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The effect of supply chain risk management on supply chain resilience: The intervening part of Internet-of-Things

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The aim of this study is to investigate the effect of supply chain risk management on supply chain resilience in the presence of Internet-of-Things as an intermediate variable. In other words, the study seeks to identify whether supply chain risk management completely affects supply chain resilience. Collecting data by a questionnaire from a sample composed of managers of Jordanian industrial firms, the results show that supply chain risk management has a direct and indirect effect on supply chain resilience through Internet-of-Things. These results do not support the hypothesis that supply chain risk management completely affects supply chain resilience and accepted the hypothesis that Internet-of-Things intervenes the effect of supply chain risk management on supply chain resilience. The study contributes to the literature through filling a research gap regarding the mediating role of Internet-of-Things in the relationship between supply chain risk management and supply chain resilience and contributes to the industry through instructing managers to adopt technologies such as Internet-of-Things to help their firms cope with supply chain risks.

1. Introduction

Supply chains all over the world are subject to a variety of risks that emerge from different sources such as firms, suppliers, customers, and exterior environment factors like marketplaces. For that reason, there is an urgent need to manage these risks through applying effective practices to boost supply chain (SC) competencies to make SCs more resilient to unsteady situations due to unforeseen events. As such, it was understood that a strategic target of firms is to cognize and apply the ways by which supply chain resilience (SCRS) is developed or recovered. Scholars (e.g., Rajesh & Ravi, 2015; Um and Han, 2021) describe making decisions to manage SC tasks and to control SC risks as a complicated process.

Pertaining to such an aim, numerous works on SCRS acknowledged effective practices of SC risk management in boosting SCRS. Cause-focused and effect-directed practice are examples of these practices (Wagner and Bode, 2009). Other scholars (e.g., Rajesh & Ravi, 2015; Simba et al., 2017; Um & Han, 2021) advocate risk mitigation strategies and resilience proficiencies as valuable approaches that firms could use to boost SCRS. Risk mitigation facilitators that are suggested by scholars include strategies for reactive prices, precise predicting of customer demands, acclimatization of relevant technologies, strategic shaping of SC risks, SC receptiveness, and cognizance of future events (Rajesh & Ravi, 2015).

In the same vein, scholars (e.g., Li & Li, 2017; Ben-Daya et al., 2019, 2022; Kothari et al., 2018; Gerami & Sarihi, 2020) recognize the importance of information technologies advancements such as Internet-of-Things (IoT) in SC management. Despite the importance of IoT, its critical potential in supply chain management has not until now been acknowledged (Li & Li, 2017). Moreover, the intermediating part of IoT between SC risk management practices and SCRS has not yet been established in the literature. On the ground of such a research gap and in order to gauge the role of IoT in parallel with SC

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risk management procedures, this study aims at opening up if IoT complements or substitutes SC risk management preparations in boosting SCRS through investigating the mediating role of IoT between SC risk management and SCRS.

The following section presents a review of the related literature on SC risk management, IoT, SCRS as well as hypotheses development. Section 3 clarifies research methodology in terms of research sample and data collection, research measures, research conceptual model, along with reliability and validity tests. Section 4 displays the results that are induced based on data analysis and results discussion. Finally, research theoretical and practical implications and conclusions are illustrated in section 5.

2. Literature review and hypotheses development

2.1 SC risk management

Definitions of SC risk management cover two major aspects related to objectives and practices of managing SC risk. Ho et al. (2015, p. 5036) described SC risk management as "an inter-organizational collaborative endeavor utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain". This definition indicates that the aims of SC risk management are embedded into four functions: risk detection, risk estimation, risk observing, and risk modification. As a process, SC risk management aims at fulfilling strategies that support in getting along SC risks through risk review to diminish liability and guarantee endurance (Simba et al., 2017). Examples of SC risks include risks related to sourcing such as risks associated with quality of materials and relationships, risks interrelated to manufacturing like production capacity and cost, and risks allied to delivery such as logistics costs and inventory disturbance (Um and Han, 2021). Such risks may possibly be managed via processes used to identify SC risk, assess SC risks, mitigate SC risks, and monitor SC risks (Simba et al., 2017). Good practices of SC risk management as conveyed in the literature include well SC communications, training program on SC risk management and management of business stability, as well as foundation of chief risk officer (Blos et al., 2009). Moreover, sharing risk information and sharing risk mechanisms are two effective practices of SC risk management (Li et al., 2015). Other common practices of SC risk management are risk identification, risk evaluation, risk monitoring, and risk mitigating (Ho et al., 2015; Simba et al., 2017). For this study, SC risk management practices, following Wagner and Bode (2009), are operationalized in terms of risk causes and risk effects. On one hand, practices of risk causes refer to preemptive and avoidance activities aiming at shrinking the possibility of risk happening. On the other hand, practices of risk effects refer to flexible and redundant activities striving to mitigate risk upshots. According to Wagner and Bode (2009), cause-directed activities include swapping to financially long-standing suppliers, moving production processes to not dangerous regions, and educating employee to acquire good skills in information security, while effect-focused activities embrace designing multiple sourcing portfolio to increase SC diversity, designing standardized products to augment firms' tolerance in contradiction of demand and supply insecurities. These practices are suitable for the present study as it seeks to identify the potentials of SC risk management practices for SCRS.

2.2 IoT

IoT was first introduced by Kevin Ashton in 1999 who defined this term as "the network of physical objects embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data, often using the Internet" (Kothari et al., 2018, p. 257). The idea behind IoT is drawn by three characteristics refer to objects interaction with the surrounded environment, objects communication with each other, and optimized functions of objects (Witkowski, 2017; De Vass, Shee & Miah, 2021a,b; Nozari, Fallah, Szmelter-Jarosz, 2021). Ben-Daya et al. (2019, p. 4723) defined IoT in SC management context as "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". According to Li and Li (2017), IoT includes data collection using sensors, the Internet to connect physical objects, data storage using a cloud, data analysis by means of digital applications such as machine learning. Benefits of IoT in SC risk management context as reported in some previous works include ensuring right goods with right quantities and quality in right places within the right time (Ben-Daya et al., 2019, 2022), enhancing logistics control, improving real-time visibility, as well as timely tracking of inventory (Kothari et al., 2018), increasing firms' productivity (Al-Tit, 2016), increasing speed of SC decision making, and reducing SC risks (Gerami & Sarihi, 2020).

2.3 SCRS

SCRS has been defined as an acclimatized competence that empowers firms to be equipped for unpredicted occasions, neutralizes troubles, and restores jobs to a steady status by means of control across SC organization and roles (Simba et al., 2017). Fiksel et al. (2015 cited in Um and Han, 2021, p. 243) perceive SCRS in terms of three crucial proficiencies: firm ability to continue, firm aptitude to adjust, and firm capability to develop despite disordered surrounded changes. Um and Han (2021, p. 243) define SCRS as "the ability to tolerate supply chains in sourcing, manufacturing and delivery". The importance of SCRS surfaces from preparing firms for future events, decreasing disruption impacts, strengthening firms' abilities to recover rapidly from interruptions (Um and Han, 2021) and, therefore, enhancing firms' efficiency, cost-effectiveness, and effectiveness (Simba et al., 2017). In terms of SCRS proficiencies, Simba et al. (2017) viewed SC flexibility and SC redundancy as two key competencies of SCRS. The authors labeled flexibility as a risk conduct feature through response speed and characterized SC redundancy as a risk preventive feature through reserves like stock readiness and multiple-supplier sourcing.

2.4 SC risk management, IoT and SCRS

The positive influence of SC risk management processes on SCRS has been mentioned in numerous works. Investigating such an influence in the grocery industry, Simba et al. (2017) found that SCRS could be enhanced through managing processes of SC risks such as risk detection, risk valuation, risk moderation, and risk checking. Zineb et al. (2017) examined the effect of SC risk management practices (flexibility, collaboration, and redundancy) on supply chain resilience and found a positive impact of both flexibility and collaboration on supply chain resilience. Saglam et al. (2020) studied the effects of some risk mitigation strategies (i.e., SC flexibility, SC responsiveness and resilience, and SC risk management performance) and pointed out a significant effect of SC responsiveness and resilience on SC risk management performance. These results signal a possible effect of SC risk management on SCRS using data of the current study.

One more vein of the literature underscores the consequence of innovative information technology solutions such as IoT to cope with SC challenges. Ben-Daya et al. (2019) state that producing practical information using IoT supports firms to early detect circumstances that entail resolutions, timely respond to surprising distractions, limit real-time concerning data acquisition and decision making, enhance SC visibility and agility as well as recover SC good organization. Li and Li (2017) emphasized the importance of IoT in terms of data sharing and analysis, demand and supply matching, quality improving, and logistics integrating. Kothari et al. (2018) interpreted IoT as an optimal solution for supply chain management challenges such as deficit of physical assets visibility, ineffective control of inventory, inadequate processing of data, and ineffective management of SC risks. For Gerami and Sarihi (2020), IoT is a critical factor for SC management as it leads to well-timed decisions, enhanced productivity, and diminished risks. Kothari et al. (2018) added significant features of IoT such as appropriate tracking, suitable identification of locations, and replication avoidance.

Inferring assumptions about the influence of SC risk management practices on SCRS through IoT from the aforementioned studies leads to presuming that SC risk management practices guide SCRS to the better. Plus, it was rumored that IoT has a critical capacity in this regard. Explicitly, IoT intermediates the influence of SC risk management practices on firm's SCRS state. Hence, the following two hypotheses are postulated:

H_1: *SC risk management practices completely affect SCRS.*

H_2: *IoT intervenes the effect of SC risk management on SCRS.*

3. Research methodology

3.1 Sample and data collection

The population of the study consists of managers of Jordanian industrial firms. A convenience sample consisting of 123 managers was used to gather research data using an online questionnaire, which was designed using five points Likert scale (5: strongly agree, 4: agree, 3: neutral, 2: disagree, and 1: strongly disagree). The final number of responses that was accepted for data analysis is 112 questionnaires after excluding 11 questionnaires as outliers.

3.2 Measures

Measures of SC risk management practices are grounded on Wagner and Bode (2009) who recognized two key sets of these practices, which are "cause-oriented practices" and "effect-oriented practices". The former one appraised 5 items about information tractability, censoring, marketplaces, origins of supplies, and geographical areas. The second one was gauged passing through 5 items concerning risk transmission, unforeseen event plans, extra inventory, and insurance. SC resilience enumerated by 5 items constructed based on Um and Han's (2021) work, by which SC resilience was conceptualized in terms of supplier risk, customer risk, firm quick response, frim operations, and firm-supplier information sharing. Finally, IoT was weighed through 5 items developed based on previous studies (i.e., Li & Li, 2017; Kothari et al., 2018; Gerami & Sarihi, 2020; Kumar et al., 2022; Nozari et al., 2022; Prajapati et al., 2022).

3.3 Conceptual model

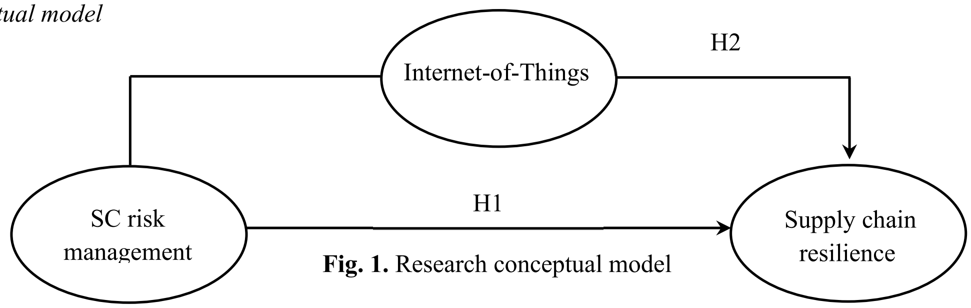

Fig. 1. Research conceptual model

Fig. 1 shows the conceptual model in which two hypotheses were postulated. The first one (H1) represents the effect of SC risk management on supply chain resilience, and the second one (H2) reflects the intermediating role of Internet-of-Things in the effect of SC risk management on supply chain resilience. Testing these two hypotheses requires testing the effect of

SC risk management on both Internet-of-Things and supply chain resilience and testing the effect of Internet-of-Things on supply chain resilience.

3.4 Validity and reliability

Validity was computed based on convergent validity and discriminant validity. Convergent validity in the current study is a function of the standardized factor loadings (SFL) and the average variance extracted (AVE) while discriminant validity is a function of the square roots of AVE values and factor cross loadings. Then again, reliability was measured using coefficients of Cronbach's alpha (α) and composite reliability (CR). Thresholds of these indexes as reported in the literature assume that SFL should be upper than 0.5, AVE values should be greater than 0.50, values of Cronbach's alpha and CR should be better than 0.70 (Zineb et al., 2017). The results of validity and reliability as made known in Table 1 specify the stated thresholds encountered. The standardized factor loadings of SC risk management items are within 0.717 and 0.876, SFL of Internet-of-Things items are between 0.761 and 0.878, and SFL of SCRS items are from 0.735 to 0.867. As well, AVE values SC risk management, Internet-of-Things, and SCRS are 0.625, 0.662, and 0.670, respectively. All these values are more than 0.5. These results indicate that the current items have an acceptable convergent validity.

Table 1
Results of validity and reliability

Variables	Items	Convergent validity		Discriminant validity			Reliability	
		SFL	AVE	(1)	(2)	(3)	CR	α
(1) SC risk management	SCRM1	0.811	0.625	**0.790**			0.943	0.933
	SCRM2	0.831						
	SCRM3	0.758						
	SCRM4	0.720						
	SCRM5	0.833						
	SCRM6	0.876						
	SCRM7	0.717						
	SCRM8	0.798						
	SCRM9	0.768						
	SCRM10	0.777						
(2) Internet-of-Things	IoT1	0.761	0.662	0.452	**0.814**		0.907	0.873
	IoT2	0.852						
	IoT3	0.801						
	IoT4	0.878						
	IoT5	0.769						
(3) SCRS	SCRS1	0.735	0.670	0.493	0.473	**0.818**	0.910	0.877
	SCRS2	0.855						
	SCRS3	0.796						
	SCRS4	0.833						
	SCRS5	0.867						

Moreover, the results in Table 1 show that the discriminant validity as measured by the square roots of AVE values is accepted as the square roots is higher than the correlation coefficients between research variables. In terms of reliability, the results in Table 1 illustrate that all alpha coefficients and CR values are higher than 0.70. These results indicate that reliability is accepted.

Table 2
Factor cross loadings

Items	Internet-of-Things	SC risk management	SCRS
SCRM1	0.368	0.811	0.464
SCRM2	0.307	0.831	0.418
SCRM3	0.347	0.758	0.363
SCRM4	0.308	0.720	0.424
SCRM5	0.370	0.833	0.418
SCRM6	0.402	0.876	0.425
SCRM7	0.360	0.717	0.387
SCRM8	0.378	0.798	0.342
SCRM9	0.397	0.768	0.314
SCRM10	0.324	0.777	0.298
IoT1	0.761	0.241	0.214
IoT2	0.852	0.316	0.404
IoT3	0.801	0.391	0.467
IoT4	0.878	0.391	0.397
IoT5	0.769	0.443	0.369
SCRS1	0.338	0.249	0.735
SCRS2	0.400	0.461	0.855
SCRS3	0.390	0.431	0.796
SCRS4	0.420	0.375	0.833
SCRS5	0.384	0.459	0.867

Another indicator of discriminant validity, which is factor cross loadings, as shown in Table 2 indicate that the items SCRM1-SCRM10 have high factor loadings with their latent variable, i.e., SC risk management, items IoT1-IoT5 are related to their latent variable, i.e., Internet-of-Things, and items SCRS1-SCRS5 have high factor loadings with SCRS rather than with the other two latent variables, i.e., SC risk management and Internet-of-Things.

4. Results and discussion

The structural model in Fig. 2 describes the graphical results of hypothesis testing in which SC risk management represents an exogenous variable and SCRS is an endogenous variable intermediate by IoT. The structural model fit as measured by the standardized root mean square residual (SRMR) is fewer than 0.08 (SRMR = 0.072), and the normed fit index (NFI) is adjacent to 0.90 (NFI = 0.807), Chi-square = 301.698. In addition, Stone-Geisser's (Q2 = 1-SSE/SSO) value is lower than zero (Hair et al., 2016). The figure shows the direct effects of SC risk management on IoT (β = 0.452), the direct effect of SC risk management on SCRS (β = 0.350), and the direct effect of IoT on SCRS (β = 0.315). Complete results of total, direct, and indirect effects are revealed in Table 3.

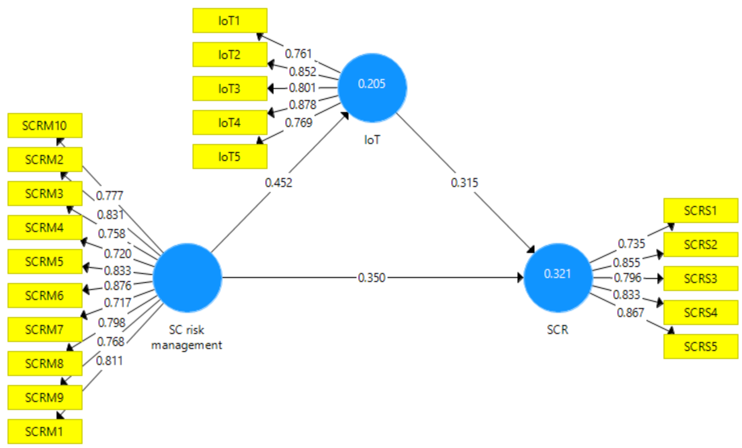

Fig. 2. Research structural model

The results of hypothesis testing in Table 3 discloses the effects of SC risk management on IoT and SCRS and the effect of IoT on SCRS. It is noted that the total effect of SC risk management on IoT is significant (β = 0.452, P = 0.000), which equals to the direct effect of the same construct on the response construct, and there is a significant total (direct) effect of IoT on SCRS (β = 0.315, P = 0.000). Also, the results show that there is a significant total effect of SC risk management on SCRS (β = 0.493, P = 0.000), which is divided into a significant direct effect (β = 0.350, P = 0.000) and a significant indirect effect (β = 0.142, P = 0.000). These results suggest that SC risk management does not completely affect SCRS but rather its effect is mediated by the effect of IoT. Therefore, the first hypothesis was not supported and the second hypothesis is accepted, which means IoT significantly mediated the effect of SC risk management on SCRS.

Table 3
Results of hypotheses testing

Variables and paths			Total effects	P value	Direct effect	P value	Indirect effect	P value
SC risk management	→	IoT	0.452	0.000	0.452	0.000	-	-
IoT	→	SCRS	0.315	0.000	0.315	0.000	-	-
SC risk management	→	SCRS	0.493	0.000	0.350	0.000	0.142	0.000

The aim of the study is twofold. First, to explore the effect of SC risk management on supply chain resilience and, second, to identify if IoT mediates such an effect. The results pointed out that IoT plays a significant mediating role in the effect of SC risk management on supply chain resilience. It was found that SC risk management exerted a big and positive effect on supply chain resilience. Similar results were reported in the literature. According to Simba et al. (2017), supply chain resilience can be strengthened through effective management of SC risks. Saglam et al. (2020) added that an effective method to improve supply chain resilience is through applying risk mitigation strategies. On the other hand, some previous related studies (e.g., Kothari et al., 2018; Li & Li, 2017; Lee et al., 2022; Tan & Sidhu, 2022; Ben-Daya; Hassini & Bahroun, 2022) indicate that the importance of IoT in supply chain risk management context can be recognized by IoT effects on SC information sharing, SC tracking, location identification, replication avoidance, SC visibility, demand and supply matching, and inventory control. Hence, the hypothesis that SC risk management has a complete effect on supply chain resilience has been rejected as it works concurrently with IoT to affect supply chain resilience.

5. Implications and Conclusion

5.1 Theoretical implications

Research on the mediating effect of IoT between SC risk management and supply chain resilience is still rare. Improving supply chain resilience in the present digital era should consider the effects of advanced technologies such as Internet-of-Things, which means that investigating the effects of SC risk mitigation strategies without bearing in mind nowadays digital solutions adds no value to the literature. This study contributes to the literature on supply chain resilience through considering the influence of SC risk management practices as an exogenous construct on supply chain resilience as an endogenous construct in the occurrence of Internet-of-Things as a mediating construct and initiates that SC risk management practices and Internet-of-Things are significant momentous forecasters of supply chain resilience. This result fulfills a research gap concerning the effects between these constructs. Moreover, the results suggest that Internet-of-Things as a smart technology is one additional tool or enabler of supply chain resilience. Therefore, scholars are advised to perform further studies to endorse these results and examine the influence of other sorts of smart technologies such as big data analytics in getting supply chain resilience better. Further results are requested to support the current results concerning and to suggest new technology advancements that enhance supply chain resilience by complementing the effects of SC risk management processes.

5.2 Empirical implications

Firms seek to improve supply chain resilience. Therefore, many of them keep a bird eye on supply chain risks following several actions such as those related to sourcing, manufacturing, and logistics. In fact, firms apply varied strategies to mitigate supply chain risks. However, not all these strategies result in positive outcomes due to numerous reasons such as lack of connectivity between supply chain objects, no timely sharing of supply chain information, and absence of real-time supply chain tracking. These drawbacks have negative effects on supply chain decisions, supply chain logistics control, supply chain agility and responsiveness, and supply chain integration. Such defects can be eliminated or at least reduced through introducing new technologies such as Internet-of-Things. Firms in light of the current results are instructed to adapt smart technology applications such as Internet-of-Things to support their efforts regarding the effective management of SC risks. The present results point toward an auxiliary factor, i.e., Internet-of-Things, by which firms can do best in parallel with practices of SC risk management. Utilizing this factor helps firms capture an additional ability of multiple features such as real-time SC planning, organizing, leading and controlling, risk early and recovery response, and real-time through exchanging real-time information and making real-time decisions. As a result, firms are invited to use a blended strategy consisting of SC risk management practices and Internet-of-Things. It should be noted that Internet-of-Things does not substitute SC risk management practices but rather supplement these practices in making supply chain resilience stronger.

6. Conclusion

Making supply chains ready in the current digital era to cope with unpredicted occasions requires not only effective practices of supply chain risk management, but also in effect adaptation of newly smart technologies such as Internet-of-Things. Such technologies support the functions that firms execute to manage and mitigate supply chain potential risks as it be there for tracking SC operations, exchanging relevant information, detecting real-time interruptions, increasing firms sensing of disruption signals, expanding responsiveness to sudden incidents, refining agility, improving risk alleviation efforts, and encouraging well-timed decisions.

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