Leveraging Supply Chain Digitalization Through Supply Chain Responsiveness, Resilience, and Restoration

Haidi Zhou and Qiang Wang(✉)

School of Management, Xi'an Jiaotong University, Xi'an, China
qiangwang@xjtu.edu.cn

Abstract. This study aims to examine how supply chain digitalization (SCD) affects supply chain responsiveness, resilience, and restoration (3Rs) and supply chain performance. Further, this study explores the moderating role of pandemic impact of the COVID-19. Based on survey data from 215 firms in China, the hypothesized relationships were tested using a SPSS macro program (i.e., PROCESS regression analysis). The results show that SCD enhances supply chain 3Rs, and the supply chain 3Rs positively mediate the relationships between supply chain digitalization SCD and supply chain performance. Further, the mediating effects are strengthened under a high degree of pandemic impact during the COVID-19.

Keywords: Supply chain digitalization · Supply chain responsiveness · Supply chain resilience · Supply chain restoration · Supply chain performance

1 Introduction

The COVID-19 pandemic has posed huge threats to global supply chains. According to Fortune [1], 94% of the top 1000 firms were heavily affected by supply chain disruptions during this outbreak. Such sudden shock has aroused firms to pay more attention on building supply chain responsiveness, resilience, and restoration (3Rs) to survive in the difficult times [2, 3]. Likewise, van Hoek and Lacity [4] also urge scholars to investigate how managers address the challenges posed by disruption risks as the existing research has not fully realized its potential to understand supply chain risk management capabilities yet.

The supply chain 3Rs are the abilities of supply chains to plan for, respond to, and recover from disruptions in a timely and cost-effective manner. Among the approaches proposed by supply chain experts to enhance resilience and develop recovery plans, supply chain digitalization (SCD) has received much attention recently [4]. Previous studies have found that firms can benefit from developing digitalization to gain competitive advantage [5]. It has been suggested that digitalized supply chains serve to increase information visibility and optimize inter-organizational logistics through end-to-end real-time information access, integration, and control [6, 7]. However, most of the existing research on digitalization is rooted in conventional business operating context,

X. Zhao et al. (Eds.): ICOSCM 2021, RII, pp. 72–86, 2022.
https://doi.org/10.1007/978-981-19-1464-5_7

few have explored the underlying mechanism of digitalization affecting performance from the supply chain risk management perspective, especially during the crisis time.

To address this gap, this study draws on organizational information processing theory (OIPT) [8, 9] to empirically explore supply chain 3Rs as the underlying mechanism through which SCD contributes to improved supply chain performance. We further examine how the influence mechanism of SCD affecting supply chain performance would be contingent upon pandemic impact.

2 Theoretical Background and Literature Review

2.1 Organizational Information Processing Theory

The central logic of OIPT is that firms must effectively collect and process information when performing tasks with great uncertainty [8–10]. To address the uncertainty and eventually achieve organizational effectiveness, organizations should fit their information processing capabilities to the information processing requirement [11]. Information processing capabilities are defined as the abilities to reconfigure resources and technical capital that facilitate information gathering, transformation, communication, and storage [8, 12, 13].

Past studies have identified digital information systems as important ways to enhance the information processing capabilities. In this study, we conceptualize SCD as an effective information processing capability which serves as an information architecture for the information flow along the supply chains. Further, the OIPT also reasons that despite uncertainties/disruptions in the environment, organizations should develop capacity buffers and build a stabilization mechanism that incorporates resources and capabilities to manage unexpected business uncertainty and thus improve performance [5, 8, 14]. In this study, we suggest that the supply chain 3Rs are information intensive process and represent higher-order information processing capabilities which can help firms to utilize and transform the collected data and make effective decisions.

Therefore, drawing on OIPT, we propose that in the context of disruption impact during the COVID-19 pandemic, SCD, representing primary information processing capabilities, enables firms to gather and collect data in real time and promote intensive-information processing mechanisms (i.e., supply chain 3Rs), which contributes to enhanced supply chain performance. The OIPT provides a holistic theoretical base to build a solid research framework for SCD, supply chain 3Rs, and supply chain performance under the disruption impact.

2.2 Supply Chain Digitalization (SCD)

SCD is reshaping business ecosystems and changing the ways of interaction between upstream and downstream stakeholders. From the OIPT perspective, SCD creates increased information processing capabilities through strengthening data collection, storage, big data analysis and implementation [15]. It can release tremendous potential to form super-perceptive, intelligent decision-making, and rapid implementation ability, especially when facing supply chain disruptions [16]. While the value of the SCD has

been recognized in the prior studies (such as speed, visibility, connectivity, transparency, real-time inventory, etc.), it is still not clear how the adoption of SCD affects supply chain performance when faced devasting catastrophes, especially ones such as the largest-scale supply chain disruptions of the COVID-19 pandemic.

2.3 Supply Chain Responsiveness, Resilience, and Restoration (3Rs)

The outbreak of COVID-19 has put the supply chain risk management capabilities the priority of managers [17, 18]. Supply chain risk management is a multi-faceted process, including aspects of proactive planning, quick recovery, and sustainable growth. Accordingly, the 3Rs represent the abilities of supply chains to proactive planning before disruptions, quick recovery during disruptions, and the sustainable growth after disruptions. Specifically, supply chain responsiveness involves the ability of proactive planning, so that the supply chain can respond quickly and accurately to the short-term changes of customer demands and market needs [19–21]. Supply chain resilience concerns the ability to ensure continuity of SC operations and recover quickly from the disruptions caused by external disasters to the original operating level in the damage repair stage [22]. Supply chain restoration refers to the ability to restart supply chain after disruptions and redesign/reconfigure the supply chain to meet new demands under/after external disasters [23].

3 Theoretical Model and Hypotheses Development

3.1 Theoretical Model

Based on OIPT, we develop a conceptual model addressing the relationships among SCD, supply chain 3Rs, supply chain performance, and pandemic impact (see Fig. 1).

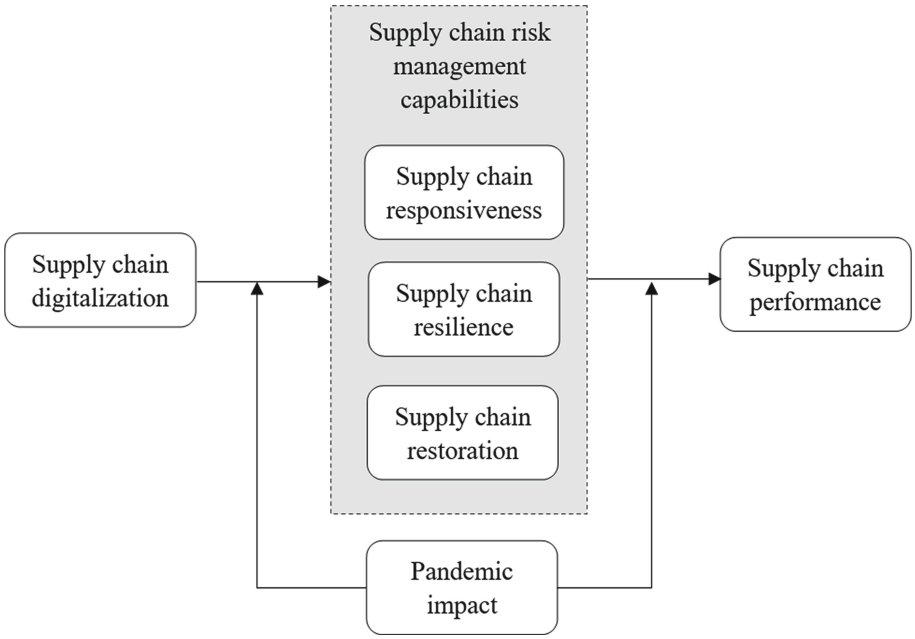

Fig. 1. Conceptual model.

3.2 Hypotheses Development

3.2.1 The Relationships between SCD and Supply Chain 3Rs

The digitalization of the supply chain is enabled by data interaction and it brings new patterns of supply chain risk management with the continuous integration and deepening of advanced technologies and supply chain structure [24]. From the OIPT perspective, supply chains are information-processing systems [8, 14]. Digitalization represents the information processing capabilities of the supply chain and provides the information infrastructure. It can support supply chain 3Rs through connectivity, aggregation, and screening functions, respectively. SCD accelerates the speed of information collection and expands the capacity of information processing, which shortens the distance of information access among the supply chain members. In this way, supply chain managers can quickly perceive the scope of impacts and damage of crisis events, thus improving supply chain 3Rs. Accordingly, we propose the following hypothesis:

Hypothesis 1. *SCD positively influences supply chain (a) responsiveness, (b) resilience, and (c) restoration.*

3.2.2 The Mediating Roles of Supply Chain 3Rs

Building on OIPT, this study proposes that supply chain 3Rs act as underlying mechanism which mediates the relationship between SCD and supply chain performance. Previous literature has highlighted the strategic value of SCD in improving operational efficiency and integrating value chains in terms of high speed, intelligence, transparency, visualization, and scalability [7]. However, recent studies show that solely investing in digitalization along supply chains are not sufficient to achieve desirable performance [16]. Organizations can reap the benefits of digitalization only when they develop necessary capabilities to utilize and capitalize on the collected data [25]. In other words, firms need to update supply chain structure and develop more comprehensive risk management capabilities to sense, shape and seize opportunities through using digital technologies and data effectively, and create and capture supply chain performance in new ways. The digital information systems are considered as the lower-order resource capabilities that generate and collect fragmented data and create a profound ground for building higher-order capabilities, such as supply chain risk management capabilities [5, 26]. Particularly, supply chain 3Rs imply more information-intensive process and further information processing capabilities. The 3Rs provide firms with available assets across supply chain partners, as well as sharing and processing information collected through digital information systems to ensure the normal operations and improve supply chain performance during the crisis. Therefore, we argue that deploying supply chain 3Rs capabilities can help firms leverage the value of SCD. Accordingly, we propose the following hypotheses:

Hypothesis 2. *Supply chain (a) responsiveness, (b) resilience, and (c) restoration mediates the relationship between SCD and supply chain performance.*

3.2.3 The Moderating Role of Pandemic Impact

The disruption impacts during the COVID-19 pandemic has been widely identified as a contextual factor that influence supply chain operations [2, 4]. As the disruption impact increases, firms need to obtain more accurate and sufficient external information to quickly predict change and reduce uncertainty. The value of digitalization is magnified in this context as digitalization infrastructure incorporating supply chain partners can play a more effective role in connecting, aggregating, and screening for recovery and rebound of supply chain operations than those that do not. Therefore, when firms are affected by the supply chain disruption during the COVID-19 heavily, they tend to extend the application of SCD into the process of supply chain risk management to integrate information from both suppliers and customers and establish a relatively stable mechanism.

Moreover, under the impacts of supply chain disruptions, firms tend to establish 3R supply chains to better activate, reconfigure, and transform critical resource endowment. The higher-order information processing capabilities are matched with higher information processing requirements, ultimately achieving the improved supply chain performance [5]. The recent evidence indicates that the relationships between supply chain risks management capabilities and supply chain performance strengthens with the scale of pandemic impact [14], which provides a strong basis for the arguments made in this study. Consequently, the following moderated-mediation hypotheses are proposed in this study.

Hypothesis 3. *The pandemic impact positively moderates the indirect effect of SCD on supply chain performance, such that this indirect effect is stronger with higher degree of pandemic impact.*

4 Research Methodology

4.1 Sampling and Data Collection

The research model was tested using web-based survey data in China in 2021. First, a stratified sampling method was adopted to identify 600 firms from the potential sample pool of Yellow Pages of China Telecom. Senior managers and supply chain managers were targeted for this study. Finally, 215 valid questionnaires were received.

4.2 Measures

To measure SCD, we comprehensively considered the scales of Xue et al. [27] and Xue [28]. Supply chain responsiveness were measured in line with the definitions in the mainstream supply chain literature [29]. The measurements of the supply chain resilience were adopted from Elbaz and Ruel [30]. Supply chain restoration was developed and adapted from Essuman et al. [31]. Based on insights from Belhadi et al. [5] and Srinivasan and Swink [32], identified four items were used to capture supply chain performance. The measurement of pandemic impact was drawn from El Baz and Ruel [30]. A Likert

scale with seven points was used to measure each of the items, in which 5 indicates strongly agree and 1 indicates strongly disagree. Respondents were required to indicate their degree of recognition regarding the statements. We also controlled for ownership type, firm age, and development stage. Scholars have indicated that ownership type may influence supply chain activities and performance [33]. This study used dummy variables for ownership types. Firm age and development stage have often been used as control variables in previous studies.

5 Results

5.1 Measurement Validation and Construct Development

Content validity was verified as the measurement constructs were strongly supported by theories and practice developed in previous studies, and it was also verified in pre-tests. The results of the overall exploratory factor analysis (EFA) indicate that the factor loading of each item on its corresponding construct was greater than 0.6, while the cross loadings on other constructs were less than 0.4. This provides comforting evidence of convergent and discriminant validity for the whole measurement model.

Confirmatory factor analysis (CFA) was used to verify the reliability and convergent validity of the whole measurement (Table 1). The factor loadings of the items range from 0.740 to 0.987, with all above the 0.7 threshold. Cronbach's alphas for the constructs were above the 0.70 threshold recommended by Nunnally and Bernstein [34], and the composite reliability (C.R.) values all reached the recommended 0.7 threshold [34, 35]. The average variance extracted (AVE) values of the constructs also reached the 0.5 threshold recommended by Fornell and Larcker [36].

Table 1. Construct reliability and validity.

Item	Factor loading	AVE	CR	Cronbach's alpha
Supply chain digitalization		0.761	0.927	0.983
SCD1	0.972			
SCD 2	0.969			
SCD 3	0.973			
SCD 4	0.987			
Supply chain responsiveness		0.644	0.878	0.919
SCRESP1	0.837			
SCRESP2	0.899			
SCRESP3	0.932			
SCRESP4	0.918			
Supply chain resilience		0.665	0.888	0.932
SCRESI1	0.874			
SCRESI2	0.940			
SCRESI 3	0.918			

(*continued*)

Table 1. (*continued*)

Item	Factor loading	AVE	CR	Cronbach's alpha
SCRESI 4	0.915			
Supply chain restoration		0.704	0.905	0.954
SCREST1	0.946			
SCREST 2	0.905			
SCREST 3	0.959			
SCREST 4	0.941			
Supply chain performance		0.618	0.865	0.899
SCP1	0.740			
SCP 2	0.925			
SCP 3	0.933			
SCP 4	0.903			
Pandemic impact		0.516	0.984	0.918
PI1	0.923			
PI2	0.935			
PI3	0.924			

Table 2 shows the correlation coefficients of the constructs, with numbers on the diagonal representing the arithmetic square root of each construct's AVE. The arithmetic square root of each construct's AVE was greater than its correlation coefficients with the other constructs, indicating adequate discriminant validity [36]. In general, the results shown in Table 1 and Table 2 support the measurement model.

Table 2. Mean, standard deviations, and correlations

Variables	Mean	SD	1	2	3	4	5	6
1.Supply chain digitalization	2.64	0.86	**0.873**					
2.Supply chain responsiveness	3.17	0.80	0.418***	**0.802**				
3.Supply chain resilience	3.22	0.66	0.539***	0.493***	**0.815**			
4.Supply chain restoration	3.31	0.70	0.488***	0.537***	0.517***	**0.839**		
5.Supply chain performance	3.08	0.62	0.484***	0.394***	0.507***	0.437***	**0.786**	
6.Pandemic impact	3.42	0.90	0.229**	0.287***	-0.068	-0.036	-0.013	**0.718**

(Note: N = 215. The diagonal elements (in bold) are the square roots of the AVE values. Off-diagonal elements are the correlations among constructs in the model; +p <0.10, *p < 0.05, **p < 0.01, ***p < 0.001)

5.2 Hypotheses Testing

This study used the PROCESS proposed by (Hayes 2017) to validate the hypotheses. The results are shown in Table 3. To test hypotheses 1a, 1b, 1c, 2a, 2b, 2c, we built the mediation model using "Model 4" in PROCESS. Controlling for the firm size, firm age, development stages, and ownership, SCD positively influences supply chain responsiveness ($\beta = 0.40$, $t = 6.54$, and $p = 0.00$), supply chain resilience ($\beta = 0.39$, $t = 8.22$, and $p = 0.00$), and supply chain restoration ($\beta = 0.39$, $t = 7.61$, and $p = 0.00$). Therefore, H1a, H1b, and H1c were strongly supported. H2a, H2b, and H2c tested the mediation effects of supply chain 3Rs on the relationship between SCD and supply chain performance. The results in Table 4 showed that the indirect effects of SCD on supply chain performance through supply chain responsiveness ($\beta = 0.07$), supply chain resilience ($\beta = 0.18$), and supply chain restoration ($\beta = 0.09$) were all significant. Therefore, H2a, H2b, and H2c were supported in this study.

To test H3, PROCESS macro in SPSS with a bootstrapping analysis on default 5000 resamples and 95% CI were used. The regression results were shown in panel A and panel B of Table 5 and 6. The results indicated that the interaction effect between SCD and pandemic impact had a positive effect on supply chain responsiveness ($\beta = 0.20$, $t = 3.47$, and $p = 0.00$), supply chain resilience ($\beta = 0.17$, $t = 3.92$, and $p = 0.00$), and supply chain restoration ($\beta = 0.13$, $t = 2.68$, and $p = 0.01$). Similarly, the interaction term between pandemic impact and supply chain 3Rs had significant and positive impact on supply chain performance, with the $\beta = 0.06$, $t = 1.23$, and $p = 0.22$ for supply chain responsiveness, $\beta = 0.11$, $t = 2.30$, and $p = 0.02$ for supply chain resilience, and $\beta = 0.16$, $t = 3.15$, and $p = 0.00$ for supply chain restoration. The regression results of the conditional indirect influence of SCD on supply chain performance through supply chain 3Rs are reported in Table 7. The findings indicated that the mediation effects of supply chain 3Rs on the relationship between SCD and supply chain performance was stronger when pandemic impact was higher. Therefore, H3 was also supported in this study.

Table 3. Regression results for H1a, H1b, and H1c

Variables	Supply chain responsiveness			Supply chain resilience			Supply chain restoration		
	β	T	p	B	T	p	β	T	p
Constant	2.25	8.28	**0.00**	2.02	9.69	0.00	2.13	9.39	0.00
Firm size	0.07	0.81	**0.42**	0.08	1.23	0.22	0.10	1.42	0.16
Firm age	−0.07	−1.01	**0.31**	−0.02	−0.33	0.75	−0.02	−0.27	0.79
Development stage1	−0.07	−0.37	**0.71**	0.03	0.20	0.84	0.04	0.25	0.81
Development stage2	−0.20	−1.08	**0.28**	0.11	0.73	0.46	−0.01	−0.06	0.95
Development stage3	−0.05	−0.30	**0.77**	0.22	1.69	0.09	0.18	1.25	0.21
Ownership	−0.23	−1.15	**0.25**	0.04	0.25	0.81	−0.12	−0.73	0.46
SCD	0.40	6.54	**0.00**	0.39	8.22	0.00	0.39	7.61	0.00
R^2	0.19			0.31			0.26		
F	8.02***			13.19***			10.40***		

(Notes: *p < 0.05,**p < 0.01,***p < 0.001).

Table 4. Regression results for H2a, H2b, and H2c

Variables	Supply chain performance			Supply chain performance			Supply chain performance		
	β	T	p	β	T	p	β	T	p
Constant	1.83	8.00	0.00	1.32	6.06	0.00	1.75	7.41	0.00
Firm size	−0.03	−0.54	0.59	−0.06	−1.01	0.31	−0.04	−0.71	0.48
Firm age	0.03	0.65	0.52	0.03	0.61	0.54	0.02	0.47	0.64
Development stage1	−0.13	−0.97	0.33	−0.16	−1.27	0.20	−0.15	−1.14	0.26
Development stage2	−0.19	−1.40	0.16	− 0.27	−2.20	0.03	−0.22	−1.66	0.10
Development stage3	0.04	0.28	0.78	−0.07	−0.64	0.52	−0.01	−0.12	0.91
Ownership	−0.09	−0.60	0.55	−0.15	−1.10	0.27	−0.10	−0.69	0.49
SCD	0.28	5.64	0.00	0.17	3.70	0.00	0.26	5.15	0.00
SCRESP	0.18	3.53	0.00						
SCRESI				0.45	7.45	0.00			
SCREST							0.23	3.78	0.00
R^2	0.30			0.42			0.31		
F	10.92***			18.17***			11.22***		
Indirect effect	0.07			0.18		z	0.09		
95%CI	[0.03, 0.12]			[0.11, 0.26]			[0.04, 0.16]		

(Notes: *p < 0.05, **p < 0.01, ***p < 0.001).

Table 5. Regression results for moderation effect of pandemic impact (Panel A)

Variables	Supply chain responsiveness			Supply chain resilience			Supply chain restoration		
	β	T	p	β	T	p	β	T	p
Constant	3.11	5.47	0.00	3.75	8.41	0.00	3.44	6.90	0.00
Firm size	0.14	1.64	0.10	0.09	1.43	0.16	0.11	1.55	0.12
Firm age	−0.09	−1.40	0.16	−0.04	−0.82	0.41	−0.03	−0.60	0.55
Development stage1	−0.01	−0.07	0.95	0.01	0.01	0.98	0.02	0.11	0.91
Development stage2	−0.19	−1.08	0.28	0.06	0.42	0.67	−0.04	−0.29	0.77
Development stage3	0.01	0.06	0.95	0.17	1.33	0.18	0.14	0.99	0.32
Ownership	−0.14	−0.73	0.47	0.08	0.52	0.60	−0.09	−0.55	0.58
SCD	−0.26	−1.39	0.17	−0.17	−1.10	0.27	−0.03	−0.19	0.85
PI	− 0.28	−1.82	0.07	− 0.52	−4.34	0.00	−0.39	−2.93	0.00
SCD*PI	0.20	3.47	0.00	0.17	3.92	0.00	0.13	2.68	0.01
R^2	0.29			0.37			0.29	z	
F	9.26***			13.23**			9.30***		

(Notes: *p < 0.05, **p < 0.01, ***p < 0.001).

Table 6. Regression results for moderation effect of pandemic impact (Panel B)

Variables	Supply chain performance			Supply chain performance			Supply chain performance		
	β	T	p	β	T	p	β	T	p
Constant	2.67	5.14	0.00	2.67	4.32	0.00	3.81	5.71	0.00
Firm size	− 0.04	−0.77	0.45	−0.04	−0.72	0.47	−0.04	−0.62	0.53
Firm age	0.03	0.59	0.56	0.02	0.35	0.73	0.01	0.13	0.90
Development stage1	−0.13	−0.98	0.33	−0.16	−1.31	0.19	−0.20	−1.53	0.12
Development stage2	−0.19	−1.41	0.16	−0.26	−2.11	0.04	−0.27	−1.99	0.05
Development stage3	0.02	0.18	0.86	−0.05	−0.45	0.65	−0.05	−0.44	0.66
Ownership	−0.08	−0.57	0.57	−0.13	−0.96	0.34	−0.05	−0.38	0.71
SCD	0.27	5.51	0.00	0.17	3.68	0.00	0.25	4.91	0.00
SCRESP	0.02	0.12	0.90						
SCRESI				0.05	0.25	0.80			
SCREST							−0.32	−1.75	0.08
PI	−0.27	−1.86	0.06	−0.36	−2.33	0.02	−0.59	−3.29	0.00
SCRESP *PI	0.06	1.23	0.22						
SCRESI*PI				0.11	2.30	0.02			
SCREST*PI							0.16	3.15	0.00
R^2	0.32			0.43			0.34		
F	9.62***			15.33***			10.45***		

(Notes: *p < 0.05, **p < 0.01, ***p < 0.001).

Table 7. Conditional indirect effect of supply chain digitalization on supply chain performance at different levels of pandemic impact

Mediators	Condition of pandemic impact	Indirect effect	Bootstrapped SE	95%CI
Supply chain responsiveness	Low (−1SD)	0.04	0.02	[0.01, 0.09]
	Mean	0.09	0.02	[0.05, 0.14]
	High (+1SD)	0.15	0.05	[0.07, 0.25]
Supply chain resilience	Low (−1SD)	0.09	0.04	[0.02, 0.18]
	Mean	0.18	0.04	[0.11, 0.27]
	High (+1SD)	0.30	0.07	[0.17, 0.43]
Supply chain restoration	Low (−1SD)	0.03	0.03	[−0.03, 0.09]
	Mean	0.10	0.03	[0.05, 0.17]
	High (+1SD)	0.21	0.05	[0.11, 0.32]

6 Discussion and Conclusions

6.1 Theoretical Implications

Based on the OIPT, we propose and examine the mediation effects of supply chain 3Rs and the moderation effect of pandemic impact during the COVID-19. The empirical results contribute to literature of supply chain management in the digital age from the following three aspects.

First, this study finds that SCD is positively associated with supply chain 3Rs. Past research suggests that SCD involves information generation and collection processes, but the existing literature lacks an understanding of the role of SCD in achieving supply chain risk management [37]. The findings enrich the existing literature of SCD, and respond to the calls of Seyedghorban et al. [7] and Appio et al. [37] to explore how digitalization can enhance supply chain risk management capabilities. Our results contribute to a better understanding of the integration of the advanced SCD and its significant effect on firms' supply chain 3Rs capabilities development.

Second, this study proposes and investigates the mediating roles of supply chain 3Rs serving as the underlying mechanisms through which SCD affects supply chain performance. The increasingly frequent supply chain disruptions have led to calls for more empirical research on supply chain 3Rs to help firms survive through the difficult times. In this study, we clarify supply chain risk management capabilities from three different aspects, that is responsiveness, resilience, and restoration. The empirical findings extend the existing research of the supply chain 3Rs and identify the 3Rs as the mediating roles which explain why investment in SCD is likely to improve supply chain performance.

Finally, this study indicates that pandemic impact positively moderates the indirect effect of SCD on supply chain performance through supply chain 3Rs. To the best of our knowledge, empirical research on the pandemic impact as a moderating factor in the field of supply chain management is limited. Our results reveal that, when suffering from the COVID-19 pandemic, firms should not only rely on the information collected by the digitalization infrastructure but also build higher-order information processing capabilities and stabilization mechanisms, i.e., supply chain 3Rs, to utilize and transform the collected information, thereby realizing higher supply chain performance. Overall, SCD and supply chain 3Rs play a more critical role during the COVID-19 pandemic.

6.2 Practical Implications

Our empirical results also provide insightful practical implications. Digitalization is promoting firms to update supply chain management strategies and practices. Firms are thus suggested to apply digital supply chain information systems to achieve the sustainable development of supply chains. It should be noted that supply chain management activities in the current turbulent business environment are highly information-intensive. Firms can only gain a competitive advantage if they have access to adequate, accurate, and real-time information. SCD is destined to be one of the most important choices for firms to succeed in supply chain management, especially under the ongoing impact of supply chain disruptions during the pandemic.

Our results further imply that companies should integrate the adoption of SCD into supply chain risk management processes and build supply chain 3Rs capabilities. Previous literature has highlighted the significant value of supply chain risk management capabilities in dealing with the disruption events [38, 39]. This study indicates that supply chain 3Rs play crucial roles in achieving supply chain performance during the crisis.

6.3 Limitations and Future Research

The following are the limitations of this research and the future research directions. First, the data in this study was only obtained from China. Although the outbreak of COVID-19 sweeps through global supply chains, the impact pattern may differ across each country. Therefore, further research is suggested to examine whether the conclusion in this study is applicable to other countries' supply chains. Moreover, we used cross-sectional data to analyze the relationships, and further longitudinal studies are called for to verify the causal relationships dynamically over time. Finally, we only examined the impact of SCD on the supply chain performance. Other aspects of performance, such as financial performance, innovation performance, etc. can be considered in the future research.

Appendix. Measurement Items

Supply Chain Digitalization

(1) The proportion of suppliers that our firm transacts with and collects real-time information from through digital supply chain systems, such as the Internet of Things, artificial intelligence (AI), cloud computing, and big data analytics, etc.
(2) The proportion of transaction volume and activities that our firm conducts with our suppliers through digital supply chain systems, such as the Internet of Things, artificial intelligence (AI), cloud computing, and big data analytics, etc.
(3) The proportion of customers that our firm transacts with and collects real-time information from through digital supply chain systems, such as the Internet of Things, artificial intelligence (AI), cloud computing, and big data analytics, etc.
(4) The proportion of transaction volume and activities that our firm conducts with our customers through digital supply chain systems, such as the Internet of Things, artificial intelligence (AI), cloud computing, and big data analytics, etc.

Supply Chain Responsiveness

(1) Our supply chain can make full preparations and effectively handle the difficult nonstandard orders.
(2) Our supply chain can make full preparations and quickly meet special customer specification.

(3) Our supply chain can make full preparations and rapidly adjust production capacity in response to changes in customer demand.
(4) Our supply chain can introduce large numbers of product improvement quickly to deal with the unforeseen demands.

Supply Chain Resilience

(1) Material flow would be quickly recovered.
(2) It would not take long for our supply chains to recover normal operating performance.
(3) The supply chain would easily recover to its original state.
(4) Supply chain disruptions would be dealt with quickly.

Supply Chain Restoration

(1) Our supply chain can restore operations and grow to a more desirable state quickly and effectively when faced with supply chain disruption.
(2) Our supply chain can redesign the structure to a more desirable state quickly and effectively when faced with supply chain disruptions.
(3) Our supply chain can restart operations to a more desirable state reliably when faced with supply chain disruption.
(4) Our supply chain can transform the customer value to a more desirable state easily when faced with supply chain disruption.

Supply Chain Performance

(1) The costs of per unit of goods and service are lower than our competitors.
(2) Our supply chain can deliver goods and service more punctually than our competitors.
(3) Our supply chain can deliver goods and service more reliably than our competitors.
(4) Our supply chain has a shorter lead time for order fulfillment than our competitors.

Pandemic Impact

(1) The extent of the impact of the pandemic on the supply chain's overall operating efficiency.
(2) The extent of the impact of the pandemic on the customers' order fulfillment.
(3) The extent of the impact of the pandemic on the procurement from suppliers.

References

1. Fortune.: 94% of the Fortune 1000 are seeing coronavirus supply chain disruptions (2020). https://fortune.com/2020/02/21/fortune-1000-coronavirus-china-supply-chain-impact/. Accessed 10 Jul 2021
2. Ivanov, D., Dolgui, A.: Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. Int. J. Prod. Res. **58**(10), 2904–2915 (2020)
3. Linton, T., Vakil, B.: Coronavirus is proving that we need more resilient supply chains. Harvard Business Review. https://hbr.org/2020/03/coronavirus-isproving-that-we-need-more-resilient-supply-chains#comment-section. Accessed 1 Jul 2021
4. Van Hoek, R., Lacity, M.: How the pandemic is pushing blockchain forward, Harvard Business Review. https://hbr.org/2020/04/how-the-pandemic-ispushing-blockchain-forward. Accessed 1 Jul 2021
5. Belhadi, A., Mani, V., Kamble, S.S., Khan, S.A.R., Verma, S.: Artificial intelligence-driven innovation for enhancing supply chain resilience and performance under the effect of supply chain dynamism: an empirical investigation. Ann. Oper. Res. 1–26 (2021). https://doi.org/10.1007/s10479-021-03956-x
6. Kache, F., Seuring, S.: Challenges and opportunities of digital information at the intersection of big data analytics and supply chain management. Int. J. Oper. Prod. Manag. **37**(1), 10–36 (2017)
7. Seyedghorban, Z., Tahernejad, H., Meriton, R., Graham, G.: Supply chain digitalization: past, present and future. Prod. Plan. Control **31**(2–3), 96–114 (2020)
8. Galbraith, J.R.: Designing Complex Organizations. AddisonWesley Pub. Co., Reading (1973)
9. Galbraith, J. R.: Organization Design. Addison-Wesley Pub. Co., Reading (1977)
10. Galbraith, J.R.: Organization design: an information processing view. Interfaces (Providence) **4**(3), 28–36 (1974)
11. Egelhoff, W.G.: Information-processing theory and the multinational enterprise. J. Int. Bus. Stud. **22**(3), 341–368 (1991)
12. Tushman, M.L., Nadler, D.A.: Information processing as an integrating concept in organizational design. Acad. Manag. Rev. **3**(3), 613–624 (1978)
13. Li, Y., Dai, J., Cui, L.: The impact of digital technologies on economic and environmental performance in the context of industry 4.0: a moderated mediation model. Int. J. Prod. Econ. **229**, 107777 (2020)
14. Wong, C., Lirn, T.C., Yang, C.C., Shang, K.C.: Supply chain and external conditions under which supply chain resilience pays: an organizational information processing theorization. Int. J. Prod. Econ. **226**, 107610 (2020)
15. Porter, M.E., Heppelmann, J.E.: How smart, connected products are transforming companies. Harv. Bus. Rev. **93**(10), 96–114 (2015)
16. Kohtamäki, M., Parida, V., Patel, P.C., Gebauer, H.: The relationship between digitalization and servitization: the role of servitization in capturing the financial potential of digitalization. Technol. Forecast. Soc. Change **151**, 119804 (2020)
17. Sarkis, J.: Supply chain sustainability: learning from the COVID-19 pandemic. Int. J. Oper. Prod. Manag. **41**(1), 63–73 (2020)
18. Remko, V.H.: Research opportunities for a more resilient post-COVID-19 supply chain–closing the gap between research findings and industry practice. Int. J. Oper. Prod. Manag. **40**(4), 341–355 (2020)
19. Asamoah, D., Nuertey, D., Agyei-Owusu, B., Akyeh, J.: The effect of supply chain responsiveness on customer development. Int. J. Logist. Manag. **32**(4), 1190–1213 (2021)

20. Christopher, M.: Logistics and Supply Chain Management. Pearson Education, London (2016)
21. Danese, P., Romano, P., Formentini, M.: The impact of supply chain integration on responsiveness: the moderating effect of using an international supplier network. Transp. Res. Part E Logist. Transp. Rev. **49**(1), 125–140 (2013)
22. Jain, V., Kumar, S., Soni, U., Chandra, C.: Supply chain resilience: model development and empirical analysis. Int. J. Prod. Res. **55**(22), 6779–6800 (2017)
23. Norrman, A., Jansson, U.: Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. Int. J. Phys. Distrib. Logist. Manag. **34**(5), 434–456 (2004)
24. Schniederjans, D.G., Curado, C., Khalajhedayati, M.: Supply chain digitisation trends: an integration of knowledge management. Int. J. Prod. Econ. **220**, 107439 (2020)
25. Hasselblatt, M., Huikkola, T., Kohtamäki, M., Nickell, D.: Modeling manufacturer's capabilities for the internet of things. J. Bus. Ind. Mark. **33**(6), 822–836 (2018)
26. Wamba, S.F., Dubey, R., Gunasekaran, A., Akter, S.: The performance effects of big data analytics and supply chain ambidexterity: The moderating effect of environmental dynamism. Int. J. Prod. Econ. **222**, 107498 (2020)
27. Xue, L., Zhang, C., Ling, H., Zhao, X.: Risk mitigation in supply chain digitization: system modularity and information technology governance. J. Manag. Inf. Syst. **30**(1), 325–352 (2013)
28. Xue, L.: Governance–knowledge fit and strategic risk taking in supply chain digitization. Decis. Support Syst. **62**, 54–65 (2014)
29. Qrunfleh, S., Tarafdar, M.: Lean and agile supply chain strategies and supply chain responsiveness: the role of strategic supplier partnership and postponement. Supply Chain Manag. Int. J. **18**(6), 571–582 (2013)
30. El Baz, J., Ruel, S.: Can supply chain risk management practices mitigate the disruption impacts on supply chains' resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era. Int. J. Prod. Econ. **233**, 107972 (2021)
31. Essuman, D., Boso, N., Annan, J.: Operational resilience, disruption, and efficiency: conceptual and empirical analyses. Int. J. Prod. Econ. **229**, 107762 (2020)
32. Srinivasan, R., Swink, M.: An investigation of visibility and flexibility as complements to supply chain analytics: an organizational information processing theory perspective. Prod. Oper. Manag. **27**(10), 1849–1867 (2018)
33. Liu, H., Wei, S., Ke, W., Wei, K.K., Hua, Z.: The configuration between supply chain integration and information technology competency: a resource orchestration perspective. J. Oper. Manag. **44**, 13–29 (2016)
34. Nunnally, J.C., Bernstein, I.H.: Psychometric Theory. McGraw-Hill, New York (1994)
35. Dijkstra, T.K., Henseler, J.: Consistent partial least squares path modeling. MIS Q. **39**(2), 297–316 (2015)
36. Fornell, C., Larcker, D.F.: Evaluating structural equation models with unobservable variables and measurement error. J. Mark. Res. **18**, 39–50 (1981)
37. Appio, F.P., Frattini, F., Petruzzelli, A.M., Neirotti, P.: Digital transformation and innovation management: a synthesis of existing research and an agenda for future studies. J. Prod. Innov. Manag. **38**(1), 4–20 (2021)
38. Yang, J., Xie, H., Yu, G., Liu, M.: Antecedents and consequences of supply chain risk management capabilities: an investigation in the post-coronavirus crisis. Int. J. Prod. Res. **59**(5), 1573–1585 (2021)
39. Revilla, E., Saenz, M.J.: The impact of risk management on the frequency of supply chain disruptions: a configurational approach. Int. J. Oper. Prod. Manag. **37**(5), 557–576 (2017)