chain performance but also moderates the relationship between supply chain resilience and robustness on supply chain performance. Ultimately, this paper contributes to the theory and practice in the following ways:

(i) Drawing on the Knowledge-Based and Contingent resource-based views and Pettit et al. (2013) and Fiksel et al.'s (2015) arguments, our paper brings new insights to supply chain disruption management and knowledge management theory by proposing and testing a model that contributes to the understanding about the conditions in which the impact of both resilience and robustness on performance occurs. Our results not only show that resilience and robustness are impacted by previous knowledge to deal with disruptions but, more importantly, that the effects of resilience on performance is improved by memory, and the robustness impact is conditioned on memory levels.

(ii) The "uses of the past" studies (Wadhwani et al., 2018) and the benefits of painful memories (Crawford et al., 2022) by pointing out how disruptive events and their impacts can be used to generate supply chain performance in the future.

(iii) Proving that supply chain memory about disruptive events is quantitatively relevant for supply chain disruption management performance, the mixed-methods approach allowed to qualitatively exploit how supply chains can build, access, and keep it alive to deal with future disruptions.

The remainder of this paper is organized as follows. Section 2 provides the background and develops the theoretical construction of the hypotheses. Section 3 describes the quantitative data collection, measurement, and analysis procedures. In Section 4, we present the structural equation results. Section 5 presents the methodology and results from the qualitative interviews. Section 6 discusses the results and provides our theoretical and managerial implications. Finally, in Section 7, we present the conclusion, limitations, and directions for future research.

2. Theoretical construction of the hypotheses

2.1. Supply chain resilience, robustness, and performance

Supply chain resilience and robustness concepts are not new (Jüttner et al., 2003; Sheffi and Rice Jr., 2005; Stonebraker et al., 2009), but such concepts are trending nowadays since managers and academics are looking for more efficient ways to avoid, prepare, respond and recover from disruptions (Ali et al., 2017; Pettit et al., 2019). These terms are constantly used interchangeably, but we see them as different concepts like Brandon-Jones et al. (2014) and Mackay et al. (2019). In the ongoing paragraphs, we exploit the arguments for such differences.

There is no universally accepted supply chain resilience concept (Abeysekara et al., 2019; Pires Ribeiro and Barbosa-Povoa, 2018). Definitions range from those who consider only recovery as a resilience dimension (Brandon-Jones et al., 2014; Jüttner et al., 2003; Sheffi and Rice Jr., 2005) to those who consider either response and recovery (Jüttner and Maklan, 2011) or prevention, response and recovery (Ponomarov and Holcomb, 2009). Perspectives range from those who consider being resilient to deal with the moment both after and during an interruption to those who also consider a moment before an interruption (Ali et al., 2017). For a new perspective on supply chain resilience, see Wieland (2021), Wieland et al. (2023), Ivanov and Dolgui (2020), and Ruel et al. (2021).

In this paper, only recovery is considered a resilience dimension. Alvarenga et al. (2022) show that a supply chain can be good in preventing disruptions but not as good in recovering from them. As not all disruptions can be identified and mitigated before they happen (Fiksel et al., 2015; Wong et al., 2020), we define supply chain resilience as the chain's ability to recover or move to a more desirable state after a disruption occurs (Brandon-Jones et al., 2014; Christopher and Peck, 2004; Wong et al., 2020).

Like supply chain resilience, the supply chain robustness concept is unclear (Brandon-Jones et al., 2014). "*Robustness is generally taken to mean the ability to resist a disturbance by not changing*" (Walker, 2020, p. 1). Instead, we assume that to avoid being disrupted in today's supply chain environment, it is only possible by a somewhat flexible capability to accommodate changes and be prepared to deal with these events (Brandon-Jones et al., 2014; Mackay et al., 2019). Therefore, we define supply chain robustness as the chain's ability to remain effective when disruptive events occur (Brandon-Jones et al., 2014; Klibi et al., 2010; Kwak et al., 2018; Stonebraker et al., 2009). It is evident that not being disrupted is better than being disrupted and having to recover. However, as mentioned before, not all disruptions can be avoided (Wong et al.,

2020).

Whenever defined, these concepts are strongly related to supply chain performance since they relate to the ability to deal proactively and reactively to supply chain disruptions. Resilience has been proved to impact several types of performance, both in the chain (Altay et al., 2018; Chowdhury and Quaddus, 2016, 2017; Chowdhury et al., 2019; Ruel and El Baz, 2021) and in the organization (Abeysekara et al., 2019; Kumar and Anbanandam, 2019; Liu and Lee, 2018; Wong et al., 2020; Yu et al., 2019), as well as in competitive advantage (Abeysekara et al., 2019; Dubey et al., 2021; Kwak et al., 2018) and service performance (Liu and Lee, 2018). Robustness has also been proved to impact supply chain customer value and business performance (Wieland and Marcus Wallenburg, 2012) or competitive advantage (Kwak et al., 2018). Therefore, the impact of supply chain resilience and robustness on supply chain performance is an assumption in this study.

2.2. What is supply chain memory?

Many kinds of memory are described in the literature, specifically at least 256 (Tulving, 2007). Procedural, declarative, and episodic are just a few examples (M. D. Cohen and Bacdayan, 1994; Rowlinson et al., 2009). For the aims of this study, organizational memory is considered as something remembered from the past that influences the way analysts and decision-makers interpret events and react to them since its where cognitive maps and reference frameworks are embedded (Baron and Ensley, 2006; Huber, 1991; Miller and Sardais, 2013). Simon (1987), for example, states that individuals store a large amount of knowledge obtained from training and experienced situations and organize it in terms of "recognizable blocks" that can be evoked from their memory whenever a pattern is recognized in a current situation. Given its importance, the memory metaphor has been discussed over the years in organizational studies (Cegarra-Navarro and Martelo-Landroguez, 2020; Fiedler and Welpe, 2010; Huang, 2013; Stein, 1995).

Organizational studies present four main memory perspectives: functional, interpretative, critical, and performative (Coraiola and Murcia, 2020; Foroughi et al., 2020). This study is based on a functional view of organizational memory (Walsh and Ungson, 1991) work. This view looks for ways to benefit organizational outcomes by properly managing the acquisition, retention, maintenance, and retrieval of knowledge (Fiedler and Welpe, 2010; Foroughi et al., 2020; Stein, 1995). Also, it is understood that memory is present in a series of retention bins, such as routines, employees, culture, ecology, and structure (M. D. Cohen and Bacdayan, 1994; Foroughi et al., 2020; Kmieciak, 2019; Walsh and Ungson, 1991). Overall, memory is the current knowledge that the organization/chain members have based on previous successes and failures and that can be used in the present and future (Anand et al., 1998; Hult et al., 2004; Walsh and Ungson, 1991). Memory is a map of an organization's past (Stein, 1995), being a valuable resource, as it provides action guidelines and facilitates the interpretation of information (Hanvanich et al., 2006; Huber, 1991; Moorman and Miner, 1998), improving decision making efficiency (Ozorhon et al., 2005).

Despite seeming similar, the memory concept is different from absorptive capacity. Absorptive capacity is defined as the firm's ability to *"[…] recognize the value of new, external information, assimilate it, and apply it to commercial ends"* (Cohen and Levinthal, 1990, p. 128). Memory is where new knowledge learned, assimilated, and applied is stored and can be retrieved to influence future behavior (Antunes and Pinheiro, 2020; Chou, 2005). This study considers learning as a process, with memory as an outcome of this process (Antunes and Pinheiro, 2020; Huang, 2013). An organization only learns if the new knowledge is established in its memory (Argyris and Schön, 1978; Levitt & March 1988). Since information interpretation depends on memory (Huber, 1991), prior experience grants the ability to properly exploit new external knowledge (Cohen and Levinthal, 1990; Flatten et al., 2011; Zahra and George, 2002). Therefore, memory can impact and be impacted by absorptive capacity.

Supply chain memory is defined here as the amount of experience, familiarity, and knowledge articulated by supply chain members (Hult et al., 2006; Moorman and Miner, 1997) to deal with disruptive events. Memory is not developed to overcome an original problem, but it is used to learn and retain the knowledge of past events to deal efficiently with future problems (Huang, 2013). The repetition of the same mistakes and the rediscovery of successful formulas for the same issues are characteristics of organizations that cannot remember what went wrong or right in their history (Day, 1994). Previous studies have shown the positive effects of memory on value creation (Martelo-Landroguez and Cepeda-Carrión, 2016), engagement in knowledge acquisition activities (Hult et al., 2004), sustainable competitive advantage (Ebbers and Wijnberg, 2009; Moorman and Miner, 1998), organizational agility (Cegarra-Navarro and Martelo-Landroguez, 2020), and performance (Kmieciak, 2019).

2.3. The role of supply chain memory for resilience and robustness development

According to the knowledge-based view, knowledge is the most valuable strategic resource an organization can have (Grant, 1996a, 1996b). As evidenced by Scholten et al. (2019), the lack of a supply chain's collective knowledge can cause it to suffer from the same disruption as in a previous moment. An example presented by Anand et al. (1998, p. 800) demonstrates the importance of information stored in the chain's memory. In this example, taken from an interview excerpt, a paper producer modified the wood used to pack the papers, and this wood was vulnerable to insect attack, which destroyed tons of paper. During a conversation with a distributor, managers were told: "If you had asked us … One of your competitors used the same wood as you years ago and suffered from the same problem" (Anand et al., 1998). This illustrates that building, storing, and retrieving information about how to deal with disruptions is a critical aspect of avoiding new disruptions (Labib et al., 2019; Ponomarov and Holcomb, 2009; Scholten et al., 2019).

New insights from the literature show that learning from experience (Roh et al., 2022), as well as cross-boundary information exchange (Adel et al., 2022), are important to deal with disruptive events. Baghersad et al. (2022) found that prior experience decreases the disruption severity suffered by firms after internal supply chain disruptive events. Also, preparation to deal with disruptions is related to prior experience (Daghar et al., 2022). Therefore, we understand that supply chain resilience and robustness levels will be impacted by the capacity to develop, store and retrieve knowledge about details of a disruptive event and about the patterns of actions that were taken to recover the flow of operations from it (Scholten et al., 2019; Walsh and Ungson, 1991). Therefore:

H1. Supply chain memory has a positive impact on supply chain resilience

H2. Supply chain memory has a positive impact on supply chain robustness

2.4. The moderation role of supply chain memory in the relationship between resilience and robustness on supply performance

The third and fourth hypotheses are mainly based on the intersection of two well-known theories, the contingent resource-based view and the knowledge-based view of the firm. The contingency resource-based view argues that not all resources and capabilities are needed in all environments, so what generates competitive advantage is an alignment between capabilities and the environment (Aragón-Correa and Sharma, 2003). The disruptive impact of a risk event in the supply chain demonstrates that the chain's capabilities were inadequate for the environment in which it was inserted, affecting the delivery of value to the final

customer (Madsen and Desai, 2010; Pettit et al., 2019).

In the supply chain disruption management field, specifically supply chain resilience, Pettit et al. (2013, 2019) and Fiksel et al. (2015) discuss this fit between capabilities and environment. As stated by the authors, this fit between capabilities and vulnerabilities places the chain in a balanced zone of resilience, where it is neither failing to profit by having too many capabilities in the face of its vulnerabilities nor losing due to excessive exposure to risks. We believe that the same can be said about robustness. Based on the knowledge-based view, we argue that it is the supply chain memory on how to deal with disruptions that allows supply chain members to fit capabilities and vulnerabilities, leading to greater adequacy of prevention, response, and recovery to disruptions, consequently, greater performance (Kim and Bui, 2019; Pettit et al., 2019; Scholten et al., 2019).

It is worth mentioning that it is understood in this paper that being resilient or robust does not depend on memory, as a chain can recover, respond or prevent a disruptive event without having familiarity, knowledge, or experience in dealing with risks and uncertainties. However, this process would be less efficient than if there were memories to be used, considering that it makes a recovery, response, and prevention more adequate while avoiding the waste of resources, consequently generating greater performance. In this sense, it is expected that the impact of resilience and robustness on the chain's performance will be moderated positively by the degree of knowledge, familiarity, and experience in dealing with disruptions by supply chain members, namely, supply chain memory. Therefore:

H3. Supply chain memory about how to deal with disruptions moderates the impact of supply chain resilience on supply chain performance

H4. Supply chain memory about how to deal with disruptions moderates the impact of supply chain robustness on supply chain performance

Fig. 1 summarizes the research model with all the hypotheses.

3. Quantitative survey method

3.1. Data collection and sample description

Data were collected from June 2021 to May 2022 using an online three-block questionnaire applied to supply chain management professionals around the globe. Altogether, 5771 professionals were invited to participate in the survey, 3967 from base 1, 1239 from base 2, and 565 from LinkedIn. The final questionnaire version was developed in SurveyMonkey, and the access link was sent by email to the research target professionals, except for the LinkedIn professionals. In addition to the first invite, key professionals received a reminder about participating in the survey containing the importance of their participation. Respondents were advised that their responses were anonymous and that the survey results would be disclosed to them to achieve a higher response rate and information reliability.

The questionnaire obtained 348 complete responses, a response rate of 6.03%, 290 of which were considered valid for this study. Notably, most of the answers were removed because they were from consultants who provide services to some organizations and their supply chains. Besides being low, this response rate is compatible with similar studies (Brusset and Teller, 2017; Jin et al., 2014; Li et al., 2020). Of these responses, 218 are from base 1 and 42 from base 2, and 30 from LinkedIn. We examined the data set for equivalence between bases 1, 2, and 3. The measurement invariance of composite models (MICOM) (Henseler et al., 2016) procedure was conducted to check the configural and compositional invariance (Hair et al., 2018; Henseler et al., 2016). The same scale and treatment were applied for the three groups, ensuring configural invariance. Pairwise evaluation with permutation technique (Cheah et al., 2023; Chin and Dibbern, 2010) was used to assess compositional invariance. The results demonstrated partial measurement invariance, supporting pooled data analysis (Hair et al., 2018).

Table 1 presents the sample demographic description. It should be noted that in the case of a multinational, the respondent was asked to respond based on the base of operations in which they spent the most hours in the last year. Even so, 17 respondents classified their organizations as global or included more than one country from a different mainland in the response. This aspect may imply that these respondents are responsible for operations in more than one country to the same extent.

3.2. Common method variance and non-response bias

Non-response bias and the common method variance were checked.

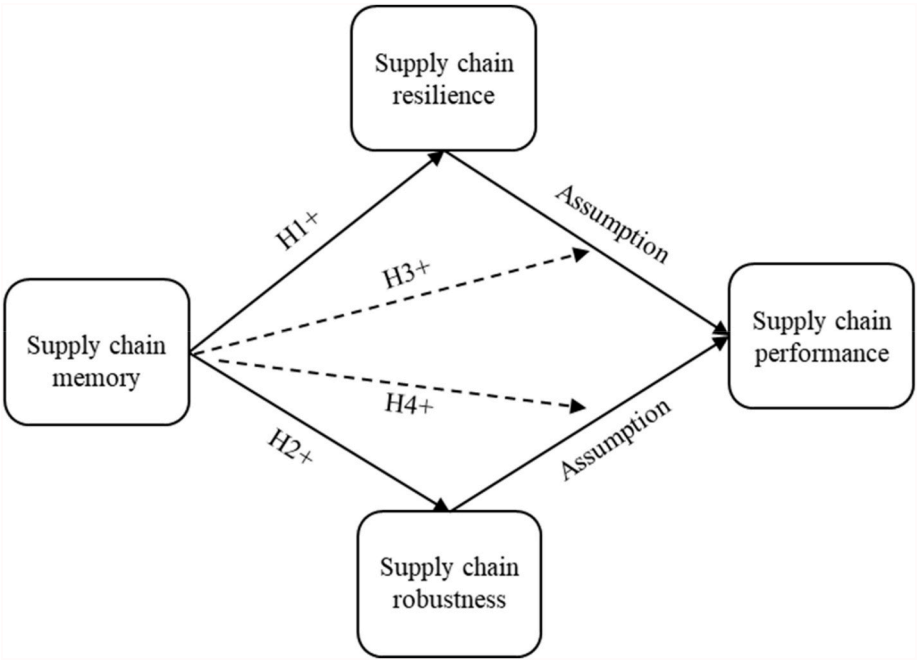

Fig. 1. Research model.

Table 1
Sample description.

Question	Counts	% of total	Question	Counts	% of total
Which job function better describes your activities?			**Years worked at the organization**		
Distribution	6	2.07%	<2	67	23.10%
Inventory Planning/ Control	22	7.59%	2–5	83	29.57%
Logistics Planning/ Management	35	12.07%	6–10	40	12.84%
Manufacturing/ Operations	36	12.41%	>10	100	36.19%
Marketing/ Sales	5	1.72%	**Number of employees:**		
Purchasing/ Procurement	31	10.69%	<100	63	21.72%
Supply chain management	118	40.69%	100–499	71	24.48%
Transportation management	8	2.76%	>499	156	53.79%
Other	29	10.00%	**What is your type of industry? (SIC code)**		
What is your Job title?			Agriculture, Forestry, And Fishing (1–9)	2	0.69%
CEO/President	16	5.52%	Chemicals, Petroleum (28, 29)	44	15.17%
Vice President	13	4.48%	Construction (15, 16, 17)	10	3.45%
Director	42	14.48%	Food, Beverage Tobacco (21, 22)	30	10.34%
Manager	107	36.90%	Furniture and Fixtures (25)	3	1.03%
Analyst	39	13.45%	Health Services (80)	7	2.41%
Supervisor	24	8.28%	Instruments (38)	12	4.14%
Other	49	16.90%	Machinery, electr. Equipment (35, 36)	34	11.72%
Mainland			Metal (33, 34)	11	3.79%
Africa	36	12.41%	Mining (10–14)	6	2.07%
Asia	51	17.59%	Miscellaneous Manufacturing Industries (39)	37	12.76%
Central America	1	0.34%	Paper, printing, publishing (26, 27)	2	0.69%
Europe	34	11.72%	Rubber, plastics (30)	3	1.03%
Global	17	5.86%	Stone, Clay, Glass, and Concrete Products (32)	2	0.69%
North America	140	48.28%	Textile, Apparel (22, 23)	9	3.10%
Oceania	6	2.07%	Transportation Equipment (37)	18	6.21%
South America	5	1.72%	Transportation, Communications, Electric, Gas, And Sanitary Services (40–49)	31	10.69%
			Wholesale/Retail (50–59)	15	5.17%
			Other	14	4.83%

A *t*-test of the mean difference was performed between the first 50 and the last 50 respondents for all indicators involved in this study to verify the existence of serious problems of non-response bias (Armstrong and Overton, 1977). The results showed that the indicator's means are statistically equal between the groups. Regardless of the variance caused by the method, we followed procedures suggested by Podsakoff et al. (2003). (1) Anonymity was guaranteed to respondents. (2) Simple and specific questions were chosen. (3) Each question and indicator were randomized for each respondent. (4) The respondents are mostly supply chain management specialists in their organizations, with the majority having more than ten years of experience, showing adequate knowledge to answer the questionnaire. Furthermore, the single-factor Harman's test was used through exploratory factor analysis to check for statistical problems related to the common method variance. The test result showed that the first factor could explain 47.13% of the observed variance, not pointing to serious issues.

3.3. Measurement scales

Whenever possible, established scales were chosen. Wagner and Bode's (2008) indicators were used to measure supply chain performance, with items related to delivery reliability, order fulfillment capacity, delivery speed, and customer satisfaction. Supply chain resilience was measured as recovery capability to disruption, and indicators proposed by Brandon-Jones et al. (2014) were adopted. Indicator RES5 was used since it is aligned with the supply chain resilience definition. We adopted indicators from Kwak et al. (2018) and Wieland and Wallenburg (2013) to measure supply chain robustness and the supply chain memory scale that was used by Moorman and Miner (1997). The latter's scale was already used, at least by Hult et al. (2004), Hanvanich et al. (2006), Hult et al. (2006), and Lee et al. (2017) to measure the memory construct.

All constructs were measured as reflective. Therefore, the scales were evaluated for reliability, convergent validity, and discriminant validity using Smart-PLS software (Ringle et al., 2014). Table 2 presents the loadings, the average variance extracted (AVE), and McDonald's omega, making it possible to verify the convergent validity and reliability of the indicators (Fornell and Larcker, 1981; Hair et al., 2017; Hayes and Coutts, 2020). The discriminant validity was checked by comparing the square root of the AVE of each construct with its correlation with the other constructs (Table 3) (Fornell and Larcker, 1981).

4. Quantitative data analysis and results

4.1. Main effects, moderations, and full model analysis

The hypotheses were tested by structural equation modeling with a partial least squares estimator. A bootstrapping with 5000 subsamples was conducted to check for statistical significance in the relationships. According to Hair et al. (2009), structural equation modeling estimates a series of separate multiple regression equations that can be simultaneously calculated. The variance inflation factor (VIF) was used to check the collinearity between the predictive constructs of the model, and no problem was found since all VIFs were far from five.

The results are presented in Table 4. The first model (M1) checked for the main effects of supply chain resilience (H1) and robustness (H2) on supply chain performance, as well as the impact of supply chain memory on resilience (H3) and robustness (H4). Model 2 (M2) adds to the model the interaction effect between memory and resilience on performance (H5), whereas Model 3 (M3) concentrates on the interaction between memory and robustness on performance (H6). Finally, model (M4) tested all interactions to reveal increments in the supply chain performance coefficient of determination in comparison with Model 1 (M1) (Dawson, 2014).

All proposed theoretical hypotheses of main effects were confirmed by empirical tests (M1). Supply chain memory has a positive and statistically significant effect on both supply chain resilience (path coefficient 0.608 and p-value <0.001) and robustness (path coefficient 0.637 and p-value <0.001), while resilience (path coefficient 0.436 and p-value <0.001) and robustness (path coefficient 0.171 and p-value <0.05) have a positive and significant effect on supply chain performance. Also, this Model (1) was capable of explaining 36.91% of supply chain resilience, 40.36% of supply chain robustness, and 31.09% of supply chain performance.

Individual moderation analysis confirmed hypotheses 3 (M2) and 4 (M3). Therefore, as theoretically proposed, the impact of supply chain

Table 2
Measurement results.

Construct	Indicator	Description	Loadings	AVE	McDonald's omega
Please evaluate your supply chain performance indicators compared to your major competitors' supply chains on the scale below: 1- Much worse to 7 - Much better					
Supply chain performance (SCP)	SCP1	Order fill capacity: Provision of desired quantities consistently	0.916	0.799	0.917
	SCP2	Delivery dependability: Meeting quoted or anticipated delivery dates and quantities consistently	0.917		
	SCP3	Customer satisfaction: Meeting customer satisfaction with supply chain performance consistently	0.881		
	SCP4	Delivery speed: Time between order receipt and customer delivery	0.860		
To what extent do the statements apply to your supply chain in case of disruption? (considers your organization, your critical suppliers, and customers): 1 - Strongly disagree to 7 - Strongly agree					
Supply chain resilience (SCRES)	RES1	Material flow would be quickly restored	0.879	0.712	0.900
	RES2	It would not take long to recover normal operations performance	0.777		
	RES3	The supply chain would easily recover to its original state	0.895		
	RES4	Disruptions would be dealt with quickly	0.847		
	RES5	The supply chain could easily move to a new desirable state	0.814		
To what extent do you agree with the statements about your supply chain? (considers your organization, your critical suppliers, and customers): 1 - Strongly disagree to 7 - Strongly agree					
Supply chain robustness (SCRO)	RO1	Our supply chain can remain effective and sustained even when disruptive events occur (e.g., Natural disasters, labor strikes, fire, industrial accidents, shortages on the supply markets)	0.836	0.705	0.896
	RO2	Our supply chain can avoid or minimize risk occurrence by anticipating and preparing for them	0.789		
	RO3	Our supply chain can absorb a significant level of negative impacts from recurrent risks	0.860		
	RO4	When changes occur, our supply chain grants us sufficient time to consider a reasonable reaction	0.822		
	RO5	Our supply chain performs well over a wide variety of possible scenarios	0.889		
To what extent do you agree with the statements about your supply chain? (considers your organization, your critical suppliers, and customers): 1 - Strongly disagree to 7 - Strongly agree					
Supply chain memory (SCME)	M1	We have a great deal of knowledge about how to handle supply chain disruptions	0.907	0.793	0.915
	M2	We have a great deal of experience about how to handle supply chain disruptions	0.914		
	M3	We have a great deal of familiarity about how to handle supply chain disruptions	0.918		
	M4	We have invested a great deal of research and development about how to handle supply chain disruptions	0.821		

Table 3
Fornell Larcker analysis.

Construct	Mean	SD	1	2	3	4
1. Supply chain performance	4.83	1.16	**0.894**			
2. Supply chain resilience	4.15	1.33	0.541	**0.844**		
3. Supply chain robustness	4.25	1.26	0.439	0.615	**0.840**	
4. Supply chain memory	4.40	1.44	0.492	0.608	0.637	**0.891**

resilience and robustness on supply chain performance is stronger when supply chain memory is high, with moderation coefficients of 0.155 (p-value <0.001) and 0.113 (p-value <0.01), respectively. However, a full model analysis demonstrated that when the supply chain memory moderates the relationships of both resilience and robustness with performance, the moderation effect of supply chain memory on the supply chain robustness relationship with performance loses its value. Significant interaction effects were also explored, plotting the relationship between the −1 standard deviation (SD) and +1 standard deviation (SD) (Fig. 2).

Some insights can be drawn from the interaction plots. As expected from the moderation analysis results, the slopes for high memory are bigger than low memory for the relationship between resilience with performance (M2) and the relationship between robustness with performance (M3). Also, the M3 interaction plot reveals that the costs associated with being robust without proper knowledge, experience, and familiarity for it (low supply chain memory) undermine supply chain performance. Finally, the interaction between memory and robustness does not affect supply chain performance when the interaction between memory and resilience is present (M4).

5. Interviews on the role of supply chain memory for supply chain disruption management

5.1. Qualitative method

Post-hoc storytelling interviews with seven experts were conducted in March 2023 to validate and exploit our quantitative findings (See Table 5 for interviewee profiles). As storytelling draws tacit knowledge from interviewees' experiences (Whyte and Classen, 2012), the

Table 4
Research results.

Hypotheses test	M1 - (H1-H2)			M2 - (H3)			M3 - (H4)			M4 - Full model		
	DV			DV			DV			DV		
Constructs	SCRES	SCROB	SCP	SCRES	SCROB	SCP	SCRES	SCROB	SCP	SCRES	SCROB	SCP
SCME	0.608***	0.637***	–	0.607***	0.636***	0.252**	0.607***	0.636***	0.245***	0.607***	0.636***	0.252***
SCRES	–	–	0.436***	–	–	0.356***	–	–	0.339***	–	–	0.356***
SCROB	–	–	0.171*	–	–	0.050	–	–	0.075	–	–	0.049
Interaction term												
SCME*SCRES	–	–	–	–	–	0.155***	–	–	–	–	–	0.158**
SCME*SCROB	–	–	–	–	–	–	–	–	0.113**	–	–	−0.004
Rsquare	36.91%	40.56%	31.09%	36.86%	40.49%	37.19%	36.86%	40.49%	35.54%	36.86%	40.49%	37.19%
Rsquare-adjusted	36.69%	40.36%	30.60%	36.64%	40.29%	36.31%	36.64%	40.29%	34.64%	36.64%	40.29%	36.09%
Rsquare change	–	–	–	–	–	6.10%	–	–	4.45%	–	–	6.10%

Notes***p < 0.001 **p < 0.01 * p < 0.05.

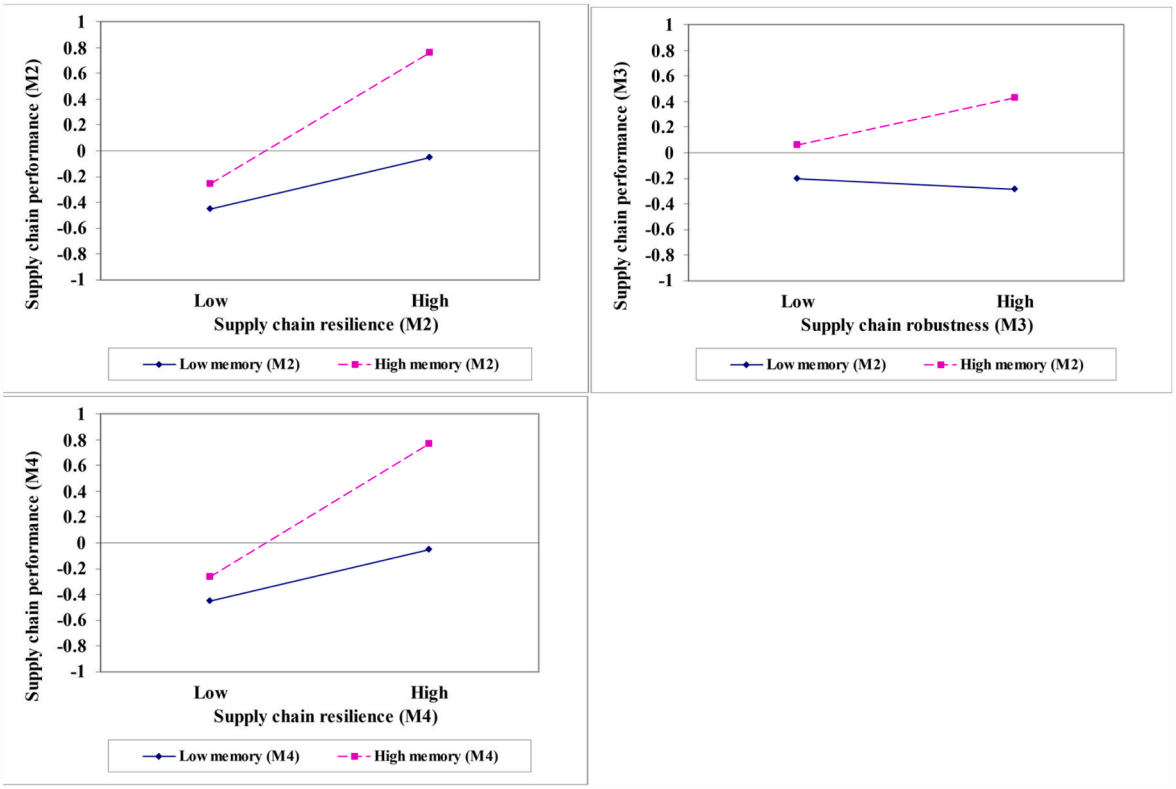

Fig. 2. Interaction plots for significant moderation effects.

mixed-methods approach allowed us to offer a more robust understanding and bring valuable insights into the role of supply chain memory for supply chain disruption management (Boyer and Swink, 2008; Venkatesh et al., 2016).

The interviews were conducted via Google Meet or Microsoft Teams, five via video call, and two via audio call. We adopted a cleaner transcription to facilitate the understanding of the transcribed content. After transcription, data were analyzed using the MAXQDA software (Kuckartz and Rädiker, 2019; VERBI Software, 2021), following the hypothesis coding method (Chandra et al., 2022; Saldaña, 2013) and some pre-defined memory processes categories (build, store, keep, retrieve) from the literature (Stein, 1995). The qualitative results are presented in the following sub-section.

5.2. Qualitative results

We validated the hypotheses in four ways. First, the experts were asked to explain the main impacts of COVID-19 on their supply chain and how previous knowledge and experience in dealing with disruptions helped their supply chain to deal with the COVID-19 pandemic. Second, the experts were requested to remember a prior disruptive event that their supply chain had plenty of knowledge or experience in managing and to explain the actions taken to handle it. Third, the experts were requested to define the steps taken to deal with a disruptive event with which their supply chain had little or no knowledge or experience. Finally, we asked them which situation they believed was easier to deal with.

Table 5
Interviewees description.

Participant	Position	Industry type	Number of employees	Location
A	Board member	Hospital	250–499	Puerto Rico
B	Director	Coatings manufacturing	>1000	Switzerland
C	Vice president	Transit	>1000	United States
D	Manager	Aerospace	>1000	United States
E	Manager	Aerospace	500–999	United States
F	Director	Laboratory Animal Equipment	250–499	Italy
G	Manager	Electronics Manufacturing	>1000	India

The interviewees' stories confirmed that memory about dealing with disruptions turns supply chains into more robust and resilient systems in several ways. Past knowledge and experience in dealing with disruptive events can help supply chains develop their capabilities and become more prepared to apply the appropriate resources to handle them efficiently. Likewise, the lack of memory about how to deal with a situation makes the response and recovery more difficult. Also, all the interviewees confirmed that it was easier to deal with a disruptive event where the supply chain had more experience or knowledge about how to deal with it. The effects of having a memory from efficient disruption management are seen in the following excerpts.

Excerpts that the interviewee considered to have high memory to deal with and their impacts on supply chain disruption management performance:

> ***We are used to having to deal with those emergencies.*** *So when COVID came around, with the* ***experience and learning*** *about resilience from dealing with hurricanes and other events, then COVID was* ***not as bad.*** *Not* ***nearly as bad*** *in terms of unexpected circumstances as dealing with those catastrophic hurricanes. […] After hurricane Maria, we did have the condition of rejecting bodies at the morgue because it was full. But not during COVID. We never had our morgue full, and it's due in part because of* ***preparedness.*** (PA)

*We **had already put in place a process** that we use to identify secondary and additional suppliers for specific product groups that are critical to our manufacturing processes. So rather than **scrambling to** identify alternate sources, we already had a listing of companies that our buyers were able to approach that we had already engaged with previously […]. **We already had all of the things in place** in order to move those back orders or those canceled orders to a different source. So thankfully, by our **pre-planning** […], we have been proactive and **built the process and procedures** in order to react when a disruption that was not planned, of course, uncontrollable, happens. We were able to react and have **minimal impacts on our production**.* (PE)

*In the chemical industry, it takes 30 days to start up the manufacturing plant. It's a very complex manufacturing setup. We had a large shutdown all of a sudden. So we had to dismantle, and we had to repair all that stuff. […] **We immediately found** contract manufacturers who could make these five raw materials separately and all shipped together at the same time to one of our alternate plants. **We should have lost 60 days from the original plan, but we actually lost 10 days,** and within 10 to 15 days, we could start the same product being manufactured in another site. […] **How to manage this situation, that kind of knowledge was there […].*** (PG)

*We **always had** a force majeure declaration by our customer, **we knew how to handle a shortage of raw materials**. What was the difficulty, that all of these elements came together, and they came together in much higher volume because sometimes it's an individual manufacturing plant which has force majeure from our suppliers […]. **We didn't adjust that much to standard operating procedures**.* (PB)

*We **didn't experience many issues** from the supply side because **we're already working on that […]**. It was new for us, facing a pandemic that size. But dealing with risk **wasn't new**. We already **had an Enterprise risk management structure in place** and used that.* (PF)

Excerpts about a situation that the interviewees considered to have low memory to deal with and it's impacts on supply chain disruption management:

*"**We had no knowledge of how to deal with that situation before. It was kind of unprecedented for us**. And so, it turns out that the paperwork process was pretty straightforward, but **it led to months' worth of delay as we tried to figure it out**. Since then, we certainly keep a lot more proactively on top of like regulatory risks of that sort, but before then, we were just completely **unprepared,** and **it took months and months to recover** the volume that we lost during our downtime there. I don't think that sort of thing will happen to us again, we're a lot more **prepared now**, but certainly hit that time […] […], but we were very **unprepared**".* (PD)

*Our collective knowledge that we have in our staff really, you know, looking back, there's no **there's no precedent for this**. So regardless of our memories, and we collectively have hundreds of years of experience across multiple industries, **we're struggling to use our memory** to understand the best way to approach this".* (PC)

*I think that the blockades in the Suez Canal were something where there is always a likelihood that it will happen, but the effect was much bigger than we expected […]. We **didn't have a real solution** because that delay multiplied as a result of that conversation, and that's where **we're in a situation that we had to wait or accept certain air freight** where we could.* (PB)

*We faced a stockout situation, so there was a lot of demand, but there was absolutely no product. […] **We had never faced shipment delays** […]. But this was happening for the first time, **we were absolutely clueless about what to do**. We had demand, sales orders coming in every day, and **our tank was completely empty**.* (PG)

Even if actions taken in the past are not fully applicable in the current situation, memory can help supply chains make sense of the situations and find the appropriate mitigation strategy (Oliveira and Handfield, 2017; Weick, 1988; Weick et al., 2005).

*The memory was helpful to the extent that **they knew we needed to change how we did things**.* (PC)

*Having dealt with that previously, **we had an idea of how to address this** and how to start looking for alternative products or learning how to reuse specific products […], and it really ended up having a **limited impact**.* (PE)

*Obviously, every situation is a little bit different, but I think the principles that **we've learned along the way are pretty generally applicable**. We haven't really come up with a process or a tool built around one disruption that we **can't take and at least partially** apply to another.* (PD)

Using a mixed methods approach helped us validate and bring a more robust overview of the role of supply chain memory for supply chain disruption management performance.

6. Discussion

6.1. Theoretical implications

Our paper provides new insights into supply chain disruption management, uses of the past, and knowledge management studies. Despite some previous studies having already empirically pointed out the impact of both resilience and robustness on supply chain performance (Altay et al., 2018; Chowdhury and Quaddus, 2016, 2017; Chowdhury et al., 2019; Wieland and Marcus Wallenburg, 2012), we contribute to theory by combining the contingent resource-based and knowledge-based views to explain supply chain performance, highlighting supply chain memory as a condition in which supply chain resilience and robustness are highly efficient for it. The quantitative and qualitative results demonstrated that when supply chains have knowledge or experience to deal with a disruption, operations maintenance or recovery is faster and easier to achieve with proper management than when supply chains have little or no knowledge.

The quantitative results are more critical to understanding supply chain robustness's impact on supply chain performance, as we reveal (Fig. 2, M3) that dealing with disruptive events without proper knowledge undermines supply chain performance. This facet means that being robust in itself is essential to survive but not to prosper, supply chain memory being a mechanism that makes robustness relevant for supply chain performance. The study's mixed-method approach uncovered that supply chains that faced recent disruptions, such as the COVID-19 pandemic or the Suez Canal blockage, took steps to improve their disruption management capabilities according to their vulnerabilities. This strategy, in turn, enabled them to become better equipped to efficiently deal with future disruptive events and transform their robustness into better performance in the future. The fact that most supply chains did not have sufficient memory to deal with the COVID-19 outbreak could complement why Ruel and El Baz (2021) did not find a positive impact of robustness on financial performance in the COVID-19 context.

We also demonstrated (M1) that previous knowledge about how to deal with disruptions improves supply chains' capacity not to be disrupted in case of risk occurrence and, in case of being disrupted, they have a faster recovery from it, resulting in an indirect effect on supply chain performance. According to recent literature, this dimension is expected (Baghersad et al., 2022; Leoni et al., 2022) and was validated through the qualitative results. Results also show a stronger direct impact of resilience on performance than robustness on performance. This aspect is quite curious since it looks better not being disrupted than having to recover from disruptions. However, as COVID-19 somehow disrupted most global supply chains, it seems plausible that their knowledge, experience, and familiarity in becoming resilient, dealing with disruptions, and recovering their operations, have a higher

perceived value for performance than robustness. We also demonstrated that the interaction effect of memory with resilience better explains the variance of supply chain performance and decimates the moderation effect of memory on the robustness relationship with performance (M4). After all, the complete model explained 36.73% of supply chain performance. Therefore, new evidence about the benefits of supply chain resilience and robustness is pointed to theory in the COVID-19 era.

Finally, two more minor contributions can be drawn from the results. Like Brandon-Jones et al. (2014) and Ruel and El Baz (2021), confirmatory factor analysis confirmed that supply chain robustness and resilience are distinct constructs. This means that despite being used interchangeably, maintaining the operations at an acceptable level in case of a disruptive event and recovering from disruptions are perceived in practice as different concepts. Also, we contributed to a better understanding of the link between the contingent resource-based and knowledge-based views in the supply chain disruption management field. The link between resources and knowledge has already been mentioned by Barney et al. (2001).

6.2. Practical implications

> The best way to deal with disruptions is having a method for dealing with them […]. Every battle is different, but if you have a method for planning, making decisions, etcetera, this works. (PF)

"Organizations commonly regard memories of pain and destruction as being unwanted" (Crawford et al., 2022, p. 1). However, since it is never too early to be prepared to deal with the next disruption (Hudecheck et al., 2020), this research result shows supply chain managers the need to build supply chain memory about disruptions to gain an advantage from being both resilient and robust. Therefore, remembering these unwanted memories instead of forgetting them, using them to learn to deal with future disruptions, and employing this knowledge to avoid or adequately recover from disruptions seems essential for today's supply chains. So, our results encourage managers to discuss their experiences and share their knowledge internally and externally, since, as interviewee B strongly asserted: *We are all in the same deep ****[…]. Right now, everyone was on the same page, we are in the same storm, so that gave much more willingness to share knowledge and the will to collaborate more.*

Second, in the interviews, we explored how memory about dealing with disruptions can be built, accessed, kept alive, and retrieved. Our results show the benefits of learning from our own mistakes and through the mistakes and successes of others (vicarious learning). As mentioned before, talking about those experiences and sharing knowledge within the organization, with suppliers and customers, as well with competitors, also emerged as a way of learning. As expected from the theory, our qualitative results also reinforced that memories about unwanted events and the respective lessons learned are documented in written procedures and are stored, accessed, and shared through information systems (Barros et al., 2015; Nilakanta et al., 2006). Notwithstanding this convention, more importantly for practice, valuable lessons have to become routines to be kept alive (M. D. Cohen and Bacdayan, 1994; Scholten et al., 2019) and reviewed to not lead to some kind of rigidity when something extremely new occurs (Alvarenga et al., 2023; Chang and Cho, 2008; Sen et al., 2021).

> *[…] we have a **centralized repository** for all of our **processes and procedures** that are **revision controlled** […].* (PE)

> *That memory needs to go **first in writing into the procedures**. But the point I'm bringing is: you **cannot leave the words in a document**. The newcomers, they need to see the words in action. The "click" comes when they **see this procedure**.* (PA)

> *All kinds of procedures we had in place, so we rewrite, but we make sure **this is where you find how we're working on**. We have a regular **review cycle** of all of our quality procedures; normally, that is every two to three years. For risk management, we did it every half year over the last few years, and **we adjusted our procedures as well based on disturbances that we did not foresee coming in that size**. […] With the situation now, let's say coming back more to normality, that's **easily forgotten.** So it helps us to review it internally and bring it back to senior leadership not to forget what happened two years ago or even a year ago. It can happen again, and it will happen again, perhaps not in the size, but **we have to remain vigilant**.* (PB)

Third, our qualitative results demonstrated that developing an environment of trust, collaboration, and real-time visibility, allowing real-time memory building is essential to know what is happening, make plans, and take proper actions to deal with supply chain challenges. The interviewees exemplified several situations when the knowledge about what was happening and the collaboration with supply chain members changed how they do things. Therefore, we underline the need for practice to develop those supply chain capabilities.

> *Other than that, it really does come down to the **word of the buyer**; if they hear or they learn something from a supplier, when there's a tier one supplier or tier two supplier, they forward it to me […]. There was a train rail in Germany that was wiped out by rocks about a couple of years ago, and it's one of the largest manufacturers of rolled aluminum foil; actually, that was their only means to ship material, and we were able to shift some of our orders to another one of their competitors based on **knowing the impact that would have on our business**.* (PE)

> *It gets stuck for three days due to weather in Tennessee, that could add five days in total to our lead time, which might drive a shortage. So we've started to intercept a lot of parcel shipments at those terminals, and it's actually a very easy thing to do, **as long as you know exactly what you're looking for**, so that's been very helpful as well.* (PD)

> *We had a disruption to our diesel flow due to a cyber-attack on one of the main pipelines in the southeastern United States that feeds up into Washington, D.C. […] We were able to get together all of the right people quickly […] to explain what was going on so that their contract administrator could reach out to the vendor and **get a better understanding instead** of just saying "well, it's outside the contractual terms, so our answer is no."* (PC)

Additionally, supply chain memory can be built and improved in real-time without experiential learning, as supply chain managers now have better tools like blockchain technology, digital twins, big data analytics, and the internet of things to deal with disruptions (Acito and Khatri, 2014; Alvarenga et al., 2023; Zouari et al., 2020). Our previous study (Alvarenga et al., 2023) already demonstrated that those advanced technologies are being underused for supply chain disruption management purposes. The same was observed through the interviews. Some of the interviewees mentioned the use of business intelligence tools and the adoption of visibility platforms to obtain real-time information. Interviewee D noted that his supply chain has implemented *"[…] different BI tools to help us identify when we might be getting into a risk area within either inventory or lead time […],"* as a lesson learned from COVID-19. Since learning by doing is undesirable because of the high costs associated with supply chain disruptions (Hora and Klassen, 2013), these digital technologies, along with vicarious learning, help acquire experience, familiarity, and knowledge about possible interruptions without having to face them beforehand. Therefore, they are essential to address the issue of supply chain memory building (Alvarenga et al., 2023).

Finally, drawing on Pettit et al. (2013, 2019) and Fiksel et al.'s (2015) papers, we argued that memory helps to balance capabilities and vulnerabilities better, and that is why supply chains with higher memory achieve an optimized impact of resilience and robustness on supply chain performance. Since our arguments were confirmed by empirical testing, supply chain managers have to work to identify the right capabilities for the right environmental challenges, the Supply Chain

Resilience Assessment and Management (SCRAM) (Fiksel et al., 2015; Pettit et al., 2013, 2019) being an analytical tool that may help.

7. Conclusions, future research, and limitations

Throughout an empirical study with supply chain managers worldwide, this paper addresses a relevant supply chain management topic exploiting the role of supply chain memory on supply chain management disruption performance. This research concluded that supply chain memory acts as an antecedent of supply chain resilience and robustness and moderates the relationship between supply chain resilience and robustness on supply chain performance. Therefore, supply chains must exert efforts to develop a supply chain memory about dealing with supply chain disruptions. The findings also support that memory can act to balance capabilities and environmental disruptions, allowing supply chains to shape both robustness and resilience capabilities reaching a fit between the resources invested and the environmental characteristics. Such an idea of fit is grounded by a vital intersection of the contingent resource-based view with the knowledge-based view. Thus, as the study explores and demonstrates the value of keeping memory about experiences involving disruptive events alive, let's talk about bad experiences instead of forgetting them.

Like all research, this paper is not without limitations. A single respondent of one company with a supply chain strategy was used to make this research viable, despite a multiple-chain members strategy being a better approach. Also, it was not possible to test differences in the results inside the sample in terms of industry type. Finally, this paper suggests but does not really test if memory allows better adequacy of capabilities and vulnerabilities but uses theory to build this argument to explain and test the impact of memory in the relationship between supply chain resilience and robustness on supply chain performance.

The research results and limitations offer some possibilities for future work. Future quantitative researchers may explore the antecedents of proven supply chain memory value or check the impact of well-known resilience and robust capabilities under different contexts. In addition, qualitative studies should better explore how supply chains combine old with new knowledge to adjust their capabilities and vulnerabilities and lead to superior performance.

Data availability

Data will be made available on request.

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3 PAPER TWO - THE IMPACT OF USING DIGITAL TECHNOLOGIES ON SUPPLY CHAIN RESILIENCE AND ROBUSTNESS: THE ROLE OF MEMORY UNDER THE COVID-19 OUTBREAK

Paper History

Paper two was also developed during my Sandwich Ph.D. at NOVA Information Management School in Lisbon, Portugal. It was submitted to the Supply chain management: an international journal in July 2022 and was accepted in December, 2022 after one major revision and two minor revisions. The initial version of the paper received the best Logistics and Operations Management area paper of the XLVI Anpad 2022 award.

Due to copyright reasons, this paper can only be accessed via DOI: https://doi.org/10.1108/SCM-06-2022-0217

4 PAPER THREE - FROM CRISIS TO OPPORTUNITY: COMBINING MEMORY AND ABSORPTIVE CAPACITY TO ENHANCE SUPPLY CHAIN DISRUPTION MANAGEMENT

Paper History

The last paper was developed this year, 2023. It was developed after analyzing opportunities from the other two paper results. We understood that the absorptive capacity construct, which we already had data from, but it had not been explored in the previous models, could complement the previous results and provide a better understanding about the role of memory for supply chain disruption management. The paper was accepted in the Enanpad 2023 and is now submitted to the International Journal of Operations and Production Management.

FROM CRISIS TO OPPORTUNITY: COMBINING MEMORY AND ABSORPTIVE CAPACITY TO ENHANCE SUPPLY CHAIN DISRUPTION MANAGEMENT

ABSTRACT

Purpose: The present study aims to expand the knowledge about the impact of memory on resilience and robustness by testing the moderating role of absorptive capacity in these relationships.

Design/methodology/approach: The study presents the results of a quantitative survey performed among 257 supply chain management professionals. The data were analyzed using structural equation modeling.

Findings: The results indicated that absorptive capacity positively moderates the relationship between memory and robustness but does not have the same effect on the relationship between memory and resilience. Moreover, direct effects were also confirmed. The proposed model was able to explain 37.96% of supply chain resilience and 49.94% of supply chain robustness.

Originality: The results in this paper contribute to theory and practice offering new insights into the role of knowledge in disruption management, specifically for the relationship between supply chain memory and supply chain absorptive capacity for supply chain resilience and robustness. Moreover, the paper contributes to a better understanding of the benefits and harmful effects of supply chain memory for supply chain disruption management capabilities.

Keywords: Knowledge, Absorptive capacity, Memory, Resilience, Robustness, Supply Chain.

1 Introduction

There have been numerous recent instances where risk and uncertainty have negatively impacted supply chain performance. These include the COVID-19 pandemic (Craven *et al.*, 2020; Hudecheck *et al.*, 2020), Tropical Storm Nicole (Garland, 2022), and the potential for a rail labor strike (Zimmerman, 2022), among others. Therefore, the quest to make chains more capable of recovering quickly and adequately from disruptions (i.e., resilience) (Brandon-Jones *et al.*, 2014; Ruel and El Baz, 2021) and to keep the level of operations at an acceptable level in case of a disruptive event (i.e., robustness) (Kwak *et al.*, 2018; Mackay *et al.*, 2019), has gained notoriety in recent years.

With much of the literature placing greater emphasis on studying the impact of certain capabilities on both resilience and robustness (Brandon-Jones *et al.*, 2014; Dubey *et al.*, 2021; Jüttner and Maklan, 2011), recent studies demonstrated the importance of knowledge as a key factor in dealing with disruptions (Alvarenga *et al.*, 2023b, 2023a; Buhagiar and Anand, 2023; Leoni *et al.*, 2022; Umar *et al.*, 2020). Previous models found, for example, that experience, familiarity, and prior knowledge (i.e., memory) (Hult *et al.*, 2004; Moorman and Miner, 1997) in handling disruptions antecedes resilience and

robustness and moderates the relationships of resilience and robustness with supply chain performance, as well as partially mediates the relationship between digital technology use, resilience, and robustness (Alvarenga *et al.*, 2023b, 2023a). However, the findings also brought new questions, given that memory proved to be less efficient for robustness in the case of a non-routine event.

Walsh and Ungson (1991) have already warned about the need for an association between previous knowledge and the current situation. When patterns are firmly established, changes become more complicated, and flexibility decreases (Chang and Cho, 2008; Dougherty, 1992; Moorman and Miner, 1997). Therefore, memory can lead to unsatisfactory outcomes if the stored information is not critically analyzed for its relevance in the current context (Sen *et al.*, 2021). So, the chain's capacity to absorb and apply new knowledge (i.e., absorptive capacity) (Cohen and Levinthal, 1990) appears to be a fundamental factor in maximizing the effects of memory on how to deal with disruptive events on resilience and robustness. Thus we pose the question:

RQ) Does absorptive capacity improve the impact of memory on supply chain resilience and robustness?

Therefore, this paper aims to expand the knowledge about the impact of memory on resilience and robustness, verifying the moderating effect of absorptive capacity. We contribute to theory and practice by offering new insights into the role of knowledge in disruption management, specifically about the relationship between supply chain memory and supply chain absorptive capacity for improving supply chain resilience and robustness. Although the direct impact of absorptive capacity to deal proactively or reactively with disruptive events has already been found in at least three studies (Cheng and Lu, 2017; Dennehy *et al.*, 2021; Gölgeci and Kuivalainen, 2020; Roh *et al.*, 2022), as well as the importance of knowledge for disruption management (Ali *et al.*, 2023; Alvarenga *et al.*, 2023a; Leoni *et al.*, 2022), the relationship between new and old knowledge to improve supply chain disruption management is underexplored.

Hence, this paper contributes to knowledge management theory and supply chain disruption management literature by pointing out that absorptive capacity amplifies the effects of memory on supply chain robustness but does not have the same effect on the impact of memory on supply chain resilience. The findings also expanded the understanding about the combined impact of memory and absorptive capacity on supply chain resilience and robustness and reinforce the individual impacts in a new model. For practice, this result shows the importance of keeping memory alive and updated through the ability to acquire and assimilate new knowledge to be able to maintain operations at an acceptable level in case of non-routine events like COVID-19. Moreover, to work on memory and absorptive capacity development to deal with future events effectively.

The remainder of this paper is organized as follows. Section 2 provides the research model. Section 3 defines the constructs and presents the research hypotheses. Section 4 describes the quantitative data collection, measurement, and analysis procedures. In Section 5, we present the quantitative results. Section 6 discusses the results and provides

our theoretical and managerial implications. Finally, in Section 7, we outline the conclusion and directions for future research.

2 Research model

The research model is presented in Figure 1. Considering that the impact of supply chain memory on resilience and robustness has already been verified in previous studies, as well as that of absorptive capacity, this study assumes these relations as premises, focusing on verifying the moderating effect of absorptive capacity on the relation of memory with both resilience and robustness. Therefore, the direct impacts are considered the premises of the present study.

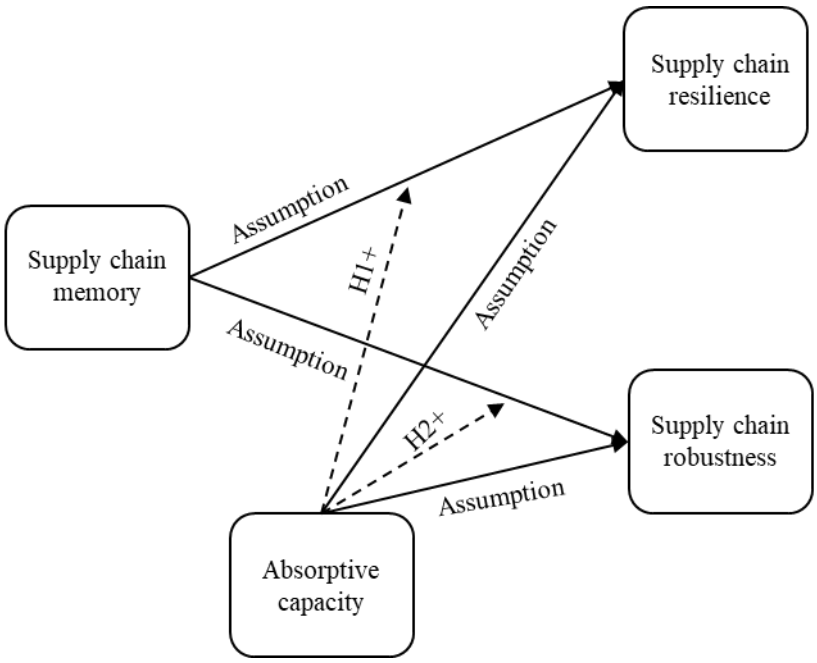

Figure 1. Research model.

3 Definition of the constructs and hypotheses

3.1 Supply chain resilience and robustness

Resilience and robustness, although used interchangeably in the literature, are defined and measured as different constructs in this paper (Brandon-Jones *et al.*, 2014; Mackay *et al.*, 2019). Despite the resilience concept having evolved recently to an ecological perspective (Castillo, 2023; Wieland *et al.*, 2023; Wieland and Durach, 2021) or to a viability view (Ivanov, 2021; Ruel *et al.*, 2021), we adopt an engineering view of resilience in this paper. Therefore, we define it as the chain's ability to return to its normal state or move to a more desirable one after a disruption (Brandon-Jones *et al.*, 2014; Christopher and Peck, 2004; Sheffi and Rice Jr., 2005; Wong *et al.*, 2020). Otherwise, robustness is the ability of the chain to maintain an acceptable level of operations even in the case of a disruptive event (Brandon-Jones *et al.*, 2014; Kwak *et al.*, 2018). Briefly, robustness involves not deviating too much from normal performance, while resilience means recovery.

3.2 Memory

The present study adopts a functional view of the memory construct (Foroughi *et al.*, 2020). Thus, memory is understood as possible to be built and used at a given time for decision-making. Therefore, memory is a set of information generated by the organization's history that can be used in future decisions (Walsh and Ungson, 1991). In this sense, "information about decisions made and problems solved form the core of organizational memory over time" (Walsh and Ungson, 1991, p. 62). Day (1994, p. 44) argues that organizational memory serves as "a repository for collective insights that contains policies, procedures, and rules that can be retrieved when needed." Bringing these aspects of memory into the context of the study, it is defined as supply chain members' knowledge, experience, and familiarity with how to handle disruptions (Hult *et al.*, 2004, 2006).

According to the literature, supply chain memory can have both positive and negative effects on organizations, depending on how it is constructed, maintained, and retrieved for decision-making purposes (Chou, 2005). Previous studies have shown the positive effects of memory on performance (Kmieciak, 2019), organizational agility (Cegarra-Navarro and Martelo-Landroguez, 2020), value creation (Martelo-Landroguez and Cepeda-Carrión, 2016), organizational ambidexterity (Cegarra-Navarro *et al.*, 2017) and sustainable competitive advantage (Ebbers and Wijnberg, 2009). On the other hand, memory is also associated with higher process rigidity (Newey and Zahra, 2009), leading to difficulty in interpreting market changes as well as low flexibility in dealing with these changes (Chang and Cho, 2008; Dougherty, 1992; Kyriakopoulos and Ruyter, 2004). Therefore, this brings to the table the role of absorptive capacity in enhancing the positive effects of supply chain memory.

3.3 The moderating effect of absorptive capacity on memory's relationship with resilience and robustness

Absorptive capacity was initially defined as the ability to "[...] recognize the value of external knowledge, assimilate it, and apply it for commercial ends [...]" (Cohen and Levinthal, 1990, p. 128). Overall, the literature on the subject divides absorptive capacity into two dimensions with complementary roles: potential and realized capacity. (Roh *et al.*, 2022). Acquisition and assimilation are part of potential capacity, which are related to the ability to identify and acquire new external knowledge as well as to understand it (Zahra and George, 2002). On the other hand, realized capacity is composed of the ability to transform and exploit, which involves eliminating, modifying, and creating new processes and competencies based on the newly acquired and assimilated knowledge (Zahra and George, 2002).

In the present paper, the process-based absorptive capacity perspective (Lane *et al.*, 2006) was adopted, as followed by Cheng and Lu (2017) in their study of disruption management. This view understands absorptive capacity as a sequential set of three processes, which are: (1) recognizing and understanding potentially valuable new knowledge outside the firm through exploratory learning, (2) assimilating valuable new

knowledge through transformative learning, and (3) using assimilated knowledge to create new knowledge and commercial outputs through exploitative learning." (Lane *et al.*, 2006, p. 856).

Accordingly to Bherg and Lim (2008), memory and absorptive capacity can be exploited to deal efficiently with restructuration. Given that a high proportion of disruptions occur from unexpected events (Hora and Klassen, 2013), often the knowledge established in memory about how to deal with these events may be insufficient to take actions that maintain operations at an acceptable level in the event of a disruptive event or to recover quickly and adequately (Craighead *et al.*, 2020), making it necessary to eliminate incompatible procedures, improve them, or develop new ones. Moreover, the positive effects of memory are dependent on its ability to be critically analyzed for the current context (Walsh and Ungson, 1991). In this sense, absorptive capacity would be fundamental, given the processes involved with transformational learning, which affect the combination of new and old knowledge (Lane *et al.*, 2006). Overall, absorptive capacity gives supply chains a change management capability to supply chain memory (Sadeghi *et al.*, 2020; Trichterborn *et al.*, 2016).

Therefore, based on the foregoing, the following research hypotheses are stated:

H1: *Absorptive capacity positively moderates the relationship between chain memory and the resilience of supply chains*

H2: *Absorptive capacity positively moderates the relationship between chain memory and supply chain resilience*

4 Methodology

4.1 Data Collection

The data was collected between July and October 2021 by surveying global supply managers found in two databases. The first database contained 1,239 registered professionals, while the second had 3,967. Therefore, the online questionnaire, prepared in SurveyMonkey, was emailed to 5,206 supply chain management professionals, understanding that they have more refined knowledge about the studied topic (Brusset and Teller, 2017). In all, 216 professionals from Database 1 and 41 from Database 2 responded to the questionnaire, totaling 257 valid responses. Table I presents the sample description:

Table I. Sample description.

Question	Counts	% of total	Question	Counts	% of total
Which job function better describes your activities?			**Mainland**		
Distribution	6	2.33%	Africa	31	12.59%
Inventory Planning/Control	22	8.56%	Asia	42	16.91%
Logistics Planning/Management	28	10.89%	Central America	1	0.36%
Manufacturing/Operations	35	13.62%	Europe	31	12.23%
Marketing/Sales	4	1.56%	Global	16	6.12%
Purchasing/Procurement	29	11.28%	North America	127	48.20%
Supply chain management	103	40.08%	Oceania	4	1.80%
Transportation management	5	1.95%	South America	5	1.80%
Other	25	9.73%	**What is your type of industry? (SIC code)**		
What is your Job title?			Agriculture, Forestry, And Fishing (1-9)	2	0.78%
CEO/President	15	5.84%	Chemicals, Petroleum (28, 29)	40	15.56%
Vice President	13	5.06%	Construction (15, 16, 17)	8	3.11%
Director	37	14.40%	Food, Beverage Tobacco (21, 22)	27	10.51%
Manager	97	37.74%	Furniture and Fixtures (25)	3	1.17%
Analyst	36	14.01%	Health Services (80)	5	1.95%
Supervisor	16	6.23%	Instruments (38)	12	4.67%
Other	43	16.73%	Machinery, electr. Equipment (35, 36)	32	12.45%
Years worked at the organization			Metal (33, 34)	11	4.28%
<2	55	21.40%	Mining (10-14)	4	1.56%
2–5	76	29.57%	Miscellaneous Manufacturing Industries (39)	35	13.62%
6–10	33	12.84%	Paper, printing, publishing (26, 27)	2	0.78%
>10	93	36.19%	Rubber, plastics (30)	3	1.17%
Number of employees:			Textile, Apparel (22, 23)	6	2.33%
< 100	54	21.01%	Transportation Equipment (37)	18	7.00%
100 - 499	55	21.40%	Transportation, Communications, Electric, Gas, And Sanitary Services (40-49)	22	8.56%
> 499	148	57.59%	Wholesale/Retail (50-59)	14	5.45%
			Other	13	5.06%

To avoid ambiguous or incorrect conclusions, the authors of this study examined the dataset for equivalence between databases 1 and 2. We used the Measurement Invariance of Composite Models (MICOM) procedure (Henseler *et al.*, 2016) to check for configural and compositional invariance, as well as equality of composite means and variances (Hair *et al.*, 2018; Henseler *et al.*, 2016). The same scale and treatment were applied to both groups, ensuring configural invariance. PLS-SEM multigroup analysis (Hair *et al.*, 2018) with permutation technique (Chin and Dibbern, 2010) was conducted to assess compositional invariance, as well as equality of composite means and variances. The results showed full measurement invariance, supporting pooled data analysis (Hair *et al.*, 2018).

4.2 Non-response Bias and common method variance

It was decided to compare the first responders with the last responders to check for the existence of serious non-response bias issues (Armstrong and Overton, 1977). Therefore, a t-test for mean differences was conducted between the first 100 and the last 100 participants for all indicators involved in this study, but no statistically significant mean difference was found. We attempted to minimize method-induced variance by following some procedures suggested by Podsakoff et al. (2003). Respondents were guaranteed anonymity, and simple and specific questions were selected. Each construct was separated by its question, and each question and indicator were randomized for each participant. Furthermore, the respondents, as evidenced in the description of the sample, are mostly supply chain management specialists in their organizations, with the majority having more than ten years of experience, showing adequate knowledge to answer the questionnaire

4.3 Constructs measurement

Whenever possible, we chose to use scales already validated in articles published in journals with a high impact factor. Resilience in supply chains was measured using the Brandon-Jones (2014) indicators. The indicators of Kwak, Seo, and Mason (2018) and Wieland and Wallenburg (2013) were adapted to measure the robustness of supply chains. For absorptive capacity, the scale of Cheng and Lu (2017) and, finally, the Moorman and Minner scale (1997), applied by Hult et al. (2004) in a supply chain management context, was adapted in the present study for supply chain memory.

The scales were assessed for reliability, convergent validity, and discriminant validity in SMART-PLS software (Hair *et al.*, 2016). Table II presents the average variance extracted (AVE), composite reliability, and factor loadings, while Table III presents the Fornell-Lacker analysis for discriminant validity. No problems were identified in the measurement analysis (Fornell and Larcker, 1981; Hair *et al.*, 2017; Hayes and Coutts, 2020).

Table II. Constructs measurement

Construct	Indicator	Description	Loadings	AVE	CC
In case of disruption, to what extent do the statements apply to your supply chain? (consider your organization, your critical suppliers, and your customers): 1 - Strongly disagree to 7 - Strongly agree					
Supply chain resilience	RES1	Material flow would be quickly restored	0.885	0.721	0.928
	RES2	It would not take long to recover normal operations performance	0.768		
	RES3	The supply chain would easily recover to its original state	0.901		
	RES4	Disruptions would be dealt with quickly	0.854		
	RES5	The supply chain could easily move to a new desirable state	0.831		
To what extent do you agree with the statements about your supply chain? (consider your organization, your critical suppliers, and your customers): 1 - Strongly disagree to 7 - Strongly agree					
Supply chain robustness	RO1	Our supply chain can remain effective and sustain even when disruptive events occur (e.g., Natural disasters, labor strikes, fires, industrial accidents, shortages in the supply markets)	0.826	0.704	0.922
	RO2	Our supply chain can avoid or minimize risk occurrence by anticipating and preparing for them	0.786		
	RO3	Our supply chain can absorb a significant level of negative impacts from recurrent risks	0.873		
	RO4	When changes occur, our supply chain grants us sufficient time to consider a reasonable reaction	0.815		
	RO5	Our supply chain performs well over a wide variety of possible scenarios	0.891		
To what extent do you agree with the statements about your supply chain? (consider your organization, your critical suppliers, and your customers): 1 - Strongly disagree to 7 - Strongly agree					
Supply chain absorptive capacity	AB1	We thoroughly maintain relevant knowledge over time	0.910	0.793	0.920
	AB2	We quickly analyze and interpret changing market demands for our technologies	0.887		
	AB3	We continuously improve the existing operational processes	0.874		
To what extent do you agree with the statements about your supply chain? (consider your organization, your critical suppliers, and your customers): 1 - Strongly disagree to 7 - Strongly agree					
Supply chain memory (SCME)	M1	We have a great deal of knowledge about how to handle supply chain disruptions	0.905	0.790	0.938
	M2	We have a great deal of experience about how to handle supply chain disruptions	0.912		
	M3	We have a great deal of familiarity about how to handle supply chain disruptions	0.915		
	M4	We have invested a great deal of research and development about how to handle supply chain disruptions	0.820		

Table III. Latent variables mean, standard deviations (SD), composite reliability (CR), the root of AVE (in bold), and constructs correlations.

	Mean	SD	SC Absorptive Capacity	SC Memory	SC Resilience	SC Robustness
SC Absorptive Capacity	4.72	1.34	**0.890**			
SC Memory	4.32	1.43	0.616	**0.889**		
SC Resilience	4.08	1.33	0.491	0.592	**0.849**	
SC Robustness	4.18	1.26	0.622	0.630	0.609	**0.839**

5 Results

The hypotheses were evaluated using structural equation modeling with a partial least squares estimator. Hair et al. (2009) state that structural equation modeling allows for the efficient estimation of a series of multiple regression equations, all of which can be calculated simultaneously by considering the relationships between the observed variables and their underlying constructs. A bootstrap procedure with 5,000 subsamples was employed to test the significance of the relationships. It is important to note that collinearity among the predictor constructs was assessed using the variance inflation factor (VIF), and no issues were detected as all VIFs were well below five.

The paper's results are presented in Table IV. Model 1 presents the results of the direct relationships, while the full model presents the results of the model with the insertion of the moderating effect. The full model was able to explain 37.96% of supply chain resilience and 49.95% of supply chain robustness.

Table IV. Results.

Hypotheses test	Model 1		Full Model	
	DV		DV	
Constructs	SCRES	SCROB	SCRES	SCROB
Memory	0.466***	0.397***	0.458**	0.381***
Absorptive capacity	0.203*	0.378***	0.221*	0.412***
Interaction term				
Memory * Absorptive capacity	-	-	0.057	0.106*
Rsquare	37.56%	48.53%	37.96%	49.95%
Rsquare-adjusted	37.07%	48.13%	37.23%	49.35%
Rsquare change	-	-	0.40%	1.41%

Notes
*** p<0.001 ** p<0.01 * p<0.05 NS = Not significant

It was observed that both memory (path coefficient 0.466 and p-value<0.05) and absorptive capacity (path coefficient 0.203 and p-value<0.05) positively impact resilience

in supply chains. The same can be said for robustness, with path coefficients of 0.397 ($p<0.05$) and 0.378 ($p<0.05$), respectively. Regarding moderating effects, the results made it possible to confirm Hypothesis 2 but not Hypothesis 1. Thus, absorptive capacity positively moderates the relationship between memory and robustness (moderating effect of 0.106 and p-value<0.05) but does not moderate the relationship between memory and resilience. The moderating effect can be observed in Figure 2.

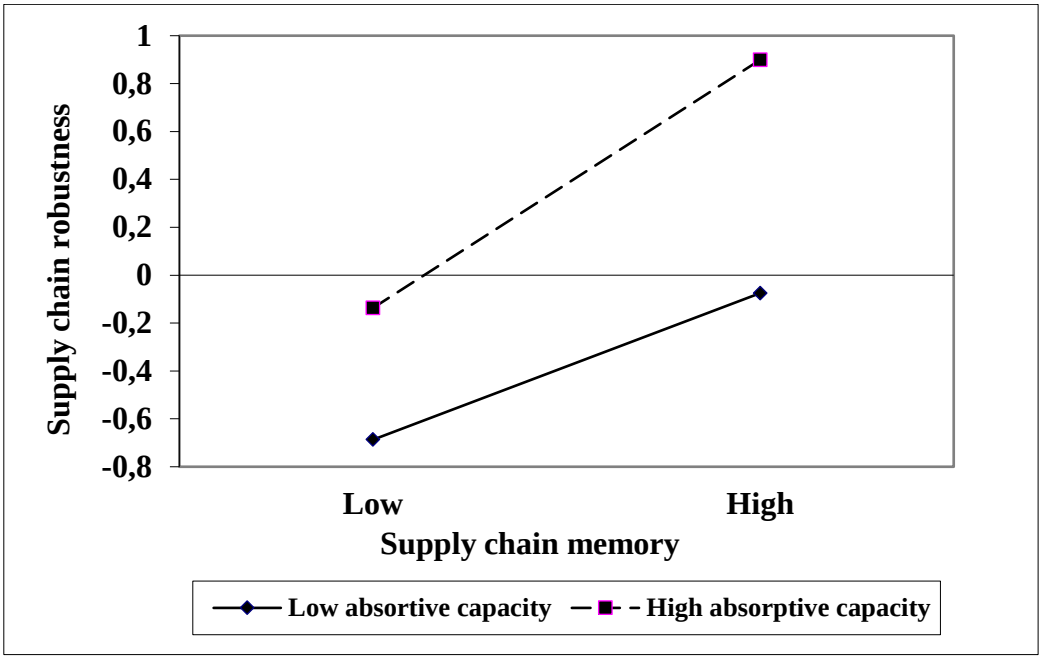

Figure 2: Moderating effect.

6 Contributions to theory and practice

The results of this paper offer theoretical and practical contributions by presenting new insights into the role of knowledge in disruption management. The paper mainly contributes to a better understanding of the impact of memory on the robustness and resilience of supply chains and provides new insights for the literature about the synergy between memory and absorptive capacity. It was found that the ability to acquire, transform and explore new external knowledge amplifies the positive effects of memory in maintaining operations at an acceptable level in case of a disruptive event, corroborating what was theoretically developed. As previously pointed out by Alvarenga, Oliveira, and Oliveira (2023b), memory is less efficient for robustness in case of the occurrence of a non-routine event, such as COVID-19. The results of the present paper make it possible to better understand this result by pointing out that the efficiency of memory for supply chain robustness is impacted by the supply chain absorptive capacity, corroborating with what has been built theoretically.

On the other hand, the moderating effect of absorptive capacity on the relationship between memory and supply chain resilience was not found. This aspect implies that the effect of memory on recovery from disruptions is not amplified by absorptive capacity. This result can be explained by (1) as resilience is defined here as recovering quickly

from disruptions, prior knowledge on how to recover is more relevant for this first moment than absorptive capacity; (2) Although several disruptive events can lead to a disruption (e.g., Natural disasters, labor strike, fire, industrial accidents, shortages on the supply markets), its forms are limited (Carvalho and Machado, 2007), which makes the knowledge established in the memory sufficient for recovery speed. It is worth mentioning that only the experience, familiarity, and knowledge of how to deal with disruptions do not necessarily make the chain prepared to deal with a new disruption. From the perception that the patterns of action rooted in memory are not adequate to the context experienced by the organization, it is necessary to search for a new theory of action (Argyris and Schön, 1978; Levitt and March, 1988), which is made easier by the learning power generated by the absorptive capacity.

The findings also expand the understanding about the combined impact of memory and absorptive capacity on supply chain resilience and robustness and reinforce the individual impacts in a new model. Cheng and Lu (2017), for example, found that the trajectory of inter-organizational relationships, represented by routines, has a greater impact on the ability to maintain operations at an acceptable level in the event of a disruptive event than absorptive capacity, whereas absorptive capacity has a greater impact on the ability to adapt and respond to disruptions than trajectory. The results of Model 1 expand this knowledge by demonstrating that memory, stored as routines (Cohen and Bacdayan, 1994), has a greater impact on the ability to recover from disruptions than absorptive capacity. However, it is the synergy between memory and absorptive capacity that makes chains capable of eliminating incompatible procedures, improving them, or developing new ones, making supply chains more capable of rapidly adapting in the event of disruptive events.

For practice, we demonstrated the importance of keeping memory alive and updated through the ability to acquire and assimilate new knowledge to be able to maintain operations at an acceptable level in case of new non-routine disruptive events. Therefore, the use of new digital technologies facilitates the acquisition, storage, transparency, absorption, and exploitation of knowledge (Büyüközkan and Göçer, 2018; Manupati *et al.*, 2022; Moshood *et al.*, 2021; Oliveira and Handfield, 2019; Teo *et al.*, 2016), being a way out for supply chain managers. Recent studies demonstrate that supply chain digitalization has a positive effect on absorptive capacity (Zhao *et al.*, 2023), as well the use of advanced digital technologies like digital twins and the internet of things have a positive effect on supply chain memory development (Alvarenga *et al.*, 2023b).

7 Conclusions

The article aimed to expand the knowledge about the impact of memory on the resilience and robustness of supply chains by verifying the moderating effect of absorptive capacity in these relationships. Therefore, hypotheses ***H1***: *Absorptive capacity positively moderates the relationship between chain memory and supply chain resilience,* and ***H2:*** *Absorptive capacity positively moderates the relationship between chain memory and*

supply chain robustness, were developed theoretically. It was concluded, through structural equation modeling performed with data collected from supply chain managers around the world, that absorptive capacity moderates the relationship between chain memory and robustness. On the other hand, absorptive capacity does not moderate the relationship between memory and resilience. Furthermore, the assumptions of this study were reinforced, given that the direct impacts of memory and absorptive capacity on resilience and robustness were found in a new model.

This paper contributed to the theories of knowledge management and disruption management in supply chains, as well as to practice, by demonstrating how the alignment between new and old knowledge can be crucial for the survival of supply chains in an increasingly uncertain environment. Therefore, this finding opens up new research possibilities, such as exploring how old knowledge is discarded or combined to generate new knowledge applied to the current context. Furthermore, future studies can investigate how these newly acquired and applied stocks of knowledge during a disruption are transformed into memory to deal with future disruptions or avoid them.

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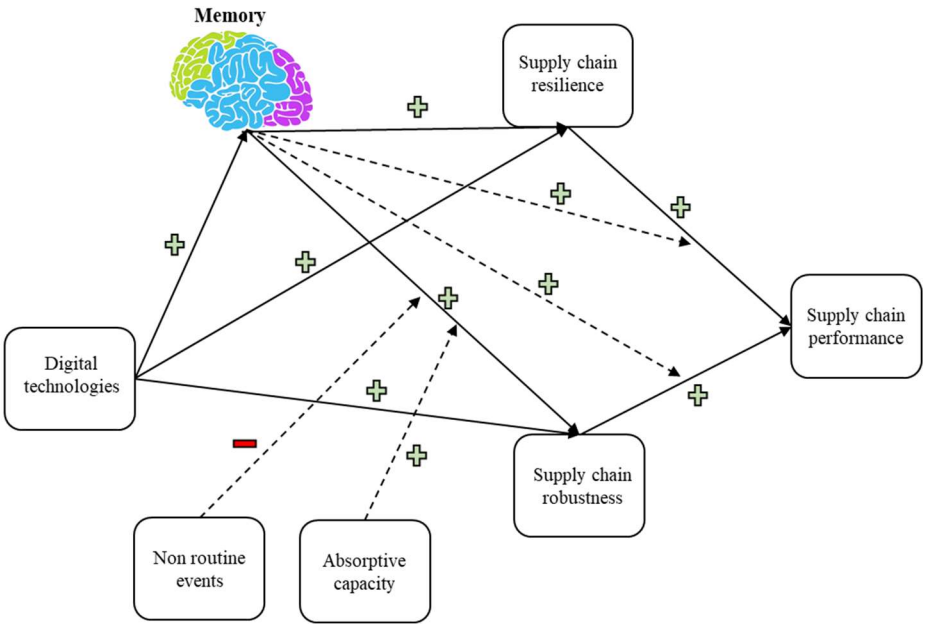
5 THESIS GENERAL CONCLUSION

5 Thesis general conclusion

The thesis argument of this research effort was that memory positively impacts the supply chain resilience and robustness, leverages the effects of resilience and robustness on their outcomes, and serves as a mechanism through which the use of new digital technologies impacts resilience and robustness, though, its effects might be influenced by the type of the disruptions as well the ability to acquire and assimilate new knowledge. To support this argument, three complementary papers and models were developed, collecting and analyzing quantitative and qualitative data from supply managers across multiple countries.

The conclusion is that supply chain memory acts as an antecedent of supply chain resilience and robustness, moderates the impact of resilience and robustness on performance, and is a mediator between the use of digital technologies (Blockchain, Internet of Things, Big Data Analytics, Cloud Computing, and Digital Twins) and resilience and robustness. Additionally, for robustness, its positive effects are impacted by the novelty of the disruption and the ability to acquire, assimilate and apply new knowledge (i.e. absorptive capacity). Figure 1 **establishes conceptually the findings on how supply chain memory can interplay with absorptive capacity, resilience, robustness, and digital technologies to enhance supply chain disruption management and generate better performance**.

Figure I. The interplay between memory, absorptive capacity, resilience, robustness, and digital technologies to enhance supply chain disruption management and improve supply chain performance.



Source: Research results.

Papers and thesis main implications for practice and theory

The thesis contributes to the literature and practice in several ways. By combining established theories to explore relationships previously discussed in the literature, the results demonstrated that previous knowledge of how to deal with disruptions can make supply chains more prepared to take efficient actions to proactively and reactively deal with disruptions. However, in non-routine situations where chains lack prior knowledge about how to handle them, the findings suggest that the capacity for collaboration, visibility, and flexibility is what enhances their robustness during such disruptions. This involves combining new knowledge with existing knowledge. Moreover, actively working towards developing a memory after an interruptive event can further fortify the chains for future disruptive events. Nevertheless, even in non-routine events, memory remains crucial for resilience, with older knowledge being more pertinent than new knowledge for achieving faster recovery (Alvarenga et al., 2023b, 2023a).

Paper 1 identified memory as an antecedent of both resilience and robustness and highlighted supply chain memory as a condition in which supply chain resilience and robustness are highly efficient for supply chain performance. This implies the need to develop a memory of how to deal with disruptions to enable a balance between capabilities and vulnerabilities, ultimately achieving performance outcomes. The results were critical for understanding the impact of robustness on supply chain performance, demonstrating that taking actions to maintain operations at an acceptable level without prior knowledge of how to handle the disruption only ensures survival, rather than an increase in performance compared to competitors (Alvarenga et al., 2023b).

Moreover, we demonstrated that keeping the memory alive and updated, to avoid process inflexibility when dealing with disruptive events, is necessary. In this sense, in addition to having written procedures, we recommend supply chain managers to work on keeping this memory alive by conducting training/simulations, as well as periodic reviews of these procedures. Discussing past negative experiences with members within the chain, even if they are painful, has also emerged as a way to keep successful formulas alive and avoid repeating the formulas of failure.

The study also contributed to understanding how to develop a memory regarding disruptions. Results demonstrated that supply chains can leverage digital technologies to construct, retain, and access real-time knowledge regarding disruptive events and how to

manage them, without having to rely solely on experiential disruptions for learning (Alvarenga et al., 2023a). Therefore, it is suggested that supply chain managers adopt and utilize digital technologies, as mentioned earlier, for disruption management. Furthermore, the research results demonstrated that developing collaborative, visible, and analytical chains becomes essential for the memory to be developed, shared among chain members, and accessible for decision-making (Alvarenga et al., 2023b).

The negative effects that memory might have on supply chain disruption management were also explored. (Paper 2) revealed that contingent factors like COVID-19 could influence the effectiveness of knowledge created, stored, and retrieved using digital technologies in building more resilient and robust supply chains. In the context of COVID-19, memory has proven to be relevant for recovering from its effects but less effective for the robustness of supply chains. Therefore, it becomes necessary to combine both old and new knowledge to maintain operations at acceptable levels in the face of non-routine disruptive events, such as the COVID-19 pandemic, as pointed out in Paper 3. Therefore, the development of absorptive capacity becomes essential to thrive in this highly uncertain operational context and to leverage the memory of past experiences.

The limitations of this thesis align with the limitations of the papers comprising it. Therefore, it was not possible to explore whether the model results discussed here behave similarly or not according to industry types or countries. Additionally, the data was collected only from a single tier of the supply chain, while it would be more appropriate to gather data from multiple members within the same supply chain.

The results of this research and its limitations present opportunities for further studies.

- Considering the importance of memory for supply chain disruption management, quantitative research is needed to understand factors beyond the use of digital technologies that can impact it.
- Although briefly addressed in Paper 1, more precise studies are required to comprehend how to keep the memory of non-routine events alive, as disruptions often stem from such events, and memory is commonly embedded in routines.
- The reasons why supply chain memory remains relevant for supply chain resilience, but not for supply chain robustness could also be better explored.

- Studies could explore how memory impacts the viability of the chain, as well as the effects of memory on collaboration, visibility, and flexibility within supply chains and vice versa.
- Lastly, studies could delve deeper into how the alignment between capabilities and vulnerabilities, based on knowledge of handling risk events, leads to financial performance gains.

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Appendix A. Interview Script

Interview script (semi-structured)

This interview is part of a project that aims to understand the role of experience, familiarity, and knowledge about how to deal with disruptions for supply chain disruption management. We seek to test supply chain memory as a construct that affects previously established relationships in the supply chain resilience and robustness literature.

The first result of this project is: The impact of using digital technologies on supply chain resilience and robustness: the role of memory under the covid-19 outbreak | Emerald Insight

IJPE Paper results: The main results from quantitative analysis demonstrated that the experience, knowledge, and familiarity to deal with disruption (i.e. memory) impact the supply chain's ability to maintain operations at an acceptable level when a disruptive event occurs (i.e. robustness) or to recover (i.e. resilience) when necessary. More importantly, we found out that the effect of resilience on performance is improved by memory, and the robustness impact is conditioned on memory levels.

Respondent description:

Nationality:

Job title:

Years in the company:

Industry type:

The main location of company operations:

Questions related to the research problems (COVID-19):

What were the main impacts of COVID-19 on your supply chain?

Has your supply chain needed to recover, or managed to maintain operations at an acceptable level during the period of COVID-19?

During COVID-19, did prior knowledge about dealing with disruptions helped to deal with this event, or had to be discarded? Please exemplify

During COVID-19, was some new knowledge acquired, assimilated, and applied by your supply chain members to deal with this event? Please exemplify

What was learned from this event that can be used in a new disruption?

How can this knowledge be accessed in the future by your supply chain members?

Questions related to the research problems (learning and remembering from disruptions):

What are the means used for your chain to learn about and from risk events? (learn from the mistakes of others, from your own mistakes, digital technologies, and others).

Where this knowledge is stored and how it is shared between supply chain members? Could you exemplify?

Could you exemplify a disruption in which prior knowledge or experience on how to deal with a similar event influenced your chain to adequately and quickly recover its performance? What actions were taken?

Could you exemplify a disruptive event in which prior knowledge or experience on how to deal with a similar event influenced your chain to maintain its operations at an acceptable level? What actions were taken?

Could you describe the actions taken to recover the operations from a disruptive event that your chain had little or no prior knowledge/experience about how to deal with?

Could you describe the actions taken to maintain the supply chain operations at an acceptable during a disruptive event that your chain had little or no prior knowledge/experience about how to deal with?

Additional information:

Examples of disruptive events: Natural disasters, labor strikes, fire, industrial accidents, shortages on the supply markets

Appendix B. Research questionnaire

PPG ADM Programa de Pós-graduação em Administração UFES Mestrado e Doutorado

THESIS RESEARCH - MURILO ZAMBONI ALVARENGA

Hi there,

I invite you to voluntarily participate in my thesis research of the Doctorate in Administration at the Federal University of Espírito Santo-Brazil, whose objective is to contribute to the competitiveness of organizations based on the concepts of supply chain resilience. This study aims to better understand how prior knowledge about how to deal with disruptions can assist in future disruptions and promote superior performance.

Your participation is extremely important for the conclusion of the research. The questionnaire consists of objective questions and have an estimated response time of 12 minutes. The data will be collected worldwide and will be used only for academic purposes. Respondents' identities will not be disclosed. At the end of the questionnaire, you can provide your email if you wish to receive the survey results.

Thank you in advance,

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In the case of a multinational, answer the questions below based on the base of operations you spent most of your time in the last year.

* 1. **What is your Job title?** 0

- ◯ CEO/President
- ◯ Vice President
- ◯ Director
- ◯ Other (please specify)
- ◯ Manager
- ◯ Analyst
- ◯ Supervisor

* 2. **Which job function better describe your activities?** 0

- ◯ Distribution
- ◯ Manufacturing/Operations
- ◯ Supply chain management
- ◯ Inventory Planning/Control
- ◯ Marketing/Sales
- ◯ Transportation management
- ◯ Logistics Planning/Management
- ◯ Purchasing/Procurement
- ◯ Other (please specify)

* 3. **Years worked at the organization:** 0

- ◯ <2 years
- ◯ 2–5 years
- ◯ 6–10 years
- ◯ >10 years

* 4. **What is your type of industry?** 0

* 5. **Number of employees in your company:** 0

* 6. **In which country is your company located?** 0

* 7.
In case of disruption, to what extent do the statements apply to your supply chain? (considers your organization, your critical suppliers and customers):
0

	1. Strongly desagree	2	3	4	5	6	7. Strongly agree
Material flow would be quickly restored	◯	◯	◯	◯	◯	◯	◯
It would not take long to recover normal operations performance	◯	◯	◯	◯	◯	◯	◯
The supply chain would easily recover to its original state	◯	◯	◯	◯	◯	◯	◯
Disruptions would be dealt with quickly	◯	◯	◯	◯	◯	◯	◯
The supply chain could easily move to a new desirable state	◯	◯	◯	◯	◯	◯	◯

* 8. **To what extent do you agree with the statements about your supply chain?** (considers your organization, your critical suppliers and customers): 0

	1. Strongly desagree	2	3	4	5	6	7. Strongly agree
We have a great deal of knowledge about how to handle with supply chain disruptions	○	○	○	○	○	○	○
We have a great deal of experience about how to handle with supply chain disruptions	○	○	○	○	○	○	○
We have a great deal of familiarity about how to handle with supply chain disruptions	○	○	○	○	○	○	○
We have invested a great deal of research and development about how to handle with supply chain disruptions	○	○	○	○	○	○	○

* 9. **To what extent do you agree with the statements about your supply chain?** (considers your organization, your critical suppliers and customers): 0

	1. Strongly desagree	2	3	4	5	6	7. Strongly agree
We use available supply chain members data to derive business insights from it	○	○	○	○	○	○	○
We make sense of data	○	○	○	○	○	○	○
Decisions are driven by facts and data and not just by instinct	○	○	○	○	○	○	○
We use statistical analysis to 'describe' supply chain scenarios and problems	○	○	○	○	○	○	○
We use statistical analysis to 'forecast' supply chain scenarios and 'anticipate' problems	○	○	○	○	○	○	○
We use statistical analysis to 'drive' actions	○	○	○	○	○	○	○

We exploit (make productive use) the supply chain's members stored data	○	○	○	○	○	○	○
We ensure to protect the quality of stored data	○	○	○	○	○	○	○
Business data is available from a single data access point (user does not have to assemble fragmented data from different sources)	○	○	○	○	○	○	○

* 10.

Please evaluate in the scale below your supply chain performance indicators compared to your major competitors supply chain's:

0

	1. Much worse	2	3	4	5	6	7. Much better
Order fill capacity: Provision of desired quantities on a consistent basis	○	○	○	○	○	○	○
Delivery dependability: Meeting quoted or anticipated delivery dates and quantities on a consistent basis	○	○	○	○	○	○	○
Customer satisfaction: Meeting customer satisfaction with supply chain performance on a consistent basis	○	○	○	○	○	○	○
Delivery speed: Time between order receipt and customer delivery	○	○	○	○	○	○	○

* 11.

How did COVID-19 negatively affect your:

0

	1. No affect	2	3	4	5	6	7. Major affect
Overall efficiency of operations	○	○	○	○	○	○	○
Lead time for delivery (delivery reliability)	○	○	○	○	○	○	○
Purchasing costs for supply	○	○	○	○	○	○	○

* 12.
Please evaluate in the scale below in terms of financial performance how your firm compares to your major competitors over the last three years:
0

	1. Much worse	2	3	4	5	6	7. Much better
Growth in sales	○	○	○	○	○	○	○
Growth in return on sales	○	○	○	○	○	○	○
Growth in profit	○	○	○	○	○	○	○
Growth in market share	○	○	○	○	○	○	○

* 13.
To what extent do you and your supply chain partners use these tools to learn about or from supply chain risks?
0

	1. Not at all	2	3	4	5	6	7. Always
Internet of Things	○	○	○	○	○	○	○
Cloud Computing	○	○	○	○	○	○	○
Big data analytics	○	○	○	○	○	○	○
Digital twins	○	○	○	○	○	○	○
Blockchain technology	○	○	○	○	○	○	○

* 14. **To what extent do you agree with the statements about your supply chain?** (considers your organization, your critical suppliers and customers): 0

	1. Strongly desagree	2	3	4	5	6	7. Strongly agree
Our supply chain can remain effective and sustain even when disruptive events occur (e.g., Natural disasters, labor strike, fire, industrial accidents, shortages on the supply markets)	○	○	○	○	○	○	○
Our supply chain can avoid or minimize risk occurrence by anticipating and preparing for them	○	○	○	○	○	○	○
Our supply chain can absorb a significant level of negative impacts from recurrent risks	○	○	○	○	○	○	○
When changes occur, our supply chain grants us sufficient time to consider a reasonable reaction	○	○	○	○	○	○	○
Our supply chain performs well over a wide variety of possible scenarios	○	○	○	○	○	○	○

* 15. **To what extent do you agree with the statements about your supply chain?** (considers your organization, your critical suppliers and customers): 0

	1. Strongly desagree	2	3	4	5	6	7. Strongly agree
We can successfully reconfigure supply chain resources to come up with new productive assets	○	○	○	○	○	○	○
We can effectively integrate and combine existing resources into novel combinations in this supply chain	○	○	○	○	○	○	○
We are able to engage in resource recombinations to better match the product-market areas in this supply chain	○	○	○	○	○	○	○

* 16. **To what extent do you agree with the statements about your supply chain?** (considers your organization, your critical suppliers and customers): 0

	1. Strongly desagree	2	3	4	5	6	7. Strongly agree
We throroughly maintain relevant knowledge over time	○	○	○	○	○	○	○
We quickly analyze and interpret changing market demands for our technologies	○	○	○	○	○	○	○
We continuously improve the existing operational processes	○	○	○	○	○	○	○

* 17.
Please indicate the degree to which you disagree or agree with the following statements relating to your supply chain dynamism:
0

	1. Strongly desagree	2	3	4	5	6	7. Strongly agree
Operating processes become outdated at a high rate	○	○	○	○	○	○	○
Customers' requirements change at a high rate	○	○	○	○	○	○	○

Unexpected and disruptive events (i.e. shocks, outbreaks, disruptive technologies) occur at a high rate	○	○	○	○	○	○	○
Competitors' capabilities change at a high rate	○	○	○	○	○	○	○

* 18.

Would you participate in an interview to complement the results of this quesitonnaire? The interview will seek to better explore how memory about how to deal with interruptions is built and used.

0

○ Yes

○ No

19.

If you answered yes to the last question , please enter your e-mail below:

0

20.

If you wish to receive the results of this survey, please enter your e-mail below:

0