Risk Mitigation in Supply Chain Digitization: System Modularity and Information Technology Governance

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Abstract:

Firms face significant risk when they adopt digital supply chain systems to transact and coordinate with their partners. Drawn upon modular systems theory, this study proposes that system modularity mitigates the risk of adopting digital supply chain systems and therefore motivates firms to digitize more of their supply chain operations. The study theorizes how the risk-mitigating effect of system modularity can be enhanced by the allocation of decision rights to the IT (information technology) unit. The main logic is that IT managers with more domain IT knowledge can better utilize their knowledge in decision making to achieve effective system modularity. We tested these theoretical propositions using a survey study of Chinese companies and found empirical support. We also found that the allocation of decision rights to the IT unit does not directly mitigate the perceived risk of digital supply chain systems, which highlights the role of decision allocation to the IT unit as a key moderator in risk mitigation. The study generates theoretical and practical implications on how IT governance and system modularity may jointly mitigate risk and foster supply chain digitization.

Keywords: IT governance | modular systems | risk mitigation | supply chain management

Article:

Information technology (IT) initiatives have been well recognized by practitioners and scholars as risky initiatives because IT investments are always associated with more uncertainties than other investments [16, 63]. Compared to internal IT projects, the implementation and use of IT systems in the interorganizational environment, such as digital supply chain systems, are considered even more risky. Digital supply chain systems are interorganizational systems (IOSs) that firms implement to digitize the processes of transaction and collaboration with their supply chain partners (i.e., upstream suppliers and downstream customers). The risky nature of digital supply chain systems is largely attributable to the fact that the successful implementation of these systems requires focal firms to adapt to the external environment and various outside parties, which are often beyond their control [51].

Firms face both technological risk and transactional risk when they adopt digital supply chain systems to support their interfirm business processes [31]. Technological risk mainly refers to the uncertainties and potential negative outcomes caused by technological changes and challenge in building, implementing, and using digital supply chain systems together with partners [31, 81]. Transactional risk mainly refers to the uncertainties and potential negative outcomes caused by the strategic behaviors of supply chain partners in misusing digital linkages and exploiting the interfirm relationships[14, 52]. The concern over these risks often discourages focal firms from adopting digital supply chain systems to support their interorganizational operations.

Many prior information systems (IS) studies took the risk perspective to examine the adoption of IT [27, 28, 41]. In this study, we also take this perspective to explore how supply chain digitization is influenced by the organization's risk concerns and what factors foster supply chain digitization through risk mitigation. Drawing upon modular system theory [55, 56], we first posit that maintaining modularity between the focal firm's internal IT systems and its digital supply chain system mitigates the perceived risk of the digital supply chain system and motivates the focal firm to digitize its supply chain operations. Although the literature on modular systems theory generally suggests that many principles of modular design, such as loose coupling between components, information hiding (or encapsulation), and interface standardization, have a risk-mitigating effect [3, 32], the existing research on IT risk has not explicitly tested this effect. In addition, the extant IS literature has underexamined how the risk-mitigating effect of system modularity enables the focal firm to support more of its operations in the risky interfirm environment. Our study bridges this gap between modular systems theory and the risk perspective in organizational IT adoption.

We also consider how the risk-mitigating effect of system modularity can be enhanced by a key organizational factor, the decision right of the IT unit, which captures the extent to which the strategic decision rights on adopting digital supply chain system are allocated to the IT unit so that IT managers are actively engaged in the strategic decision-making processes. The consideration of this factor mainly concerns how strategic-level IT governance may interact with the modular design of the IT infrastructure to mitigate the risk associated with the adoption of a digital supply chain system.

We posit that the decision right of the IT unit enhances the effect of system modularity in risk mitigation. This proposition of interaction between system modularity and the decision right of the IT unit is in accordance with the view of governance–knowledge fit in the IT governance literature [68] and the perspective of fit between modular IT architecture and decision allocation [70]. The central logic here is that the effective modularization of IT systems requires IT knowledge at both the architecture level and the component level. Compared to organizational decision makers from other functional areas, IT managers possess more IT domain knowledge that is needed in IT modularization. Allocating more decision rights to IT managers enables the IT unit to better leverage its domain knowledge in decision making and thus facilitates the effective utilization of IT modularity in risk mitigation. We therefore expect that the decision right of the IT unit enhances the effect of system modularity in mitigating the risk associated with digital supply chain systems, and such risk mitigation in turn motivates the focal firm to digitize its supply chain operations to a greater extent.

We empirically tested the theoretical framework using a survey sample of Chinese companies. In an emerging economy such as China's, the environment of IOS usage is much less established than in developed economies (e.g., the United States). For example, according to the Global Information Technology Report [19], China ranks 36 among 138 countries (the United States ranks 5) in terms of the Networked Readiness Index (NRI). The NRI evaluates the overall country-level technological, business, and regulatory readiness for information and communication technologies (ICT). Therefore, China's rank clearly indicates that it lags behind developed countries in ICT development. As such, the risk faced by Chinese companies in adopting digital supply chain systems is significantly higher. This study of supply chain digitization by Chinese companies helps us better understand the strategic adoption of IT in a risky environment.

The theoretical framework and empirical study in this paper contribute to multiple streams of literature. First, the paper contributes to the growing literature [64, 70] on how IT modularity supports business strategies. This literature has so far focused on the strategic flexibility that firms can achieve through modular design of their IT infrastructure. Our study extends this view to consider the risk-mitigating effect of IT modularity. This extension is logical as strategic flexibility is also an important strategy for risk management [42]. Second, this paper contributes to the IT governance literature by illustrating how the allocation of decision rights to the IT unit influences risk mitigation and the strategic decisions of supply chain digitization. Decision allocation has been identified as the central element of IT governance [53, 68, 71]. However, the role of IT decision allocation in risk mitigation has been underinvestigated in the extant literature. An important finding of this study is that allocating more strategic decision rights to the IT unit does not directly reduce the perceived risk of digital supply chain systems. Rather, decision allocation mitigates risk through interacting with system modularity.

Third, this paper contributes to the IT risk literature by considering organizational factors that address IT risk. Although firm-level IT risk has been well recognized in the literature [16, 63], the existing studies examining how IT risk influences IT adoption have largely focused on the individual-level factors[25, 41, 43]. This study focuses on the organizational adoption of digital supply chain systems. The study illustrates how organizational-level risk in supply chain digitization can be mitigated by the modular design of the IT infrastructure and strategic-level IT governance. Finally, this study contributes to the literature on digital supply chains [29, 48, 49] by adopting the risk perspective to explain how IT infrastructure design supports supply chain management and operations.

The rest of the paper is organized as follows. The next section presents the theory and hypotheses development. The third section describes the data and measures used in this study. The fourth section presents the empirical analysis results. The fifth section discusses the implications of this study and, finally, the last section concludes the paper.

Theory and Hypothesis Development

Modular Systems Theory

Modularity is a general system concept that describes the tightness of coupling between a system's components and the extent to which the interactions between these components are standardized [55, 56]. Modular systems usually have loosely coupled components and subsystems that interact through well-defined standardized interfaces. Increasing system modularity allows flexibility in configuring systems and mixing and matching of components and subsystems from different sources.

The concept of modularity can be applied to not only product and technological systems but also organizational forms. Modularity in organizational forms refers to the case where operations are partitioned into tasks that are completed by independent and loosely coupled organizational units [22, 32, 55]. Interorganizational interaction and collaboration (e.g., contract manufacturing and strategic alliance) reflect the use of modular organizational forms [57]. In interorganizational collaboration, focal firms and their supply chain partners act as independent and loosely coupled units and assume different vertical responsibilities. They connect their business processes through specified interfaces, and there is less overt exercise of hierarchical authority across organizational boundaries. The adoption of modular organizational forms allows firms to achieve strategic flexibility, that is, firms are able to respond more readily to changing environments and technologies by leveraging the combinations of various internal and external resources [55, 74].

IT systems are often used as the key technological infrastructure to support the coupling of business processes in modular organizational forms [47, 64]. For example, digital supply chain systems and applications, such as EDI (electronic data interchange), CPFR (collaborative planning, forecasting, and replenishment), and VMI (vendor-managed inventory), enable supply chain partners to exchange information and connect their business processes together [40, 51, 77, 81]. The strategic flexibility of modular organizational forms is therefore difficult to achieve if the supporting IT systems lack modularity. For example, if a focal firm's internal IT infrastructure is tightly integrated with its external partners' IT infrastructure through digital system linkages (e.g., proprietary EDI), the focal firm will find it difficult to change its internal IT-enabled processes without affecting its partners. Similarly, when the tightly integrated IT systems of the focal firm and its partners are relationship specific, the high switching cost will prevent the focal firm from changing partners and achieving strategic flexibility.

In this paper, we consider how IT modularity facilitates the focal firm to support its operations in modular organizational forms, that is, digitizing its supply chain operations. As IT modularity is a broad concept, in this study, we focus on the modularity between the focal firm's internal IT systems (which mainly support the focal firm's internal operations) and its digital supply chain system (which mainly supports the focal firm's electronic linkages with its supply chain partners). A higher level of modularity means that the focal firm's internal systems and digital supply chain system are more independent of each other and they communicate through more standardized interfaces. For example, using a standard enterprise software platform of SAP, a supplier can make its internal IT processes of inventory management less coupled with its IT linkages with retailers (e.g., electronic ordering systems). The recombination of the inventory management and the IT processes of other retailers is thus comparatively easier [64]. By contrast, a lower level of modularity means that the focal firm's internal systems and digital supply chain system are more interrelated with each other and they communicate through more specialized interfaces. For example, compared to open-standard EDI, private network EDI is usually more integrated with the focal firm's internal IT processes [77]. We examine how this modularity between the focal firm's internal systems and digital supply chain system (named system modularity hereafter) reduces the focal firm's perceived risk of the digital supply chain system, and motivates the focal firm to digitize more of its supply chain operations.

Perceived Risk of Digital Supply Chain Systems

In this study, we consider supply chain digitization (hereafter, SC digitization) as the extent to which the focal firm adopts digital supply chain systems to transact electronically with its suppliers and customers. Perceived risk in this context refers to the extent to which the organizational decision makers of the focal firm believe that uncertainty exists about whether desirable outcomes of adopting digital supply chain systems will occur [41].

Compared to other intraorganizational systems, the adoption of digital supply chain systems is influenced by more external factors that are beyond the control of the focal firm. As summarized in Kumar and van Dissel [31], firms are concerned about both the technological risk and transaction risk associated with the adoption of digital supply chain systems. Technological risk mainly refers to the challenge in imposing technological standards for different supply chain parties and the uncertainty of future technological changes. For example, in EDI implementation, a typical risk is that the focal firm cannot control how its trading partners implement the system inside their own facilities[52]. In migrating from proprietary EDI to open-standard EDI, a typical concern of the focal firm is the managerial complexity incurred in adapting to the new technological standards [77, 81].

Unlike technological risk, which may be minimized as technological standards become more mature and stable, the transaction risk associated with the adoption of digital supply chain systems is even less controllable. Transaction risk mainly refers to the uncertainty caused by transactional partners' strategic or self-interested behaviors in misusing information resources and exploiting the relationships [31, 81]. One source of transaction risk is transaction-specific investment [14]. Transaction-specific investment is inputs made by one party that has little or no value in uses other than the specific interaction for which it was originally undertaken. The focal firm often has to tailor its digital supply chain system to accommodate special needs of certain partners, which makes the digital supply chain system more transaction specific and increases transaction risk [36]. Another source of transaction risk is the loss of resource control [14]. When the focal firm implements digital supply chain systems along with its partners, some critical resources, such as sensitive information and know-how, are transferred as part of the relationship and cannot be returned or controlled when the relationship is terminated. The misuse of these resources by partners will destruct the focal firm's competitive advantages in the future.

The concerns about technological risk and transaction risk may significantly impede the focal firm's pursuit of SC digitization. Traditional risk theories, such as the risky decision-making theory [58] and the behavioral agency model [72], suggest that risk perception reduces risky actions. Prior IS studies have also evidenced a negative relationship between risk perception and IT adoption [27, 41]. When firms have multiple risk initiatives and need to balance between them, the increase in perceived risk of a certain initiative may make this initiative less attractive compared to others[39]. In this regard, the perceived risk of digital supply chain systems should discourage the focal firm from adopting this technology to support its supply chain operations. Therefore, in line with existing studies, we expect that the perceived risk of digital supply chain systems is negatively associated with the level of SC digitization.

System Modularity, Risk Perception, and Supply Chain Digitization

The perceived risk of digital supply chain systems, however, is likely to be mitigated if the focal firm maintains a high level of modularity between its internal systems and the digital supply chain system. The strategic flexibility perspective [54] helps explain such a relationship. The concept of strategic flexibility has been used in the strategy research to describe the focal firm's ability to respond to uncertain external environment [54, 74]. Systems modularity is a key source of strategic flexibility as it enables the focal firm to develop flexible IT resources that are useful in dynamic environments and configures varied resources in more flexible ways to take advantage of dynamic opportunities. Through achieving strategic flexibility, system modularity helps mitigate both the technological risk and transaction risk associated with digital supply chain systems.

System modularity keeps the disturbances experienced by specific subsystems from spreading to other subsystems [42]. As a result, significant technological change in any specific subsystem often causes little or no modification on other subsystems and the overall systems. Compared to the focal firm's internal systems, a digital supply chain system is subject to more changes as the focal firm needs to constantly adapt to the external technological evolution and heterogeneous technological backgrounds of its partners [80]. System modularity allows the focal firm to easily configure its digital supply chain system for flexible uses. Using technologies with modular features (e.g., Web-based EDI with well-defined application programming interfaces [APIs]), the focal firm does not have to substantially modify its internal systems when it changes the technological features of the digital supply chain system. The focal firm thus should have less concern over the technological uncertainty and managerial complexity caused by the adoption of a digital supply chain system. The perceived technological risk is therefore likely to be reduced. This logic is consistent with the strategic flexibility perspective that the increased ability in keeping the flexible usage of a resource (the digital supply chain system in our case) leads to decreased risk of adopting this resource for strategic purposes [18, 45].

The strategic flexibility perspective also helps explain how system modularity reduces transaction risk. By making the internal systems and digital supply chain system less interdependent, the focal firm can avoid making a transaction-specific investment on its internal systems to digitize transactions with its partners. For example, the adoption of Internet-based supply chain systems requires less customization on the internal systems than that of proprietary supply chain systems [10]. When the internal systems can interact with the digital supply chain system through standardized APIs, the configuration of the digital supply chain system to specific transaction processes with certain partners does not require a similar adjustment on the internal systems. As the internal systems are less tied to the specific transaction processes of partners, the focal firm has more flexibility to adapt its digital supply chain system to more partners or switch to other partners. In addition, the realization of system modularity also requires the focal firm to use reusable code/applications and open standards in developing its digital supply chain system. This may in turn make the digital supply chain system itself less tied to specific transaction processes with partners (or less transaction specific). The transaction risk caused by transaction-specific investment is thus reduced. Some features of system modularity, such as encapsulation, also help address the issue of loss of resource control. Encapsulation enables the focal firm to prevent its information in the internal systems from being overexposed to the outside [56, 66]. The focal firm, therefore, can be less concerned about the leakage of sensitive information from its internal systems to the external partners. The transaction risk caused by the loss of resource control is also reduced.

Considering the risk-mitigating effect of system modularity, we expect a negative relationship between system modularity and the focal firm's perceived risk of digital supply chain systems. Also, as mentioned above, we expect that less perceived risk of digital supply chain systems motivates the focal firm to digitize its supply chain operations to a greater extent. Therefore, we develop the following mediation hypothesis:

Hypothesis 1: System modularity enhances SC digitization by mitigating the perceived risk of digital supply chain systems.

Decision Right of the IT Unit and Supply Chain Digitization

Although system modularity is an important antecedent of perceived risk, its riskmitigating effect is likely to be influenced by other organizational factors. Modular systems theory suggests that effective design and use of modular systems require relevant domain knowledge, such as architecture knowledge and component knowledge [55]. Such knowledge usually resides in the IT unit. Therefore, the extent to which the IT unit is involved in the strategic decision making for SC digitization should influence how knowledge is used in decision making to better leverage system modularity for risk mitigation. Therefore, in this study, we also consider the role of the IT unit's decision right (labeled IT-DR) in risk mitigation. IT-DR here is defined as the extent to which the strategic decision rights of SC digitization are allocated to the IT unit. The allocation of IT decision rights has been considered as the central issue in IT governance [53, 68, 71, 75]. When decision rights of the IT unit increases, IT managers are more engaged in the decision-making processes for SC digitization. IT managers therefore generate more influences on the decision outcomes and other decision makers in the strategic decision teams. Next, we consider how IT-DRs may enhance SC digitization by directly mitigating the perceived risk of the digital supply chain system and then consider how IT-DRs may interact with system modularity in mitigating the perceived risk of the digital supply chain system and enhancing SC digitization.

A greater involvement of IT managers in the decision-making process is likely to reduce the perceived risk of the digital supply chain system. The knowledge perspective in risk theories provides explanation about this negative relationship. Compared to other functional managers, IT managers have more IT domain knowledge and are often more familiar with the risky IT environment. Existing theories on strategic risk taking suggest that risk perception is often mitigated by the decision makers' overall knowledge about the problem domain [2, 72]. When IT managers act as decision makers, their knowledge base about IT should make them perceive less risk of adopting a digital supply chain system compared to other functional managers. In this regard, when IT managers are engaged more in decision making through IT-DR, the overall risk perception of the strategic decision team should also decrease.

The knowledge base of IT managers may influence not only IT managers' own risk perception but also the risk perception of other decision makers. IT managers can use their domain knowledge to help identify potential risk-mitigating solutions that other functional managers may not be able to identify themselves. With professional opinions from IT managers, decision makers from other functional areas should be able to form more objective expectations about the potential consequences of adopting digital supply chain systems and avoid overweighing the possible negative outcomes [23]. They should also be more confident about their capabilities to manage risk in SC digitization. As a consequence, with IT managers involved more in decision making, other decision makers' perceived risk of digital supply chain systems are also likely to decrease.

We therefore expect that the allocation of more decision rights to the IT unit leads to less overall perceived risk of digital supply chain systems. Again, as we also expect that less risk perception of digital supply chain systems motivates the focal firm to digitize more of its supply chain operations, we develop the following mediation hypothesis:

Hypothesis 2: IT-DR enhances SC digitization by mitigating the perceived risk of digital supply chain systems.

Decision Right of the IT Unit and Supply Chain Digitization

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The Moderating Effect of IT-DR

Although system modularity mitigates the perceived risk of digital supply chain systems, its risk-mitigating effect is likely to be limited if organizational decision makers do not have enough knowledge about the implications of system modularity. To better understand the implications of system modularity, decision makers need specific knowledge at both the architectural level and the component (or subsystem) level [50, 55]. At the architectural level, the focal firm needs knowledge about the interfaces and coordination mechanisms through which its internal systems and digital supply chain system work together smoothly. At the component level, the focal firm needs knowledge about the functionalities of its internal systems and digital supply chain systems. Compared to IT managers, decision makers from other functional areas often lack the domain knowledge about the design and coordination of the modular components of internal systems and digital supply chain systems. Without the required domain knowledge, even if modular systems are in place, decision makers may still have various concerns over the implementation of a digital supply chain system and the perceived risk may not be sufficiently alleviated.

The allocation of decision rights to the IT unit allows IT managers to utilize more of their IT domain knowledge in the strategic decision making for SC digitization. The utilization of such knowledge enables the focal firm to better leverage system modularity to achieve strategic flexibility and mitigate technological risk and transaction risk. This logic is in line with the view of governance–knowledge fit in achieving IT agility [70]. Tiwana and Konsynski [70] found that compared to the corporate-level IT group, departmental line managers may be more familiar with specific IT needs in their functional areas. In other words, line managers may have more componentlevel knowledge of the internal systems. Therefore, with a modular architecture of corporate IT systems in place, decentralizing departmental IT decision making to line managers enables them to better build their functional subsystems based on the modular corporate IT architecture to achieve IT agility. In our case, we consider the corporate-level strategic IT decision making. Compared to other functional managers, IT managers should be more familiar with the corporate-level IT resources that support a modular corporate IT architecture. In other words, the IT unit has more architecturelevel knowledge of IT modularity and is therefore in a better position to use this architecture-level modularity knowledge. The higher the level of system modularity, the more architecture-level knowledge is needed for understanding and realizing the risk-mitigating effect of modularity. In this regard, bringing more architecture-level IT knowledge into the decision-making team through IT-DR should strengthen the risk-mitigating effect of system modularity.

In addition to architecture-level knowledge of IT modularity, component-level knowledge about the digital supply chain system is also crucial in the decision making for SC digitization. Even though functional managers may be familiar with their corresponding internal IT systems, they are less likely to have sufficient componentlevel knowledge about the interorganizational IT systems that are used to connect with their external partners (e.g., the detailed technological requirements of their partners and specific industry standards). In other words, the component-level knowledge about digital supply chain systems is the peripheral IT knowledge, rather than the core domain IT knowledge, to the focal firm. In the context of interfirm alliance, however, peripheral knowledge is still needed in order to warrant the effect control over external partners [69]. Compared to non-IT managers, IT managers should have more peripheral IT knowledge and be able to utilize this knowledge in risk mitigation. The higher the level of system modularity, the more peripheral knowledge is needed for managing the modular digital supply chain system to address various technological risks and transaction risks. In this regard, bringing more componentlevel IT knowledge into the decision-making team through IT-DR should strengthen the risk-mitigating effect of system modularity.

Therefore, we expect that IT-DR is likely to enhance the risk-mitigating effect of system modularity. Such risk mitigation, in turn, should encourage more SC digitization by the focal firm. Therefore, we develop the following hypothesis of mediated moderation:

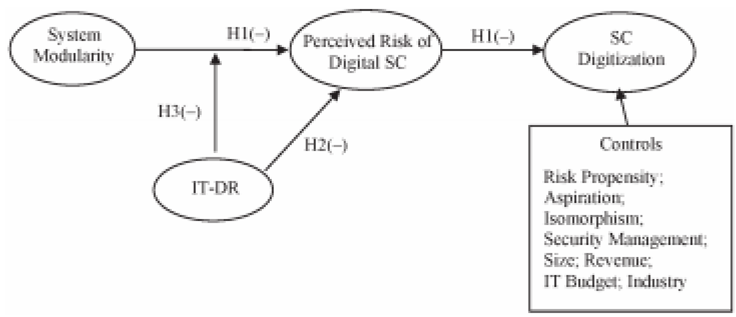

Figure 1. Research Framework

Table 1. Definition of Key Constructions

Construction	Definition
System modularity	The extent to which the focal firm's internal systems and digital supply chain system are more independent of each other and communicate through more standardized interfaces.
Decision right of IT unit	The extent to which the strategic decision rights of SC digitization are allocated to the IT unit and IT managers join other top executives to engage in the strategic decision making for SC digitization.
Perceived risk of digital supply chain system	The extent to which organizational decision makers of the focal firm believe that uncertainty exists about whether desirable outcomes of adopting a digital supply chain system will occur.
SC digitization	The extent to which the focal firm adopts a digital supply chain system to transact electronically with its suppliers and customers.

Hypothesis 3: IT-DR enhances SC digitization by strengthening the negative effect of system modularity on the perceived risk of digital supply chain systems.

Figure 1 illustrates the theoretical framework of this study, and the definition of the main theoretical constructs are listed in Table 1.

Data and Variables

Data Collection

We empirically test the theoretical framework using a survey data set. The survey questionnaire was designed based on a comprehensive literature review. A panel of both academic scholars and practitioners was used to review the questionnaire items. We tailored the survey questions to fit with the context of SC digitization. A pretest of ten randomly selected firms was used to verify the content validity of the survey. The firms in the pretest were similar to the firms used in the analysis in terms of sizes and revenue. After the pretest and revision of the questionnaire, the survey was conducted in two rounds in March and December 2010 using a Chinese consulting company. Responses were collected by the consulting company using both telephone interviews and online surveys. The key informants were top executives or directors who were responsible for leading the projects of implementing and adopting digital supply chain systems in the firms.

We contacted 5,128 firms in total. The final sample for this study contains 324 firms that returned completed survey questionnaires. Another 17 firms returned incomplete questionnaires and were excluded from the analysis. The sample covers a variety of industries, with 48.8 percent of the companies in construction, mining, and manufacturing industries, and 51.2 percent in service-oriented industries. Geographically, the sample covers 31 of the total 34 provinces and municipalities in China. Within this sample, 123 firms have annual revenue below $1.5 million, 115 firms between $1.5 million and $15 million, and 86 firms above $15 million. To assess the nonresponse bias, we used t-tests to compare the 324 firms that provided complete questionnaires with the 17 firms that provided incomplete questionnaires, and did not find any statistically significant difference between the two groups in terms of their average firm sizes, revenue, and IT budgets. We also compared early responses (the first 25 percent of the sample in terms of response time) and late responses (the last 25 percent of the sample) [1]. The t-tests did not indicate any significant difference between these two groups of firms in terms of their sizes, revenue, and IT budgets.

Measurement

We used a seven-point Likert scale to measure questionnaire items, where 1 = “low degree/strongly disagree” and 7 = “high degree/strongly agree.” Table 2 presents the measurement details of the key constructs used in this study. Table 3 presents the summary statistics and correlation matrix.

Dependent Variable

SC digitization (SCD): The measure for SC digitization captures the extent to which firms connect and conduct transactions with their key suppliers and customers using digital supply chain systems. We adapted three items from Barua et al. [4] to measure firms’ electronic connection with their customers using digital supply chain systems. We also included three corresponding items to measure the supply-side connection. Similar items on supply-side connection have also been used in prior research on electronic supply chain management [15, 37].

Explanatory Variables

Perceived risk (Risk): The measure of perceived risk reflects typical risks that may be perceived in adopting digital supply chain systems, including technological risk, implementation risk, management complexity, and transactional risk. The measurement items were developed primarily based on the prior research on the adoption of IOSs[41, 81]. We used one item (Risk1) from Nicolaou and McKnight [41] to capture the general risk perception about the adoption of a digital supply chain system. We also included three items from Zhu et al. [81] to captures the perceived managerial, transactional, and technological aspects of risk.

System modularity (Mod): The measure of modularity between a digital supply chain system and other internal systems captures to what extent the internal IT systems and digital supply chain system are interrelated with each other and communicate through standardized interfaces. We adopted five existing measurement items from prior studies on IT modularity, including Tanriverdi et al. [64] and Tiwana [66, 67].

Decision right of the IT unit (ITDR): In this study, the decision right of the IT unit is defined as the degree to which the IT unit takes responsibilities and has authorities in the key decision making for the adoption of digital supply chain systems and SC digitization. We developed seven measurement items based on the measure of decision control right used in Tiwana [68] and the measures of IT specification and implementation rights used in Tiwana and Konsynski [70].

Controls

To account for alternative explanations of SC digitization, we employ a number of control constructs in the model. First, we include the general risk propensity (Propen) of the strategic decision group as a control variable because risk theories [58] suggest that the willingness of decision makers to take risky actions affects their risk perception. Risk propensity is measured using three items adopted from Sitkin and Weingart [59] and adapted to fit the context of SC digitization. Prior IS research [27, 28, 41] has also used similar measurement items to assess the willingness to undertake risky IT initiatives.

Second, we include the strategic aspiration (Asp) of managers as a control for SC digitization. Strategic aspiration mainly refers to the extent to which the decision making managers expect that SC digitization will benefit the focal firm. Prospect theory [7, 26] suggests that when decision makers expect a high return from the risky action, they would like to proactively take the risk to pursue the high return. Therefore, managerial aspiration may lead to a high level of SC digitization even in presence of perceived risk. We developed the six measurement items of strategic aspiration based on the theory on goal setting [8, 9] and prior studies on the benefits of IOS [36]. The items asked the respondents to assess the aspirations of their managers on various benefits of supply chain digitization.

Third, we control for the isomorphic IT adoption (Iso) by the focal firm's external partners, suppliers, customers, and competitors. The high IT adoption by these external parties often generates institutional pressures on the focal firm to take risk in adopting digital supply chain systems [13, 21, 65, 78, 79]. Based on the scales used in Teo et al. [65] and Xue et al. [76] on the isomorphic environment in IOS adoption, we developed four items to assess the general IT adoption in the focal firm's competitors, suppliers, customers, and other business partners.

Table 2. Constructs and Measures

Construct	Measurement items	Literature
SC digitization	The proportion of (1) suppliers that the firm transacts with through the digital SC system; (2) transaction volume that the firm conducts with its suppliers through the digital SC system; (3) transaction activities that the firm conducts with its suppliers through the digital SC system; (4) customers that the firm transacts with through the digital SC system; (5) transaction volume that the firm conducts with its customers through the digital SC system; (6) transaction activities that the firm conducts with its customers through the digital SC system. (Cronbach's $\alpha = 0.97$)	[4,15, 37]
Decision right of IT unit	The IT unit has the power to decide on the following aspects of the adoption of digital SC system: (1) long-term strategies and goals; (2) system functionality; (3) budget; (4) management policies; (5) project priorities; (6) performance evaluation; (7) time scheduling. (Cronbach's $\alpha = 0.94$)	[68, 70]
Perceived risk	Our decision makers feel that (1) the implementation of the digital SC system is a risky project; (2) the digital SC system may potentially generate a negative impact on our business processes; (3) the use of the digital SC system may enable our suppliers or customers to take advantage of us; (4) there is technological uncertainty of the implementation of the digital SC system in our company. (Cronbach's $\alpha = 0.94$)	[41, 81]
System modularity	The digital SC system and other internal systems (1) are highly interrelated (reverse coding); (2) are highly independent; (3) are highly functionally integrated (reverse coding); (4) interact through standardized interfaces; (5) the changes in digital SC systems affect the internal systems to a great extent and vice versa (reverse coding). (Cronbach's $\alpha = 0.91$)	[64, 66, 67]
Security management	Our managers (1) put weight on IS security management; (2) have developed short- and long-term policies on IS security management; (3) are actively involved in IS security management. We have implemented (4) advanced hardware and software on IS security management; (5) effective internal controls over the data and the systems; (6) authentication and authorization systems for identity management. (Cronbach's $\alpha = 0.95$)	[30, 62]
Strategic aspiration	Our top executives have clear aspirations for (1) the use of the digital SC system; (2) the contribution of the digital SC system to the future success of the company; (3) the strategic benefits of the digital SC system to the company. Our middle managers have clear aspirations for (4) the contribution of the digital SC system to the future success of the company; (5) the positive impact of the digital SC system on the business processes; (6) the operational benefits of the digital SC system to their function departments. (Cronbach's $\alpha = 0.95$)	[8, 9, 36]

Isomorphic IT adoption	The levels of IT adoption of (1) key competitors; (2) key suppliers; (3) key customers; (4) key business partners. (1 = "very low," 7 = "very high") (Cronbach's α = 0.94)	[65, 76]
Risk propensity	Regarding the adoption of digital supply chain system, our decision makers are willing to (1) try unfamiliar new technology; (2) invest aggressively in emerging applications; (3) take the challenge of adapting the business/organization to the new technology implementation. (Cronbach's α = 0.91)	[41, 59]

Note: SC = supply chain.

Table 3. Descriptive Statistics

	Correlation matrix										
Measures	1	2	3	4	5	6	7	8	9	10	11
1. SC digitization	0.89										
2. Perceived risk	−0.46	0.86									
3. Risk propensity	0.68	−0.49	0.84								
4. Decision right of the IT unit	0.65	−0.42	0.74	0.89							
5. System modularity	0.60	−0.53	0.62	0.70	0.77						
6. Security management	−0.57	−0.42	−0.64	−0.58	−0.73	0.86					
7. Strategic aspiration	0.59	−0.34	0.59	0.69	0.61	−0.59	0.85				
8. Isomorphic IT adoption	0.71	−0.50	0.64	0.61	0.58	−0.50	0.53	0.86			
9. Employee (log)	0.20	−0.11	0.15	0.15	0.24	−0.26	0.30	0.24	—		
10. Revenue (log)	0.14	−0.07	0.05	0.06	0.06	0.14	0.30	0.13	0.73	—	
11. IT spending (log)	0.24	−0.17	0.20	0.15	0.25	−0.30	0.22	0.21	0.53	−0.13	—
Mean	4.40	3.66	4.67	4.72	5.37	3.34	4.77	4.51	5.76	17.75	7.10
Standard deviation	1.45	1.42	1.47	1.46	1.29	1.41	1.57	1.34	1.67	1.70	1.11

Notes: Pearson's correlation is reported for construct correlation. Diagonals represent the square root of the average variance extracted (AVE) for multi-item scales. $|p|$ above 0.15 is significant at the 0.01 level; $|p|$ above 0.11 is significant at the 0.05 level.

Fourth, we include security management (Sec) as a control variable, as prior research has identified information security management as a critical success factor in the implementation of digital supply chain systems [33, 60]. The measure of security management captures to what extent firms develop IS security policies and implement advanced IS security safeguards. Based on instruments used in Straub [62], we developed four items measuring firms' security policies (Sec2) and their protective security programs (Sec4, Sec5, and Sec6). Based on other prior studies on IS security [30], we also included two items capturing to what extent the top management is involved in security management (Sec1 and Sec3).

Finally, we employed several firm characteristic variables, such as firm size (measured by the log value of number of employees), revenue, IT spending, and industry as controls to SC digitization. These variables capture general firm heterogeneity.

Methodology

Convergent and Discriminant Validity of Measurement

Table 4 depicts the results of an exploratory factor analysis (EFA). In total, the eight key factors explained 65.13 percent of the total variance. We used confirmatory factor analysis (CFA) to verify the convergent and discriminant validity of the multi-item constructs. All of the items have high loadings on the constructs they were designed to capture and low loadings across the other constructs. This provides evidence of convergent and discriminant validity. An overall test of convergence validity was also provided by the Bentler's comparative fit index (CFI) of the measurement model, which estimates the percentage of variation explained by a proposed model relative to a model of complete independence [5]. The CFI of our eight-factor model is 0.904, above the threshold 0.9 for a good fitting model [5].

We also used CFA to compare the eight-factor measurement model with four alternative measurement models to confirm the dimensionality, convergent validity, and discriminant validity of the eight-factor model. Table 5 summarizes the results. We used sequential chi-square difference tests (SCDTs) by contrasting the chi-square of the eight-factor model (Model 1) with those of the alternative models [61]. Model 2 was a model with a unidimensional construct that contains all of the measurement items. The significantly higher chi-square of Model 2 ($\Delta\chi2$ 28df = +5,947.90, $p < 0.001$) indicates that Model 2 left more residual and did worse than Model 1 in explaining the data. Model 3 and Model 4 were considered to justify the modeling of perceived risk and risk propensity as two distinct but related factors. Model 3 assumed no distinction between these two factors and Model 4 assumed independence between them. The superiority of the eight-factor model over Model 3 ($\Delta\chi2$ 7df = +739.72, $p < 0.001$) and over Model 4 ($\Delta\chi2$ 1df = +81.04, $p < 0.001$) suggests the appropriateness of modeling perceived risk and risk propensity as two distinct but related factors. Finally, Model 5 assumed no distinction between risk propensity and the actual SC digitization (the risk-taking action). The superiority of the eight-factor model over Model 5 ($\Delta\chi2$ 7df = +483.58, $p < 0.001$) indicates that it is appropriate to separate the risk propensity and the actual risk behavior of SC digitization.

Table 4. Exploratory Factor Analysis

Item	1	2	3	4	5	6	7	8
ITDR1	**0.719**	0.206	0.208	0.305	0.086	0.200	0.227	0.222
ITDR2	**0.750**	0.198	0.247	0.298	0.121	0.195	0.249	0.143
ITDR3	**0.741**	0.145	0.226	0.325	0.147	0.167	0.197	0.158
ITDR4	**0.795**	0.157	0.236	0.291	0.124	0.134	0.201	−0.079
ITDR5	**0.796**	0.192	0.226	0.242	0.097	0.131	0.244	−0.095
ITDR6	**0.792**	0.170	0.221	0.239	0.143	0.111	0.172	−0.137
ITDR7	**0.763**	0.197	0.248	0.248	0.152	0.180	0.148	−0.083
Sec1	0.094	**0.748**	0.234	0.216	0.106	0.094	0.255	0.311
Sec2	0.160	**0.737**	0.224	0.278	0.134	0.081	0.267	0.252
Sec3	0.165	**0.791**	0.262	0.135	0.071	0.129	0.246	0.104
Sec4	0.248	**0.776**	0.175	0.267	0.157	0.076	0.134	−0.057
Sec5	0.201	**0.812**	0.135	0.187	0.206	0.122	0.129	−0.137
Sec6	0.298	**0.759**	0.126	0.209	0.122	0.133	0.134	−0.219
SCD1	0.215	0.185	**0.755**	0.230	0.149	0.282	0.171	0.127
SCD2	0.238	0.159	**0.795**	0.241	0.158	0.227	0.133	0.089
SCD3	0.262	0.207	**0.802**	0.180	0.168	0.256	0.166	0.008
SCD4	0.293	0.168	**0.802**	0.192	0.174	0.212	0.131	−0.016
SCD5	0.278	0.266	**0.785**	0.194	0.144	0.185	0.090	−0.028
SCD6	0.255	0.245	**0.793**	0.216	0.197	0.203	0.052	−0.057
Asp1	0.278	0.190	0.210	**0.775**	0.072	0.121	0.175	0.234
Asp2	0.324	0.191	0.191	**0.763**	0.074	0.165	0.162	0.182
Asp3	0.305	0.236	0.251	**0.785**	0.089	0.116	0.122	0.104
Asp4	0.195	0.145	0.124	**0.776**	0.056	0.121	0.177	−0.183
Asp5	0.290	0.248	0.205	**0.777**	0.138	0.103	0.062	−0.111
Asp6	0.277	0.297	0.232	**0.736**	0.136	0.155	−0.001	−0.054

(continues)

Table 4. Continued

Item	1	2	3	4	5	6	7	8
Risk1	0.146	0.148	0.183	0.045	**0.817**	0.114	0.207	0.073
Risk2	0.143	0.123	0.205	0.104	**0.866**	0.133	0.121	0.029
Risk3	0.142	0.149	0.147	0.108	**0.857**	0.170	0.103	−0.027
Risk4	0.122	0.137	0.098	0.099	**0.893**	0.141	0.080	−0.022
Iso1	0.203	0.144	0.318	0.217	0.196	**0.703**	0.155	0.232
Iso2	0.244	0.143	0.360	0.183	0.178	**0.764**	0.145	0.009
Iso3	0.253	0.167	0.304	0.162	0.180	**0.783**	0.125	−0.072
Iso4	0.276	0.151	0.337	0.148	0.264	**0.730**	0.116	−0.073
Mod1	0.260	0.361	0.091	0.328	0.198	0.147	**0.656**	0.082
Mod2	0.283	0.225	0.268	0.048	0.242	0.072	**0.603**	0.183
Mod3	0.345	0.392	0.157	0.259	0.167	0.233	**0.692**	−0.069
Mod4	0.349	0.387	0.154	0.233	0.198	0.210	**0.720**	−0.164
Mod5	0.245	0.414	0.227	0.170	0.319	0.151	**0.741**	−0.099
Propen1	0.305	0.325	0.225	0.163	0.297	0.300	−0.021	**0.817**
Propen2	0.165	0.435	0.345	0.182	0.196	0.254	−0.057	**0.738**
Propen3	0.022	0.430	0.273	0.179	0.230	0.273	−0.088	**0.763**
Eigenvalue	4.624	3.874	3.620	3.030	2.673	2.173	2.094	1.780
Percent of variance explained	9.870	8.663	8.565	8.168	8.021	7.539	7.474	6.827

Notes: ITDR: IT unit's decision right; Sec: security management; SCD: SC digitization; Asp: strategic aspiration; Risk: perceived risk; Iso: isomorphic IT adoption; Mod: modularity between the digital SC system and other internal systems; Propen: risk propensity. Boldface values show the loadings of indicators on their corresponding factors.

Table 5. Fit Indices for Measurement Models

Model	CFI	ΔCFI	χ^2_{df}	$\Delta\chi^2_{\Delta df}$
1. Eight-factor model	0.904		2,316.71***	
2. Single-factor model	0.541		8,264.61***	
Model 2: 1 difference		−0.363		+5,947.90***
3. Equate perceived risk with risk propensity	0.859		3,056.42***	
Model 3: 1 difference		−0.045		+739.72***
4. Independent perceived risk and risk propensity	0.889		2,397.75***	
Model 4: 1 difference		−0.015		+81.04***
5. Equate risk propensity with SC digitization	0.874		2,800.28***	
Model 5: 1 difference		−0.030		+483.58***

*** $p < 0.01$.

Structural Model

We used partial least squares (PLS) to test the hypothesized structural model. The use of PLS was motivated by several considerations. First, the difference between formative and reflective constructs is not a concern in PLS since PLS has the advantage of handling both types of constructs [12]. Second, relatively high correlation exists between certain constructs in our model. However, the potential multicollinearity issue is less of a concern in PLS, compared to traditional approaches such as ordinary least squares (OLS) regression. Third, PLS does not have the restriction on the normal sampling distribution as in OLS [73]. To assess the significance of path coefficients, we employed the resampling technique of bootstrapping. Following the existing literature [20, 70], we used a bootstrapping procedure with replacement using 1,000 subsamples to assess the significance of parameter estimates for the singular and interaction terms in the model. The use of bootstrapping also benefits the test of mediation (e.g., the Sobel test) since it relaxes the restriction of normal distribution for the coefficient of interaction terms [6].

Table 6. Results of PLS Structural Models

	Coefficients (β)			
Path	Model 1	Model 2	Model 3	Model 4
Mod → SCD	0.154** (2.102)	0.016 (0.625)	0.117* (1.712)	0.011 (0.350)
ITDR → SCD	0.074** (1.983)	0.092** (2.353)	0.060* (1.804)	0.058* (1.708)
Propensity → SCD	0.160*** (2.567)	0.134** (2.228)	0.275* (1.679)	0.315** (2.318)
Asp → SCD	0.182*** (2.412)	0.168** (1.985)	0.171** (2.446)	0.179** (2.518)
ISO → SCD	0.391*** (3.352)	0.350*** (3.465)	0.316*** (3.234)	0.324*** (3.251)
Sec → SCD	0.181** (2.079)	0.190** (2.166)	0.137* (1.952)	0.099* (1.793)
Size → SCD	0.028 (0.283)	0.016 (0.457)	0.014 (0.242)	0.014 (0.240)
Revenue → SCD	–0.077 (0.794)	–0.071 (–0.601)	–0.015 (–0.660)	–0.008 (–0.625)
IT budget → SCD	0.070 (1.270)	0.092 (1.230)	0.123 (1.612)	–0.123 (–1.619)
Mod × ITDR → SCD			0.274** (2.247)	0.071 (1.613)
Mod → Risk		–0.265*** (–4.526)		–0.245*** (–3.346)
ITDR → Risk		0.026 (0.353)		0.115 (0.609)
Risk → SCD		–0.133** (–2.232)		–0.134** (–2.273)
Mod × ITDR → Risk				–0.307*** (–3.185)
R^2 (Risk)		0.297		0.324
ΔR^2 (Risk)				
$F(\Delta R^2$ Risk)				12.821***
R^2 (SCD)	0.537	0.589	0.572	0.603
ΔR^2 (SCD)		0.052		0.031
$F(\Delta R^2$ SCD)		37.956***		23.426***

Notes: Mod: systems modularity; ITDR: IT unit's decision right; Sec: security management; SCD: SC digitization; Asp: strategic aspiration; Risk: perceived risk; ISO: isomorphic IT adoption; Propensity: risk propensity. $n = 324$. t-statistics are in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

The PLS results are included in Table 6. We present estimation for various model specifications to better illustrate the several hypotheses tests on mediation and moderation. To test H1, which suggests that the effect of system modularity on SC digitization is mediated by perceived risk, we followed the steps of mediation testing in Edwards and Lambert [20]. In Model 2, the relationship between system modularity and perceived risk was negative and significant (β = –0.265, t = –4.526, p < 0.01), suggesting that system modularity helps mitigate the perceived risk of the digital supply chain system. The relationship between perceived risk and SC digitization was also negative and significant ($\beta = –0.133$, $t = –2.232$, $p < 0.05$), suggesting the perceived risk of the digital supply chain system leads to a lower level of SC digitization. A Sobel test was then conducted to confirm the mediating effect of perceived risk. The test statistics had a significant value of 1.988 ($p < 0.05$), suggesting that perceived risk mediates the relationship between system modularity and SC digitization. The main effect of system modularity on SC digitization when perceived risk was not included (in Model 1) was positive and significant ($\beta = 0.154$, $t = 2.102$, $p < 0.05$). In contrast, the direct effect of system modularity on SC digitization when perceived risk was included (in Model 2) was not significant ($\beta = 0.016$, $t = 0.625$, $p > 0.1$). This suggests that the relationship is fully mediated by perceived risk, supporting H1.

The results, however, did not support H2. Specifically, in Model 2, the relationship between ITDR and perceived risk was not significant ($\beta = 0.026$, $t = 0.353$, $p > 0.1$). In addition, the relationship between ITDR and SC digitization was positive and significant both when perceived risk was included (in Model 2: $\beta = 0.092$, $t = 2.353$, $p < 0.05$) and when perceived risk was not included (in Model 1: $\beta = 0.074$, $t = 1.983$, $p < 0.05$). A t-test indicated no significant difference between these two cases ($t = 0.33$, $p > 0.1$). Therefore, these results suggest that perceived risk does not mediate the positive effect of IT-DR on SC digitization. A plausible explanation is that allocating more decision rights to the IT unit motivates the focal firm to become more proactive in risk taking.

The testing of mediated moderation in the theoretical framework requires that perceived risk mediates the effects of the interaction between system modularity and IT-DR as well as the interaction between system modularity and security management. A multistep procedure is needed here [20, 38, 70] to show that (1) the interaction between system modularity and IT-DR as well as the interaction between system modularity and security management have significant effects on SC digitization (the outcome); (2) the interaction between system modularity and IT-DR as well as the interaction between system modularity and security management have significant effects on perceived risk (the mediator); and (3) the effects of these interaction terms on SC digitization decrease in magnitude in the presence of the mediator.

With regard to the interaction between system modularity and IT-DR, Model 3 in Table 6 indicates that this interaction term had a positive and significant effect on SC digitization ($\beta = 0.274$, $t = 2.247$, $p < 0.05$). Model 4 indicates that this interaction term had a negative and significant effect on perceived risk ($\beta = –0.307$, $t = –3.185$, $p < 0.01$), suggesting that system modularity and IT-DR reinforce each other in mitigating perceived risk. A Sobel test generated a significant test statistic value of 1.852 ($p < 0.1$), suggesting that the effect of the interaction term on SC digitization is mediated by perceived risk. In addition, Model 4 indicates that the effect of this interaction term on SC digitization became smaller and insignificant ($\beta = 0.071$, $t = 1.613$, $p > 0.1$) when perceived risk was added. This suggests that perceived risk fully mediates the positive effect of this interaction term on SC digitization. Therefore, H3 is supported.

We also consider the rivalry explanations of the perceived risk of digital supply chain system and SC digitization based on the estimated coefficients of the control variables. As the full model (Model 4) in Table 6 indicates, the coefficient of risk propensity on SC digitization was positive and significant ($\beta = 0.315$, $t = 2.318$, $p < 0.05$), which implies that even in the presence of perceived risk, organizations with risk-seeking propensity still pursue higher levels of SC digitization. This finding complements the IT risk literature [16, 63] in suggesting that organizations often strategically take risk in investing in IT when they are rationally aware of IT risk. The coefficient of managerial aspiration was positive and significant ($\beta = 0.179$, $t = 2.518$, p

< 0.05). This suggests that when decision makers expect a large benefit of SC digitization, even if they perceive risk, they are willing to take the risk and adopt digital supply chain systems. This finding is in line with the logic of the prospect theory [26], which suggests that aspiration leads to risk-taking actions. The coefficient of isomorphic IT adoption was positive and significant ($\beta = 0.324$, $t = 3.251$, $p < 0.01$), suggesting that higher levels of IT adoption by the focal firm's interacting partners motivate the focal firm to digitize its supply chains cooperation. This result is consistent with the institutional view that the adoption of IOSs is subject to environmental and peer influence [65]. Finally, the coefficient of security management was positive and significant ($\beta = 0.099$, $t = 1.793$, $p < 0.1$). This implies that more security management is associated with a higher degree of SC digitization.

Common Method Bias

We used multiple approaches to assess the potential threat of common method bias (CMB). First, we conducted Harman's single-factor test, where existence of a single factor that accounts for a large proportion of the variance indicates CMB [24]. In our results, no such single factor emerged in the factor analysis with all the constructs. The first factor accounted for 9.87 percent of the 67.75 percent explained variance. Second, we employed Lindell and Whitney's [35] approach of a marker variable test. We used the dummy of company location and the dummy of company type (i.e., 1 for state-owned; 2 for private; 3 for foreign-invested) as marker variables, which are theoretically uncorrelated with the other constructs. The average correlation between the study's principal constructs and location dummy ($r = 0.033$, $t = 0.559$) and type dummy ($r = –0.027$, $t = 0.856$) was low and nonsignificant, providing no evidence of CMB. Third, we also conducted a CMB assessment using a PLS approach as in Liang et al. [34] and Podsakoff et al. [46]. We included in the PLS model a common method factor whose indicators included all of the principal constructs' indicators. Each indicator's variances explained by its principle construct and by the common method factor are calculated. The average variance substantively explained by the corresponding principal constructs is 0.702, and the average variance explained by the method factor is 0.018. The ratio of substantive variance to method variance is 39:1. Most method factor loadings were small and insignificant. These results suggest that CMB is not likely to be a serious concern. Overall, there is no evidence of CMB.

Formative and Reflective Constructs

We followed Petter et al. [44] to conduct robustness analyses to take into account the potential formative nature of some of the constructs used in the model. We first specified SC digitization, perceived risk, IT-DR, security management, and isomorphism as formative constructs. We used principal components analysis to extract constructs from the measurement items [11] and were able to extract these constructs correctly from their measures. We found that the weights of the measurement items on the corresponding constructs were all significant. However, we also found high multicollinearity between the measurement items of each construct (with variance inflation factors > 10), which was not surprising given the corresponding high Cronbach's alpha values). High multicollinearity between the construct items is desirable for reflective constructs, but not for formative constructs [17]. It essentially means that multiple indicators are tapping into the same aspect of the construct. Therefore, to avoid the statistical issue caused by multicollinearity, we followed Petter et al. [44] to model these constructs as multidimensional constructs (rather than directly modeling them as formative constructs). For each of these multidimensional constructs, each measurement item was used as a reflective item of a separate subconstruct. We compared the original PLS models using all the reflective constructs and the hybrid PLS models using both the multidimentional and the reflective constructs and found that the results were fairly consistent. This confirmed the robustness of the original PLS models [12].

Discussion

In this section, we discuss the implications and contributions of the key empirical findings. This study first contributes to the stream of research on IT modularity by examining whether the modular design of IT systems mitigates IT risk and enables the focal firm to mitigate IT risk in the interorganizational environment. Drawing upon the logic of strategic flexibility in modular systems theory [54, 55], we posit that the modularity between internal IT systems and digital supply chain systems mitigates the organizational decision makers' perceived risk of adopting digital supply chain systems and motivates them to digitize their supply chain operations to a greater extent. Our empirical investigation confirms the risk-mitigating effect of system modularity. The results of our mediation analysis suggest that risk mitigation is an important way through which system modularity fosters supply chain digitization. The study thus reveals the value of modular systems design in the interorganizational business environment.

Second, this study contributes to the IT governance literature [53, 68, 71] by examining how decision allocation to the IT unit enables firms to adopt risky IT to support their interfirm business operations. The results suggest that decision allocation to the IT unit is associated with a higher degree of supply chain digitization, which is consistent with the existing view that the IT unit favors more IT initiatives [71]. However, this study also illustrates that the enhancement on SC digitization by the decision rights of the IT unit does not manifest itself through risk mitigation. We find that allocating more decision rights to the IT unit does not directly alleviate the perceived risk of digital supply chain systems. Instead, decision allocation generates a moderating effect to make system modularity further reduce the perceived risk of digital supply chain systems. This finding is consistent with the logic of modularity–governance fit in recent research on IT governance [70]. In other words, a decentralized IT governance pattern is complementary to modular IT architecture. Decentralization of decision rights allows organizational units to better manage IT components and subsystems in the autonomous ways supported by modular IT architecture. Such a moderating effect should benefit the focal firm in mitigating risk in the interorganizational environment.

Third, our study contributes to the literature on digitally enabled supply chain management by incorporating the risk perspective. The existing research in this stream has illustrated how the implementation and the performance of digitally enabled supply chain management are dependent on factors such as IT customization [29] and the firms' ability to integrate their IT infrastructure to facilitate information flow [48, 49]. The risk-mitigating effect of system modularity we identified is aligned with this logic. By providing the focal firm the strategic flexibility to customize and adjust its electronic supply chain linkages with its partners, system modularity reduces risks in digitally enable supply chain operations. In addition, such a risk-mitigating effect is stronger when the IT unit has more decision rights. Therefore, an important implication of this study is that modular system design and strategic-level IT governance arrangement (i.e., IT-DR) are two key mechanisms through which the focal firm better supports its digitally enabled supply chain operations.

Given the aforementioned contributions, it is worthwhile to recognize some limitations of this study. First, our argument on the moderating effect of IT-DR on system modularity is based primarily on the knowledge perspective. However, in this study, we did not directly measure the IT unit's knowledge. Second, this study focuses more on the risk mitigation in SC digitization. As IT risk is well recognized and it is usually associated with a higher return on investment [16], firms may strategically take risks in pursuit of higher returns. Focusing only on risk mitigation may not fully explain firms' intention to pursue risky IT initiatives such as digital supply chain systems. Third, our study relies on a sample from a single country, which may potentially limit the generalizability of the findings. Fourth, our study did not consider the performance effect of supply chain digitization in the risky environment.

Conclusion

By developing and testing a theoretical framework of risk mitigation in supply chain digitization, this study addresses an important research topic at the intersection of modular system design, organizational IT adoption, and IT governance. The theoretical framework conceptualizes how system modularity fosters SC digitization through mitigating risk of adopting digital supply chain systems. Moreover, the framework theorizes how the decision allocation to the IT unit interacts positively with system modularity in mitigating risk and motivating SC digitization. The empirical study provides evidence on the risk-mitigating effect of system modularity in SC digitization. Moreover, the empirical findings also indicate that the decision allocation to the IT unit enhances the effect of system modularity in mitigating the risk of adopting digital supply chain systems and fostering SC digitization. The theoretical implications and empirical evidence of this study contribute to multiple streams of literature on modular systems theory, IT governance, and digitally enabled supply chains.

The study also paves ways for future research. First, future research may examine the performance effect of SC digitization and see whether the risk-mitigating effects of system modularity and the decision allocation to the IT unit also make the focal firm generate higher returns from SC digitization. Second, future research may consider how firms proactively seek risk, rather than mitigate risk, in adopting digital supply chain systems, and how organizational factors such as IT decision allocation may influence firms' strategic risk-seeking behaviors. Third, in this study, we focus on the risk associated with the adoption of digital supply chain systems. Future research may examine other areas of IT-related risk. Future research may also validate the findings and insights of this study using samples of organizations with different cultural backgrounds.

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