The impact of using digital technologies on supply chain resilience and robustness: the role of memory under the covid-19 outbreak

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

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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 organisation			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%

Table II. Loadings and cross-loadings for the measurement model.

Construct	Item	Covid-19 impact	Memory	Resilience	Robustness
Covid-19 impact	CO1	**0.798**	-0.019	-0.210	-0.143
	CO2	**0.869**	-0.165	-0.257	-0.195
	CO3	**0.783**	-0.068	-0.213	-0.147
Memory	M1	-0.075	**0.906**	0.508	0.558
	M2	-0.102	**0.909**	0.526	0.524
	M3	-0.102	**0.912**	0.536	0.574
	M4	-0.112	**0.826**	0.528	0.575
Resilience	RES1	-0.268	0.501	**0.887**	0.572
	RES2	-0.246	0.388	**0.772**	0.453
	RES3	-0.267	0.554	**0.902**	0.521
	RES4	-0.209	0.530	**0.853**	0.557
	RES5	-0.200	0.517	**0.827**	0.475
Robustness	RO1	-0.183	0.491	0.478	**0.834**
	RO2	-0.116	0.546	0.402	**0.781**
	RO3	-0.181	0.543	0.537	**0.875**
	RO4	-0.210	0.460	0.546	**0.814**
	RO5	-0.157	0.588	0.588	**0.889**

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

	Mean	SD	CR	Covid-19 impact	SC Memory	SC Resilience	SC Robustness
Covid-19 impact	5.05	1.31	0.858	**0.817**			
SC Memory	4.32	1.43	0.938	-0.110	**0.889**		
SC Resilience	4.08	1.33	0.928	-0.279	0.591	**0.849**	
SC Robustness	4.18	1.26	0.922	-0.200	0.630	0.608	**0.839**

Table IV. Mean, standard deviations (SD), VIF, and relevance and significance of formative indicators.

Construct	Item	Mean	SD	VIF	Weight	Sig.	Loading
Digital technologies	I1	3.23	1.93	2.16	0.223	0.028	0.802
	I2	3.85	1.98	1.80	0.289	0.005	0.797
	I3	3.71	1.94	2.24	0.367	0.002	0.882
	I4	2.56	1.81	2.65	0.135	0.307	0.796
	I5	2.4	1.76	2.53	0.199	0.107	0.805

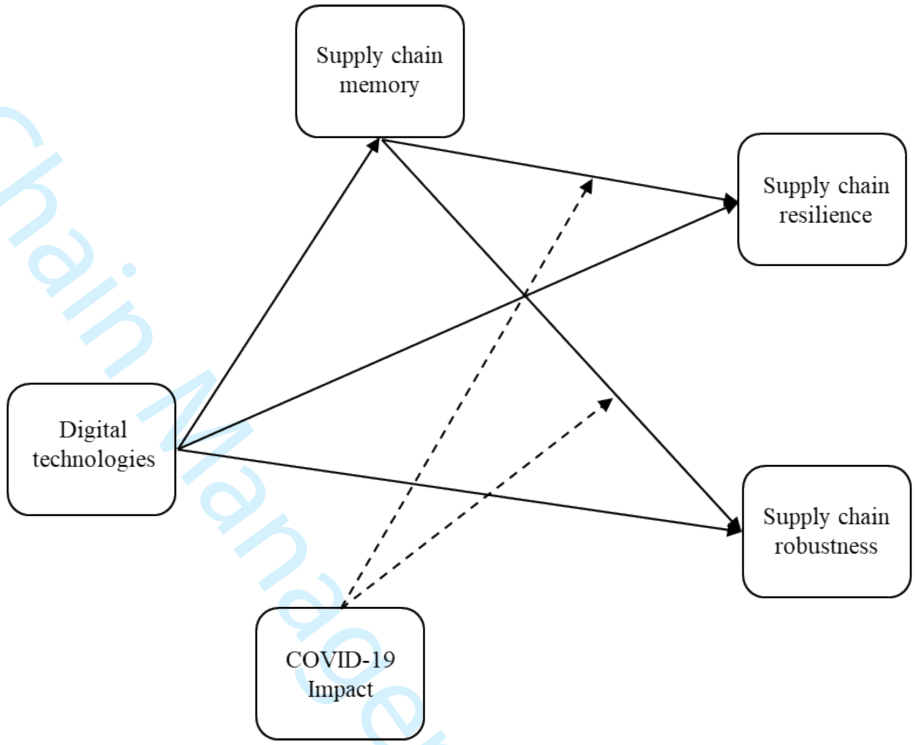


Figure 1 Caption: *Theoretical framework.*

Figure 1 Alt Text: *Figure 1 presents all the five constructs discussed in the paper, with seven arrows indicating their relationships. Digital technologies construct has an arrow pointing to supply chain memory, supply chain resilience and supply chain robustness. Supply chain memory has an arrow pointing to both supply chain resilience and robustness. Finally, COVID-19 impact has a dotted arrow pointing out to the relationship between memory and resilience, as well between memory and robustness.*

Table V. Results.

Hypotheses test	Model 1		Model 2			Full Model		
	DV		DV			DV		
Constructs	Supply chain resilience	Supply chain robustness	Supply chain memory	Supply chain resilience	Supply chain robustness	Supply chain memory	Supply chain resilience	Supply chain robustness
Digital technologies	0.490***	0.533***	0.594***	0.204**	0.252***	0.594***	0.176**	0.227***
Supply chain memory	-	-	-	0.477***	0.475***		0.463***	0.474***
COVID-19	-	-	-	-	-		-0.200***	-0.107*
Control Variables								
Size	0.002 NS	0.015 NS	0.022 NS	-0.010 NS	0.002 NS	0.022 NS	-0.010 NS	0.004 NS
Disruptive events rate	-0.010 NS	0.064 NS	0.081 NS	-0.048 NS	0.025 NS	0.081 NS	0.005 NS	0.048 NS
Interaction term								
COVID-19*SCME	-	-	-	-	-	-	-0.016 NS	-0.089*
Rsquare	24.03%	29.46%	36.90%	37.98%	43.86%	36.90%	41.58%	46.21%
Rsquare-adjusted	23.13%	28.63%	36.15%	36.99%	42.97%	36.15%	40.18%	44.92%
Rsquare change	-	-	-	13.95%	14.40%	-	3.61%	2.35%

Notes

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

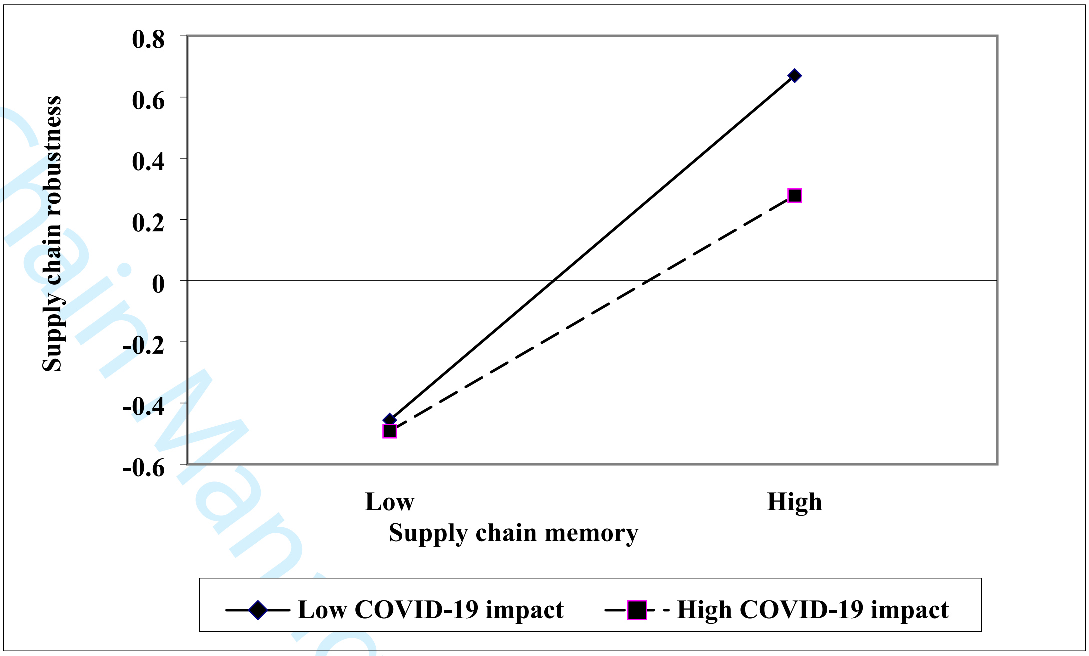


Figure 2 Caption: *Moderation plot.*

Figure 2 Alt Text: The figure has low and high supply chain memory values on the X axis and values for supply chain robustness on the Y axis. In the middle, there is a line representing the effect of memory on robustness when the impact level of COVID-19 was low and another line (dashed) for when the impact of COVID-19 was high. The figure demonstrates that the slope line for the dashed line is smaller than the normal line.

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

Purpose: This paper's main aim was to check the mediating effect of supply chain memory in the relationship between using digital technologies and both supply chain resilience and robustness. Additionally, the impact of the COVID-19 disruption was tested as a moderator of the impact of supply chain memory on supply chain resilience and robustness.

Design/methodology/approach: Altogether, 257 supply chain managers answered the questionnaire, and data were analyzed through structural equation modelling.

Findings: This paper contributes to theory and practice by demonstrating that the experience, familiarity, and knowledge to deal with disruptions partially mediate the relationship between digital technologies, resilience, and robustness. Moreover, our results show that memory is less efficient for the supply chain to maintain an acceptable level of performance in case of a new extreme disruptive event like COVID-19. The full model was able to explain 36.90% of supply chain memory, 41.58% of supply chain resilience, and 46.21% of supply chain robustness.

Originality: (1) The study 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) Knowledge about the impact of industry 4.0 technologies on disruption management is quantitatively improved. (4) It demonstrates that digital technologies impact resilience and robustness mainly through supply chain memory. (5) The study proves that supply chain memory is less efficient for the chain remains effective when a non-routine disruptive event occurs, but it is still imperative to recover from it.

Keywords: supply chain; resilience; robustness; memory; digital technologies; COVID-19.

Introduction

It is already known that competitiveness has shifted from organisations to supply chains (Stadtler, 2008). When working efficiently, supply chains make it possible for products to be produced and distributed in the correct quantity, to the right places, at the right time and profitably (Christopher and Peck, 2004). Amazon, Coca-Cola and Intel are just a few examples of how proper supply chain management can leverage organizational performance. With the increasing attention to supply chain management and its benefits (Shi and Yu, 2013), academia has studied the phenomenon through different but limited lenses, with most emphasis on the resource-based view, transaction cost economics and game theory (Gligor *et al.*, 2019).

Recent problems faced by supply chains might require different theoretical lenses to explain their performance (Craighead *et al.*, 2020). Today's supply chains are susceptible to myriad risks and uncertainties that can disrupt their operations (Ben-Daya *et al.*, 2019). In this scenario, it is crucial to understand factors that cause some organisations to thrive when faced with disruptive events while others collapse (Soni *et al.*, 2014). Therefore, both managers and academics are looking for better ways to improve supply chain resilience and robustness (Brusset and Teller, 2017; Pettit *et al.*, 2019). The dynamic capability view (Altay *et al.*, 2018; Brusset and Teller, 2017; Chowdhury *et al.*, 2019), resourced-based view (Bühler *et al.*, 2016; Kumar and Anbanandam, 2019; Liu and Lee, 2018) as well as information processing theory (Dubey *et al.*, 2020, 2021; DuHadway *et al.*, 2019) has been extensively explored in recent disruption management literature, with most of the attention given to the impact of visibility, collaboration, flexibility and analytics on the abilities to prevent, respond and recover from disruptions (Alvarenga *et al.*, 2022). However, studies based on the knowledge-based view lens are underexplored (Kochan and Nowicki, 2018).

Despite knowledge being a strategic resource (Grant, 1996a, 1996b), discussions about the effectiveness of previous knowledge in dealing with disruptions (Adel *et al.*, 2022; Scholten *et al.*, 2019; Singh and Singh, 2019) are still inconclusive, especially taking into account non-routine events like COVID-19 (Ivanov, 2021; Pimenta *et al.*, 2022). The COVID-19 supply chain disruption is a special kind of upheaval that still affects many supply chains worldwide, primarily because of its long-term, high uncertainty, and ripple effect propagation characteristics (Craighead *et al.*, 2020; Ivanov, 2021; Ruel and 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 *et al.*, 2020), are only a few examples of how the pandemic affected people lives, organisations and their supply chains (Kalkın *et al.*, 2021).

It is also a fact that, nowadays, managers have better tools to make decisions based on facts and data (Acito and Khatri, 2014; Büyüközkan and Göçer, 2018; Srinivasan and 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 worlds. This shift favours obtaining and analyzing data in real time and providing useful information to the production system, making it more adaptive (Dalenogare *et al.*, 2018; Li *et al.*, 2020; Weyer *et al.*, 2015). The internet of things (Ben-Daya *et al.*, 2019; Birkel and Hartmann, 2020), digital twins (Ivanov *et al.*, 2019; Moshood *et al.*, 2021), blockchain (Galati, 2022; Manupati *et al.*, 2022; Wamba *et al.*, 2020), big data analytics (Dubey *et al.*, 2021; Singh and Singh, 2019; Souza, 2014), and cloud computing (Frank *et al.*, 2019; Li *et al.*, 2020) are examples of tools that supply chain managers can use to learn about disruptive events.

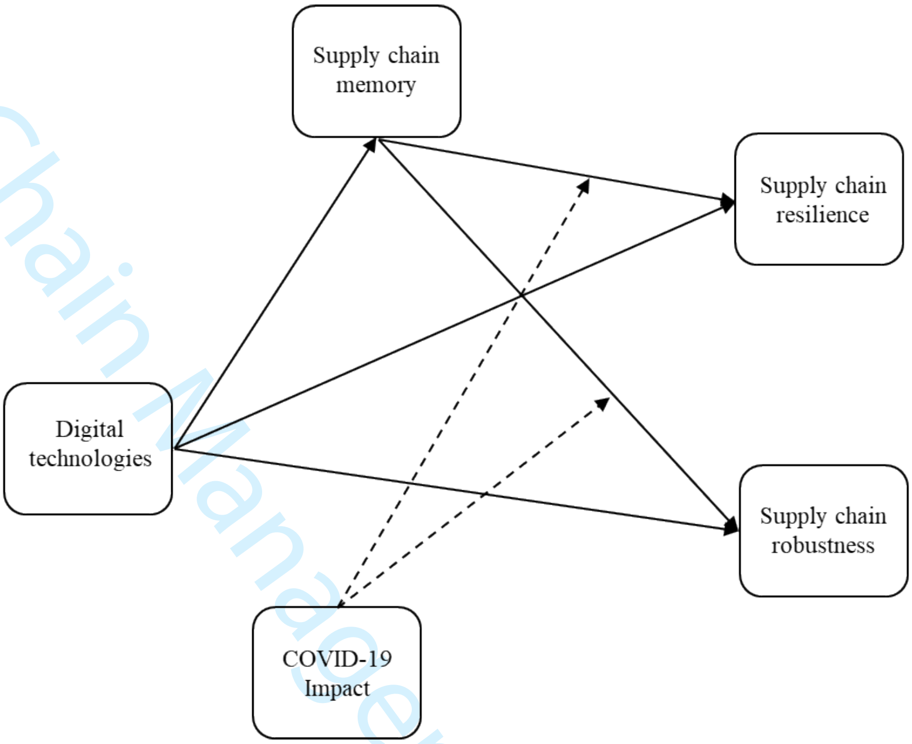
Fresh literature reveals the need for more empirical studies linking those technologies and the capability to deal with disruptions (Ivanov *et al.*, 2022; Spieske and Birkel, 2021; Xu *et al.*, 2020). Some papers affirmed how the general adoption of these technologies impacts performance (Li *et al.*, 2020; Tortorella *et al.*, 2020) or the impact of specific digital technologies on supply chain disruption management capabilities (Alvarenga *et al.*, 2022; Dubey *et al.*, 2021; Singh and Singh, 2019). However, although previous direct effects (Zouari *et al.*, 2020), little is known about the mechanisms that act in the relationship between the use of digital technologies, resilience, and robustness.

Based on the preceding, this paper's aims are twofold. First, we intend to expand the knowledge about the impact of digital technologies on supply chain resilience and robustness, pointing out supply chain memory as a mediator. Since information processing is needed in turbulent environments (Galbraith, 1974), digital technologies help supply chains have a great deal of experience, knowledge, and familiarity about how to deal with disruptions, namely – throughout supply chain memory (Hult *et al.*, 2004) and so on, making them more resilient and robust. Second, as the efficiency of both resilience and robustness is dependent on the fit between supply chain capabilities and the environment (Aragón-Correa and Sharma, 2003; Fiksel *et al.*, 2015; Pettit *et al.*, 2019), we questioned and tested if when extremely new disruptive events like the COVID-19 outbreak occur, previous knowledge to deal with disruption is still essential to continue operations effectively (i.e., robustness) or to recover faster from them (i.e., resilience).

The paper makes several contributions to the existing supply chain 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) Knowledge about the impact of industry 4.0 technologies on disruption management is quantitatively improved. (4) It demonstrates that digital technologies impact resilience and robustness mainly through supply chain memory. (5) Combining the knowledge-based view (Grant, 1996a), information processing theory (Galbraith, 1974) and contingent resource-based view (Aragón-Correa and Sharma, 2003), the study proves that supply chain memory is less efficient for the chain remains effective when a non-routine disruptive event occurs. Nonetheless, it is still imperative to recover from it. This aspect means that knowledge as a resource is context dependent for robustness.

Theoretical model and hypotheses development

We hypothesise that there is a link between digital technology use and supply chain disruption management capabilities' results (resilience and robustness) (Dubey *et al.*, 2021; Zouari *et al.*, 2020). Furthermore, this relationship is mediated by supply chain memory. Additionally, we discuss and test if previous knowledge is sufficient to deal with extremely new outages like the COVID-19 impact, testing its moderating effect on the impact of supply chain memory on supply chain resilience and robustness. Figure 1 presents the model which will be better explored in ongoing topics.



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Supply chain resilience and robustness

Resilience is a multidisciplinary topic with numerous facets, including the ecological, psychological, economic and organisational perspectives (Bhamra *et al.*, 2011; Ponomarov and Holcomb, 2009). With a lack of consensus about its definition inside the supply chain management field (Hohenstein *et al.*, 2015; Pires Ribeiro and Barbosa-Povoa, 2018; Wong *et al.*, 2020), views vary among those that consider resilience as how to deal with a disruption and the subsequent moments, and those who also consider the moment before a disruption (Ali *et al.*, 2017). Overall, readiness, response, recovery and growth are commonly inserted into the resilience domain (Hohenstein *et al.*, 2015). Ponovarov and Holcomb (2009, p. 131), for example, define the construct as "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function", while Wieland and Wallenburg (2013) argue that it means the ability to cope with changes. New perspectives about supply chain resilience have emerged in recent years. They can be seen in Wieland (2021), who suggests an ecological view and Ivanov and Dolgui (2020), who suggest a shift to the viability idea.

A supply chain can be good enough to prevent it from suffering too much from a disruption but not as good in recovering from it (Alvarenga *et al.*, 2022; Jüttner and

Maklan, 2011). In this paper, ante-post disruption moments are not considered a resilience domain. We adopt an engineering view of resilience, considering it 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). Not being disrupted is better than being disrupted and having to recover; nonetheless, not all disruptions can be avoided or mitigated (Fiksel *et al.*, 2015; Wong *et al.*, 2020).

Like supply chain resilience, the supply chain robustness concept is unclear and routinely used interchangeably with the resilience concept (Brandon-Jones *et al.*, 2014). Although, like Ruel and El Baz (2021), Kwak et al. (2018), and Brandon-Jones et al. (2014), we see them as different. "*Robustness is generally taken to mean the ability to resist a disturbance by not changing"* (Walker, 2020, p. 1) and is associated with dealing with recurrent risk events (Klibi *et al.*, 2010). However, we understand that robustness is not static (Brandon-Jones *et al.*, 2014) because the capability to cope with variability without a major impact on performance (Kwak *et al.*, 2018) includes a certain degree of flexibility (Brandon-Jones *et al.*, 2014; Stonebraker *et al.*, 2009). Supply chain robustness is operationalized in this study as the chain's ability to remain effective in case of disruptive events occurring (Brandon-Jones *et al.*, 2014; Klibi *et al.*, 2010; Kwak *et al.*, 2018; Stonebraker *et al.*, 2009). In short, while resilience deals with disruptions reactively, robustness is a proactive capability.

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

Digital technologies use is associated with developing resilience and robustness capabilities discussed in the literature as essential for supply chains to prevent, adapt and recover from interruptions. Their use improves information collection, processing, and sharing, providing supply chains with greater visibility, transparency, and real-time information (Oliveira and Handfield, 2019; Zhu *et al.*, 2018). This paper addresses the following digital technologies: the internet of things, cloud computing, big data analytics, digital twins, and blockchain (see Appendix 1 for definitions). 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 favour the obtaining of real-time information by supply chain members and the connection between the virtual and the real world (Ivanov *et al.*, 2020; Min, 2019).

Blockchain technology, for example, enables greater traceability and collects and shares information in the same network, increasing operational transparency and trust between members of the chains, which leads to greater pre and post-disruption response (Dubey *et al.*, 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 fulfilment. Cloud computing and the internet of things also favour supply chain members to collect, transfer, store, and share a massive amount of data, making them more collaborative, visible, and flexible (Al-Talib *et al.*, 2020; Ben-Daya *et al.*, 2019; Birkel and Hartmann, 2020; Gnimpieba *et al.*, 2015). Birkel and Hartmann (2020) show that the internet of things impacts supply chain risk management steps. It 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 Supply Chain Operations Reference Model dimension. Also, analytics has a proven impact on supply chain performance as well as on its member's performance (Chae *et al.*, 2014; Trkman *et al.*, 2010). An analytical approach plays an essential role in supply chain disruption management since it helps identify, assess, mitigate and monitor risks, enabling a better preventive capability (Frank *et al.*, 2019; Ittmann, 2015; Tummala and Schoenherr, 2011). The impact of big data analytics on supply chain resilience has also 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 processing 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

There are at least four main memory perspectives in the literature: functional, interpretative, critical, and performative (Foroughi *et al.*, 2020). Our study is based on a functional view of organisational memory, which has its foundation in Walsh and Ungson's (1991) work. Therefore, memory is the current knowledge that the organisation/chain members have based on previous decisions that can be used in the present and future (Anand *et al.*, 1998; Hult *et al.*, 2004; Walsh and Ungson, 1991). Supply chain memory is defined here as achieved memory (Hult *et al.*, 2004, 2006) to deal with disruptions, that is, the amount of experience, familiarity, and knowledge articulated by supply chain members (Hult *et al.*, 2006; Moorman and Miner, 1997) to deal with these undesired events. Previous studies have shown, for example, that memory is a critical factor for value creation (Martelo-Landroguez and Cepeda-Carrión, 2016), in building sustainable competitive advantage (Ebbers and Wijnberg, 2009; Moorman and Miner, 1998), providing supply chains members engagement in knowledge acquisition activities (Hult *et al.*, 2004), for organisational agility (Cegarra-Navarro and Martelo-Landroguez, 2020) and organisational performance (Kmieciak, 2019).

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 in memory was mentioned by Cross and Baird (2000), Day (1994), Huber (1991), Oliveira (2000), Nikalanta, Miller, and Zhu (2006), and Stein and Zwass (1995), for example. 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, retrieval, and application of knowledge are improved by them (Barbosa and Vicente, 2018; Côrte-Real *et al.*, 2016; Oliveira and Handfield, 2019). Recently, Tortorella et al. (2020) found that industry 4.0 technologies positively influence learning capabilities at all levels (individual, team, organisational). In addition to promoting proactive learning (Ivanov et al., 2019), Singh and 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 memory

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

Supply chain collective memory is essential to prevent supply chain members from facing the same or similar disruptions as in a previous moment (Scholten *et al.*, 2019). Since organisations that cannot remember what went right or wrong in their history have to rediscover their successful formulas (Day, 1994), memory is used to learn and retain knowledge from past events to deal with future problems appropriately. In this sense, obtaining, storing, and retrieving information about decision-making regarding disruption prevention, response and recovery appear to be critical aspects of supply chain resilience and robustness (Labib *et al.*, 2019; Ponomarov and Holcomb, 2009; Scholten *et al.*, 2019). Retaining "what," "who," "where," "when," "why," and "how" this event occurred (Walsh and Ungson, 1991), as well as identifying and understanding the actions that were taken to maintain the operations at an acceptable level or recover the flow of operations play a critical role in recovery from a new outage, as well as avoiding it (Chowdhury and Quaddus, 2016; Scholten *et al.*, 2019; Verma and Tiwari, 2009). Roh, Tokar, and Swink (2022) found that chains with low-impact disruption resilience are more likely to have high-impact disruption resilience, showing the importance of learning from experience.

H4: Supply chain memory positively impacts supply chain resilience

H5: Supply chain memory positively impacts supply chain robustness

The mediating effect of supply chain memory

Since disruptions often negatively impact supply chain members, the high costs of learning by doing are undesirable, limiting experiential learning (Hora and Klassen, 2013). Therefore, digital technologies facilitate acquiring experience, familiarity, and knowledge about possible interruptions without facing them beforehand. Digital twins, for example, enable chains to perform experiments in the virtual world to take actions in the real world (Ivanov *et al.*, 2019, 2020; Moshood *et al.*, 2021). Thus, chain members can perform simulations about the impact of possible interruptions or actual interruptions to find satisfactory solutions to minimise their effects and recover properly (Ivanov *et al.*, 2019). Also, they make it possible to identify hidden vulnerabilities, favouring 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 between members (Birkel and Hartmann, 2020; Min, 2019; Oliveira and Handfield, 2019; Zhu *et al.*, 2018). Therefore, disruption knowledge is improved, and proper actions to deal with them can be taken (Birkel and 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 previously discussed memory benefits, researchers have also postulated some negative roles of its use (Chang and Cho, 2008; Lee *et al.*, 2017). Misusing memory can lead an organisation or chain to unsatisfactory results if achieved memory is not critically analyzed for reuse in the current context (Sen *et al.*, 2021; Walsh and Ungson, 1991). Memory is also associated with rigidity (Newey and Zahra, 2009). Therefore, when patterns are well established in a particular domain, changes become more complex, and flexibility decreases (Chang and Cho, 2008; Dougherty, 1992). Also, too much memory about how to do things (procedural memory) leads to difficulty interpreting market changes, so that actions may be delayed (Kyriakopoulos and Ruyter, 2004). That being said, memory may be less efficient in dealing with extremely new disruptions like COVID-19, where operations needed to achieve a new normal, and chains had little knowledge, experience, and familiarity in dealing with this kind of disruption.

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

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

Methodology

Data collection and sample description

Purposive sampling was adopted for sample selection to consider respondents' knowledge of supply chain processes and firm size. Data were collected from July to October 2021 using an online questionnaire applied to supply chain management professionals around the globe registered on two bases to test the model (Figure 1). Supply chain managers have the most expertise and access to information in their organisations related to the study topics (Brusset and Teller, 2017). It should be noted that Base 1 and 2 are both well-known global supply chain management professional associations. Altogether, 5,206 professionals were invited to participate in the survey, 3,967 from base 1 and 1,239 from base 2. The questionnaire obtained 315 complete responses, a response rate of 6.05%, 257 of which were considered valid for this study. This response rate is compatible with similar studies (Brusset and Teller, 2017; Jin *et al.*, 2014; Li *et al.*, 2020). Of these responses, 216 are from base 1 and 41 from base 2. Table I presents the sample demographic description.

Insert Table I here.

Ignoring equivalence issues can lead to ambiguous or erroneous conclusions (Knoppen *et al.*, 2015). Therefore, we examined the data set for equivalence between bases 1 and 2. The measurement invariance of composite models (MICOM) (Henseler *et al.*, 2016) procedure was conducted to check the configural and compositional invariance, as well as the equality of composite means and variances (Hair *et al.*, 2018; Henseler *et al.*, 2016). The same scale and treatment were applied for the two 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 equality of composite means and variances. The results demonstrated a full measurement invariance, supporting pooled data analysis (Hair *et al.*, 2018). It should be noted that base 1 is more than double the size of base 2. Thus, as Hair et al. (2018) recommended, a comparable sample size with base 2 was randomly drawn from base 1 to conduct the analysis.

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 and 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 minimise the variance caused by the method by following some procedures that Podsakoff et al. (2003) suggested. 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 randomised for each respondent.

Furthermore, as evidenced in the description of the sample, the respondents are mostly supply chain management specialists in their organisations, with the majority having more than ten years of experience, thus showing adequate knowledge to answer the questionnaire. Additionally, Harman's single-factor test was used through exploratory factor analysis to check statistical problems related to the common method variance. The test result showed that the first factor could explain 40.39% of the observed variance, not pointing to noteworthy issues.

Measurement scales

Established scales were used to measure the constructs whenever possible (see Appendix 2 for indicators). Like in Li, Dai, and Cui (2020), the indicators applied by Frank et al. (2019) were used to measure the digital technologies construct, including digital twins, blockchain technology, and unifying big data and analytics in a single indicator in the questionnaire. The indicators used by Brandon-Jones et al. (2014) were adopted to measure supply chain resilience. Indicator RES5 is new in the scale and was used since it is aligned with the supply chain resilience definition. The 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. The Moorman and Minner (1997) scale, used in the supply chain context by Hult, Ketchen, Cavusgil, and Calantone (2006), was also used. We measured the experience, familiarity, and knowledge articulated by supply chain members to deal with disruptions. Their scale has already been used by at least Hult et al. (2004), Hanvanich, Sivakumar and Hult (2006), Hult et al. (2006), and Lee, Kim, and Joshi (2017) to measure memory construct. Finally, the disruption impact construct focused on the degree of impact suffered by the chains of the organisations studied during the COVID-19 pandemic until the questionnaire was applied; thus, the indicators used by El Baz and Ruel (2021) were adopted.

The reflective scales (memory, resilience, robustness, and COVID-19 impact) were evaluated for reliability, convergent validity, and discriminant validity using Smart-PLS software (Ringle *et al.*, 2014). Table II presents the loadings and cross-loadings for the measurement model (Hair *et al.*, 2017). Table III presents the square root of the average variance extracted (AVE) of each construct and the correlation between the constructs (Fornell and Larcker, 1981), constructs' latent variables means, standard deviations (SD), and composite reliability (CR). It should be noted that, as recommended, all AVEs are greater than 0.50 (Hair *et al.*, 2017). Finally, the heterotrait-monotrait ratio of correlations (HTMT) was checked, and all values were far from 0.90 (Hair *et al.*, 2017).

Insert Table II here.

Insert Table III here

The digital technologies construct was measured in a formative way. Therefore, it was evaluated by the collinearity between the indicators and their significance and relevance (Cenfetelli and Bassellier, 2009). Table IV shows the inexistence of collinearity problems between the indicators since all variance inflation factor values are below five (Hair *et al.*, 2021). Regarding the significance and relevance of the indicators, it is observed that the indicators I4 (digital twins) and I5 (blockchain) are non-significant but contribute to the construct formation in an absolute way since their loadings are greater than 0.5.

Therefore, it is not evidence of a poor measurement model (Cenfetelli and Bassellier, 2009; Hair *et al.*, 2021).

Insert Table IV here

Results

Direct, indirect, and total effects

The hypotheses were tested using structural equation modelling with a partial least squares estimator. According to Hair et al. (2009), structural equation modelling 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 discern statistical significance in the relationships. It should be noted that collinearity between predictive constructs was evaluated through the variance inflation factor (VIF), and no problem was found since all VIFs were distant from five.

The results are presented in Table V. The first model presents the model without the mediator. Model 2 added the mediator to the model and was used to test the main effects and the mediation effects, while the full model presents the insertion of the interaction effect between COVID-19 disruption impact and memory on resilience and robustness. It should be noted that firm size in terms of the number of employees and the occurrence rate of disruptive events ("Unexpected and disruptive events occur at a high rate", 1-7 scale, mean 4.22) were included in the model as control variables that may affect memory, resilience and robustness. Firm size might impact the advantages gained from being in a supply chain (Arend and Wisner, 2005; Brusset and Teller, 2017). Also, a supply chain can feel a higher level of resilience and robustness only because it does not suffer from disruptive events in its environment or have a higher level of memory only because of its experiential learning, not because of efforts to learn about or from the risks. However, they did not show a significant role, demonstrating that the control variables do not confound the proposed model relationships.

Insert Table V here

All proposed theoretical hypotheses of the main effects (1 to 5) were confirmed by empirical tests. Supply chain memory has a positive and statistically significant effect on both supply chain resilience and robustness, while digital technologies use impact supply chain memory, robustness, and resilience. Despite the direct effects, our paper's main hypotheses are focused on the mediation effect of supply chain memory and the moderation effect of the 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 digital technologies on resilience and robustness. The indirect effect of digital technologies on resilience through supply chain memory has a path coefficient of 0.283 ($p<0.001$) and robustness of 0.282 ($p<0.001$). This result means that the indirect effect is higher than the direct effect of digital technologies' uses on resilience and robustness, resulting in a total effect of 0.487 ($p<0.001$) and 0.535 ($p<0.001$), respectively.

Moderation analysis

Moderation analysis confirmed hypothesis 9 (Model 3) but did not confirm hypothesis 8 (Model 3). Therefore, the impact of supply chain memory on supply chain robustness was weaker for those chains more affected by the COVID-19 disruption, with a moderation coefficient of -0.089 (p-value <0.05). However, memory remains effective in dealing reactively with extreme new disruptions like COVID-19. It is also important to note that, as expected, the COVID-19 crisis negatively affected supply chain resilience (path coefficient -0.200 and p-value <0.001) and robustness (-0.107 and p-value <0.05).

The full model was able to explain 36.90% of supply chain memory, 41.58% of supply chain resilience, and 46.21% of supply chain robustness. The significant interaction effect was also explored, plotting -1 standard deviation (SD) and +1 standard deviation (SD) relationships (Figure2).

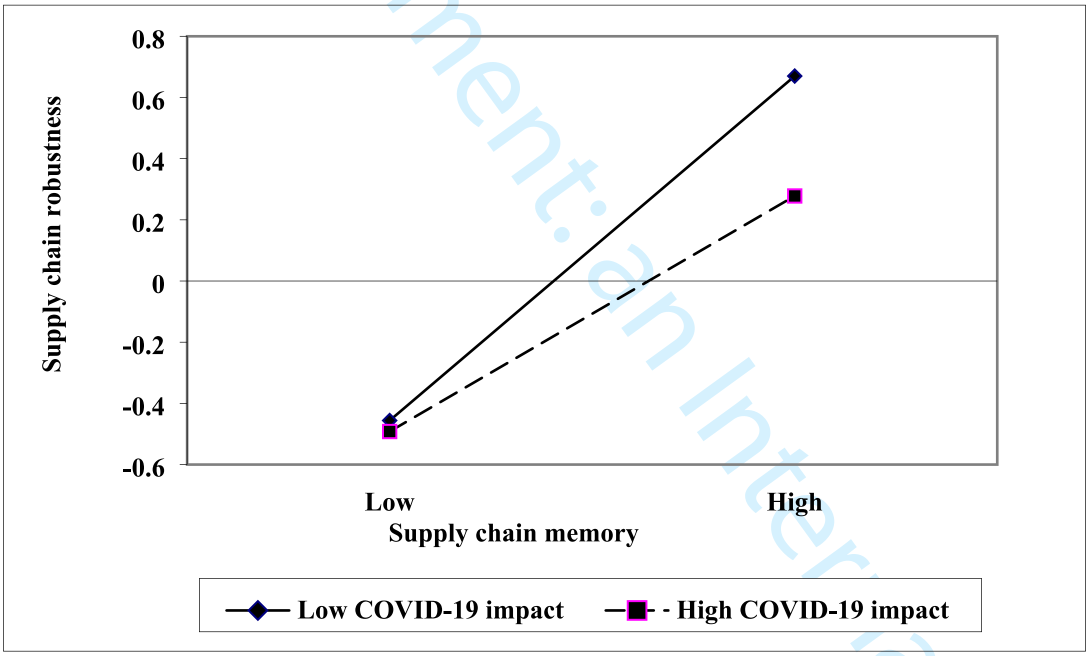

Figure 2 Caption: Moderation plot.

Figure 2 Alt Text: The figure has low and high supply chain memory values on the X axis and values for supply chain robustness on the Y axis. In the middle, there is a line representing the effect of memory on robustness when the impact level of COVID-19 was low and another line (dashed) for when the impact of COVID-19 was high. The figure demonstrates that the slope line for the dashed line is smaller than the normal line.

Contributions to theory and practice

Our paper has several contributions to organisational and supply chain theory and practice. First, it reinforces that the use of digital technologies impacts supply chain resilience (Zouari *et al.*, 2020). To the best of our knowledge, this investigation 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, which are not mentioned in the previous literature. Therefore, supply chains must exploit collaboration and integrate data, share experiences, and use data analytics to help build knowledge about disruptions if they want to take advantage in an actual context since these disruption management capabilities are strongly related to supply chain performance (Chowdhury *et al.*, 2019; Dubey *et al.*, 2021; Kwak *et al.*, 2018; Wieland and Marcus Wallenburg, 2012).

Second, this paper extends actual theory by bringing new insights into the knowledge-based view lens in the supply chain disruption management field, pointing out supply chain memory as an antecedent of supply chain resilience and robustness. 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 and Singh, 2019). While Singh and Singh (2019) found that institutional response to disruptions does not have a positive direct impact on supply chain risk resilience, recently, Adel, Vries, and Donk (2022) found that cross-boundary information exchange, which means supply chain memory building, is essential to deal with non-routine events. This paper's results show that 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 *et al.*, 2015; Pettit *et al.*, 2019). Therefore, Supply Chain Resilience Assessment and Management (SCRAM) (Fiksel *et al.*, 2015; Pettit *et al.*, 2013, 2019) might be an excellent tool for supply chain managers to transform efforts to deal with disruptions into superior profit.

Third, although the link between digital technologies use and a higher level of disruption management capabilities is consolidated (Dubey *et al.*, 2021; Zouari *et al.*, 2020) and reinforced in this paper, the study contributes to theoretical development with the empirical evidence that most of its digital impact occurs through supply chain memory. This aspect means that supply chain memory plays a mediating role in the relationship between digital technologies and both resilience and robustness. Based on the information processing theory (IPT) (Galbraith, 1974), the greater uncertainty, the greater amount of information needed to be processed. Research results contribute to IPT by exploiting the role of memory reducing uncertainty after information processing through digital technologies to improve both resilience and robustness. As theoretically constructed, digital twins, cloud computing, the internet of things, blockchain, and big data analytics award the chain with great experience, familiarity, and knowledge about how to deal with disruptions. These tools can build, improve and make sense of supply chain memory without experiential learning (Al-Talib *et al.*, 2020; Ben-Daya *et al.*, 2019; Birkel and Hartmann, 2020; Moshood *et al.*, 2021; Zouari *et al.*, 2020). So, despite all barriers to their adoption (Raj *et al.*, 2020), the results show that efforts to use them to deal with disruptions are essential (Spieske and Birkel, 2021).

Finally, despite others having already combined the lens of IPT and knowledge-based view (Herden, 2020; Song *et al.*, 2005), or knowledge based view and disruption management (Kwak *et al.*, 2018; Leoni *et al.*, 2022; Scholten *et al.*, 2019), this study offers new and valuable insights to those theories and for the supply chain disruption management field 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. The results demonstrated that the impact of memory on robustness is negatively moderated by the COVID-19 impact on the supply chains, i.e., the higher the impact of COVID-19, the lower the impact of memory would be on robustness. However, the same cannot be said about the memory and resilience relationship. This facet means that higher levels of memory are less efficient in maintaining operations at an acceptable level when some non-routine event happens but remain with the same level of importance to recover from it. This result is aligned with previous memory organisational studies, which postulate that memory can bring some rigidity to the organisational/supply chain process as it is embedded in routines (Newey and Zahra, 2009). At the same time, memory is a source of improvisation (Antunes and Pinheiro, 2020; Moorman and Miner, 1998), which is needed to recover from and become more resilient after this type of disruptive event (Adobor, 2020; Craighead *et al.*, 2020; Ketchen and Craighead, 2020). The results are also an insight into the supply chain disruption management field, as they reinforce that robustness is not about not changing; instead, changing rapidly is a necessary condition to remain effective when a disruptive event emerges. Combining the knowledge-based and contingent resource-based views demonstrates that knowledge as a resource is context-dependent for robustness.

Conclusions, future research, and limitations

This paper addresses a relevant trending topic in supply chain management through an empirical study with supply chain managers. We investigated the mediating role of supply chain memory in the impact of digital technologies on supply chain resilience and robustness. The COVID-19 impact on supply chain operations was also tested as a moderator of the impact between supply chain memory, resilience, and robustness. The 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 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:*** *The Covid-19 disruption impact negatively moderates the relationship between supply chain memory and supply chain robustness.* However, ***H8:*** *the 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 devoid of limitations. A single respondent of one company of a supply chain strategy was used to make this research viable, despite the authors being aware that a multiple-chain members strategy would 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, our research results demonstrated that previous experience, familiarity, and knowledge to deal with disruptions are less efficient in maintaining the efficiency of operations when an extremely new disruptive event happens, suggesting that perhaps it 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 investigate if results differ between procedural (i.e., memory about how things are done) (Cohen and Bacdayan, 1994) or declarative (i.e., memory of facts) (Cohen, 1991).

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Appendix 1: Digital technologies definition

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 and Grance, 2011, p. 2)
Big data Analytics	Use of advanced statistics to exploit structured and unstructured data collected internally and externally in the organisation to improve decision making (Kache and Seuring, 2017). Simplifying, *"big data analytics is where advanced analytic techniques operate 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 transactions), 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 and Schüritz, 2017, p. 15)

Appendix 2: Constructs operationalisation

Construct	Type	Indicator	Description	Source
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)	Formative	I1	Internet of Things	Frank et al. (2019)
		I2	Cloud Computing	
		I3	Big data analytics	
		I4	Digital twins	New in the scale
		I5	Blockchain technology	New in the scale
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)	Reflective	RES1	The material flow would be quickly restored	Brandon-Jones et al. (2014)
		RES2	It would not take long to recover normal operations performance	
		RES3	The supply chain would easily recover to its original state	
		RES4	Disruptions would be dealt with quickly	
		RES5	The supply chain could easily move to a new desirable state	New in the scale
To what extent do you agree with the statements about your supply chain? (considers your organisation, your critical suppliers, and customers): 1 - Strongly disagree to 7 - Strongly agree				
Supply chain robustness (SCRO)	Reflective	RO1	Our supply chain can remain effective and sustain even when disruptive events occur (e.g., Natural disasters, labour strikes, fire, industrial accidents, shortages in the supply markets)	Adapted from Kwak, Seo, and Mason (2018) and Wieland and Wallenburg (2013)
		RO2	Our supply chain can avoid or minimise risk occurrence by anticipating and preparing for them	
		RO3	Our supply chain can absorb a significant level of negative impacts from recurrent risks	
		RO4	When changes occur, our supply chain grants us sufficient time to consider a reasonable reaction	
		RO5	Our supply chain performs well over a wide variety of possible scenarios	
To what extent do you agree with the statements about your supply chain? (considers your organisation, your critical suppliers, and customers): 1 - Strongly disagree to 7 - Strongly agree				
Supply chain memory (SCME)	Reflective	M1	We have a great deal of knowledge about how to handle supply chain disruptions	Moorman and Minner (1997)
		M2	We have a great deal of experience about how to handle supply chain disruptions	
		M3	We have a great deal of familiarity about how to handle supply chain disruptions	
		M4	We have invested a great deal of research and development about how to handle supply chain disruptions	
How did COVID-19 negatively affect your: 1- No effect to 7 - Major effect				
COVID-19 impact	Reflective	CO1	Overall efficiency of operations	El Baz and Ruel (2021)
		CO2	Lead time for delivery (delivery reliability)	
		CO3	Purchasing costs for supply	