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The impact of using digital technologies on supply chain resilience and robustness: The role of supply chain memory

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Resumo
Supply chains have now better tools to deal with disruptions. Despite the impact of some digital technologies on supply chain disruption management has already been shown in other papers, the mechanisms that work to this impact occurs are not so clear. This paper's main aim was to check the mediating effect of supply chain memory in the relationship between using digital technologies and supply chain resilience and robustness. Additionally, the impact of COVID-19 disruption was tested as a moderator of the impact of supply chain memory on supply chain resilience and robustness. Altogether, 257 supply chain managers or related areas answered the questionnaire and data were analyzed through structural equation modeling. This paper contributes to theory and practice by showing that experience, familiarity, and knowledge partially mediates the relationship between digital technologies, resilience and robustness. Moreover, results show that memory is less efficient for the supply chain to maintain an acceptable level of performance in case of an extremely new disruptive event like COVID-19. The full model was able to explain 35.18% of supply chain memory, 41.77% of supply chain resilience and 45.88% of supply chain robustness.

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Abstract

Supply chains have now better tools to deal with disruptions. Despite the impact of some digital technologies on supply chain disruption management has already been shown in other papers, the mechanisms that work to this impact occurs are not so clear. This paper's main aim was to check the mediating effect of supply chain memory in the relationship between using digital technologies and supply chain resilience and robustness. Additionally, the impact of COVID-19 disruption was tested as a moderator of the impact of supply chain memory on supply chain resilience and robustness. Altogether, 257 supply chain managers or related areas answered the questionnaire and data were analyzed through structural equation modeling. This paper contributes to theory and practice by showing that experience, familiarity, and knowledge partially mediates the relationship between digital technologies, resilience and robustness. Moreover, results show that memory is less efficient for the supply chain to maintain an acceptable level of performance in case of an extremely new disruptive event like COVID-19. The full model was able to explain 35.18% of supply chain memory, 41.77% of supply chain resilience and 45.88% of supply chain robustness.

Keywords: Supply chain; Resilience; Robustness; Memory; COVID-19.

Introduction

Today's supply chains are susceptible to myriad risks and uncertainties that can disrupt their operations (Ben-Daya, Hassini, & Bahroun, 2019). The most recent examples of how these events can negatively affect supply chains performance are the COVID-19 pandemic, which has affected and still affects countless supply chain's around the world (El Baz & Ruel, 2021; Hudecheck, Sirén, Grichnik, & Wincent, 2020), and the war between Russia and Ukraine (Bousquin, 2022). In this scenario, it is important to understand factors that cause some organizations to thrive when faced with disruptive events, while others collapse (Soni, Jain, & Kumar, 2014). Therefore, both managers and academics are looking for better ways to improve supply chain resilience and robustness (Brusset & Teller, 2017; Pettit, Croxton, & Fiksel, 2019).

It is also a fact that managers have better tools to make decisions based on facts and data nowadays (Acito & Khatri, 2014; Büyüközkan & Göçer, 2018; Srinivasan & Swink, 2018). We are experiencing the fourth industrial revolution, named Industry 4.0, which involves the integration of technologies that enable the interconnection between the real and virtual world, favoring obtaining and analyzing data in real-time and providing useful information to the production system, making it more adaptive (Dalenogare, Benitez, Ayala, & Frank, 2018; Li, Dai, & Cui, 2020; Weyer, Schmitt, Ohmer, & Gorecky, 2015). The Internet of Things (Ben-Daya et al., 2019; Birkel & Hartmann, 2020), Digital Twins (Ivanov, Dolgui, Das, & Sokolov, 2019; Moshood, Nawanir, Sorooshian, & Okfalisa, 2021), Blockchain (Fosso Wamba, Queiroz, & Trinchera, 2020; Manupati et al., 2022; Min, 2019), Big Data Analytics (R Dubey et al., 2021; Singh & Singh, 2019; Souza, 2014), and Cloud Computing (Frank, Dalenogare, & Ayala, 2019; Li et al., 2020) are examples of tools that supply chain managers can use to learn about and with disruptive events.

Some papers showed how the general adoption of these technologies impacts performance (Li et al., 2020; Tortorella, Cawley Vergara, Garza-Reyes, & Sawhney, 2020) or the impact of specific digital technologies on supply chain disruption management capabilities (Alvarenga, Oliveira, Zanquetto-Filho, Desouza, & Ceryno, 2022; R Dubey et al., 2021; Singh & Singh, 2019). However, despite previous direct effects (Zouari, Ruel, & Viale, 2020), little is known about the mechanisms that act in the relationship between the use of digital technologies, resilience, and robustness. Also, Xu, Zhang, Feng and Yang (2020) postulate the need for more research about the role of analytics in the supply chain disruption field.

We argue that digital technologies help supply chains to have a great deal of experience, knowledge, and familiarity about how to deal with disruptions, namely - supply chain memory (Hult, Ketchen, & Slater, 2004), and, so on, turn them more resilient and robust. Based on the preceding, this paper's main aim is to expand the knowledge about the impact of digital technologies on supply chain resilience and supply chain robustness, pointing out supply chain memory as a mediator. Additionally, we questioned if when some extremely new disruptive events like a COVID-19 outbreak occurs, previous knowledge to deal with disruption is still important to continue the operations in an effective way (i.e. robustness) or to recover faster from it (i.e. resilience).

The paper has four main contributions to theory and practice. (1) It helps to understand how to develop supply chain memory, positioning digital technologies as an antecedent of it. (2) The impact of supply chain memory on supply chain resilience and robustness is proved. (3) It demonstrates that most of the digital technologies' impact on resilience and robustness occurs mainly through supply chain memory. (4) Supply chain disruption memory is less efficient to the chain remains effective when a new disruptive event occurs, but remains important to recover from it.

Briefly definition of the constructs

Supply chain resilience

It is already known that the supply chain resilience concept is divergent in literature (Abeysekara, Wang, & Kuruppuarachchi, 2019; Pires Ribeiro & Barbosa-Povoa, 2018). Definitions range from those who consider only recovery as a resilience dimension (Brandon-Jones, Squire, Autry, & Petersen, 2014; Jüttner, Peck, & Christopher, 2003; Sheffi & Rice Jr., 2005) to those who consider either response and recovery (Jüttner & Maklan, 2011) or prevention, response and recovery (Ponomarov & Holcomb, 2009). New perspectives about supply chain resilience can be sawn in Wieland (2021) and Ivanov and Dolgui (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 & Peck, 2004; Wong, Lirn, Yang, & Shang, 2020), therefore, indicators used by Brandon-Jones et al. (2014) were adopted. Indicator RES5 (Table I) is new in the scale and was used since it is aligned with the supply chain resilience definition.

Supply chain robustness

Like supply chain resilience, the supply chain robustness concept is unclear (Brandon-Jones et al., 2014). We define supply chain robustness as the chain's ability to remain effective in case of disruptive events occurrence (Brandon-Jones et al., 2014; Klibi, Martel, & Guitouni, 2010; Kwak, Seo, & Mason, 2018; Stonebraker, Goldhar, & Nassos, 2009). It is evident that not being disrupted is better than being disrupted and having to recover. However, not all disruptions can be avoided (Jüttner & Maklan, 2011). Indicators used in Kwak, Seo, and Mason (2018) and Wieland and Wallenburg (2013) were adopted to measure supply chain robustness and are related to maintaining supply chain operations at an acceptable level even when disruptive events arise.

Supply chain memory

There are at least four main memory perspectives in literature: functional, interpretative, critical, and performative (Foroughi, Coraiola, Rintamäki, Mena, & Foster, 2020). Our study is based on a functional view of organizational memory, which has its foundation in Walsh and Ungson's (1991) work. Therefore, memory is the current knowledge that the organization/chain members have based on previous decisions, and that can be used in the present and future (Anand, Manz, & Glick, 1998; Hult et al., 2004; Walsh & Ungson, 1991). Supply chain memory is defined here as achieved memory (Hult, Ketchen, Cavusgil, & Calantone, 2006; Hult et al., 2004) to deal with disruptions, that is, the amount of experience, familiarity, and knowledge articulated by supply chain members (Hult et al., 2006; Moorman & Miner, 1997) to deal with these undesired events.

Moorman and Minner (1997) scale, used in the supply chain context by Hult, Ketchen, Cavusgil, and Calantone (2006) was used. We measured the experience, familiarity, and knowledge articulated by supply chain members to deal with disruptions. Their scale was already used at least by Hult et al. (2004), Hanvanich, Sivakumar and Hult (2006), Hult et al. (2006) and, Lee, Kim and Joshi (2017) to measure memory construct.

Digital technologies

This paper addresses the following digital technologies: Internet of Things, Cloud Computing, Big Data Analytics, Digital Twins, and Blockchain. Cloud computing, the Internet of Things, and Big Data Analytics are considered Industry 4.0 base technologies (Ben-Daya et al., 2019; Frank et al., 2019; Tortorella et al., 2020), while Digital Twins and Blockchain are new technologies that favor the obtaining of real-time information by supply chains members and the connection between the virtual and the real world (Ivanov, Dolgui, & Hristova, 2020; Min, 2019). Definitions are presented in Table I.

Indicators applied by Frank et al. (2019) were used, including in the questionnaire the Digital Twins, the Blockchain technology, and unifying Big Data and Analytics in a single indicator. Since those technologies are integrated and interconnected, so the use of one is dependent on the other, implying higher levels of correlation (Li et al., 2020), as, like Li et al. (2020), it was measured reflectively.

Table I. Digital technologies definitions.

Technology	Definition
Internet of things	"*The Internet of Things is a network of physical objects that are digitally connected to sense, monitor and interact within a company and between the company and its supply chain enabling agility, visibility, tracking and information sharing to facilitate timely planning, control and coordination of the supply chain processes.*" (Ben-Daya et al., 2019, p. 4721)
Cloud Computing	"*Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction*." (Mell & Grance, 2011, p. 2)
Big Data Analytics	Use of advanced statistics for exploitation of structured and unstructured data collected internally and externally the organization to improve decision making (Kache & Seuring, 2017). Simplifying, *"big data analytics is where advanced analytic techniques operates on big data"* (Russom, 2011, p. 8)
Digital Twins	*"A Digital Twin is a virtual representation (or model) of a physical object or process that is continuously updated with real-time data to reflect the physical object or process's current state and behavior. The Digital Twins can help visualize and analyze the physical object or process, and by use of machine learning, further optimizations and predictions can be made."* (Moshood et al., 2021, p. 12)
Blockchain	*"A blockchain is a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks (a storage unit of transaction), holding timestamped transactions that are secured by public-key cryptography (i.e., "hash") and verified by the network community. Once an element is appended to the blockchain, it cannot be altered, turning a blockchain into an immutable record of past activity."* (Seebacher & Schüritz, 2017, p. 15)

Source: The author's

Covid-19 disruption impact

Supply chain COVID-19 disruption is a special kind of disruption that still affects many supply chains around the world, especially because of its characteristic of long term, high uncertainty, and ripple effect propagation (Ivanov, 2021; Ruel & El Baz, 2021). The toilet paper shortage, with a shift of demand from commercial to domestic (Moore, 2020) or the impact of the pandemic on the global aviation sector, with operations not fully recovered until today (Haydon, Kumar, & Brooks, 2020), are only a few examples of how the pandemic affected people lives, organizations and their supply chains. The disruption impact construct focused on the degree of impact suffered by the chains of the organizations studied during COVID-19 until the questionnaire was applied, thus, the indicators used by El Baz and Ruel (2021) were adopted.

Theoretical construction of the hypotheses

The impact of using digital technologies on supply chain resilience and robustness

Digital technologies use is associated with the development of resilience and robustness capabilities discussed in the literature as essential for supply chains to prevent, adapt and recover from interruptions. Their use improves the collection, processing, and sharing of information, providing supply chains with greater, visibility, transparency, and real-time information (Oliveira & Handfield, 2019; Zhu, Song, Hazen, Lee, & Cegielski, 2018). Blockchain technology, for example, enables greater traceability, as well as collecting and sharing information in the same network, increasing operational transparency and trust between members of the chains, which leads to greater pre and post disruption response (Rameshwar Dubey, Gunasekaran, Bryde, Dwivedi, &

Papadopoulos, 2020; Manupati et al., 2022). Min (2019) presents several examples of the effects of applying this technology for resilience and robustness, such as the lower risk of loss or damage to shipments, as well as the lower risk of error in order fulfillment.

Cloud Computing and the Internet of Things also favor supply chains members to collect, transfer store and, share a huge amount of data, making them more collaborative, visible, and flexible (Al-Talib et al., 2020; Ben-Daya et al., 2019; Birkel & Hartmann, 2020; Gnimpieba, Nait-Sidi-Moh, Durand, & Fortin, 2015). The internet of things impact on supply chain risk management steps is shown by Birkel and Hartmann (2020), and improves, for example, the identification of low-frequency high-impact risks and a better proactive and reactive time to deal with risks. Also, resilience capabilities are improved by the data quality, faster reconfiguration capacity, and, reduced unexpected outcomes that their use provides (Al-Talib et al., 2020).

Chains can also achieve these values by the use of Big Data Analytics. Souza (2014) presents prescriptive, descriptive, and predictive analytical techniques for each dimension of the Supply Chain Operations Reference Model. Also, analytics has a proven impact on supply chain performance as well as on its member's performance (Chae, Olson, & Sheu, 2014; Trkman, McCormack, Oliveira, & Ladeira, 2010). An analytical approach has an essential role in supply chain disruption management since it helps to identify, assess, mitigate and monitor risks, enabling a better preventive capability (Frank et al., 2019; Ittmann, 2015; Tummala & Schoenherr, 2011). Also, the impact of Big Data Analytics on supply chain resilience has been shown in Alvarenga, Oliveira, Zanquetto-Filho, Desouza and Ceryno (2022), Dennehy et al. (2021), Dubey et al. (2021) and Singh and Singh (2019). Furthermore, Big Data Analytics is essential for the processing of data collected and stored by other digital technologies, like Cloud Computing and the Internet of Things (Frank et al., 2019).

H1: *The use of digital technologies positively impacts supply chain resilience*

H2: *The use of digital technologies positively impacts supply chain robustness*

The impact of using digital technologies on supply chain memory

The analytical approach improves the knowledge established in the memory about the disruptions and how to manage them, allowing the application of appropriate actions to avoid or recover from interruptions. The role of Information Technologies for memory was mentioned, for example, by Cross and Baird (2000), Day (1994), Huber (1991), Oliveira (2000), Nikalanta, Miller and Zhu (2006) and Stein and Zwass (1995). Since the mentioned technologies enable the interconnection between the real and virtual world (Frank et al., 2019; Li et al., 2020), the creation, processing, storing, sharing and, retrieval and, application of knowledge are improved by them (Barbosa & Vicente, 2018; Côrte-Real, Oliveira, & Ruivo, 2016; Oliveira & Handfield, 2019). Recently, Tortorella et al. (2020) found that industry 4.0 technologies positively influence learning capabilities at all levels (individual, team, organizational). In addition to promoting proactive learning (Ivanov et al., 2019), Singh e Singh (2019) argue that the analytical approach makes it possible to effectively take advantage of the lessons instituted in the memory of a previous interruption.

H3: *The use of digital technologies positively impacts supply chain disruption memory*

The impact of supply chain memory on supply chain resilience and robustness

Memory is used to learn and retain knowledge from past events to deal properly with future problems (Huang, 2013). The repetition of the same mistakes and the rediscovery of successful formulas for the same problems are characteristics of organizations that cannot remember what went wrong or right in their history (Day, 1994). Previous studies have shown, for example, that memory is a critical factor for value creation (Martelo-Landroguez & Cepeda-Carrión, 2016), to build sustainable competitive advantage (Ebbers & Wijnberg, 2009; Moorman & Miner, 1998), to provide supply chains members engagement in knowledge acquisition activities (Hult et al., 2004), for organizational agility (Cegarra-Navarro & Martelo-Landroguez, 2020) and organizational performance (Kmieciak, 2019).

As evidenced by Scholten, Scott, and Fynes (2019), the lack of a supply chain collective memory can cause it to suffer from the same disruption as in a previous moment. An example presented by Anand, Manz, and Glick (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 proved to be susceptible to insect attack, which destroyed tons of paper. However, 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). Since the chain's know-how is established in memory (Verma & Tiwari, 2009), it is crucial for the recovery of action patterns for the solution or elimination of risks (Singh & Singh, 2019).

In this sense, obtaining, storing, and retrieving information about decision-making regarding disruption prevention, response and recovery appears to be a critical aspect of supply chain resilience and robustness (Labib, Hadleigh-Dunn, Mahfouz, & Gentile, 2019; Ponomarov & Holcomb, 2009; Scholten et al., 2019). The disruptive impact of a risk event in the supply chain demonstrates that the chain's capabilities were not adequate to the environment in which it was inserted, affecting the delivery of value to the final customer (Madsen & Desai, 2010; Pettit et al., 2019). During and after this event, retaining "what," "who," "where," "when," and "how" this event occurred (Walsh & Ungson, 1991), as well as identifying and understanding the actions that were taken to recover the flow of operations has a critical role for recovery from a new outage, as well as to avoid it (Scholten et al., 2019; Verma & Tiwari, 2009). That being said:

H4: *Supply chain memory positively impacts supply chain resilience*

H5: *Supply chain memory positively impacts supply chain robustness*

Since disruptions often stem from low-frequency high-impact events, the high costs of learning by doing are undesirable, as its low-occurrence characteristic limits experiential learning (Hora & Klassen, 2013). Therefore, these tools make it possible to acquire experience, familiarity, and knowledge about possible interruptions without having to face them beforehand. Digital twins, for example, enable chains to perform experiments in the virtual world to take actions in the real world (Griswold, Aronow, Ennis, & Romano, 2019; Ivanov et al., 2019). Thus, chain members can perform simulations about the impact of possible interruptions, or real interruptions, to find satisfactory solutions to minimize their effects and recover properly (Ivanov et al., 2019). Also, they make it possible to identify hidden vulnerabilities, favoring risk prevention (Continuitycentral, 2018). Overall, its use provides analytical, predictive, descriptive, and diagnostic value for supply chains (Moshood et al., 2021). Finally, memory is only useful if it is available (Anand et al., 1998). Recent studies show that an analytical approach impacts supply chain transparency, promoting real-time, timely and trustful information two their members (Birkel & Hartmann, 2020; Min, 2019; Oliveira & Handfield, 2019; Zhu et al., 2018). Therefore, disruption knowledge is improved, and proper actions to deal with them can be taken (Birkel & Hartmann, 2020).

H6: *Supply chain memory mediates the relationship between digital technologies and supply chain resilience*

H7: *Supply chain memory mediates the relationship between digital technologies and supply chain robustness*

The moderating effect of COVID-19 disruption

Despite all the memory benefits discussed before, researchers have also postulated some negative roles of its use (Chang & Cho, 2008; Lee et al., 2017). The misuse of memory can lead the organization or chain to unsatisfactory results achieved memory is not critically analyzed for reuse in the current context (Walsh & Ungson, 1991). Memory is also associated with rigidity (Newey & Zahra, 2009), therefore, when patterns are well established in a certain domain, changes become more difficult, and flexibility decreases (Chang & Cho, 2008; Dougherty, 1992). Also, too much memory about how to do things (procedural memory), leads to difficulty in interpreting market changes, so actions may be delayed (Kyriakopoulos & Ruyter, 2004). That being said, memory may be less efficient to deal with extremely new disruptions like COVID-19, where operations need to achieve a new normal and chains had little knowledge, experience and familiarity in dealing with this kind of disruption.

H8: *Covid-19 disruption impact negatively moderates the relationship between supply chain memory and supply chain resilience*

H9: *Covid-19 disruption impact negatively moderates the relationship between supply chain memory and supply chain robustness*

Methodology

Data collection and sample description

Data were collected from July to October 2021 using an online three-block questionnaire applied to supply chain management professionals around the globe. The final questionnaire version was developed in SurveyMonkey, and the access link was sent by email for the supply chain managers registered in two bases. Altogether, 5,206 professionals were invited to participate in the survey, 3,967 from base 1 and 1,239 from base 2. 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 315 complete responses, a response rate of 6.05%, 257 of which were considered valid for this study. Besides being low, this response rate is compatible with similar studies in the disruption management field (Brusset & Teller, 2017; Jin, Vonderembse, Ragu-Nathan, & Smith, 2014; Li et al., 2020). Of these responses, 216 are from base 1 and 41 from base 2. A t-test of mean difference was performed between construct scores to verify differences between the groups, and no problem was found. It is noteworthy that most of the answers were removed because they were from consultants who provide services to some organizations and their supply chains.

Table II 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, 16 respondents classified their organizations as global or included more than one country from different mainlands in the response. This aspect may imply that these respondents are responsible for operations in more than one country to the same extent.

Table II. Sample description.

Question	Counts	% of total	Question	Counts	% of total
Which job function better describe 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%

Source: The author's

Common method variance and non-response bias

Non-response bias and the common method variance were checked. It was decided to compare the first responders with the last responders to verify the existence of serious problems of non-response bias (Armstrong & Overton, 1977). Therefore, a t-test of mean difference was performed between the first 100 and the last 100 respondents for all indicators involved in this study, not showing a statistically significant mean difference. We sought to minimize the variance caused by the method by following some procedures that Podsakoff et al. (2003) suggested. As mentioned previously, anonymity was guaranteed to respondents, and, in addition, simple and specific questions were chosen. Each construct was separated by its question, and each question and indicator were randomized for each respondent. Furthermore, as evidenced in the description of the sample, 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 problems related to the common method variance statistically. The test result showed that the first factor could explain 40.39% of the observed variance, not pointing to serious issues.

Measurement scales

The scales were evaluated for reliability, convergent validity, and discriminant validity through the confirmatory factor analysis (CFA) processed using Smart-PLS software (Ringle, Wende, & Becker, 2014). Table III presents the loadings, the average variance extracted (AVE), and the McDonald's omega, making it possible to verify the convergent validity and reliability of the reflective indicators (Fornell & Larcker, 1981; Hair, Hult, Ringle, & Sarstedt, 2017; Hayes & 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 IV) (Fornell & Larcker, 1981).

Table III. Measurement results.

Construct	Indicator	Description	Loadings	AVE	Composite reliability
To what extent do you and your supply chain partners use these tools to learn about or from supply chain risks? 1 - Not at all to 7 - Always					
Digital Technologies (DT)	I1	Internet of Things	0.825	0.678	0.913
	I2	Cloud Computing	0.762		
	I3	Big data analytics	0.838		
	I4	Digital twins	0.850		
	I5	Blockchain technology	0.840		
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	0.887	0.721	0.928
	RES2	It would not take long to recover normal operations performance	0.772		
	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	0.827		
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 sustain even when disruptive events occur (e.g., Natural disasters, labor strikes, fire, industrial accidents, shortages on the supply markets)	0.834	0.705	0.922
	RO2	Our supply chain can avoid or minimize risk occurrence by anticipating and preparing for them	0.780		
	RO3	Our supply chain can absorb a significant level of negative impacts from recurrent risks	0.875		
	RO4	When changes occur, our supply chain grants us sufficient time to consider a reasonable reaction	0.814		
	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	0.906	0.790	0.938
	M2	We have a great deal of experience about how to handle supply chain disruptions	0.908		
	M3	We have a great deal of familiarity about how to handle supply chain disruptions	0.912		
	M4	We have invested a great deal of research and development about how to handle supply chain disruptions	0.826		
How did COVID-19 negatively affect your: 1- No affect to 7 - Major affect					
Supply chain disruption impact	CO1	Overall efficiency of operations	0.798	0.668	0.913
	CO2	Lead time for delivery (delivery reliability)	0.869		
	CO3	Purchasing costs for supply	0.783		

Source: The author's

Table IV. Fornell Lacker analysis.

Construct	COVID-19 impact	Digital Technologies	Supply chain memory	Supply chain resilience	Supply chain robustness
COVID-19 impact	**0.817**				
Digital Technologies	-0.158	**0.824**			
Supply chain memory	-0.110	0.593	**0.889**		
Supply chain resilience	-0.279	0.488	0.591	**0.849**	
Supply chain robustness	-0.200	0.534	0.630	0.609	**0.839**

Source: The author's

Direct, indirect and total effects

The hypotheses were tested by structural equation modeling with partial least squares estimator. According to Hair et al. (2009), structural equation modeling provides the possibility of efficiently estimating a series of separate multiple regression equations, which can all be simultaneously calculated by considering the relationships between the manifested variables and their constructs. A bootstrapping with 5,000 subsamples was conducted to check for statistical significance in the relationships. It should be noted that collinearity between predictive constructs was checked through the variance inflation factor (VIF), and no problem was found since all VIFs were far from five.

The first model verified Hypotheses 1 to 7, while Model 2 inserted the moderation effects. Model 1 direct effects are presented in Figure 1.

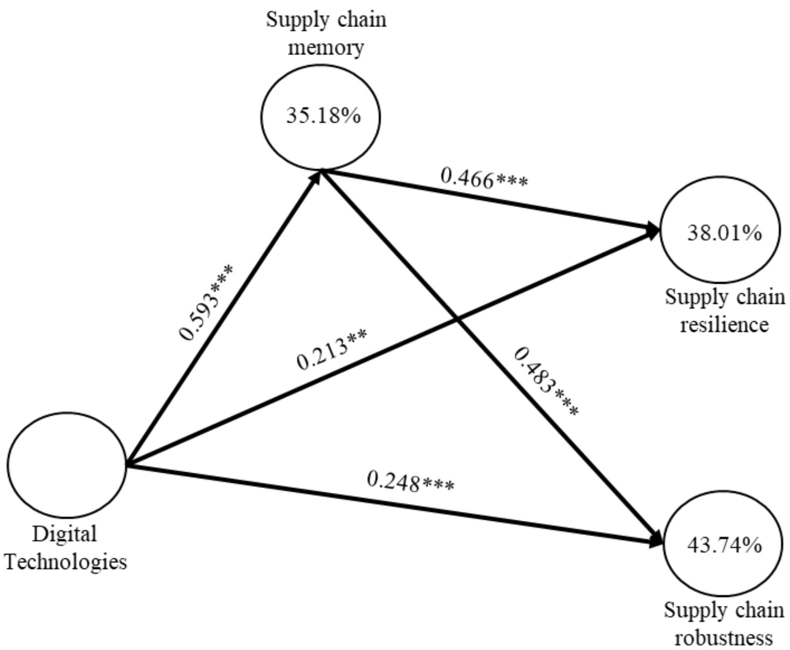

Figure I. Direct effects results.
Source: The author's

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

All proposed theoretical hypotheses of main effects (1 to 7) were confirmed by empirical tests. Supply chain memory has a positive and statistically significant effect on both supply chain resilience (path coefficient 0.466 and p-value <0.001) and robustness (path coefficient 0.483 and p-value <0.001), while digital technologies use impact supply chain memory (path coefficient 0.593 and p-value <0.001), robustness (path coefficient 0.248 and p-value <0.001), and resilience (0.213 and p-value <0.01).

Despite the direct effects presented in Figure I, our paper's main hypotheses are focused on the mediation effect of supply chain memory and the moderation effect of COVID-19 disruption. The model results demonstrated that supply chain memory partially mediates the relationships since there are both direct and indirect significant effects of supply chain analytics on resilience and robustness. The indirect effect of digital technologies on resilience through supply chain memory has a path coefficient of 0.276 (p<0.001) and robustness of 0.287 (p<0.001). This means that the indirect effect is higher than the direct effect of the digital technologies uses on resilience and robustness, resulting in a total effect of 0.489 (p<0.001) and 0.535 (p<0.001) respectively.

Moderation analysis confirmed hypothesis 9 (Model 2) but not confirmed hypothesis 8 (Model 2). Therefore, the impact of supply chain memory on supply chain robustness was weaker for those chains more affected by COVID-19 disruption, with a moderation coefficient of -0.093 (p-value 0.019). However, memory remains effective to deal reactively with extremely new disruptions like COVID-19. It’s also important to note that, as expected, COVID-19 negatively affects supply chain resilience (path coefficient -0.196 and p-value <0.001) and robustness (-0.092 and p-value <0.05).

The full model was able to explain 35.18% of supply chain memory, 41.77% of supply chain resilience and 45.88% of supply chain robustness. Full model results are presented in Table V. The significant interaction effect was also explored, plotting -1 standard deviation (SD) and +1 standard deviation (SD) relationships (Figure II).

Table V. Moderation results.

Hypotheses test	(M2) Moderation analysis Dependent variable		
Constructs	SCME	SCRES	SCROB
DT	0.593***	0.182**	0.222***
SCME		0.461***	0.486***
COVID-19 impact		-0.196***	-0.092*
Interaction term			
COVID-19*SCME	-	-0.015	-
COVID-19*SCME	-	-	-0.093*
R-square	35.18%	41.77%	45.88%

Source: The author’s

Notes

*** p<0.001 ** p<0.01 * p<0.05

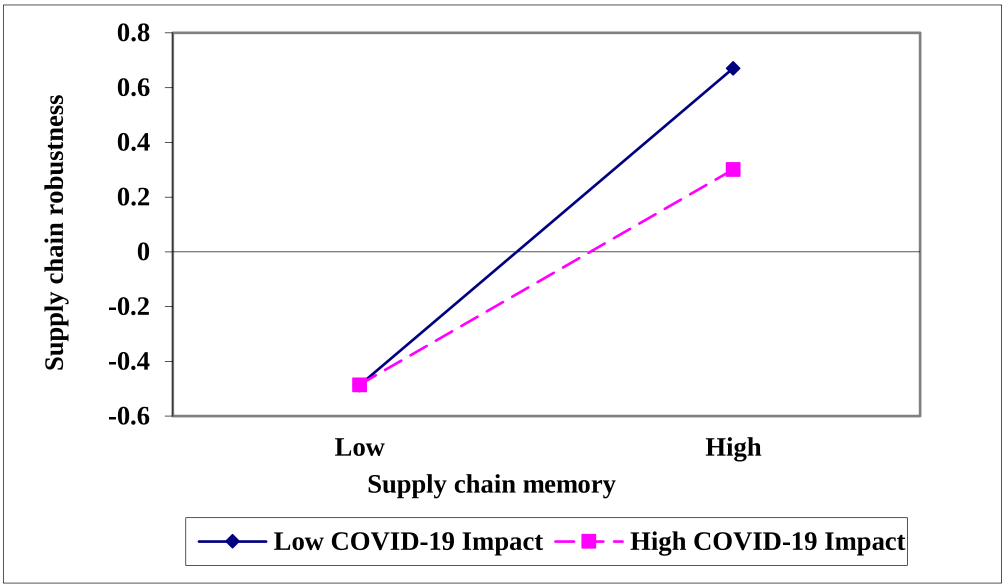

Figure II. Moderation plot.
Source: The author's

Contributions to theory and practice

Our paper has several contributions to theory and practice. First of all, it reinforces that digital Technologies use impacts supply chain resilience (Zouari et al., 2020), and, to the best of our knowledge, is the first to empirically test and prove its impact on supply chain robustness. Also, we asked the respondents about the specific use to learn from or about the risks. Therefore, supply chains must look to digitalizing their supply chain and use it to build knowledge about disruptions if they want to take advantage in actual context since these disruption management capabilities are strongly related to supply chain performance (Chowdhury, Quaddus, & Agarwal, 2019; R Dubey et al., 2021; Kwak et al., 2018; Wieland & Marcus Wallenburg, 2012).

Second, only a few studies have been concerned about the role of previous knowledge in the supply chain disruption management field (Scholten et al., 2019; Singh & Singh, 2019). Since most supply chain resilience and robustness studies are based on the resource-based view or dynamic capabilities view (Kochan & Nowicki, 2018), this paper extends actual theory by inserting knowledge-based view lens in the discussion, pointing out supply chain memory as an antecedent of supply chain disruption management. Building, storing and retrieving knowledge about how to deal with disruptions may be the key to properly fitting supply chain capabilities to their vulnerabilities, equilibrating survivability and profit (Fiksel, Polyviou, Croxton, & Pettit, 2015; Pettit et al., 2019). Therefore, Supply Chain Resilience Assessment and Management (SCRAM) (Fiksel et al., 2015; Pettit, Croxton, & Fiksel, 2013; Pettit et al., 2019) might be an excellent tool for supply chain managers to transform efforts to deal with disruptions in superior profit.

Third, the study highlights that most digital technologies' effects on resilience and robustness occur through supply chain memory. This means that supply chain memory is a mechanism that makes efforts to digitalize the supply chain leverage supply chain resilience and supply chain robustness. As theoretically constructed, Digital Twins, Cloud Computing, Internet of Things, Blockchain and Big Data Analytics award the chain with a great experience, familiarity and knowledge about how to deal with disruptions. These tools can built, improve and make sense of supply chain memory without experiential learning (Al-Talib et al., 2020; Ben-Daya et al., 2019; Birkel & Hartmann, 2020; Moshood et al., 2021; Zouari et al., 2020). Therefore, despite all barriers to their adoption (Raj, Dwivedi, Sharma, Lopes de Sousa Jabbour, & Rajak, 2020), results show that efforts to use them to deal with disruptions is essential.

Finally, the role of memory when an extremely new disruptive event occurs was checked. Results demonstrated that the impact of memory on robustness is negatively moderated by the COVID-19 impact on the supply chains, but the same can not be said about the memory and resilience relationship. This means that higher levels of memory are less efficient to maintain the operations at an acceptable level when some non-routine event happens but remains with the same level of importance to recover from it. This result is aligned with previous memory organizational studies, which postulate that memory can bring some rigidity to the organizational/supply chain process, as it is embedded in routines (Newey & Zahra, 2009). At the same time, memory is a source of improvisation (Antunes & Pinheiro, 2020; Moorman & Miner, 1998), which is needed to recover from and become more resilient after this type of disruptive event (Adobor, 2020; Craighead, Ketchen, & Darby, 2020; Ketchen & Craighead, 2020). Results are also an insight into the disruption management field. As "*Robustness is generally taken to mean the ability to resist a disturbance by not changing"* (Walker, 2020, p. 1), it reinforces that robustness is not about not changing, but change quickly is a necessary condition to remain effective when a disruptive event kick in.

Conclusions, future research, and limitations

Throughout an empirical study with supply chain managers, this paper addresses a relevant trend topic in supply chain management. We investigated the mediating role of supply chain memory in the relationship between supply chain resilience and robustness. Additionally, COVID-19 impact on supply chains operations was tested as a moderator of the impact between supply chain memory, resilience and robustness. Results through structural equation confirmed that ***H1:*** *The use of digital technologies impacts supply chain resilience;* ***H2:*** *The use of digital technologies impacts supply chain robustness;* ***H3:*** *The use of digital technologies impacts supply chain disruption memory;* ***H4:*** *Supply chain memory positively impact supply chain resilience;* ***H5:*** *Supply chain memory positively impact supply chain robustness;* ***H6:*** *Supply chain memory mediates the relationship between digital technologies and Supply chain resilience;* ***H7:*** *Supply chain memory mediates the relationship between digital technologies and Supply chain robustness and;* ***H9:*** *Covid-19 disruption impact negatively moderates the relationship between supply chain memory and supply chain robustness.* However, ***H8:*** *Covid-19 disruption impact negatively moderates the relationship between supply chain memory and supply chain resilience* was not confirmed, which makes it possible to imply that memory remains effective to lead to higher levels of recovery even when non-routine events occur.

Like all research, this paper is not without limitations. A single respondent of one company of a supply chain strategy was used to make this research viable, despite us knowing that a multiple-chain members strategy will be a better strategy. Also, the low level of respondents from the same industries did not allow to test differences in the results inside the sample. Future quantitative researchers must explore other antecedents of supply chain memory, a theme little explored by the literature. Furthermore, research results demonstrated that previous experience, familiarity and knowledge to deal with disruptions are less efficient to maintain the efficiency of operations when an extremely new disruptive event happens, suggesting that maybe is the combination between memory and absorptive capacity which convey supply chains with a superior competitive advantage. Therefore, this combination should be explored in future studies. Finally, as this paper addressed supply chain memory in a general manner, future studies should explore if results differ between procedural (i.e. memory about how things are done) (Cohen & Bacdayan, 1994) or declarative (i.e. memory of facts) (Cohen, 1991).

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