Interorganizational Systems and Supply Chain Agility in Uncertain Environments: The Mediation Role of Supply Chain Collaboration

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Abstract

Supply chain agility has been recognized as a key capability for firms working to achieve superior performance in uncertain business environments. Supply chain agility is challenging to achieve, however, because it requires the firm and its supply chain partners to collaborate closely yet flexibly across organizational boundaries. Extending the boundary object literature to the supply chain context, this study unveils the mechanism through which interorganizational systems (IOS), widely deployed to span organizational boundaries through inter-firm digital connections, promote supply chain agility in uncertain environments. The concept of supply chain collaboration (SCC) is introduced as the mediating mechanism between two key IOS characteristics (i.e., standardization and adaptability) and supply chain agility. Environmental uncertainty is incorporated as the contextual condition through contextualized theorization of IOS as boundary objects. The resulting hypotheses are tested via a two-wave, match-paired survey study on business and IT executives in 156 manufacturing firms. Empirical findings provide general support to most hypotheses, and implications for theory development and professional practice are discussed.

Keywords: *IOS adaptability, IOS standardization, supply chain collaboration, supply chain agility, environmental uncertainty*

1. Introduction

The economy is recovering in today's post-pandemic phase, but uncertainties such as supply chain disruptions remain a top risk according to the latest McKinsey Global Survey.[1] The fragility of global supply chains has been exposed in almost every industry, such as Starbucks warning customers that some items may not be available because of material shortage, and car sales at General Motors having wait lists because of a chip shortage.[2] Environmental uncertainty creates the need for swift supply chain adjustments in response to these external changes. Across industries, supply chain agility (SCA), defined as a firm's ability to sense and respond to external opportunities or threats by making quick adjustments in supply chain processes (Gligor et al., 2015), has risen to the top of the executive agenda (Ellingrud, 2020) and is recognized as a key capability for firms' survival in dynamic environments (Swafford et al., 2006). For instance, confronted with blocked distribution centers and paralyzed distribution networks caused by the pandemic, JD.com, an e-commerce giant in China, actively collaborated with over 300 suppliers and 30 warehouses to effectively implement the entire redesigned distribution network by using a distribution network optimization system (i.e., JD-NetSIM) (Shen & Sun, 2021).

For quick and effective supply chain responses, a firm must effectively span its organizational boundary by connecting and coordinating with its partners (Rai & Tang, 2013). But achieving such superior agility is challenging due to difficulties in synchronizing different firm-specific information formats, organizational processes, or business goals, especially in response to uncertain environments (Levina & Vaast, 2008; Zietsma & Lawrence, 2010). Interorganizational systems (IOS), defined as "automated information systems shared by two or more organizations and designed to link business processes" (Robey et al., 2008, p. 498), have been widely deployed to establish digital connections for process integration and information sharing across organizational boundaries (Malhotra et al., 2005; Rai & Tang, 2013; Saraf et al., 2007). Prior research has investigated how IOS should be designed to enhance SCA (e.g., Gosain et al., 2004; Malhotra et al., 2007), and the boundary object perspective has become an influential lens to conceptualize IOS (Dong et al., 2017; Malhotra et al., 2007). Star and Griesemer (1989, p. 393) introduced the concept of boundary object to explain how man-

[1] Source: https://www.mckinsey.com/featured-insights/coronavirus-leading-through-the-crisis/charting-the-path-to-the-next-normal/leaders-brace-for-supply-chain-setbacks
[2] Source: https://www.forbes.com/sites/forbescommunicationscouncil/2022/05/11/how-supply-chain-disruptions-affect-communications-across-industries/?sh=40d5ed39215e

made artifacts can be leveraged to facilitate mutual understanding and coherence across different communities, characterized as “both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites.”

Careful scrutiny of the related literature, however, suggests that the current use of boundary object perspective does not offer sufficient theoretical understanding of the IOS-SCA relationship, particularly under varying environmental conditions, due to three considerations. First, although IOS standardization—the extent to which standardized interfaces and communication protocols are built in IOS across firm boundaries—has been identified as a key IOS characteristic (Malhotra et al., 2007), empirical investigations reported inconsistent findings about its relationship with agile supply chains, and have not fully unpacked its underlying mechanism. Gosain et al. (2004) proposed that the standardization of process/ content interfaces could improve supply chain flexibility, but this relationship has not been supported, and its underlying mechanisms were not considered. Malhotra et al. (2007) explored the mechanism between the use of standard electronic business interfaces and adaptive supply chain partnership, yet only discovered a partial mediating mechanism via information exchange. Since viewing the mechanism of information exchange as the core of communication and coordination among firms is a limited perspective, a more complete comprehension of the impact that IOS standardization exerts on SCA as well as its underlying mechanism is needed.

Second, IOS adaptability—the extent to which IOS can be adjusted in case of need—has been recently introduced to the IOS research (e.g., Dong et al., 2017), but has not yet been incorporated to better understand SCA. Third, while the external environment can affect the capacity of IOS to support interfirm relationships (e.g., Dong et al., 2017), limited research has incorporated environmental uncertainty in examining how IOS affect SCA. Given these gaps in the literature, we address the research question: *To what extent and how do IOS as boundary objects, characterized by standardization and adaptability, affect supply chain agility under different levels of environmental uncertainty?*

To address this question, we develop a research model to link IOS standardization and adaptability—the two key IOS characteristics underpinned by the boundary object literature—to SCA by applying it to our focal problem domain in two major ways. Based on the seminal work of Carlile (2004) on knowledge boundaries that extends the original boundary object literature, we first introduce *supply chain collaboration* (SCC) (rather than information exchange as studied in the literature), as the comprehensive mediating mechanism between IOS characteristics and SCA. We argue that SCC serves as a more complete mediating mechanism by explaining how it explicitly unveils more facets of knowledge boundaries than information exchange alone can achieve. Second, we incorporate environmental uncertainty (EU) as the contextual condition under which IOS standardization and adaptability play differential roles in enabling SCA. This research model is tested and generally supported by data collected from a two-wave, match-paired survey of business and IT executives (supplemented by objective data on EU) from 156 manufacturing firms in the optoelectronic sector of the Greater China region.

2. Theoretical Background

2.1. Supply Chain Agility

Supply chain agility is defined as a firm's ability to sense and respond to external opportunities or threats by making quick adjustments in supply chain processes (Gligor et al., 2015). SCA is a key supply chain capability for survival in today's business environments that are characterized by uncertainty (Swafford et al., 2006). For example, to overcome the logistics disruption and cracks in the supply chain caused by the pandemic, American Eagle Outfitters (AEO), the most popular denim brand, adjusted its supply chain via standing up four fulfillment locations across the country to pull inventory from its stores and reduce in-store fulfillment (Kumar et al., 2021).

Although the potential gains from SCA are apparent, nurturing it can be difficult. A primary challenge is to effectively manage interfirm connections to span organizational boundaries with partners (Ahuja, 2000; Kogut, 2000). Organizational boundaries between firms are underpinned by differences in business processes and goals (Levina & Vaast, 2008; Zietsma & Lawrence, 2010), such as different information formats, transaction processes, or business priorities that could impede firms' effective connections with external partners. Boundary spanning is the process of transferring knowledge and establishing shared understanding and interests, which is designed to eliminate these differences among partners (e.g., manufacturer, distributor, and retailer) (Carlile, 2004; Tortoriello & Krackhardt, 2010). Firms need effective boundary spanning to identify and respond to unexpected external changes in conjunction with supply chain partners. For instance, when a firm seeks to efficiently scale capacity in response to fluctuations in product markets, they must not only collect, pool, and share real-time demand/ supply information (Gunasekaran et al., 2008), but also create mutual understandings and collaborative executions of partners' supply chain plans. For instance, in response to pandemic challenges, Henkel, a global consumer-goods firm, emphasized sharing information and resources across boundaries to assess the extended supply chain situation at any given time so that it would know what to do (Sänger, 2022).

Despite the pertinent need to understand boundary spanning, the existing literature on SCA has mainly explored organizational antecedents from the perspectives of firm resources (e.g., Blome et al., 2013; Chiang et al., 2012), strategy orientation (e.g., Braunscheidel & Suresh, 2009; Gligor et al., 2016), and IT use (e.g., Swafford et al., 2008; Yang, 2014) (Appendix A). Limited attention has been given to interorganizational systems such as Electronic Data Interchange, the Internet, and Sabre, which are regarded as core infrastructures used by firms to effectively transact with supply chain partners in a timely manner (Bensaou & Venkatraman, 1995). By establishing digital connections to span boundaries among different partners, IOS could support the rapid and effective responses to external turbulences (Malhotra et al., 2005; Rai & Tang, 2013; Saraf et al., 2007).

2.2. The Role of Interorganizational Systems – A Boundary Object Perspective

To better understand the mechanism through which IOS span organizational boundaries characterized by differences across partners, the extant research has adopted the boundary object perspective (e.g., Dong et al., 2017; Malhotra et al., 2007). This influential lens was first proposed to study collaborative problem-solving activities employed by different but interdependent scientific communities through the use of boundary objects, which serve as shared artifacts among different communities and are thought to address differences in knowledge, understandings, and interests while establishing and maintaining coherence (Carlile, 2002; Star & Griesemer, 1989). Specific to the supply chain context, boundary objects are the defined format for inventory data, structured, or semi-structured documents in Electronic Data Interchange with shared meaning (Im & Rai, 2008), as well as business models with simulation (e.g., computational models for risk and return). The boundary object perspective based on practice theory is expansive in terms of theoretical arguments (Levina & Vaast, 2005), yet it has also been appropriated to specific contexts and empirically testable models. For example, Malhotra et al. (2007) applied the boundary object literature to the extended enterprise context, and examined the impact of standard electronic business interfaces on adaptive supply-chain partnerships. Dong et al. (2017) also extended the literature by characterizing IOS, an approach our study also follows.

Drawing upon the boundary object perspective, IOS have been conceptualized as boundary objects that need to be adequately robust and plastic to meet the goals of boundary spanning (Star & Griesemer, 1989). This implies they should be standardized to allow shared use yet be adaptable to accommodate multiple applications. Specifically, IOS standardization refers to using uniform interfaces to stipulate protocols for information exchange and task processing (Malhotra et al., 2007), whereas IOS adaptability is the ability to readily adapt or reconfigure to meet constantly changing requirements (Dong et al., 2017). In practice, IOS standardization can be achieved by using common technical specifications to describe data formats, or adopting shared communication protocols (e.g., Transmission Control Protocol/Internet Protocol) for communications (Zhao & Xia, 2014). For instance, JD.com adopted a standardized automatic procurement process with its suppliers, allowing them to purchase rapidly without negotiation and further accelerate procurement (Shen & Sun, 2021). IOS adaptability can be technically achieved by deploying open-standard technological architectures (e.g., Extensible Markup Language) or applying modularized architectures and structured data formats in the design process (Dong et al., 2017; Zhu et al., 2006). For instance, ServiceGo, as a one-stop intelligent customer relationship management system with a lot of users, has flexible functional modules and visual configurations, which more fully meet the personalized needs of its users by enabling them to make customized combinations.[3]

While prior studies have recognized the essential roles of IOS standardization and adaptability in spanning organizational boundaries to exchange information based on the boundary object literature, very few have related them to interfirm agility in general and SCA in particular. For example, Dong et al. (2017) examined the positive impact of IOS adaptability on information sharing between firms, but made no connections to agility. Malhotra et al. (2007) investigated the extent to which IOS standardization makes supply chains more adaptive through the mediating mechanism of information sharing, but only found a partial mediating role, implying that information sharing *per se* is insufficient to capture the mechanism through which IOS standardization affects SCA. Carlile (2004) explored how interconnected parties that hold different knowledge bases can work jointly in managing their differences across three levels of knowledge boundaries: syntactic, semantic, and pragmatic. A syntactic boundary exists when the current lexicon is insufficient or incompatible for transferring knowledge; a sematic boundary emerges because of differences in meanings, interpretations, and understandings; and a pragmatic boundary arises when different interests or goals exist between interacting partners (Carlile, 2004).

[3] Source: https://www.udesk.cn/feature_servicego.html

These boundary levels are not independent, but are nested with increasing complexity. Effective boundary spanning involves not only sharing information and achieving common understanding, but also developing *shared goals and interests*. In this regard, information exchange studied in prior research (e.g., Malhotra et al., 2007) cannot adequately explain SCA, as partners may hold diverse interests and goals in exchanging information. A more comprehensive mediating mechanism that explicitly unveils myriad facets of boundary spanning is therefore needed to uncover the relationships between IOS standardization/ adaptability and SCA.

Moreover, the external environments in which supply chain relationships are situated may also provide insights into the conditions under which IOS take effect. For instance, Gosain et al.'s (2004) lack of empirical support may indicate that IOS standardization exhibits an impact on SCA only under certain conditions. Carlile (2004) theorized that a knowledge boundary between two collaborating partners emerges when there is *novelty in circumstances*, referring to new needs in external environments that generate new requirements of participating actors within their specialized domains. As novelty in the circumstances of concern increases, more new needs could emerge because of new differences and dependencies between two parties. This may cause the original lexicon, meanings, or interests manifested through a boundary object to be insufficient in representing or understanding these emerging relationships (Carlile, 2004) and subsequently makes spanning boundary more challenging. As the critical role of external environments in this context has been understudied, we take into account the moderating role of such conditions when exploring how IOS standardization/adaptability affect SCA.

2.3. Supply Chain Collaboration as the Mechanism to Span Inter-Firm Knowledge Boundaries

Supply chain collaboration has drawn increased attention as a key driving factor for effective supply chain management (Cao et al., 2010). Based on the development of shared goals and interests, SCC helps firms leverage, coordinate, and integrate resources and knowledge across the supply chain (Caridi et al., 2005; Lejeune & Yakova, 2005). For instance, Sears collaborated with Michelin to reduce their inventories (Steerman, 2003), and General Motors worked with its suppliers to decrease vehicle development cycle times (Gutman, 2003). Besides, during the pandemic, AEO collaborated with regional carriers to gain slack capacity in their delivery network, which enables it to cope with sudden demands (Kumar et al., 2021). Combining both process and relationship focuses common in the literature, Cao and Zhang (2011) defined SCC as a partnership process with seven dimensions—*information sharing, decision synchronization, collaborative communication*, *joint* *knowledge creation, resource sharing, incentive alignment,* and *goal congruence*—through which participating firms work closely to plan and execute supply chain operations to achieve common goals and benefits (see Appendix B for the definitions of the seven dimensions of SCC).

Supply chain collaboration is the higher-level construct underlying these inter-correlated seven dimensions that center on achieving mutual interests of supply chain partners (Cao & Zhang, 2011). As information, decisions, resources, benefits, and risks are shared among partners for beneficial results, SCC could address the boundary-spanning challenges of not only knowledge exchange, but also the differences in valued practices and interests. As such, SCC is a more comprehensive approach that reflects all three types of boundary spanning, more than what information sharing alone can achieve. Specifically, *information sharing* facilitates parties' shared knowledge and understanding across boundaries, while *decision synchronization* builds upon mutual decisions that require partners to coordinate diverse interests and transform knowledge to guide joint decision-making processes (Simatupang & Sridharan, 2005). The aim of *collaborative communication* is to form shared goals and interests between the focal firm and its partners through discussion. *Joint knowledge creation* integrates knowledge across boundaries and provides solutions collectively that can satisfy partners throughout the supply chain, while building on shared goals and interests. *Resource sharing* develops mutual support to establish shared resources, representing partners' agreements on the joint investment of resources. *Incentive alignment* enables each participant to share gains and losses equitably (Manthou et al., 2004) and requires supply chain partners to formulate incentive schemes that parties agree upon, which also builds on shared goals and interests. Finally, *goal congruence* makes partners feel that their objectives more fully coincide with the supply chain's goals, or can be achieved as a direct result of working together toward these goals (Lejeune & Yakova, 2005). Yet the compatibility or fit of objectives requires the negotiation of interests and the transformation of knowledge. SCC captures the commonality shared by all seven dimensions and reflects the extent to which compromises of partners in valued supply chain practices are enacted to achieve mutual interests. Due to its considerable reach, we theorize that SCC could be incorporated as a comprehensive influencing mechanism in the supply chain context to better explain the impacts of IOS characteristics on SCA from the boundary object perspective.

We find a relative dearth of research that has formally theorized how SCC can be facilitated by using IOS. Focus in the literature has been on whether and how intraorganizational factors such as collaborative culture and strategic elements (Barratt, 2004), IT capabilities (Chae et al., 2005), and social capital (Wu & Chiu, 2018) affect SCC (Appendix C). Recent research has explored the impact of IOS on SCC, where Zhang and Cao (2018) adopted IOS appropriation and conceptualized it as a resource in use while highlighting its external/ practical applications. Our study instead focuses on the intrinsic nature/ internal structure of IOS and identifies its two characteristics of standardization and adaptability, which impact SCC based on their specific abilities. Moreover, the extant SCA literature has not fully explained SCC's potential impacts, where its focus on firm resources, strategy orientation, and IT use (Blome et al., 2013; Gligor et al., 2016) does not clarify how SCC explicitly affects SCA (Appendix A). Two studies that considered SCA enablers from the collaboration perspective (e.g., Gligor & Holcomb, 2012; Yang 2014) selected limited dimensions (e.g., decision synchronization) of collaborative activities to capture the collaboration concept, without considering how SCC facilitates SCA as a complete boundary-spanning activity that not only transfers or interprets knowledge, but transforms knowledge and negotiates interests.

2.4. Environmental Uncertainty

Environmental uncertainty (EU) refers to the ambiguities and inherent insecurities coming from the external conditions of a focal firm (Wong et al., 2011), including insufficient information about environmental changes and the inability to predict impacts of these changes on organizational operations (Sawyerr et al., 2003). EU has been regarded as one of the key external factors affecting the development of supply chain management (Chen & Paulraj, 2004), where COVID-19 pandemic shutdowns, related labor shortages, and material lack represent a classic case of environmental uncertainty (Drenik, 2022). Carlile (2004) argued that EU (which emphasizes the unknown) captures an important aspect of novel circumstances (which underscore new needs), as it reflects changes in external environments that are not anticipated by the focal firm, such as variations in product demand, material supply, or technology (Wang et al., 2011). EU thus gives rise to emerging new needs in circumstances that require partners to respond through joint actions in the supply chain. For instance, COVID-19's impact on Schneider Electric included unrecovered upstream supply chain and limited transport, but daily contact with nearby factories (changed from weekly or monthly pre-pandemic) allowed it to quickly mobilize resources from other regions to solve resource or capacity shortages.[4] It is thus theoretically appropriate to incorporate EU as a contextual condition of this study, per the extended boundary object literature (Carlile, 2004).

3. *Model and Hypotheses Development*

Based on this theoretical foundation, we develop a research model (Figure 1) to link IOS standardization/ adaptability to SCA through the mediation of SCC, which is conditional upon EU (Table 1). To theorize the mediating mechanism, we develop the causal linkages between SCC and SCA, and between IOS adaptability/ standardization and SCC, before proposing the mediations. We then theorize the moderations of EU on the SCC-SCA relationship and the IOS adaptability/ standardization-SCC relationship, and illustrate the proposed relationships with practical examples to enhance its accessibility (Gregory & Henfridsson, 2021; Rivard, 2021).

Insert Figure 1 and Table 1 about here.

3.1. The Relationship between Supply Chain Collaboration and Supply Chain Agility

According to Carlile (2004), SCC can be conceptualized as a comprehensive boundary-spanning mechanism in the supply chain context, as it includes multiple interconnections that develop shared lexicon, meaning, and interests with supply chain partners. The boundary spanning of SCC enables firms to acquire and exploit external new knowledge and synchronize their actions with that of partners, especially in adjusting supply chain processes (Gligor et al., 2015). A firm with superior SCC is more agile at sensing and responding to market changes, largely through learning from external sources with its partners. For example, by collaborating closely with upstream suppliers, the fast fashion e-commerce platform SheIn was able to cater to customer tastes and fashion trends by providing timely products.[5] SCC helps firms synchronize supply chain partner processes, such as jointly adjusting delivery capacities. The renewed knowledge base of external markets and shared values across partners also empowers a firm to reengineer its supply chain processes to improve its products and services (Malhotra et al., 2005).

According to the three levels of syntactic, semantic, and pragmatic knowledge boundaries (Carlile, 2004), all SCC dimensions other than information sharing—which serves as the foundation of other dimensions—could span the three levels to develop shared goals and interests. Information sharing allows firms to master market

[4] Source: https://baijiahao.baidu.com/s?id=1671706923290061254&wfr=spider&for=pc
[5] Source: https://m.huxiu.com/article/575848.html

information (e.g., fluctuations from the supply/ demand side) and identify or anticipate technology development and other trends (Li et al., 2006). As the basis for developing shared goals and interests, information sharing facilitates SCA by enhancing firms' ability to sense external fluctuations (Mondragon et al., 2004). Besides, the use of decision synchronization, collaborative communication, resource sharing, incentive alignment, and goal congruence indicate the development of shared values across the supply chain. Firms can thus acquire supply-and-demand information in real time and exploit the acquired knowledge via negotiating plans or tasks with partners. This facilitates SCA by decreasing potential conflicts or opportunistic behavior, and motivating partners to deploy resources to improve supply chain efficiency. Moreover, joint knowledge creation enables firms to capitalize on external opportunities, gain a deeper understanding of external markets, and form effective responses to them (Gligor et al., 2015). Jointly managing market changes nurtures SCA by enabling firms to effectively capture opportunities in external environments. Integrating these arguments, we thus hypothesize:

H1. *Supply chain collaboration is positively related to supply chain agility.*

3.2. The Relationship between Interorganizational Systems Characteristics and SCC

Based on the boundary object literature, adaptive IOS—e.g., IOS with open-standard technological architectures, modularized architectures, or structured data formats—serve as boundary objects shared by firms to establish coherence. They allow firms to conduct iterative activities to adjust different business processes with others, and enhance their development of specific assets particular to others' requirements to achieve collaboration. Specifically, we argue that IOS adaptability contributes to managing different knowledge bases, understandings, and interests (Carlile, 2002) by allowing for adjustments to accommodate differences across organizational boundaries. This means that partners are able to quickly display, represent, and assemble supply chain processes. IOS adaptability also alleviates differences in interests (e.g., ambiguous interests or emerging disagreements) by affording the negotiation of two parties' interests, and transforming their knowledge to achieve common goals and interests.

Use of the adaptive simulation model or modularized architectures embedded in IOS between the focal firm and its partners provides a mechanism for enhanced IOS adaptability across partners (Im & Rai, 2008). For example, to realize real-time supply chain, SheIn required every supplier to use the manufacturing execution system (MES) to enable real-time communication and adjustment during manufacturing. This eliminates differences between SheIn and its thousands of suppliers (mostly small and medium-sized factories) and allows efficient interactions between them, further promoting collaboration.[6] While shared goals and interests can be achieved when all parties accept final results, IOS with higher adaptability makes it technically easier to develop them via timely adjustments to overcome differences across supply chain partners and further facilitate their collaboration. We thus hypothesize:

H2a. *IOS adaptability is positively related to supply chain collaboration.*

Similarly, standardized IOS—IOS with common technical specifications or shared communication protocols—as boundary objects could enable firms to interact across diverse boundaries, providing a robust basis for collaboration. Specifically, we argue that IOS standardization facilitates the management of different knowledge bases, understandings, and interests (Carlile, 2002) by providing standardized interfaces and structures to represent activities in a form that other firms can understand. In particular, IOS standardization could address different interests across supply chain partners by offering shared specifications and protocols to build their identification with a collective of partners. The parties could then achieve mutual goals and interests based on standardization-induced network spillovers and gain greater value from the larger range of partners that use standardized interfaces or shared specifications by planning and executing supply chain operations together (Mark et al., 2007). For instance, through the use of the standardized and efficient automatic procurement process with the suppliers of self-owned stores, JD.com was enabled to purchase rapidly without negotiation, which not only further accelerates procurement but also reinforces collaborative motivations by developing mutual recognition (Shen & Sun, 2021). Higher IOS standardization thus makes it easier to develop shared goals and interests by providing robust technical ways to specify and negotiate these interests, further promoting collaboration. We therefore hypothesize:

H2b. *IOS standardization is positively related to supply chain collaboration.*

3.3. The Mediating Role of Supply Chain Collaboration

Combining the proposed hypotheses—SCC facilitates SCA, and IOS adaptability and standardization are positively related to SCC—we suggest that SCC mediates the relationships between IOS adaptability/

[6] Source: https://new.qq.com/rain/a/20211209A09IK000

standardization and SCA. Using IOS adaptability and standardization as boundary objects could facilitate establishing coherence (i.e., SCA in this study) via addressing differences and developing shared goals and interests (i.e., SCC in this study). Through the establishment of SCC, partners could develop common lexicon and understanding, and form shared goals and interests, allowing them to acquire and exploit new external knowledge and synchronize their actions to quickly deal with external changes. For instance, through close collaboration with thousands of suppliers, SheIn's adaptive MES allowed a 7-day delivery in its digital supply chain,[7] while JD.com's standardized automatic procurement process, supported by its strong collaboration capabilities, greatly improved supply chain operations (Shen & Sun, 2021). This implies IOS adaptability and standardization could lead to SCA by promoting supply chain collaborations. We thus hypothesize:

H3a. *Supply chain collaboration mediates the relationship between IOS adaptability and supply chain agility.*
H3b. *Supply chain collaboration mediates the relationship between IOS standardization and supply chain agility.*

3.4. The Moderating Role of Environmental Uncertainty

3.4.1. The moderating role of environmental uncertainty on the SCC-SCA relationship

When the external conditions of a focal firm are unknown or unpredictable (e.g., changing customer tastes or fluctuating supply situations) (Swafford et al., 2006; Wong et al., 2011), firms need to utilize new information and novel solutions rather than past experience to deal with new external challenges (Pavlou & El Sawy, 2006). SCC—as the partnership process that enables firms to acquire and utilize new information from supply chain partners and orchestrate their behaviors to jointly manage market changes with increased efficiency—thus plays a critical role in this context. Again, taking Schneider Electric as an example, to deal with the pandemic, it changed to daily communication with nearby factories to build closer collaboration, which enabled it to resume production soon. Collaboration makes the supply chain more visible in that, supply or demand fluctuations can be more easily interpreted and addressed (Braunscheidel & Suresh, 2009). By effectively updating their knowledge base and deploying resources with partners, firms with SCC would be amenable to changes, allowing them to beneficially reshape supply chain responses to meet the needs of external environments. Conversely, under a lower level of EU, focal firms can respond to relatively familiar environmental conditions with ease. A firm usually has valuable experience to rely on, and could use formerly successful responses to manage these

[7] Source: https://new.qq.com/rain/a/20211209A09IK000

external environments. Applying proven responses can thus be more effective in managing changes than exploiting new information or synchronizing behaviors with partners (Schilke, 2014). That is, SCC plays a less helpful role in facilitating SCA when EU is lower. We thus hypothesize:

H4. *The positive relationship between supply chain collaboration and supply chain agility is positively moderated by environmental uncertainty, such that the relationship is stronger when environmental uncertainty is higher.*

3.4.2. The moderating role of environmental uncertainty on the IOS characteristics-SCC relationships

Importantly, the three levels of knowledge boundaries would emerge in turn with an increase in novel circumstances (Carlile, 2004). Less environmental predictability could cause knowledge boundaries to become more complex and unstable. With a higher level of EU, more new needs would arise between the focal firm and its supply chain partners, which could make boundary spanning more challenging (Carlile, 2004). To address changeable customer demand or fluctuant material supply, for example, merely transferring/ translating knowledge to develop common lexicon or understanding is inadequate, but nonetheless requires firms to deliberately align their goals and interests (Carlile, 2004). For instance, to deal with changes in global demand, SheIn had to rely on adaptive MES to interact (e.g., determining the style, fabric, and capacity) with different suppliers so that the response speed and efficiency of each link in the supply chain could be improved, which further leads to better collaboration.[8] IOS adaptability thus acts as a powerful and helpful boundary object because it enables a firm's iterative activities of adjusting processes, interfaces, and structures to respond to these unstable and complex boundaries (Kumar, 2004) and sustain meaningful collaborations with partners. The facilitating impact of IOS adaptability on SCC—via timely adjustments or reconfigurations to address differences in lexicon, interpretation, and interests across boundaries—would be more prominent when EU is higher. When external environments are more predictable, fewer new needs would arise between the focal firm and its partners, making boundary spanning less challenging. The firm would not necessarily be required to adjust IOS interfaces or processes to meet external changes, thus making IOS adaptability less useful when responding to simple boundaries (Kumar, 2004) or developing partnerships. That is, the facilitating impact of IOS adaptability on SCC is less prominent when EU is lower. We therefore hypothesize:

H5a. *The positive relationship between IOS adaptability and supply chain collaboration is moderated by*

[8] Source: https://finance.sina.com.cn/chanjing/gsnews/2021-08-17/doc-ikqciyzm1884388.shtml

environmental uncertainty, such that the relationship is stronger when environmental uncertainty is higher.

While standardization embedded in IOS helps build robust and valid boundary objects to better collaborate with supply chain partners, a firm's dependence on previously standardized interfaces and structures may cause restrictions when EU is high. Specifically, more unstable and complex boundaries would impose more pressures for the focal firm to identify and learn about the new differences and dependencies across boundaries; the current common lexicon, meanings, or interests would no longer be sufficient to represent or comprehend new differences and dependencies (Carlile, 2004). Previously standardized interfaces and structures (i.e., IOS standardization) would be less helpful for coping with new differences across boundaries and developing collaborations. For instance, in response to pandemic-related factors, JD.com's demand predictions and procurement plans had to be adjusted quickly, where previous procurement processes for suppliers no longer worked (Shen & Sun, 2021). The impact of IOS standardization on SCC—via providing robust technical ways to specify, negotiate, and address the differences across boundaries—would therefore weaken. When EU is lower, however, the standardized IOS would be more powerful and helpful as boundary objects. The firm could address differences in lexicon, interpretation, and interests across boundaries through previously established interfaces and structures, and further facilitate SCC. This implies the facilitating impact of IOS standardization on SCC is stronger when EU is lower. We thus hypothesize:

H5b. *The positive relationship between IOS standardization and supply chain collaboration is moderated by environmental uncertainty, such that the relationship is weaker when environmental uncertainty is higher.*

3.4.3. The moderating role of environmental uncertainty on the mediation of SCC

In extending the literature of boundary object (Carlile, 2004), we theorize why the IOS adaptability-SCC and SCC-SCA relationships are both positively moderated by EU. Integrating these arguments with the mediation of SCC between IOS adaptability and SCA, it follows that IOS adaptability would more significantly facilitate SCA through the mediation of SCC when EU is higher. Taking SheIn as an example, in response to global changes, SheIn was inclined to build and maintain close collaboration with its thousands of suppliers through the use of adaptive MES, so that it could deal with changing demand at a faster speed.[9] We also theorize why the IOS standardization-SCC relationship is negatively moderated by EU (Carlile, 2004). Combining this

[9] Source: https://new.qq.com/rain/a/20211209A09IK000

argument with the more prominent impact of SCC on SCA under a higher level of EU, and SCC mediation between IOS standardization and SCA, it follows that IOS standardization would less likely facilitate SCA through the mediation of SCC when EU is higher. For example, JD.com needed to adjust its demand predictions and procurement plans to face exceptional demands, rather than relying on collaboration with suppliers via the use of previously standardized procurement process (Shen & Sun, 2021). Accordingly, we hypothesize:

H6a. *The mediation of supply chain collaboration between IOS adaptability and supply chain agility is positively moderated by environmental uncertainty, such that the mediating effect would be stronger when environmental uncertainty is higher.*

H6b. *The mediation of supply chain collaboration between IOS standardization and supply chain agility is negatively moderated by environmental uncertainty, such that the mediating effect would be weaker when environmental uncertainty is higher.*

4. Research Methods

4.1. Research Approach and Sampling

The hypotheses were tested through a two-wave, match-paired survey of business and IT directors in 156 manufacturing firms in the optoelectronic industrial cluster of Mainland China, Taiwan, and Hong Kong. This industry cluster deals with the manufacturing and application of optoelectronic technology components, as well as all commercial activities related to equipment or systems using optoelectronic components as key tools. We selected this empirical context for three reasons. First, there is a need for firms in this industry to build collaborations with partners to ensure the supply chain is responsive to external changes. Different tiers of supply chain firms (e.g., manufacturers, distributors, or retailers) have strong interdependencies, managed together in an integrated process to manufacture raw materials into products for final delivery to customers. Second, being IT-enabled, these firms generally have sound technology architectures to build digital connections with each other (Robey et al., 2008). They usually form an extended enterprise network, in which a variety of external entities, including manufactures, suppliers, and subcontractors, are linked to each other through IOS applications. Third, different tiers of the supply chain firms exhibit huge variations in EU levels. This industry has multiple tiers that result in a step-by-step demand amplification effect toward the same product. Similar to the bullwhip effect—which happens when minor decisions at the end of a supply chain create amplified effects the farther they go down the supply chain—small demand fluctuations downstream may create progressively larger demand fluctuations upstream (Metters, 1997). For instance, our initial interviews suggest that compared to the sub-industries of electronic components and electronic assembly (i.e., the second tier to supply components and the third tier to supply final products), the sub-industry of steel and machine metals (i.e., the first tier to supply raw material) may perceive higher demand uncertainty. Also, different tiers with distinct products have quite different upgrading cycles induced by EU. Specifically, optoelectronic displays have diverse display products such as mobile devices and liquid crystal display (LCD) screens. The average mobile device rate of change is two-three (years/once), and has high uncertainty, while the average LCD screen rate of change is five-six (years/once), which has relatively low uncertainty. Optoelectronic display products are shown in Appendix D.

4.2. Measurement Development

The measurement items in this study were adopted from the established scales, and assessed using a five-point Likert scale. All items were translated into Chinese and refined through back-translation (Cai et al., 2010). We conducted a pilot test with senior business and IT managers of several firms to further refine the items, and to assess logical consistency, ease of understanding, item sequence, and contextual relevance to the optoelectronic industry. We believe that measurement error is therefore reduced by the process, and internal validity is ensured (see Appendix E for scale items).

Supply chain agility was measured by seven items (Gligor et al., 2015) to capture the firm's ability to adjust its supply chain tactics and operations and effectively detect and respond to changes, threats, and opportunities in external environments (Swafford et al., 2006). Supply chain collaboration was measured using the seven-dimensional scale items (Cao et al., 2010; Cao & Zhang, 2011), where we acknowledge SCC as a second-order reflective construct with its seven sub-dimensions (Appendix B).

The measurement of IOS adaptability includes three items reflecting whether the IOS used by supply chain partners can be (1) modified to cope with changing circumstances or customer requirements, (2) flexible enough to react to customer demand fluctuations, and (3) adjusted to accommodate changing circumstances; IOS standardization has three items that capture the extent to which (1) rules/ procedures of partner company interfaces are similar to those of partners in other channels, (2) information exchanged (e.g., sales reports and product/ inventory records) with partners needs to be converted or translated, and (3) information exchanged with partners can be interpreted in the same way as that of others (Dong et al., 2017; Malhotra et al., 2007).

The measurement items of EU (Germain et al., 1994; Wong et al., 2011) contain uncertainties from supply, demand, competition, and technology conditions. Given EU is a key construct in our study, we also obtained its objective data from archival data for post hoc analysis, to reduce the risk of common method bias and increase the validity of our findings.[10] The volatility in sub-industry sales and operating income are common indicators in the literature, and were thus used to cross-check with subjective measures on EU (Keats & Hitt, 1988). We followed the established three-step procedure to measure volatility in sales and operating income of the firms (Keats & Hitt, 1988; Xue et al., 2012).

This study also includes control variables to rule out alternative explanations. First, we controlled for potential influencing factors of SCC, including strategy, trust, and IT flexibility. Strategy was measured by three items to capture the extent to which the firm depends on selecting external partners to realize its strategic aims that cannot be accomplished on its own (Boddy et al., 2000; Barratt, 2004). Trust was measured with three items (Nyaga et al., 2010; Fawcett et al., 2008) that refer to the degree to which collaborators regard others as trustworthy. IT flexibility was measured by six items (Tallon & Pinsonneault, 2011) to capture the flexibility of internal IT infrastructure (e.g., IT hardware). We also controlled for four potential influencing factors of SCA: firm-level descriptive characteristics of location, size, and revenue as well as supply chain experience. We used total employee numbers to measure firm size and total sales to measure revenue. Supply chain experience was measured by two items (Cao & Zhang, 2011) to capture the cooperative relationship between the firm and supply chain partners.

4.3. Data Collection Procedure

We collected data from business directors (i.e., chairman, general manager, or assistant manager) and IT directors (i.e., IT manager or IT assistant manager). While IOS adaptability and IOS standardization were reported by both business and IT directors, all other constructs (i.e., SCC, SCA, and EU) were measured by business directors, per prior studies (e.g., Gligor et al., 2015; Huo et al., 2014). We used the dyadic survey design because (1) IOS characteristics, or the IOS ability to provide support for supply chain operations, need to be

[10] Objective data were collected from the statistics database of the National Ministry of Economic Affairs (https://www.moea.gov.tw/Mns/dos/home/Home.aspx). We first regressed the natural logarithm of the total sales of all sub-industries against an index variable of years, over a period of five years. Then the antilog of the standard error of the regression coefficient was calculated to measure sales volatility. The same approach was adopted to measure volatility of industry operating income. Finally, we calculated the aggregate indicators for each firm; that is, if a firm operates in multiple sub-industries, the firm's environmental uncertainty (e.g., sale volatility) is the weighted aggregate of environmental uncertainty (e.g., industry sale volatility) of all the sub-industries in which the firm participates. The weights were distributed according to the sales in each sub-industry that the firm operates.

positioned as an "end-to-end" responsibility of both business and IT; and (2), the design reduces common method bias by collecting predictors and outcomes from different sources (Podsakoff et al., 2003). For example, IT directors might tend to overrate the ability of IOS.

The survey was administrated in 2017 at two time periods (T1 and T2) with an interval of 24 weeks in between. At T1, we asked business and IT directors to evaluate the questions related to IOS adaptability and IOS standardization. At T2, we asked business directors to answer the questions about the key variables of SCC, SCA, and EU in the model. This longitudinal design incorporates three key considerations. First, if all the constructs share a common method (e.g., the same survey time point), the method may exert a systematic effect on the observed correlations between constructs (Podsakoff et al., 2003). Furthermore, use of the time lag is necessary because prior research has found that it takes months for IT variables to exert effects on business value (Avgar et al., 2018; Burton-Jones & Gallivan, 2007). In contrast to short-term transactions, achieving the benefits of IOS on the development of collaborative relationships among firms is a relatively long-run process. This data collection design also rules out the possibility that the intermediate and outcome variables (i.e., SCC and SCA) at T2 would influence the independent variables (i.e., IOS adaptability and standardization) at T1. Second, the time interval of 24 weeks is long enough for the emergence of possible supply chain changes. Third, the contextual variable of EU was evaluated at T2. That is, when evaluating the extent of uncertainty in environments between T1 and T2, business directors can be expected to have a better memory of events and activities at T2.

To collect survey data on IOS characteristics at T1, we randomly selected 250 enterprises from the industry chain of optoelectronic companies located in Mainland China, Taiwan, and Hong Kong that represent a wide range of industrial categories. We delivered the business version and IT version of the questionnaires to one business director and one IT director of each manufacturer separately. Of the 250 companies contacted, 185 paired questionnaires were collected, yielding a response rate of 74%. After removing 13 responses due to missing data, 172 valid paired responses were gathered in the first round. After 24 weeks, data at T2 were collected from the dyadic business and IT directors who participated in the first-round survey, resulting in 156 valid responses. Demographic details are shown in Appendix F.

To examine nonresponse bias, we compared available demographics (i.e., location, annual sales, and firm size) of early and late respondents, regarded as the equivalent of nonresponding respondents (Armstrong &

Overton, 1977). We found no statistical difference exists at a significant level ($p<0.05$). We ran an additional analysis to assess the non-response bias by comparing the scores from firm data at both T1 and T2 with the scores of firms that only answered at T1. Results show that the statistical difference is not significant ($p>0.05$), suggesting that nonresponse bias is not a concern in this research.

5. Analysis and Results

Pair symmetry was checked based on the widely used interrater agreement index r_{wg} and a newer α_{wg}, which can overcome the weakness of r_{wg} (Brown & Hauenstein, 2005). The values of r_{wg} for IOS adaptability and IOS standardization are 0.86 and 0.83 (>0.70), respectively, indicating that the business manager and IT manager have a strong agreement on IOS characteristics. The average α_{wg} values are 0.78 and 0.81 (>0.70), which also confirm a good pair symmetry. The data of IOS adaptability and IOS standardization from business and IT managers, respectively, are therefore aggregated.

5.1. Measurement Model: Reliability and Construct Validity

To test constructs' reliability and validity, we first conducted an exploratory factor analysis (Appendix G). Results show that all items load onto the designated constructs and show significant factor loadings on corresponding constructs ($p<0.001$), supporting a good level of convergent validity. The overall model fit was then assessed by the comparative fit index (CFI), root mean square error of approximation (RMSEA), and normed χ^2 (i.e., χ^2/degree of freedom). Results indicating that normed χ^2 (=1.54) with the CFI (=0.91) and RMSEA (=0.076) confirm that the model and all data have an appropriate fit (Segars & Grover, 1998). In addition, the composite reliabilities of all constructs go beyond 0.70 (from 0.802 to 0.970), and AVE is greater than 0.5 (Appendix H), suggesting that the scales of all constructs have adequate reliability (Lance et al., 2006). Finally, to check the discriminant validity, comparison models were performed between the constrained and unconstrained models. Results show that all chi-square differences (from 7.86 to 183.56) are significant at the $p<0.05$ level, indicating appropriate discriminant validity (Fornell & Larcker, 1981).

We conducted confirmatory factor analysis to further analyze the unidimensionality of the IOS constructs. A separate model was used to estimate IOS standardization/ adaptability and SCC. The CFA results indicate a reasonable fit between the model and dataset (Normed χ^2=1.34; CFI=0.97; RMSEA=0.07). Another model with one IOS construct, reflected by IOS standardization and adaptability as a whole, was estimated for SCC, where

CFA results indicate an acceptable fit between the model and dataset (Normed χ^2=1.22; CFI=0.93; RMSEA=0.08). As the first model shows a better fit result, we find it is empirically appropriate to break IOS into adaptability and standardization in this study.

5.2. Common Method Variance

Although the data for this study were collected at two different time points, a method variance marker was used to assess any potential common method variance. Alignment between business and IT, a six-item scale unrelated to this study, was chosen as it has the lowest positive correlation (r=0.025) with other variables. This correlation used to adjust all the construct correlations and statistical significance showed no change after the adjustment, suggesting that common method variance is not a serious concern. We also assessed the common method variance by comparing the fit between the one-factor model, the measurement model that only had traits, and the model with both traits and a method factor, where the results of χ^2 are 1554.67, 323.54 and 67.87, respectively, and significant at p<0.001. The model with both traits and a method factor shows no significant improvement over the model with only traits.

5.3. Endogeneity

Our study adopts a longitudinal design, recognized as a powerful empirical approach to address potential endogeneity concerns (Ketokivi & McIntosh, 2017). Post-hoc, we carefully evaluated such endogeneity concerns and clarified them with theoretical and empirical arguments (Lu et al., 2018). Most previous studies have suggested that IOS development shapes interfirm collaborative processes (Im & Rai, 2013; Rai & Tang, 2013). The study is consistent with the recognized wisdom in the boundary object literature, that boundary objects (e.g., IOS in our case) work to drive collaboration that emerges across boundaries among different partners (Nicolini et al., 2012). While boundary objects can become the fundamental platform for collaborative activity, there is still a possible reverse argument in that, because the firm has an aim or strategic intention to develop relationships with specific supply chain partners, it forms decisions deliberately at the IOS level to support its aim or strategy. We conducted the Durbin–Wu–Hausman (DWH) test to identify endogeneity bias (Davidson & MacKinnon, 1993). We first regressed SCC against IOS standardization and adaptability to obtain their residuals. We then performed an augmented regression by including all main effects and residuals of IOS characteristics. Results show that the coefficients for the residuals are not significant, confirming endogeneity is not a serious concern.

5.4. Hypothesis Testing

To test our hypotheses, structural equation modeling (SEM) with LISREL 8.7 was conducted. The exact model was calculated with all the main effects (i.e., IOS-SCC-SCA) with location, firm size, revenue, and supply chain experience included as SCA controls. The model result is acceptable: χ^2=567.45, CFI=0.94, RMSEA=0.057. SCC and SCA are sufficiently explained, with R^2_{SCA}=0.374, R^2_{SCC}=0.411 (Table 2). Of the control variables, location, firm size, and revenue have insignificant effects on SCA (β=0.095, -0.132, 0.048; p>0.05) and supply chain experience is positively related to SCA (β=0.235; p<0.05). Strategy as well as IT flexibility have insignificant effects on SCC (β=0.100, 0.090; p>0.05), yet trust is significantly related to SCC (β=0.180, p<0.05). Supporting H1, SCC is positively related to SCA (β=0.366; p<0.01). In support of H2a and H2b, IOS adaptability and standardization have significantly positive effects on SCC (β=0.282, 0.275; p<0.05).

Insert Table 2 about here.

To test SCC's mediating effect, we introduced a mediation model by adding the indirect effect from IOS adaptability and standardization to SCA through SCC. The direct effect of IOS standardization on SCA is insignificant (β=-0.154, p>0.05), suggesting a full mediation of SCC between IOS standardization and SCA (Table 3). The direct effect of IOS adaptability on SCA is still significant (β=0.243, p<0.05), suggesting a partial mediation of SCC between IOS adaptability and SCA. In testing indirect effects, a Sobel (1982) test we conducted shows significant mediating effects of SCC (t=0.173, 0.278; p<0.05). Besides, a bootstrapping test shows intervals between the lower level of confidence interval (LLCI) and upper level of confidence interval (ULCI) are 0.009-0.395 and 0.099-0.493, respectively. As neither mediation includes zero, the two mediations are significant. H3a and H3b are therefore supported.

Insert Table 3 about here.

Next, we tested EU as a moderator. As shown in Table 2, the interaction effect of SCC and EU on SCA is positive as predicted but insignificant (β=0.122, p>0.05) (Model 7); H4 is thus unsupported. The interaction of IOS adaptability and EU on SCC is positive and significant (β=0.153, p<0.05) (Model 3), supporting H5a; the interaction of IOS standardization and EU on SCC is insignificant (β=0.120, p>0.05), so H5b is not supported. H6a and H6b predict that EU positively moderates the indirect effect of SCC between IOS adaptability and SCA, and negatively moderates the indirect effect of SCC between IOS standardization and SCA. To test these two hypotheses, we conducted the bootstrapping test (Edwards & Lambert, 2007). As seen in Table 4, in both weak EU (mean minus 1SD) and high EU (mean plus 1SD), the effect of IOS adaptability on SCC and the effect of SCC on SCA are similar, showing that they are all positively related. The difference between the indirect effect under two conditions is 0.143 and significant ($p<0.05$). This implies that IOS adaptability affects SCA via SCC, where its effect is stronger with higher levels of EU, lending support to the moderated mediation, as proposed in H6a. As shown in Table 5, in both weak EU and high EU, the effect of IOS standardization on SCC and the effect of SCC on SCA are similar, showing they are all positively related. The difference between the indirect effect under low and high EU is 0.0006 and thus insignificant ($p>0.05$). H6b is therefore not supported.

Insert Table 4 and Table 5 about here.

To further verify our findings, we conducted post hoc tests with objective EU data to test the robustness of the results in this study. As shown in Model 4 and Model 8 of Table 2, the results with objective data of EU are similar to the original results, demonstrating the robustness of our findings.

6. Discussion

6.1. Discussion of Results

This study takes a primary step toward understanding the mechanisms through which IOS characteristics affect SCA under different environmental conditions. The empirical results support seven of the ten hypotheses we propose (Table 6 and Figure 2).

Insert Table 6 and Figure 2 about here.

First and foremost, this study confirms the important roles that IOS adaptability and standardization play in establishing SCC, the essential role of SCC in achieving SCA, and the crucial mediating role that SCC exhibits between IOS adaptability/ standardization and SCA. As expected, these findings provide evidence for our conceptualization of IOS as boundary objects. Results show that EU amplifies the relationship between IOS adaptability and SCC, which is stronger when EU is higher. This confirmed moderating effect of EU, in conjunction with the verified mediation of SCC, provides empirical support to the hypothesized moderated mediation of SCC between IOS adaptability and SCA, and thus gives backing to our arguments on how IOS adaptability affects SCA under uncertain environments.

Unexpectedly, the moderating effect of EU on the positive relationship between IOS standardization and SCC is insignificant. One plausible explanation for this outcome is that standardization may have become a basic feature after a few years of IOS development, and standardized IOS (e.g., standardized interfaces and structures) have been widely adopted by supply chain firms to facilitate boundary-spanning specification and negotiation regardless of external conditions. The moderating effect of EU on the relationship between SCC and SCA is also insignificant, which may be due to the nature of optoelectronic businesses, wherein supply chain manufacturers, distributors, or retailers have strong interdependencies and continually manage integrated processes to produce and deliver products/ services. SCC thus plays a particularly important role for supply chain firms in this industry regardless of external environment. An alternative explanation for these two insignificant effects is that EU is treated as a comprehensive construct in our study that can be segregated and examined in terms of different aspects such as supply uncertainty, demand uncertainty, and technology uncertainty (Chen & Paulraj, 2004). For instance, the effect of IOS standardization on supply chain collaboration could be more significantly reduced for firms with a high level of technology uncertainty.

In the case of SCC, the two insignificant moderating effects may also be attributable to different dimensions of SCC that can exert different impacts. To gain additional insights, we conducted post-hoc analyses by grouping the seven SCC dimensions into reasonable categories. Through seeking theoretical guidance in the literature and conducting confirmative factor analyses,[11] we classified the seven SCC dimensions into *coordination* (i.e., information sharing, decision synchronization, collaborative communication, and joint knowledge creation) and *cooperation* (i.e., resource sharing, incentive alignment, and goal congruence) according to Gulati et al. (2012). We then reran the model by replacing SCC with coordination and cooperation, respectively, to observe how the concerned moderating effects would change. Empirical results indicate that cooperation may account for the insignificant moderating effect of EU on the IOS standardization-SCC relationship, as the moderation of EU on the IOS standardization-cooperation relationship is insignificant (β=0.131; p>0.05) while its moderation on the IOS standardization-coordination relationship is marginally negatively significant (β=-0.137; p=0.053). This

[11] Results of confirmative factor analyses and details of post-hoc analyses are shown in Appendix K.

suggests that IOS standardization exerts diverse impacts on coordination and cooperation in high EU, where the effects of IOS standardization on coordination rather than cooperation would be restricted. This is consistent with our expectations that unexpected changes bring more new challenges for standardized IOS interfaces, as the previously standardized technical interfaces are less able to transfer and interpret information across organizational boundaries when the environment changes.

The empirical results also attribute the insignificant moderating effect of EU on the SCC-SCA relationship to cooperation, as the moderation of EU on the coordination-SCA relationship is positively significant ($\beta=0.226$; $p<0.05$) while its moderation on the cooperation-SCA relationship is insignificant ($\beta=0.103$; $p>0.05$). This indicates that coordination and cooperation behave differently in promoting SCA when EU is high, where the impact of coordination rather than cooperation on SCA would be promoted. Previous literature has similarly found that coordination mechanisms—such as the operation of information-sharing, decision-making, and feedback mechanism—are useful in bridging partners' efforts to respond to unexpected changes (Gulati et al., 2012). Moreover, we refer to the management literature to explain the insignificant moderating effect of EU on the cooperation-agility link. We find that partners who cooperate successfully (e.g., with successful agreements on resource investment or contributions) tend to hold with the status quo to exploit more favorable benefits from the joint resources, rather than explore new alternatives to respond to unstable environments. This is largely because the agreements on inputs and outputs create a particular configuration of resource interdependence between them (Gilbert, 2005), where they might miss the external opportunities brought by changes.

6.2. Theoretical Contributions

This study makes several theoretical contributions. First, it adds to the IOS literature by clarifying how and under what conditions IOS standardization and adaptability affect SCA. To date, the research has only examined the impact of IOS standardization on the development of flexible or adaptive supply chains, but has not provided conclusive findings (e.g., Gosain et al., 2004; Malhotra et al., 2007), while the relationship between IOS adaptability and SCA has not yet been examined. This study clarifies relationships between IOS standardization/ adaptability and SCA by introducing SCC as a comprehensive mechanism. It also uses EU to investigate the contingency of the IOS characteristics-SCA relationships. Although EU is regarded as a critical external factor in today's business environments (Chen & Paulraj, 2004), it has rarely been considered in research on the impact of IOS on SCA. Prior research has also revealed gaps in understanding of how agility is developed, stating that "organizational relationships are crucial for understanding supply chain agility" (Fayezi et al., 2017, p. 395). Our study responds to this by providing a better understanding of how SCA can be developed through SCC.

Second, this study contributes to the boundary object literature by extending it from the original anthropology/ sociology context to the supply chain context while specifying its boundary condition (Star & Griesemer, 1989). Prior research on boundary object has mainly adopted information exchange as the boundary-spanning mechanism to explain the mechanisms between IOS and SCA (e.g., Dong et al., 2017; Malhotra et al., 2007), which we argue is inadequate given the uniqueness of supply chain. By applying the boundary object literature to the supply chain context, wherein SCC—a comprehensive boundary-spanning activity that could span three levels of knowledge boundaries—is introduced as the context-specific mechanism and EU is specified as a contextual condition, it thus extends the applicability and clarifies the condition of the boundary object perspective.

Third, it contributes to our understanding of SCC by examining the impacts of IOS standardization and adaptability under different levels of EU. Prior research on SCC has mainly explored its antecedents from the perspective of intraorganizational factors (e.g., Barratt, 2004; Wu & Chiu, 2018). Some recent SCC research has explored the impact of IOS, but only focused on the external/practical application of IOS (Zhang & Cao, 2018). Our study enriches the understanding of SCC from the perspective of IOS characteristics—regarded as the intrinsic nature/ internal structure of IOS—by investigating how IOS standardization and adaptability facilitate SCC. We add further insights on the different moderations that EU has on the effects of IOS standardization and adaptability on SCC, which indicates that it is more efficient to adopt IOS adaptability to facilitate SCC when EU is higher.

6.3. Practical Implications

This study has several practical implications. First of all, it provides guidance to IT and business directors on how to achieve SCA through the design or implementation of IOS. It encourages IT directors to design IOS with standardization (e.g., common technical specifications) and adaptability (e.g., open-standard architectures) to facilitate SCA. For instance, in managing supply chains, firms should use the emerging flexible markup formats and connectivity infrastructures to collaborate with diverse enterprises. Also, business directors should emphasize the importance of both IOS adaptability and standardization in facilitating SCA. Although there are plenty of different system types, we believe that what really matters is not the type but the characteristics of IOS. Firms are not expected to implement the same type of IOS, but they should encourage IOS implementations that exhibit the same characteristics.

This study also provides guidance to business directors on how to invest more effectively to capture opportunities and deal with risks. Business directors may suffer if they misunderstand the mechanism between IOS and SCA or are uncertain which investment to make. The research implies that business directors should pay considerable attention to the collaboration with supply chain partners (i.e., SCC), which could be implemented by designing appropriate IOS characteristics (e.g., standardization and adaptability). By making investments in designing appropriate IOS characteristics and establishing sound SCC, firms could develop shared goals and interests to acquire and exploit new external knowledge and further facilitate SCA and the utility of investments. Ignoring the essential mediating mechanism of SCC may be detrimental for firms hoping to nurture SCA through the adoption of different IOS characteristics.

Moreover, this study advises business and IT directors on how to respond appropriately to different levels of EU. Under a high level of EU with the unexpected changes of new needs in circumstances, IT directors should design adaptive IOS (e.g., applying modularized architectures) to collaborate with multiple unstable partners across diverse and complex boundaries. Business directors are encouraged to invest in the establishment and maintenance of SCC to develop shared goals and interests among different partners including manufactures, general agents, distributors, and retailers, through which the facilitating impact of IOS adaptability on SCA could be implemented. Results of post-hoc analysis also indicate that when EU is higher, business directors should pay more attention to coordination aspects (i.e., information sharing, decision synchronization, collaborative communication, and joint knowledge creation), and IT directors could deliberately design more adaptable IOS structures and even avoid standardized IOS structures to promote the achievement of SCA through coordination.

6.4. Limitations and Further Research

Although this study makes both theoretical and practical contributions, several limitations exist that provide directions for future research. First, the theoretical basis of this study is the boundary object perspective, a reference theory to IS. By instantiating highly theoretical constructs (i.e., boundary objects) into the IS context (i.e., IOS in this study), we build a theoretically grounded model with strong theoretical logic. While the abstraction inherent to our constructs offers an overall comprehensive understanding of the problem studied, using a broad reference theory may risk garnering diverging theoretical interpretations (Grover & Lyytinen, 2015). To address this limitation, future research could delve into each abstract construct for more contextually concrete insights to IOS standardization and adaptability.

Second, our study takes a necessary step to theoretically establish the relationship between IOS standardization/ adaptability and SCA and explore its underlying mechanisms as well as boundary conditions. We focus on the two characteristics of IOS to explore its internal structure and nature, which plays a foundational role but cannot capture various aspects of IOS. Managers might be interested in finding other IOS aspects at the functional level such as IOS application that could be investigated by future research. Besides, building on this theoretical base, future research could open up the key constructs (e.g., IOS standardization/ adaptability, SCC, and SCA) to afford more insights, including a more complete understanding of the detailed relationships between IOS and SCA as well as a clear elucidation of nuances between different dimensions of these constructs.

Moreover, we examine the moderation of EU based on the boundary object literature, without considering other potential moderating factors. Future research could extend this study by examining moderators from other perspectives. For instance, there is reason to expect that organization culture (e.g., collaborative culture) could moderate the relationships in this study, because it is a context that may affect the process of spanning boundaries. Zhang and Cao (2018) theoretically argued that collaborative culture moderates the IOS appropriation-SCC link but failed to provide empirical support, which may be due to their focus on IOS appropriation in conceptualizing IOS as a resource in use but not IOS characteristics by emphasizing the capacity for IOS to span boundaries. It would be an interesting avenue for future research to explore other moderating factors in our model, which could provide a more comprehensive understanding about contingencies of the impact of IOS characteristics.

Finally, this study selects optoelectronic industry as an empirical context to test the proposed hypotheses. This choice is appropriate for our study but may also lead to limitations in our findings. Future research could extend the generalizability of our findings by testing the model in other empirical contexts.

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Table 1. Summary of the Key Constructs in the Model

Construct	Definition	Property	Examples
IOS standardization (IOSS)	The ability of IOS to use common specifications or formats for exchanging information and linking processes between partners (Malhotra et al., 2007).	IOS characteristics	Using common technical specifications to describe data formats, or adopting shared communication protocols for communications.
IOS adaptability (IOSA)	The ability of IOS to readily adapt or reconfigure to meet constantly changing requirements (Dong et al., 2017).	IOS characteristics	Deploying open-standard technological architectures, or applying modularized architectures and structured data formats.
Supply chain collaboration (SCC)	A partnership process where participating firms work closely to plan and execute supply chain operations to achieve common goals and benefits (Cao & Zhang, 2011).	Partnership process	Collaboration between General Motors and its suppliers to decrease vehicle development cycle times (Gutman, 2003).
Supply chain agility (SCA)	A firm's ability to sense and respond to external opportunities or threats by making quick adjustments in supply chain processes (Gligor et al., Esmark, & Holcomb, 2015).	Organizational-level ability	Adjusting replacement times of materials, manufacturing throughput times, or delivery capacities to improve market responsiveness or delivery reliability.
Environmental uncertainty (EU)	The ambiguities/inherent insecurities coming from external conditions of a focal firm that result in opportunities and threats (Wong et al., 2011).	External conditions	Changeable customer orders, fluctuant material supply, unpredictable competitors' actions, or frequently updated core technologies.

Table 2. Analysis Results of Structural Equation Modeling

Model / Variable	DV= supply chain collaboration				DV= supply chain agility			
	1	2	3	4 (EU*)	5	6	7	8 (EU*)
Strategy	0.095	0.100	0.08	0.06				
Trust	0.215*	0.180*	0.19*	0.11*				
IT flexibility	0.120	0.090	0.10	0.05				
Location					0.055	0.095	0.035	0.03
Size					-0.089	-0.132	-0.102	0.05
Revenue					0.025	0.048	0.057	0.02
SC experience					0.226*	0.235*	0.217*	0.08
IOSA		0.282*	0.223*	0.17*				
IOSS		0.275*	0.277*	0.19*				
EU			0.132	0.09			0.145	0.08
IOSA*EU			0.153*	0.11*				
IOSS*EU			0.120	0.07				
SCC						0.366**	0.324**	0.178*
SCC*EU							0.122	0.101
R^2	0.346**	0.411**	0.565**	0.399**	0.293*	0.374**	0.421**	0.386**

Notes: N=156. R^2 = overall variance explained in dependent variable by the variables in the model. *p < 0.05; **p < 0.01; ***p < 0.001. EU*, EU robustness check; SC experience, supply chain experience; IOSA, IOS adaptability; IOSS, IOS standardization; EU, environmental uncertainty. SCC, supply chain collaboration.

Table 3. Results for Mediation Effects Analysis

IV	M	DV	IV→DV	IV→M	IV+M→DV: IV→DV	IV+M→DV: M→DV	Mediating effects (LLCI-ULCI)
IOSS	SCC	SCA	-0.03	0.275*	-0.154	0.366***	0.173*(0.009-0.395)
IOSA			0.425***	0.282*	0.243*		0.278*(0.099-0.493)

Notes: *p <0.05, **p < 0.01, ***p <0.001. IOSS, IOS standardization; IOSA, IOS adaptability; SCC, supply chain collaboration; SCA, supply chain agility; LLCI, lower level of confidence interval; ULCI, upper level of confidence interval.

Table 4. Results for Moderated Mediation (IOSA)

Moderator EU	IOSA (X) → SCC (M) →SCA (Y)				
	Stage		Effects		
	Stage 1(X→M) P_{MX}	Stage 2(M→Y) P_{YM}	Direct effect P_{YX}	Indirect effect $P_{YM}\,P_{MX}$	Total effect $P_{YX}+P_{YM}\,P_{MX}$
Low	0.205*	0.327**	0.226*	0.067	0.293
High	0.480**	0.438**	0.357*	0.210	0.567
Difference	0.275*	0.111	0.131	0.143*	0.274*

Notes: ***p<0.001, ** p < 0.01, * p < 0.05; IOSA, IOS adaptability; SCC, supply chain collaboration; SCA, supply chain agility; EU, environmental uncertainty. P_{MX} represents the effect of IOS adaptability on supply chain collaboration; P_{YM} represents the effect of supply chain collaboration on supply chain agility; and P_{YX} represents the effect of IOS adaptability on supply chain agility. High EU represents increasing one standard deviation, while weak EU represents decreasing one standard deviation.

Table 5. Results for Moderated Mediation (IOSS)

Moderator EU	IOSS (X) → SCC (M) →SCA (Y)				
	Stage		Effects		
	Stage 1(X→M) P_{MX}	Stage 2(M→Y) P_{YM}	Direct effect P_{YX}	Indirect effect $P_{YM}\,P_{MX}$	Total effect $P_{YX}+P_{YM}\,P_{MX}$
Low	0.350*	0.327**	-0.038	0.1144	0.076
High	0.260*	0.438**	-0.025	0.1138	0.089
Difference	-0.09	0.111	0.013	0.0006	0.013

Notes: ***p<0.001, ** p < 0.01, * p < 0.05; IOSS, IOS standardization; SCC, supply chain collaboration; SCA, supply chain agility; EU, environmental uncertainty. P_{MX} is the effect of IOS standardization on supply chain collaboration; P_{YM} is the effect of supply chain collaboration on supply chain agility; and P_{YX} is the effect of IOS standardization on supply chain agility. High EU represents increasing one standard deviation, while weak EU represents decreasing one standard deviation.

Table 6. Results Summary

Hypotheses	Expectation	Result
H1	SCC positively relates to SCA.	Supported
H2a	IOS adaptability positively relates to SCC.	Supported
H2b	IOS standardization positively relates to SCC.	Supported
H3a	SCC mediates the relationship between IOS adaptability and SCA.	Supported
H3b	SCC mediates the relationship between IOS standardization and SCA.	Supported
H4	EU positively moderates the SCC-SCA relationship.	Not Supported
H5a	EU positively moderates the IOS adaptability-SCC relationship.	Supported
H5b	EU negatively moderates the IOS standardization-SCC relationship.	Not Supported
H6a	EU positively moderates the mediation of SCC between IOS adaptability and SCA.	Supported
H6b	EU negatively moderates the mediation of SCC between IOS standardization and SCA.	Not Supported

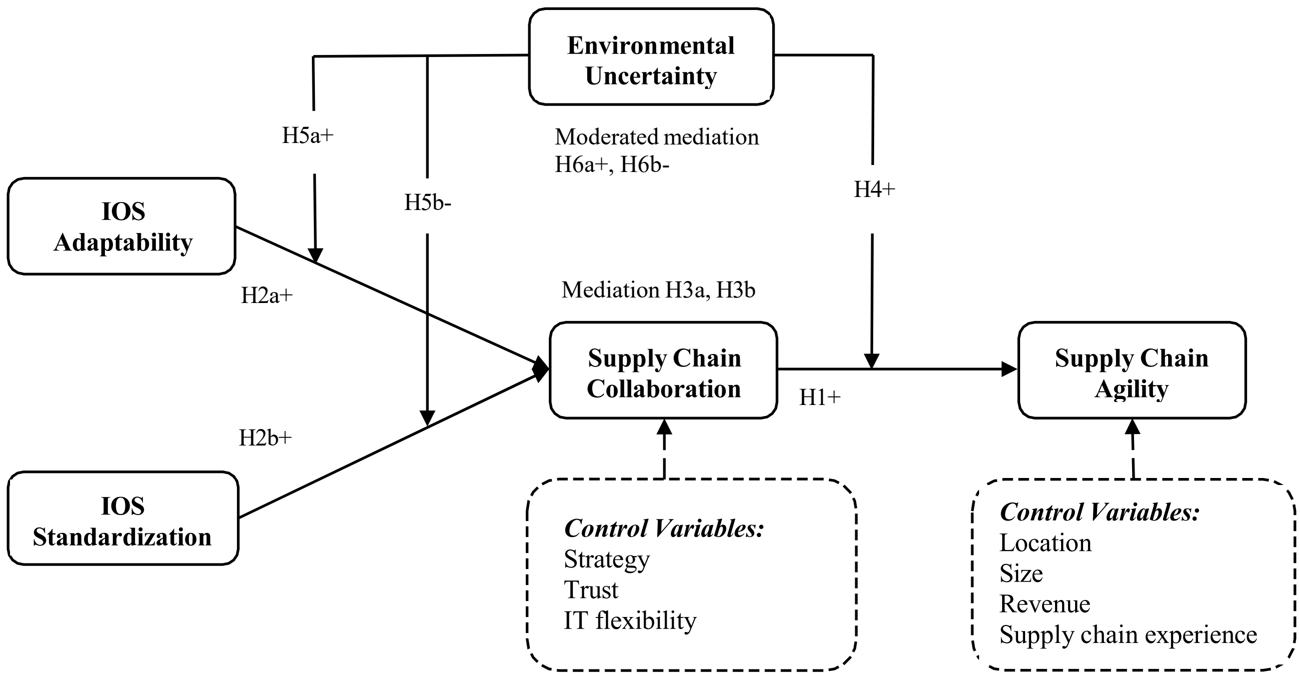

Figure 1. Research Model

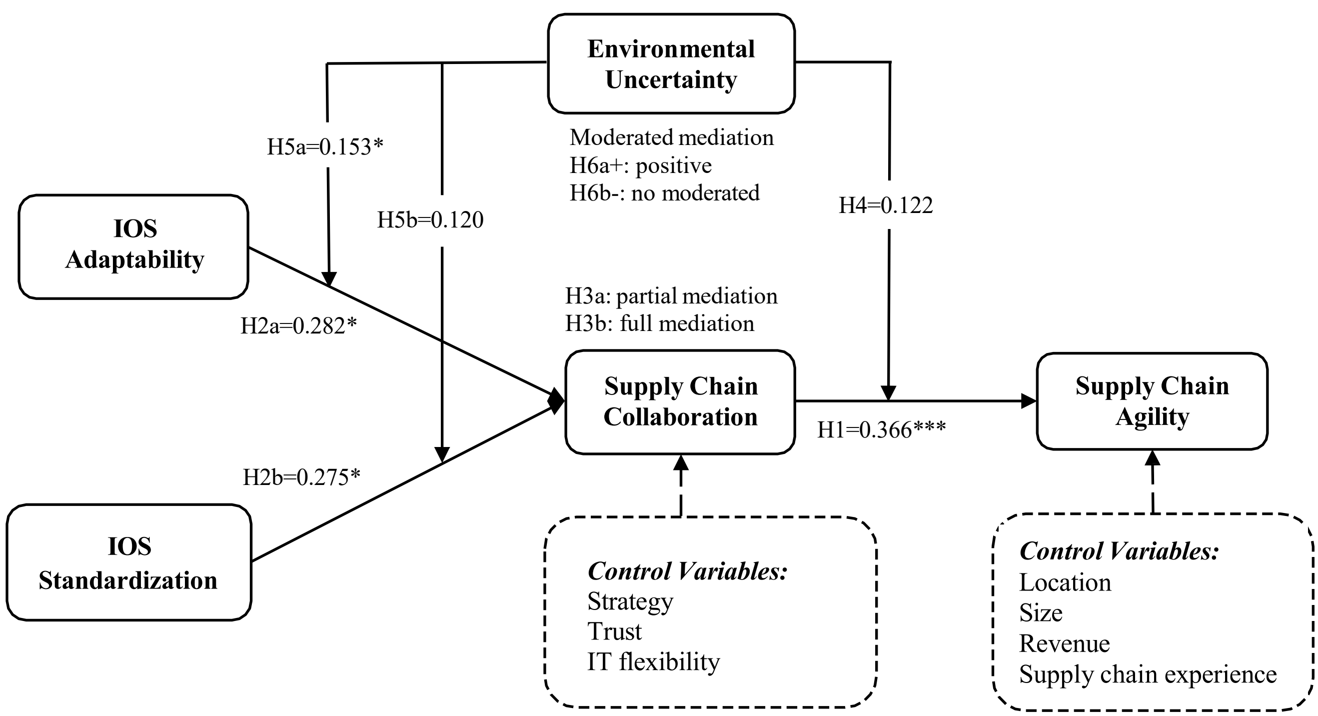

Figure 2. Research Model with Results

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APPENDICES

Appendix A. Literature Review on the Antecedents of Supply Chain Agility

Authors	**Method**	**Antecedents**	**Consequences**	**Mediators/ Moderators**	**Theories**	**Logics**	**Findings**
Blome et al. (2013)	Survey	Supply side competence, demand side competence	Supply chain agility	Mod: Process compliance	Resource-based view, dynamic capabilities perspective	View capabilities (i.e., supply chain agility) as having evolved from competencies (i.e., supply- and demand-side competence) (Braunscheidel & Suresh, 2009; Teece, 2007).	The study demonstrates the benefits of supply- and demand-side competences for supply chain agility, and verifies that process compliance positively moderates the effects of supply- and demand-side competences on supply chain agility.
Braunscheidel and Suresh (2009)	Survey	Market orientation, learning orientation	Supply chain agility	Med: internal integration, external integration, and external flexibility	Competency-capability paradigm	The two cultural antecedents of market and learning orientations are posited to affect the organizational practices of internal integration, external integration, and external flexibility, and eventually affect firm's supply chain agility.	Market and learning orientations both significantly affect internal integration, and further lead to supply chain agility. Market orientation also affects external integration and flexibility, which result in supply chain agility.
Brusset (2016)	Survey	External capabilities, visibility capabilities, internal process capabilities	Agility in supply chain	N.A.	Resource-based view, dynamic capabilities perspective	Superior firm performance comes from dynamic capability and operational capability. Dynamic capability is regarded as a higher order than operational capabilities (Drnevich & Kriauciunas, 2011). And lower order capabilities can lead to operational capabilities.	External capabilities and internal process capabilities both are positively related to supply chain agility.

Chiang et al. (2012)	Survey	Strategic sourcing	Supply chain agility	Med: firm's strategic flexibility	Dynamic capabilities theory	The ability to achieve new competitive advantage can be formed by developing ongoing competency in adapting to changing environments (Teece, 2007; Teece et al., 1997).	Both strategic sourcing and a firm's strategic flexibility are significantly related to a firm's supply chain agility, where strategic flexibility has a partial mediating effect.
Gligor et al. (2016)	Survey	Environmental uncertainty	Firm supply chain agility	Med: Supply chain orientation, market orientation	Resource-based view of the firm, strategy-structure-performance (SSP) paradigm	A firm's strategy, created in consideration of external environments, drives the development of organizational structures. Firms with aligned strategy and structure should perform better (Wolf & Egelhoff, 2002). And firms that are able to accrue rare, valuable, and non-substitutable capabilities will achieve an advantage over competitors (Wernerfelt, 1984).	There is a direct and positive relationship between a firm's environmental uncertainty and its market orientation, which can lead to firm supply chain agility; supply chain orientation is positively related to firm supply chain agility.
Gligor and Holcomb (2012)	Survey	Supply chain coordination, supply chain cooperation, supply chain communication	Supply chain agility	N.A.	Relational view (RV)	Within the RV, coordination, cooperation, and communication are considered to be knowledge-sharing routines, which lead to firm's competitive advantages. One of the firm's essential competitive advantages is supply chain agility.	Supply chain coordination, cooperation, and communication all are positively related to supply chain agility.
Liu et al. (2013)	Survey	Flexible IT infrastructure, IT assimilation	Supply chain agility	N.A.	Dynamic capabilities perspective, hierarchy of capabilities perspective	Based on a hierarchy of capabilities, a higher-order capability (i.e., supply chain agility) can be developed through a series of lower-order capabilities (i.e., IT capability) (Sirmon et al., 2007).	Results do not support the hypothesis on the association of IT capabilities (i.e., flexible IT infrastructure and IT assimilation) and supply chain agility.

Ngai et al. (2011)	Case study	Supply chain competence: IT competence, operational competence, management competence	Supply chain agility	N.A.	Resource-based view	Resource-based view posits that organizational resources are the predictors of organizational performance, providing a framework for the relationship between supply chain competence and firm performance. Supply chain agility is the ability to respond to market changes using a set of supply chain competencies that enable such capability.	The results partly support the positive impacts of supply chain competences (i.e., IT competence, operational competence, and management competence) on supply chain agility.
Swafford et al. (2006)	Survey	Procurement/ sourcing flexibility, manufacturing flexibility, and distribution/ logistics flexibility	Supply chain agility	N.A.	Competency-capability paradigm	Consistent with the strategy paradigm, supply chain agility is an externally focused capability that is derived from flexibilities in the supply chain processes (internally focused competencies).	Supply chain agility is achieved by the organization's internal abilities to capitalize on synergies/ flexibilities among the three supply chain processes.
Swafford et al. (2008)	Survey	Information technology integration	Supply chain agility	Med: Supply chain flexibility	Resource-based perspective	A firm's distinctive core competence lies in its inimitable organizational or coordinative capabilities (Teece et al., 1997).	IT integration impacts supply chain flexibility, which results in higher supply chain agility and ultimately higher competitive business performance.
Tse et al. (2016)	Survey	Supply chain integration, external learning	Supply chain agility	N.A.	Knowledge-based view	External learning defined as knowledge acquisition and creation by interorganizational learning (Huang et al., 2008) can enable firms to keep pace with competitive and uncertain environments.	Supply chain integration and external learning are found to positively influence supply chain agility.

Yang (2014)	Survey	Information sharing, IT capability, operational collaboration	Supply chain agility	N.A.	Information theory	Organizations need to access and use information in order to reduce uncertainty and take actions to increase performance.	A firm's IT capability and operational collaboration with suppliers are associated with its agility. Information sharing between buyer and supplier is not necessarily connected with agility.

Appendix B. Definition and Number of Items of Each SCC Dimension

Dimension	**Number of Items**	**Definitions** (Cao & Zhang, 2011, p. 166)
Information Sharing	Four items	The extent to which a firm shares a variety of relevant, accurate, complete, and confidential information in a timely manner with its supply chain partners.
Decision Synchronization	Four items	The process by which supply chain partners orchestrate decisions in supply chain planning and operations that optimize the supply chain benefits.
Collaborative Communication	Four items	The contact and message transmission process among supply chain partners in terms of frequency, direction, mode, and influence strategy.
Joint Knowledge Creation	Four items	The extent to which supply chain partners develop a better understanding of and response to the market and competitive environment by working together.
Resource Sharing	Three items	The process of leveraging capabilities and assets and investing in capabilities and assets with supply chain partners.
Incentive Alignment	Three items	The process of sharing costs, risks, and benefits among supply chain partners.
Goal Congruence	Four items	The extent to which supply chain partners perceive their own objectives are satisfied by accomplishing the supply chain objectives.

Appendix C. Literature Review on the Antecedents of Supply Chain Collaboration

Authors	Method	Antecedents	Consequences	Mediators/ Moderators	Findings
Barratt (2004)	Theoretical research	Collaborative culture, strategic elements	Supply chain collaboration	N.A.	This research identifies two major supporting elements of collaboration: collaborative culture and strategic elements.
Chae et al. (2005)	Case study	Interorganizational information technology	Supply chain collaboration	Mod: Interorganizational relationship between partners (i.e., trust, interdependence, long-term orientation/ commitment, and information sharing)	Results support a positive link between the level of supply chain-related IT capabilities and supply chain collaboration, where relationships between partners have a significant impact on this relationship.
Fawcett et al. (2011)	Multimethod (survey and case-study) approach	Supply chain connectivity, information-sharing culture	Supply chain collaboration	N.A.	Investments in IT make their greatest competitive contribution when they enable a dynamic supply chain collaboration capability.
Richey et al. (2012)	Survey	Technological innovativeness, technological complementarity, flexibility	Retailer-supplier collaboration	Mod: Retailer technological complementarity with supplier	Leading strategic indicators, including technological innovativeness, technological complementarity, and flexibility are positively related to higher levels of collaboration.
Wu and Chiu (2018)	Survey	Social capital, justice, user satisfaction	Supply chain collaboration	N.A.	Structural capital, distributive justice, procedural justice, and user satisfaction are positively related to supply chain collaboration.

Zacharia et al. (2011)	Survey	Perceived interdependence, absorptive capacity	Collaborative engagement	N.A.	Empirically validating the positive effect of perceived interdependence on the level of engagement.
Zhang and Cao (2018)	Survey	Collaborative culture, interorganizational system (IOS) appropriation	Supply chain collaboration	N.A.	Collaborative culture and IOS appropriation are identified as two key antecedents of supply chain collaboration.

Appendix D. Average Rate of Change and Dynamic of Products in Optoelectronic Displays

Type of display products	Average rate of change (year/once)	Dynamic
LCD screens	5-6	Low
Notebook computer	3-4	Medium
Tablet device	3-4	Medium
Mobile device	2-3	High
Wear device	2-3	High

Appendix E. Measurement Scales

Construct	Items
Supply Chain Collaboration	*Adopted from Cao et al. (2010) and Cao & Zhang (2011)*
Information Sharing (IS)	(IS1) Our firm and supply chain partners exchange timely information (IS2) Our firm and supply chain partners exchange accurate information (IS3) Our firm and supply chain partners exchange complete information (IS4) Our firm and supply chain partners exchange confidential information
Decision Synchronization (DS)	(DS1) Our firm and supply chain partners jointly develop demand forecasts (DS2) Our firm and supply chain partners jointly manage inventory (DS3) Our firm and supply chain partners jointly plan product assortment (DS4) Our firm and supply chain partners jointly work out solutions
Collaborative Communication (CC)	(CC1) Our firm and supply chain partners have frequent contacts on a regular basis (CC2) Our firm and supply chain partners have open and two-way communication (CC3) Our firm and supply chain partners have many different channels to communicate (CC4) Our firm and supply chain partners influence each other's decisions through discussion
Joint Knowledge Creation (JKC)	(JKC1) Our firm and supply chain partners jointly search and acquire new and relevant knowledge (JKC2) Our firm and supply chain partners jointly assimilate and apply relevant knowledge (JKC3) Our firm and supply chain partners jointly identify customer needs (JKC4) Our firm and supply chain partners jointly learn the intentions and capabilities of competitors
Resource Sharing (RS)	(RS1) Our firm and supply chain partners use cross-organizational teams frequently for process design and improvement (RS2) Our firm and supply chain partners dedicate personnel to manage the collaborative processes (RS3) Our firm and supply chain partners share technical supports
Incentive Alignment (IA)	(IA1) Our firm and supply chain partners co-develop systems to evaluate and publicize each other's performance (e.g., key performance index, scorecard, and resulting incentive) (IA2) Our firm and supply chain partners share any risks that occur in the supply chain (IA3) The incentive for our firm is commensurate with our investment and risk
Goal Congruence (GC)	(GC1) Our firm and supply chain partners agree on the goals of the supply chain (GC2) Our firm and supply chain partners agree on the importance of collaboration across the supply chain (GC3) Our firm and supply chain partners agree on the importance of improvements that benefit the supply chain as a whole (GC4) Our firm and supply chain partners work jointly on collaboration implementation plans to achieve supply chain goals

Supply Chain Agility (SCA) *Adapted from Gligor et al. (2015)*
(SCA1) We can quickly detect opportunities and threats in our environment
(SCA2) My firm can make decisions to respond to opportunities and threats in its environment
(SCA3) My firm can adjust our supply chain operations to the extent necessary to execute our decisions
(SCA4) My firm can quickly scale up or scale down our production/ service levels to support fluctuations in demand from the market
(SCA5) We can adjust the specification of orders as requested by customers
(SCA6) Whenever a supply disruption arises with suppliers, we can quickly make necessary alternative arrangements and internal adjustments
(SCA7) We treat market-related changes and apparent chaos as opportunities to capitalize quickly

Environmental Uncertainty (EU) *Adapted from Germain et al. (1994) and Wong et al. (2011)*
(EU1) Our customers often change their order over the month
(EU2) Our suppliers' performance is unpredictable
(EU3) Competitors' actions regarding marketing promotions are unpredictable
(EU4) Our plant uses core production technologies that often change

IOS Adaptability (IOSA) *Adapted from Dong et al. (2017)*
(IOSA1) Both partners are able to make adjustments in the joint information system to cope with changing economic circumstances or vulnerable customer demands
(IOSA2) Together, we have developed processes to increase flexibility in our joint information systems in response to customer requests
(IOSA3) We are able to make adjustments in our joint information system to accommodate changing circumstances

IOS Standardization (IOSS) *Adapted from Malhotra et al. (2007)*
(IOSS1) Extent to which the business process interfaces with partner companies are similar to the process interfaces linked with other channel partners, in terms of rules and procedures
(IOSS2) Extent to which information exchanged (e.g., sales reporting, product information, product availability, inventory information, etc.) with partner companies needs to be converted/ translated to be interpreted by the company
(IOSS3) Extent to which information exchanged (e.g., sales reporting, product information, product availability, inventory information, etc.) with partner companies can be interpreted in a manner similar to information exchanged with other partners

Appendix F. Demographic Information of Sample Firms

Industry	Total (N=156)	Employees	Total (N=156)	Sales (RMB)	Total (N=156)
Access/ Trade industry	7 (4.5%)	<100	23 (14.7%)	< 10million	22 (14.1%)
Automotive electronics industry	20 (12.8%)	100-299	35 (22.4%)	10 million to <30 million	41 (26.3%)
Chemical industry	10 (6.4%)	300-499	23 (14.7%)	30 million to <100 million	38 (24.4%)
Construction and electrical engineering industry	4 (2.6%)	500-999	23 (14.7%)	100 million to <300 million	22 (14.1%)
Electronic component industry	24 (15.4%)	1000-1999	21 (13.5%)	300 million to <500 million	17 (10.9%)
Electronic design systems industry	15 (9.6%)	2000-4000	16 (10.3%)	>500 million	16 (10.3%)
Electronics assembly industry	8 (5.1%)	>4000	15 (9.6%)		
Logistics transportation industry	7 (4.5%)				
Machinery industry	8 (5.1%)				
Medical, industrial, and wearable electronics industry	6 (3.8%)				
Optical industry	27 (17.3%)				
Semiconductor industry	12 (7.7%)				
Steel and precious metals industry	2 (1.3%)				
Others	6 (3.8%)				

Appendix G. Results of Exploratory Factor Analysis

Constructs	Items	1	2	3	4	5	6	7	8	9	10	11
1. Environmental Uncertainty	EU1	**0.783**	0.247	0.322	0.369	0.280	0.308	0.320	0.264	0.248	0.307	0.336
	EU2	**0.835**	0.287	0.323	0.354	0.279	0.304	0.365	0.263	0.240	0.381	0.271
	EU3	**0.735**	0.485	0.305	0.294	0.223	0.316	0.322	0.325	0.262	0.371	0.267
	EU4	**0.865**	0.186	0.344	0.277	0.268	0.294	0.271	0.309	0.275	0.266	0.308
2. IOS Adaptability	IOSA1	0.339	**0.953**	0.314	0.446	0.323	0.347	0.511	0.394	0.431	0.372	0.283
	IOSA2	0.349	**0.958**	0.391	0.436	0.318	0.345	0.452	0.350	0.403	0.425	0.345
	IOSA3	0.340	**0.963**	0.383	0.440	0.383	0.404	0.486	0.424	0.479	0.396	0.336
3. IOS Standardization	IOSS1	0.339	0.339	**0.927**	0.469	0.355	0.298	0.487	0.419	0.362	0.338	0.197
	IOSS2	0.347	0.349	**0.945**	0.556	0.424	0.336	0.534	0.458	0.439	0.349	0.260
	IOSS3	0.355	0.323	**0.935**	0.535	0.448	0.315	0.491	0.480	0.451	0.399	0.321
4. Information Sharing	IS1	0.265	0.428	0.427	**0.845**	0.457	0.550	0.371	0.583	0.375	0.425	0.410
	IS2	0.280	0.470	0.472	**0.832**	0.422	0.473	0.267	0.437	0.266	0.489	0.448
	IS3	0.265	0.445	0.484	**0.887**	0.375	0.526	0.296	0.480	0.359	0.484	0.336
	IS4	0.368	0.472	0.337	**0.839**	0.460	0.423	0.389	0.367	0.332	0.445	0.570
5. Decision Synchronization	DS1	0.328	0.535	0.536	0.505	**0.861**	0.527	0.577	0.474	0.401	0.533	0.405
	DS2	0.225	0.558	0.521	0.584	**0.826**	0.436	0.439	0.360	0.442	0.569	0.327
	DS3	0.303	0.517	0.563	0.558	**0.834**	0.556	0.519	0.467	0.488	0.553	0.367
	DS4	0.298	0.506	0.559	0.585	**0.874**	0.530	0.604	0.520	0.494	0.630	0.428
6. Collaborative Communication	CC1	0.350	0.437	0.405	0.531	0.471	**0.735**	0.377	0.500	0.327	0.447	0.444
	CC2	0.239	0.392	0.404	0.506	0.424	**0.793**	0.275	0.508	0.268	0.435	0.285
	CC3	0.334	0.425	0.488	0.554	0.562	**0.785**	0.487	0.590	0.412	0.507	0.460
	CC4	0.273	0.429	0.452	0.545	0.584	**0.703**	0.507	0.560	0.458	0.549	0.367
7. Joint Knowledge Creation	JKC1	0.377	0.389	0.397	0.500	0.569	0.412	**0.857**	0.476	0.576	0.427	0.396
	JKC2	0.394	0.437	0.375	0.548	0.519	0.431	**0.881**	0.509	0.546	0.496	0.380
	JKC3	0.390	0.370	0.370	0.488	0.555	0.447	**0.830**	0.527	0.505	0.556	0.388
	JKC4	0.258	0.330	0.384	0.439	0.575	0.432	**0.850**	0.493	0.523	0.499	0.406
8. Resource	RS1	0.296	0.488	0.487	0.617	0.532	0.416	0.576	**0.883**	0.563	0.532	0.328

Sharing	RS2	0.243	0.464	0.482	0.642	0.491	0.398	0.448	**0.876**	0.583	0.452	0.329
	RS3	0.316	0.484	0.438	0.683	0.523	0.266	0.501	**0.893**	0.571	0.559	0.324
9. Incentive Alignment	IA1	0.239	0.450	0.431	0.590	0.412	0.340	0.529	0.522	**0.735**	0.466	0.186
	IA2	0.249	0.409	0.427	0.591	0.531	0.443	0.557	0.509	**0.719**	0.480	0.250
	IA3	0.276	0.470	0.430	0.578	0.494	0.383	0.558	0.491	**0.775**	0.561	0.247
10. Goal Congruence	GC1	0.350	0.465	0.535	0.490	0.583	0.526	0.465	0.507	0.501	**0.897**	0.363
	GC2	0.286	0.484	0.505	0.459	0.623	0.491	0.456	0.457	0.450	**0.861**	0.374
	GC3	0.302	0.528	0.557	0.531	0.525	0.449	0.488	0.455	0.450	**0.850**	0.334
	GC4	0.320	0.525	0.485	0.533	0.628	0.540	0.571	0.583	0.568	**0.897**	0.441
11. Supply Chain Agility	SCA1	0.287	0.551	0.541	0.490	0.391	0.377	0.391	0.287	0.227	0.356	**0.805**
	SCA2	0.294	0.526	0.519	0.486	0.352	0.349	0.326	0.284	0.244	0.383	**0.839**
	SCA3	0.287	0.579	0.558	0.482	0.346	0.281	0.400	0.236	0.168	0.324	**0.792**
	SCA4	0.220	0.549	0.536	0.486	0.451	0.446	0.523	0.419	0.316	0.397	**0.736**
	SCA5	0.319	0.518	0.548	0.473	0.267	0.373	0.229	0.271	0.074	0.294	**0.742**
	SCA6	0.326	0.470	0.544	0.530	0.336	0.370	0.244	0.234	0.175	0.307	**0.754**
	SCA7	0.312	0.554	0.546	0.487	0.330	0.386	0.288	0.243	0.115	0.298	**0.795**

Appendix H. Reliability and Validity

Constructs	Item	Cronbach's alpha	Composite Reliability	AVE
Environmental Uncertainty	4	0.844	0.880	0.624
Interorganizational Systems				
IOS Adaptability	3	0.954	0.970	0.898
IOS Standardization	3	0.914	0.946	0.853
Supply Chain Collaboration				
Information Sharing	4	0.816	0.881	0.533
Decision Synchronization	4	0.850	0.899	0.752
Collaborative Communication	4	0.814	0.878	0.722
Joint Knowledge Creation	4	0.877	0.916	0.578
Resource Sharing	3	0.860	0.915	0.637
Incentive Alignment	3	0.864	0.908	0.775
Goal Congruence	4	0.898	0.929	0.705
Supply Chain Agility	7	0.857	0.894	0.689
Controls				
IT Flexibility	6	0.883	0.910	0.638
Strategy	3	0.760	0.802	0.657
Trust	3	0.810	0.890	0.625
Supply Chain Experience	2	0.877	0.904	0.548

Appendix I. Descriptive Statistics and Construct Correlations

	EU	IS	DS	CC	JKC	RS	IA	GC	SCA	IOSA	IOSS	ST	TR	ITF	SCE
EU	**0.79**														
IS	0.33	**0.73**													
DS	0.27	0.58	**0.87**												
CC	0.30	0.52	0.40	**0.85**											
JKC	0.32	0.50	0.42	0.55	**0.76**										
RS	0.27	0.65	0.60	0.58	0.52	**0.80**									
IA	0.25	0.59	0.47	0.60	0.55	0.55	**0.88**								
GC	0.34	0.51	0.40	0.58	0.45	0.54	0.56	**0.84**							
SCA	0.32	0.49	0.53	0.59	0.54	0.49	0.53	0.42	**0.83**						
IOSA	0.32	0.44	0.54	0.42	0.38	0.48	0.43	0.50	0.54	**0.95**					
IOSS	0.27	0.54	0.36	0.52	0.38	0.50	0.49	0.51	0.45	0.34	**0.92**				
ST	0.28	0.50	0.44	0.53	0.47	0.48	0.39	0.53	0.51	0.43	0.53	**0.81**			
TR	0.34	0.37	0.30	0.28	0.37	0.46	0.38	0.35	0.36	0.37	0.35	0.40	**0.79**		
ITF	0.15	0.31	0.32	0.33	0.35	0.31	0.30	0.40	0.37	0.36	0.25	0.35	0.32	**0.80**	
SCE	0.30	0.46	0.42	0.55	0.44	0.45	0.49	0.53	0.45	0.29	0.45	0.41	0.34	0.28	**0.74**
Means	3.87	3.76	4.06	3.80	4.10	3.56	3.90	3.81	3.93	4.07	3.86	3.50	3.98	3.77	3.38
S.D.	0.87	0.77	0.69	0.77	0.64	0.88	0.75	0.78	0.72	0.74	0.62	0.73	0.57	0.87	0.79

Notes: The square roots of the AVEs are in bold. EU, environmental uncertainty; IS, information sharing; DS, decision synchronization; CC, collaborative communication; JKC, joint knowledge creation; RS, resource sharing; IA, incentive alignment; GC, goal congruence; SCA, supply chain agility; IOSA, IOS adaptability; IOSS, IOS standardization; ST, strategy; TR, trust; ITF, IT flexibility; SCE, supply chain experience. N = 156

Appendix J. Differentiating Supply Chain Collaboration from Similar Construct

Difference between supply chain collaboration (SCC) and supply chain integration (SCI)

Although SCC and SCI share some similarities (Cao & Zhang, 2011), they differ in one important way, in that SCC also emphasizes relationships rather than mere transactions or processes as SCI does. These relationships work as the basis for supply chain partners to negotiate processes, plans, and goals to achieve common goals and mutual benefits. SCC necessarily addresses possible conflicting goals and interests among supply chain partners to execute mutually beneficial activities (Cao & Zhang, 2011).

By comparison, SCI is conceptualized with an assumption that supply chain partners have no conflicts of interest or goals, and puts more emphasis on process transactions, including information, physical, and financial flow among supply chain partners. SCI has been criticized for ignoring the relational components that support timely negotiation among supply chain partners, such as decision synchronization, collaboration communication, and joint knowledge creation (Cao & Zhang, 2011). This makes the conceptualization of SCI incomplete, and has reported inconsistent findings (Cao & Zhang, 2011; Flynn et al., 2010). Previous studies found that extensive supply chain integration may lead to inflexibility and reduced ability to meet operational goals (Flynn et al., 2010; Terjesen et al., 2012; Wong et al., 2011), and supply chain transactions with diverse interests among partners may induce more conflicts or opportunistic behavior that limit the firm's ability to catch external opportunities (Carson et al., 2006).

In the context of contemporary business environments that are increasingly uncertain, different interests are arising among supply chain partners, often because unknown conditions can lead to contradictions, challenges, or conflicts (Beckman et al., 2004). More attention is thus required by firms to develop common goals and interests that can provide an adequate means to effectively share and assess exchanged information across boundaries. SCC, which enables supply chain partners to achieve shared goals and interests, is therefore more useful for our purpose than SCI, which mainly focuses on transactions. Based on these distinctions, SCC (rather than SCI) is introduced as the mediating mechanism between IOS characteristics and supply chain agility.

Appendix K. Post-hoc Analyses to Tease Apart the Impacts of SCC Sub-dimensions

To gain additional insights into the two insignificant moderating effects (i.e., the moderating effects of EU on the IOS standardization-SCC relationship and the SCC-SCA relationship), we conduct post-hoc analyses by grouping the seven sub-dimensions of SCC into reasonable categories.

To do so, we seek theoretical guidance in the literature to examine different parts of SCC, meanwhile conducting confirmative factor analyses to ensure that any theoretically informed new grouping has an acceptable degree of model fit. Our CFA analyses first show that the current SCC operationalization (SCC as a second-order construct with seven distinct dimensions) has the best model fit (Normed χ^2=1.34; CFI=0.97; RMSEA=0.07), adding confidence to the robustness of the main model specification. Among theoretically justifiable groupings, we find that the classification based on the theoretical framework of Gulati et al. (2012) in the alliance literature shows the second-best model fit with our dataset, and is better than other ways of grouping. Hence, we conduct post-hoc analyses as guided by this framework, which suggests that inter-organizational collaboration has two facets: coordination and cooperation (Gulati et al. 2012).

Coordination is defined as the deliberate and orderly alignment or adjustment of partners' operational tasks and actions to achieve jointly determined goals. Coordination emphasizes management task interdependency with partners, typically involving the specification and operation of information-sharing, decision-making, and feedback mechanisms. We include the four dimensions of information sharing, decision synchronization, collaborative communication, and joint knowledge creation in the category of coordination because they focus on specific actions or tasks that supply chain partners could take to achieve joint goals.

Cooperation is defined as the joint pursuit of agreed-on goals that correspond to a shared understanding about contributions and payoffs. Cooperation focuses on the management of resource interdependencies and sharing investment risks, and usually builds on agreements regarding inputs and outputs rooted in partners' aligned interests. Unlike coordination that emphasizes operational tasks, cooperation focuses on aligned incentives supply chain partners make in resource-allocation decisions (e.g., technological investment or IP sharing). Following this definition, we group the three dimensions of resource sharing, incentive alignment, and goal congruence into the category of cooperation. Resource sharing, different from information sharing and the other three task dimensions in the coordination category, is related to creating a particular configuration of resource interdependence (Pfeffer & Nowak, 1976; Pfeffer & Salancik, 1978) between partners, since each partner's expected benefits from the relationship depend on resource contributions of others. The seven sub-dimensions of SCC are grouped as follows:

Category	Coordination	Cooperation
Key differences	Actively managing *task* interdependency	Actively managing *resource* interdependency and sharing investment risks
Sub-dimensions	▪ Information sharing ▪ Decision synchronization ▪ Collaborative communication ▪ Joint knowledge creation	▪ Resource sharing ▪ Incentive alignment ▪ Goal congruence

Drawing on this SCC classification, we tested the effects of IOS characteristics on SCC-Coordination and SCC-Cooperation and the moderating effects separately. Results of post-hoc analyses are shown in Figures 1 and 2 below:

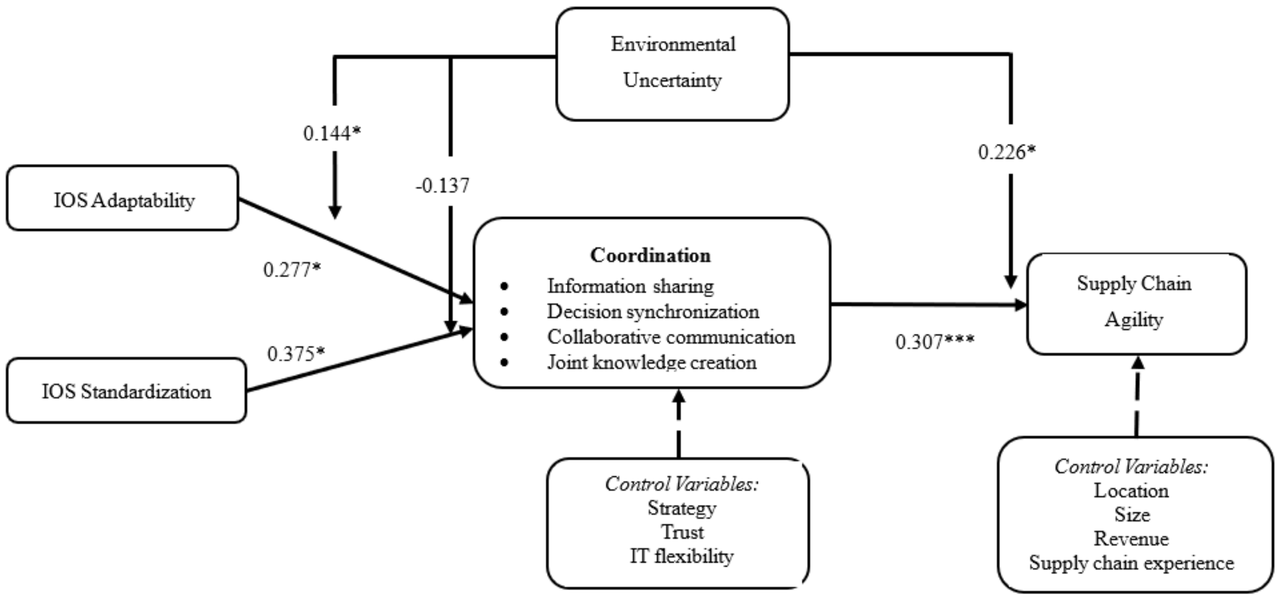

Figure 1. Research Model with Post-hoc Analysis Results (Coordination)

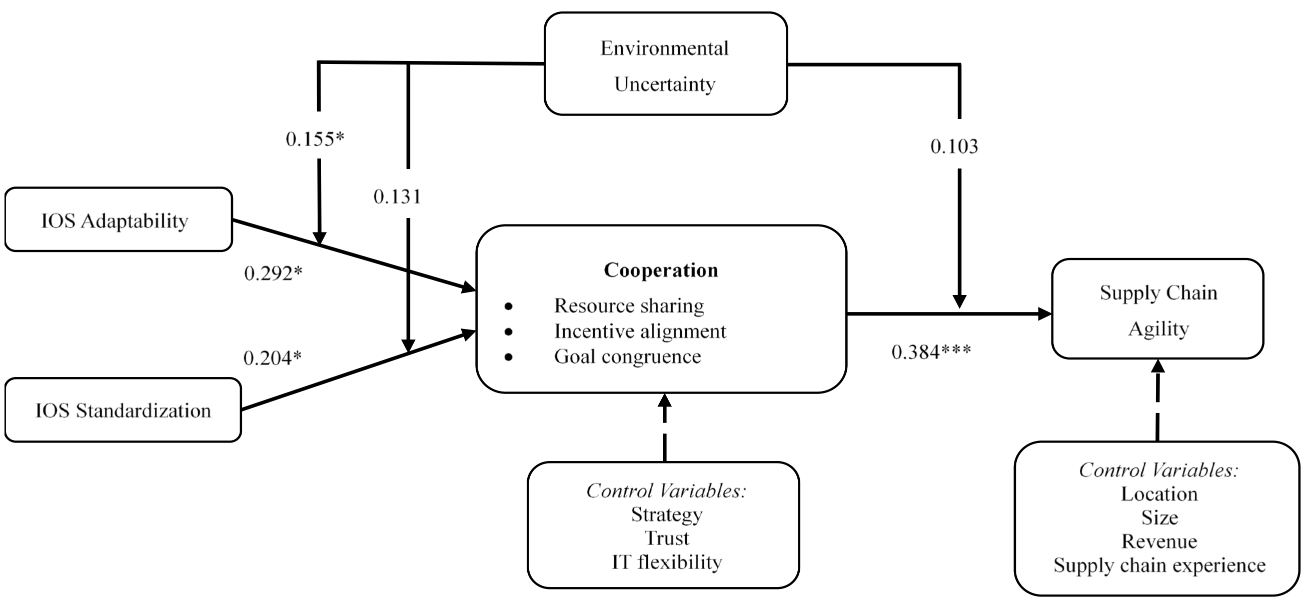

Figure 2. Research Model with Post-hoc Analysis Results (Cooperation)