Journal of Strategic Information Systems 29 (2020) 101594

Contents lists available at ScienceDirect

Journal of Strategic Information Systems

journal homepage: www.elsevier.com/locate/jsis

IOS drivers of manufacturer-supplier flexibility and manufacturer agility

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ARTICLE INFO

Keywords:
Agility
Flexibility
Inter-organizational system integration
Business analytics

ABSTRACT

In today's hypercompetitive environment, it is critical for manufacturing firms to be agile in responding to ephemeral opportunities in the marketplace. This agility often requires the collaboration with supply chain partners. However, how a manufacturing firm collaborates with its suppliers to achieve agility remains an understudied issue. This study holds that manufacturing firms and their suppliers need to develop manufacturer-supplier flexibility accompanied with well-built integrated information systems and associated analytical systems (such as business intelligence) to enable manufacturer agility. To deepen our understanding of the roles of manufacturer-supplier flexibility and IOS technologies in facilitating manufacturer agility, we build and test a model based on the real options theory and bounded rationality. Based on 141 matched-pair samples of Taiwanese manufacturing firms, our findings demonstrate the importance of manufacturer-supplier flexibility in achieving higher manufacturer agility, wherein IOS integration enables better flexibility. We also show IOS-enabled analytical ability can strengthen the effect of such flexibility on manufacturer agility. Implications of the results for practices and academics are provided.

Introduction

Today's manufacturers are facing greater market changes than ever before. Such a changing environment makes fulfilment of market demand difficult. Agility thus is the key for manufacturers to gain competitive advantage by responding to market changes with speed and dexterity (Tallon and Pinsonneault, 2011). This study focuses on manufacturer agility, which is defined as the ability of a manufacturing firm, possibly in conjunction with its key suppliers, to respond to environmental changes speedily (Braunscheidel and Suresh, 2009). Of course, in today's vertically disintegrated industries, agile responses to market dynamics requires not only individual firms' own capacities but also their suppliers' collaboration (van Oosterhout et al., 2006; Young-Ybarra and Wiersema, 1999), highlighting the importance of suppliers in facilitating manufacturer agility (Narayanan et al., 2015). This raises an interesting question: How does a manufacturing firm collaborate with its suppliers to achieve agility?

Prior studies on operations management and information systems (IS) generally have asserted that deploying flexible operations and information technology (IT) enables agility (Bernardes and Hanna, 2009; Braunscheidel and Suresh, 2009; Chakravarty et al.,

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https://doi.org/10.1016/j.jsis.2020.101594
Received 15 March 2018; Received in revised form 5 December 2019; Accepted 5 December 2019
Available online 07 February 2020
0963-8687/

2013; Felipe et al., 2016; Lee et al., 2015; Liang et al., 2017; Lu and Ramamurthy, 2011; Park et al., 2017; Swafford et al., 2006; Tallon and Pinsonneault, 2011). These studies may inform us that inter-firm flexibility and IT with suppliers are critical for manufacturing firms to achieve agility. However, the literature on operations management appears incomplete in explaining the relationship between flexibility and agility. We thus lack a good understanding about the critical operational mechanisms between flexibility and agility through which manufacturer firms and their supply partners can achieve greater agility. Also, past IS research often suggested a direct effect of IT on agility. However, whether the relationships between IT and inter-firm operations and the performance outcomes are so direct is questionable, especially the effect of IT on firm agility.

In today's business environment, manufacturing and supply chain practices have evolved into providing more advanced support to flexible operations. By investing in such practices, manufacturing firms and their suppliers can adapt their inter-firm relationships and operations to changing environments within a range without losing much time and cost (Upton, 1994). Such manufacturer-supplier flexibility (MSF) in relationships and operations can ostensibly help manufacturing firms quickly respond to market demands. At the same time, information technologies have rapidly become more assimilated within business processes, allowing firms to use such technologies as inter-organizational information systems (IOS) for sharing and analyzing information in their interactions with supply partners. These systems can support timely synchronization of information, data analysis, decision-making and operations between firms (Christopher, 2000; Christopher and Towill, 2000; Park et al., 2017; Saeed et al., 2011), thereby enhancing their abilities to detect environmental changes and adjust operations accordingly (Ngai et al., 2011; Park et al., 2017; Trinh-Phuong et al., 2012). However, more studies are needed in explaining how MSF enables manufacturing firms to achieve agility through the support of IOS technologies.

This paper then builds a research model of the relationships among MSF, manufacturer agility, and IOS, which attempts to explain the roles MSF plays in achieving manufacturer agility with the support of IOS integration and IOS-enabled analytic ability. We then invoke real options theory (ROT) to conceptualize two types of MSF: operational flexibility and relationship flexibility, proposing their effects on manufacturer agility (Kogut and Kulatilaka, 2001; Maritan and Alessandri, 2007; Tong and Reuer, 2007; Trigeorgis and Reuer, 2017) and explaining why IOS integration can support MSF to produce agility (Sambamurthy et al., 2003). The concept of bounded rationality is also utilized to explain why IOS-enabled analytic ability can complement MSF to help manufacturing firms to gain greater agility. Our study contributes to the literature in the following ways.

First, although prior studies have examined the flexibility-agility association (Blome et al., 2013; Braunscheidel and Suresh, 2009; Swafford et al., 2006, 2008), how this association works and how to ensure and strengthen this association remains unclear, especially when the flexibility requires inter-firm collaboration. According to Kogut and Kulatilaka (2001), flexibility can be viewed as real options. Firms need first to invest resources in the options, hold the options until an opportunity arrives, and then exercises a choice to strike the option so as to capture the value in the opportunity. ROT can provide a fuller and more explicit account for why MSF can enable manufacturer agility. This approach also extends the application of ROT from the firm level to the inter-firm level, contributing additional theoretical insights into the literature.

Second, although prior studies have suggested that IT is an important driver of flexibility and agility (Felipe et al., 2016; Lee et al., 2015; Liang et al., 2017; Park et al., 2017; Sambamurthy et al., 2003; Trinh-Phuong et al., 2012), they focus mainly on the effects of organizational IT on organizational flexibility rather than the effects of inter-firm IT on inter-firm flexibility (Lee et al., 2015; Lu and Ramamurthy, 2011; Tallon and Pinsonneault, 2011). Whether inter-firm IT can drive inter-firm flexibility and then lead to organizational agility deserves further study (Golden and Powell, 2000).

Third, ROT informs that firms need to find a way to analyze their operations and markets in order to strike an appropriate option at the right time. However, in today's pervasively digitized business environment, the vast amount of diverse data often creates information overload. Business managers, inevitably boundedly rational, will experience difficulty in determining which option to exercise and when. Analytic ability enabled by IOS then is a key to help the managers handle the challenge of information processing in the current big data era. We thus investigate how IOS-enabled analytical ability may support the managers of manufacturing firms to exercise MSF at the right time to enhance agility, fulfilling the gap in the literature.

Finally, two streams of studies on agility are presented in the literature (Fayezi et al., 2016); one focuses on organizational agility (Lee et al., 2015; Liang et al., 2017; Lu and Ramamurthy, 2011; Tallon and Pinsonneault, 2011) while the other focuses on supply chain agility (Braunscheidel and Suresh, 2009; Eckstein et al., 2015; Ngai et al., 2011; Trinh-Phuong et al., 2012). This study's main contribution is to the first stream as it examines how the firm responds to the market. In doing so, our research can be viewed as taking an outside-in perspective, analyzing the effect of flexibility facilitated by key suppliers (outside) on manufacturer agility (in).

The remainder of this paper is organized as follows. Based on ROT and the concept of bounded rationality, the following section develops the conceptual framework of this study. We next derive the research hypotheses and the research model. The research methods and measurements are described, followed by the data analysis. Then, the managerial and research implications, future research directions, and limitations are discussed. Finally, conclusions are presented.

Conceptual framework

The central goal of manufacturer-supplier operations is to rapidly address and respond to uncertain demands from downstream customers and markets. To achieve this goal, manufacturing firms must overcome three problems. The first problem involves a lack of adaptable inter-firm operations, causing considerable delay in fulfilling uncertain market demands. Manufacturing firms may cope with such a problem by developing flexible inter-firm relationships and operations with their suppliers, making a high manufacturer-supplier flexibility desirable. The second problem pertains to a lack of visibility and efficiency of inter-firm processes, resulting in the bullwhip effect and operational inefficiency. Dealing with this problem requires real-time information sharing and smooth inter-firm

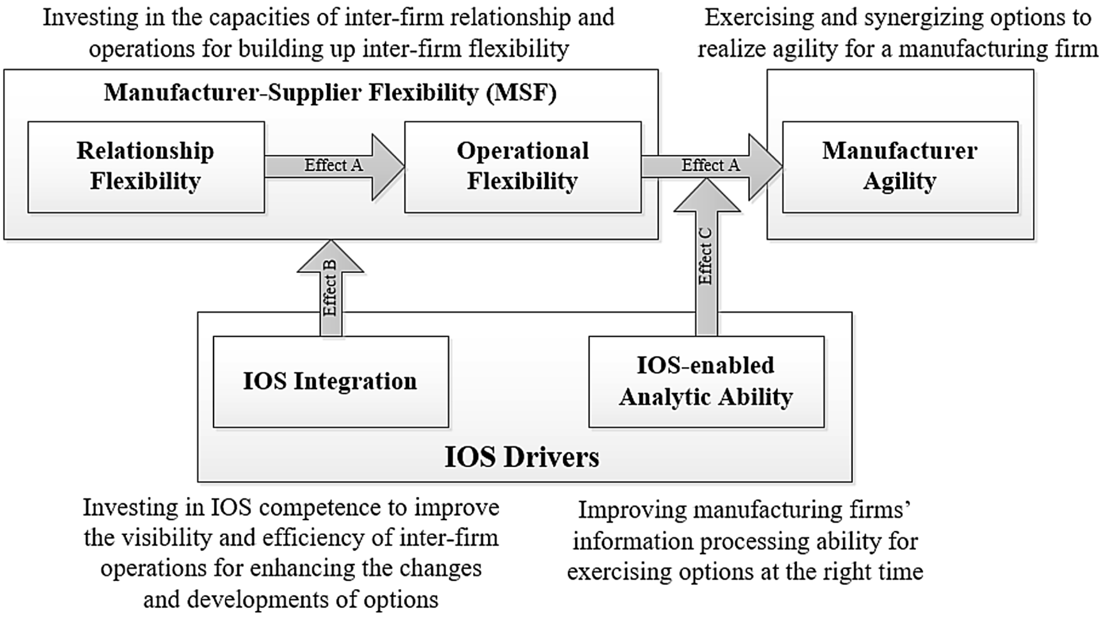

Fig. 1. Conceptual framework.

processes, raising the importance of integrated IOS. The third problem involves whether manufacturing firms can effectively adapt inter-firm operations with their suppliers to uncertain market demands. Without the support of analytic ability, the boundedly rational managers in the supply chain may suffer information overload and have difficulty in making decisions on when and how to adjust inter-firm operations, thus lowering their market responsiveness.

Overall, the above discussion can be formulated as the research framework depicted in Fig. 1. The framework suggests the following: (1) uncertain market demands can be responded to with MSF, which is conceptualized as operational flexibility and relationship flexibility (Effect A in Fig. 1); (2) an integrated IOS can improve the visibility and efficiency of inter-firm operations needed for MSF (Effect B); (3) analytic ability enabled by IOS can help manufacturing firms' decision-making on exercising MSF to facilitate manufacturer agility (Effect C). The relationships among the building blocks of the framework are addressed from the perspectives of ROT and bounded rationality. The definitions of the research constructs are summarized in Table 1.

Real options theory and manufacturer-supplier flexibility

ROT maintains that firms engage uncertainty and benefit by investing in options to respond to uncertain futures (Tong and Reuer, 2007). An option is a right, but not an obligation, to take some future specific operating action at a specified cost (Leiblein, 2003; Trigeorgis and Reuer, 2017). ROT posits that option investments are characterized by sequential, irreversible investments made under uncertainty about the unpredictable future benefits of the investments and further investments (Adner and Levinthal, 2004). To invest and hold a repertoire of options allows firms to respond to market opportunities and threats by proactively confronting uncertainty over time in a flexible manner rather than by attempting to avoid uncertainty (Leiblein, 2003). Such flexibility may be exploited when the firm receives new information regarding market demands, competitive conditions, operations, and new

Table 1
Definition of theoretical concept and research construct.

Concept/Construct	Definition	Key References
Manufacturer Agility (MA)	The ability of a manufacturing firm to respond to a changing market environment in a speedy manner.	Braunscheidel and Suresh (2009)
Manufacturer-Supplier Flexibility (MSF)	Manufacturer-supplier linkages are able to adapt within a range with less loss of time and cost.	Upton (1994)
Operational Flexibility (OF)	The capacity of a manufacturing firm to efficiently support changes in product or service offerings produced in conjunction with its key supplier.	Vickery et al. (1999)Gosling et al. (2010)
Relationship Flexibility (RF)	The capacity of a manufacturer to adapt and modify the relationship with its key supplier	Young-Ybarra and Wiersema (1999)
IOS Integration (IOSI)	A manufacturing firm's information systems linked with its key supplier's information systems as a unified whole to facilitate bidirectional information sharing and accessing.	Grover and Saeed (2007)Saraf et al. (2007)
IOS-enabled Analytical Ability (AA)	The ability of IOS in providing data and analytical tools to support decision making with respect to the functions inter-firm operations.	Saeed et al. (2011)

technologies (Leiblein, 2003). There are many different types of options (Trigeorgis and Reuer, 2017), such as the options to alter scale (e.g., the option to expand manufacturing capacity or an outsourcing arrangement) and the options to switch inputs and outputs (e.g., production volume). Different options can form a portfolio that increase the flexibility and potential benefits of the holding firms (Anand et al., 2007).

Traditionally, ROT is applied in the firm context (Trigeorgis and Reuer, 2017), but firms inevitably are embedded in networks of relationships (Dyer and Singh, 1998). Without the cooperation of business partners, individual firms are limited their ability to respond to uncertainty with sufficient flexibly. Thus, when real options are involved in the inter-firm context, co-investments, which have the characteristics of real options, are often required from both sides of a partnership (Trigeorgis and Reuer, 2017). Accordingly, to respond to uncertain market demands and achieve agility, manufacturing firms and their suppliers must invest certain resources in their operations and relationships to gain a basket of capacities, and get the timing right to leverage products and services from one application to another efficiently (Kogut and Kulatilaka, 2001). For example, to build up operational flexibility, manufacturing firms and their suppliers can invest in a set of flexible work practices and manufacturing processes (Naim et al., 2006; Van Hoek, 1998). These investments can enlarge their capacities for flexibility in inter-firm operations, such as producing different volumes and combinations of product and delivering products in different dates (Gosling et al., 2010). These capacities can be considered as options to adjust or switch manufacturing processes (Kogut and Zander, 1992; Sambamurthy et al., 2003; Trigeorgis and Reuer, 2017) even though the capacities may not be actually utilized in the future. Similarly, to build up relationship flexibility, manufacturing firms and their suppliers may invest trust (Zaheer et al., 1998) or practice incomplete contracts and informal governance (Dyer and Singh, 1998) in their relationships, thus making their relationship less binding formally. These capacities for flexibility in inter-firm relationships, in a dyadic relationship, are real options held by a manufacturer and its supplier. If the relationship is flexible with high trust, there is a greater likelihood of the dyad making investments that can be moulded according to new environmental demands. Exercising appropriate options (sometimes different types of options) at the right time then enables the manufacturer's agility directly or indirectly. Thus, if the dyad possess a repository of options as a fundamental platform, the platform offers them the basis (an organized logic, managerial rationale) for assembling capacities and fostering flexibility in the relationship (Kogut and Kulatilaka, 2001; Maritan and Alessandri, 2007), allowing the manufacturer to respond to challenges and exploit opportunities more quickly (Gallagher and Worrell, 2008). This makes MSF an important enabler of manufacturer agility (Effect A in Fig. 1). In this study, we further conceptualize MSF as composed of operational flexibility and relationship flexibility.

IOS integration

ROT suggests that the return of real options is affected by the complementarities between the capacities acquired through investments and the firm's existing resources and competences (Maritan and Alessandri, 2007). Thus, in the inter-firm context, inter-firm resources and competences may complement with inter-firm capacities to increase the return of real options. We thus argue that investments in IOS can facilitate real-time information sharing (Park et al., 2017; Saeed et al., 2011; Sandberg et al., 2014) and digitize inter-firm practices and processes (Sambamurthy et al., 2003), benefiting the development and utilization of inter-firm capacities.

IOS integration reflects tighter inter-firm linkages enabled by information systems (Grover and Saeed, 2007). Such IOS investments can enhance the integration of the systems between firms (Rai and Tang, 2010) and naturally is critical for building up IT-enabled inter-firm coordination and collaboration (Rai et al., 2006; Sambamurthy et al., 2003; Saraf et al., 2007). This study defines IOS integration as the extent to which a manufacturer's information systems are linked with those of its key supplier as a unified whole to facilitate bidirectional information sharing and access (Grover and Saeed, 2007; Saraf et al., 2007), with database interconnection, application integration, and data syntactic and semantic integration as the dimensions. IOS integration enables real-time information transfer between applications and functions of trading partners' information systems (Rai et al., 2006; Rai and Tang, 2010).

Following Sambamurthy et al. (2003), IOS integration can be considered as a digital options generator, serving as a platform for the firms to digitize inter-firm operations and develop more possible digital options. As such, the fusion between IOS and inter-firm operations permits the firms to quickly adapt to changing requirements and develop efficient work practices and manufacturing processes (Rai et al., 2006; Sambamurthy et al., 2003). These reduce the time and cost of adapting inter-firm operations to changed environments, and thereby benefit MSF (Effect B).

Bounded rationality and IOS-enabled analytic ability

Studies have indicated that a firm recognizing the embedded options does not mean that it has the required management system to support their implementation (Kogut and Kulatilaka, 1994a,b). Managers may fail to use the correct information to assess real options, and they may also find it hard to monitor the complex cues for exercising options, because of bounded rationality (Tong and Reuer, 2007; Trigeorgis and Reuer, 2017). This implies that the return from greater capacity for flexibility in inter-firm operations maybe compromised. Thus, the ability to process massive information helps managers execute real options effectively and thereby mitigates the negative impact of bounded rationality (Trigeorgis and Reuer, 2017).

Today, the mass operational, transactional, and customer data are mostly stored digitally. Business intelligence such as inter-firm operations and market demands is hidden within the data and is difficult to obtain without the support of IT. Business analytics and intelligence tools enabled by IOS can help managers to spot problems, analyze environments, and possibly extract market opportunities from the databases, thus expanding their cognitive frames (Park et al., 2017; Saeed et al., 2011; Trkman et al., 2010). As a

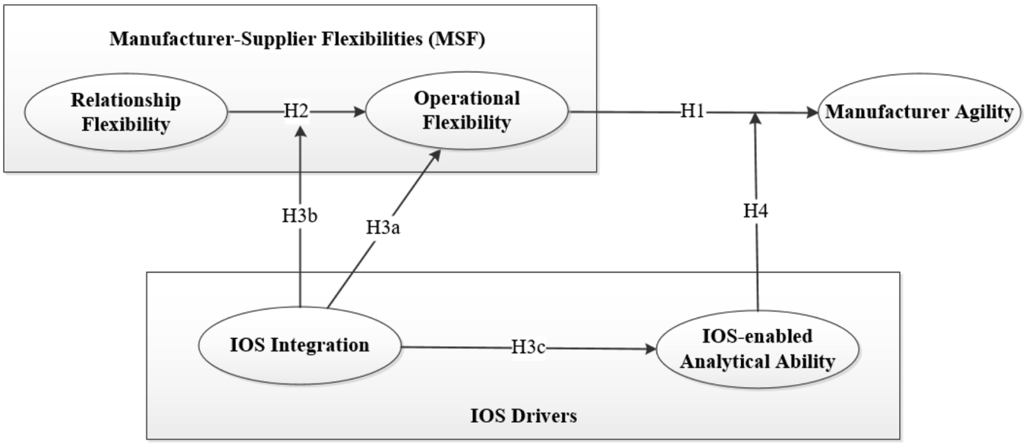

Fig. 2. Research model.

result, firms may be more effective in exercising their real options with suppliers to respond to market demands (Effect C). Consequently, this study attempts to explore the effect of IOS-enabled analytic ability on the use of MSF for greater manufacturer agility.

Research model, constructs and hypotheses

Given the conceptual framework discussed above, a research model is proposed as shown in Fig. 2 and explained below.

Manufacturer agility

Based on Braunscheidel and Suresh (2009), this study defines manufacturer agility as the extent to which a manufacturing firm has the capability to respond to a changing market environment in a speedy manner. This concept encompasses responsiveness and robustness (Golden and Powell, 2000), i.e., the ability to respond to change within an appropriate time frame and the ability to respond successfully to unforeseen environmental change (Bernardes and Hanna, 2009; Fayezi et al., 2016; Golden and Powell, 2000). The responsiveness and robustness are reflected in the aspects of customer, product, and market demands as these aspects are critical for manufacturing firms to deal with the volatility and uncertainty from downstream of the supply chain.

Effect of manufacturer-supplier flexibility

It is useful to note that while the concept of flexibility may seem similar to agility, they are different in nature (Bernardes and Hanna, 2009; Fayezi et al., 2016). Flexibility reflects the capacity, as mentioned above, to change status within a pre-established range with mobility. The range is the number of different transition states available, and the mobility is the transition penalties, including time and cost, for moving within the range (Bernardes and Hanna, 2009; Upton, 1994). Flexibility therefore can be considered as the capacity to hold a variety of options available for doing things differently to enable a desirable outcome (Bernardes and Hanna, 2009). On the other hand, agility is the ability to exercise or sometimes reconfigure available options rapidly and appropriately when uncertainty or opportunities have materialized. Hence, agility is regarded as a capability rather than a capacity. Agility focuses more on absorbing uncertainty and seizing opportunities "rapidly," as options being exercised, while flexibility is a repertory of options that supports agility (Bernardes and Hanna, 2009). Therefore, agility can be considered as the capability of utilizing flexibility to change states speedily (Bernardes and Hanna, 2009), or as an outcome capability of flexibility (Braunscheidel and Suresh, 2009; Swafford et al., 2006). Consequently, researchers suggest that agility can be enabled by tapping the synergies among different forms of flexibility (Agarwal et al., 2007; Bernardes and Hanna, 2009; Braunscheidel and Suresh, 2009; Swafford et al., 2006).

In the supply chain setting, flexibility has been described as incorporating different flexibilities to form higher order flexibility (Fayezi et al., 2016; Gosling et al., 2010; Vickery et al., 1999). By focusing on manufacturer-supplier relationship and by following Upton (1994), we define MSF as the extent to which manufacturer-supplier linkages are able to adapt within a range with certain time and cost. To incorporate different flexibilities into the definition, we further adopt the conceptualization reflected in the works of Vickery et al. (1999), Young-Ybarra and Wiersema (1999), and Gosling et al. (2010), in delineating operational flexibility and relationship flexibility as the two key types of MSF. For a dyadic relationship, operational flexibility reflects how flexible it is for the supplier to fulfil downstream demands, while relationship flexibility reflects how flexible the relationship within the dyad is, and can be adjusted. These two types of flexibility in the manufacturer-supplier relationship are needed to both fulfil changing demands from downstream manufacturers and to ensure reliable inputs from upstream suppliers (Lummus et al., 2003; Swafford et al., 2006). Consequently, we do not aggregate these two types of flexibility into a single construct in order to understand how these two types of inter-firm flexibility may enable manufacturer agility differently.

Operational flexibility reflects to the capacity of a manufacturing firm to efficiently support changes in product or service offerings produced in conjunction with its key supplier. Specifically, operational flexibility represents the capacity of the dyadic firms to accommodate changes in volumes, combinations of products produced, and delivery dates (Gosling et al., 2010), achieved by their flexible work practices and manufacturing processes. The variety of these offerings is a repertoire of available options that allows the dyad, by utilizing or reconfiguring available options rapidly, to change their operations more efficiently, and thereby helps the manufacturer meet changed demands (Teece, 2007). By further tapping the synergy of the options, the dyad may be able to uncover potential solutions more timely for unpredicted problems (Agarwal et al., 2007; Swafford et al., 2008; Yusuf et al., 1999). Thus, holding such options and efficiently changing from one to another gives manufacturers greater ability to fulfil varying demands from downstream, resulting in greater manufacturer agility. Accordingly, we propose the following hypothesis:

Hypothesis 1. Higher levels of operational flexibility between a manufacturer and its key supplier will enhance the level of the manufacturer's agility.

Relationship flexibility, defined as the capacity of a manufacturer to adapt and modify the relationship with its key supplier (Young-Ybarra and Wiersema, 1999), helps the dyad access each other's assets, competencies, and knowledge and generate synergies of these resources for rapid mastering the new demands of inter-firm operations. Relationship flexibility can also be considered as the options to expand the operating space within their relationship (Li et al., 2007). Although operational flexibility provides dyadic firms the ability to accommodate environmental changes, some changes may nevertheless be out of the range of their pre-established agreement or contract. With the capacity to modify their relationship, the dyad should be able to develop and expand their flexible work practices and processes and thus enlarge what they can offer, enabling greater operational flexibility. According to ROT, relationship flexibility can be seen as a pre-investment that creates valuable follow-on investment opportunities on new inter-firm practices and processes, increasing the capacity of inter-firm operations (Leiblein, 2003). Further, iterative loops of relationship modifications can help dyadic firms co-evolve the line-up of their assets, capabilities, and knowledge (Eisenhardt and Martin, 2000); they can acquire, assimilate, accumulate, transform, and exploit collaborative know-how over time (Wang et al., 2013). Such relational learning allows the firms to become more knowledgeable about their relationship and collaboration. This facilitates joint problem solving and mutual adaptation on their operations, supporting efficient changes in product or service offerings. Accordingly, we propose the following hypothesis:

Hypothesis 2. Higher levels of relationship flexibility between a manufacturer and its key supplier will increase the level of operational flexibility between them.

Effect of IOS integration

The investment in IOS integration can facilitate business partners to achieve operational flexibility through two mechanisms. First, IOS can digitize inter-firm practices and manufacturing processes. Such digitization facilitates various interconnections and boundary-spanning activities between dyadic firms (Overby et al., 2006), allowing such information as product specifications, production schedules, and delivery schedules to be transferred efficiently across organizational boundaries and thus realizing better process reach and richness (Sambamurthy et al., 2003; Sandberg et al., 2014). Integration also gives dyadic firms a greater span of management and control on their practices and processes (Rai et al., 2006) and thereby greater adaptability in the practices and processes (Overby et al., 2006; Rai et al., 2006; Rai and Tang, 2010; Trinh-Phuong et al., 2012). IOS integration thus facilitates inter-firm communication and collaboration with much less time and cost (Park et al., 2017) and thereby increase operational flexibility.

Second, investment in IOS integration can be considered as developing a digitized platform, which can serve as a foundation for add-on functionalities, complementing the changes or expanding on existing options in current work practice and manufacturing processes (Trinh-Phuong et al., 2012). The benefits of initial investments in IOS integration can further result in additional investments in similar or related technologies or functionalities, which are likely to enable learning-by-doing and thus expand both offering options and the knowledge of IOS and inter-firm processes (Karimi et al., 2009). IOS integration thus helps the dyadic firms achieve greater operational flexibility. Therefore, we propose the following proposition:

Hypothesis 3a. Higher levels of IOS integration will enhance the level of operational flexibility between a manufacturer and its key supplier.

The relationship in Hypothesis 2 above can be influenced by IOS Integration. The economic theory of complementarities (TOC) (Lee et al., 2010; Tanriverdi, 2006) suggests that a set of resources is complementary when the returns to a resource vary in the degrees of returns to the other resources; coordinated investments in such a set of resources would yield higher synergetic returns than uncoordinated investments (Lee et al., 2010; Tanriverdi, 2006). Thus, when dyadic firms have invested resources in relationship capacity, coordinated investments in IOS competences could generate higher synergetic returns on the improvement of operational capacities. This also implies that the firms may synergize relationship options and digital options. Specifically, when two firms invest and exercise relationship options to access each other's assets, competencies, and knowledge for mastering the inter-firm operations, IOS integration can accelerate such access by providing real-time information and knowledge sharing through digitized inter-firm practices and processes (Dong et al., 2017; Sambamurthy et al., 2003; Saraf et al., 2007). IOS integration can also help the dyadic firms continuously monitor their plans and operations, thereby enhancing their ability to recognize both opportunities and constraints for expansion. This information acquired (through exercised digital options) allows better utilization of the flexible relationship. Further, when the dyad attempts to expand offering options, larger relationship capacity also helps implement add-on functionalities. These suggest that IOS integration can synergize with relationship flexibility to produce further improvement in operational flexibility. Accordingly, we propose the following hypothesis:

Hypothesis 3b. The higher the level of IOS integration, the stronger is the positive effect of relationship flexibility on operational flexibility.

Further, IOS integration can enhance the extent to which the system provides the data and analytical tools to support decision making regarding supply chain functions (Saeed et al., 2011). IOS integration not only supports more bidirectional information accessing and sharing but also collects and stores more data about daily transactions and operations in databases or data warehouses. As more data are available, more analyses can be performed. A higher level of IOS integration thus can provide more comprehensive and complete data for the analytical tools to better support inter-firm operations and decisions, therefore making the tools more useful. Accordingly, we propose the following hypothesis:

Hypothesis 3c. Higher levels of IOS integration will increase IOS-enabled analytical ability.

Moderation effect of IOS-enabled analytical ability

In order to exercise operational options at the right time, managers of a manufacturing firm must engage in cognitively demanding activities, in which they must integrate a variety of information about inter-firm operations and market demands to arrive at an overall evaluation of option execution (Tiwana et al., 2007). When facing such a demanding evaluation task, the managers inevitably are constrained by their bounded rationality and often come to conclusions by first analyzing a broad range of information but finally conducting a detailed examination of a subset of information (Tiwana et al., 2007). Bounded rationality limits the managers in their ability to process and interpret a large volume of pertinent information when making decisions (Simon, 1979). Thus, boundedly rational managers always are constrained in exercising their inter-firm operational options at the right time to achieve agility.

In today's digitized business environment, business partners can collect data at every interaction between them and with other supply chain partners or customers. Such massive data increase the difficulty of boundedly rational managers to analyze information and exercise options at the right time. Fortunately, in the current big data era, analytic ability with advanced IT can helps managers analyze massive information and provide high quality organized information (Park et al., 2017), supporting decision-making and action-taking. Specifically, analytic ability can help managers develop richer knowledge through real-time data monitoring, pattern recognition, and strategic scenario modelling (Saeed et al., 2011). These abilities are important for firms and their managers to possess when monitoring their inter-firm operations and identifying emerging opportunities (Neill et al., 2007). Manufacturing firms and their managers may not necessarily rely on the intelligence provided by IOS to exercise different offering options, but without such intelligence, the firms will be limited in adjusting or reconfiguring these options even though they have a great capacity to do so. Consequently, we hold that IOS-enabled analytic ability can help firms utilizing their operational flexibility more fully to cope with needed changes more effectively and efficiently, attaining a higher level of manufacturer agility. Accordingly, we propose the following hypothesis:

Hypothesis 4. The higher the level of IOS-enabled analytical ability, the stronger is the positive effect of operational flexibility on manufacturer agility.

Control variables

Organizational and inter-firm characteristics are the basic lenses that drive our selection of the control variables. Five control variables, firm size, sales, the frequency of purchasing, purchasing volume, and the length of association with the key supplier, are included in our model. These variables are related to a manufacturing firm's resources and reflect the basic characteristics of its transactional relationship with the supplier (Grover and Saeed, 2007), and thus may affect operational flexibility and manufacturer agility.

Research methodology

Instrument development

Our research data were collected with a carefully developed survey instrument. We developed and validated our measures using the guidelines suggested by MacKenzie et al. (2011). We first reviewed prior studies to identify and develop measures suitable for the current study. We ensured that the measures had sufficient face validity and minimal overlaps among them. To ensure content validity, the items were independently evaluated by each of the researchers. The researchers then jointly discussed each construct and its items until they had agreement. After compiling an English version of the questionnaire, the survey items were first translated into Chinese by a bilingual researcher. The survey items were verified and refined for translation accuracy by a bilingual MIS professor and a PhD candidate. The Chinese version of the draft was then pretested with 6 senior managers (including CEO, senior business manager, procurement manager, and IS executive) for examining face and content validity again, resulting in modification of the wording of some survey items. We operationalized all constructs using multi-item reflective measures with a seven-point Likert scale anchored from “strongly disagree” to “strongly agree.” The measures are provided in Appendix A and discussed below.

Based on Braunscheidel and Suresh (2009), manufacturer agility was characterized by responsiveness with robustness in the aspects of customer, product, and market demands. We measured it with ten items assessing the extent to which the focal manufacturing firm could rapidly respond to changes in market demand and customer needs, improve customer service, customize products, introduce new products, and reconfigure production lines related to a specific supplier (Braunscheidel and Suresh, 2009; Christopher, 2000; Swafford et al., 2006). The focus on such relationship-specific manufacturer agility is because MSF involves a focal manufacturer and its specific supplier; making the level of manufacturer agility attributable to the specific relationship rather than using a broader imprecise measure that could dilute the effects of MSF.

Operational flexibility was measured by four items assessing the extent to which the focal manufacturing firm and its key supplier, when needed, can collaboratively change the output level of products produced (Gosling et al., 2010), change delivery dates (Swafford et al., 2008), change the variety of products produced (Zhang et al., 2003), and introduce new products (Gosling et al., 2010). We assessed relationship flexibility with three items assessing the extent when needed the focal manufacturing firm and its key supplier can modify their agreement and relationship accordingly (Young-Ybarra and Wiersema, 1999).

IOS integration was characterized by immediate access to databases, interconnection of applications, and data syntactic and semantic integration between the partners’ information systems. We assessed it with a ten-item scale adapted from Grover and Saeed (2007), Rai et al. (2006), Rai and Tang (2010), and Saraf et al. (2007). IOS-enabled analytic ability consists of three items assessing the ability of analytical tools of IOS to support decision making with respect to the supply chain functions (Saeed et al., 2011).

Sample and data collection

A cross-sectional and matched-pair mail survey for purchasing managers and IS executives was administrated for collecting data from the top 2000 manufacturing firms based on the Year 2012 Directory of the Top 5000 Largest Firms in Taiwan, published by China Credit Information Services Ltd. After accounting for undelivered and invalid mail, the effective mailing was 1950 surveys. Survey packages were mailed to the purchasing manager of each target firm with a request that the recipient complete Part A related to manufacturer agility, operational flexibility, and relationship flexibility. The recipient then selected an important supplier of the recipient’s firm. The recipient was asked to write down the supplier name on Part B related to IOS integration and IOS-enabled analytic ability, and distribute Part B to the suitable IS executive. It was critical that Parts A and B referred to the same supplier because our constructs largely focus on a dyadic relationship. Focusing on the dyadic relationship is because relationship flexibility, operational flexibility, and IOS integration often vary depending a manufacturer’s specific relationships with a particular supplier. For example, that a manufacturer has implemented a high level of IOS integration with one key supplier does not mean the manufacturer has also implemented the same level of IOS integration with other suppliers, making reliable assessment of the research constructs at the network or the entire supply chain level extremely difficult. We thus choose the dyadic relationship as our main unit of analysis. Overall, one hundred and seventy-two surveys pairs were returned in total, with 141 having completed the data and available for subsequent analysis, yielding an effective response rate of 7.2%. Tables 2 and 3 exhibit the characteristics of the sample.

Non-response bias was assessed using the procedure recommended by Armstrong and Overton (1977). By considering the last group of respondents as most likely to be similar to non-respondents, a comparison of the first and last quartiles of respondents based on return dates provides a test of response bias. No significant differences between the first and last quartiles of the respondents were found on firm size based on the independent sample t test ($p = 0.621$). Accordingly, non-response bias should not be a serious concern in this study.

Common method variance (CMV) was tackled by three approaches. First, a multiple informant approach allowed us to mitigate the CMV (Podsakoff et al., 2003). Second, we used Harmon’s single-factor test to assess CMV (Podsakoff et al., 2003). Six factors with eigenvalue > 1 were extracted and collectively accounted for 73.8% of the variances in the data, with the first factor accounting for 37.69% of the variances. Third, we conducted the PLS marker variable approach to diagnosing CMV (Rönkkö and Ylitalo, 2011). Following the procedures proposed by Rönkkö and Ylitalo (2011), we found that the paths significant in the baseline model were also significant in the model compared. Taken together, we concluded that CMV should not be significant in our data.

Results

A partial least squares structural equation model (PLS-SEM) using SmartPLS Version 3.2.8 was constructed for measurement assessment and hypotheses testing. PLS is appropriate for our study because it is recommended for moderating effects (Dijkstra and Henseler, 2015). We used SmartPLS to estimate the outer model through PLS algorithm with the path weighting scheme, and the inner model through consistent PLS (PLSc) algorithm. According to Dijkstra and Henseler (2015), PLSc, similar to covariance-based SEM, avoids the excessive amount of Type I and Type II errors that can occur if traditional PLS is applied to estimate structural equation models with reflective measurement models. Thus, we adopted PLSc algorithm in hypothesis testing.

Measurement model

We assessed the validity and reliability of the items and constructs according to the guidelines from Henseler et al. (2016) and Hair et al. (2017b). Outer loadings for all items were higher than 0.7 and significant at 1% level except for two items (one of agility and one of IOS integration), resulting in the deletion of the two items (Hair et al., 2017b). We then tested the model fit with the

Table 2
Profile of the respondents (N = 141).

	No.	%
Purchasing title		
Director/Manager/Assistant Manager/Section Manager of Purchasing	55	39
Management (with purchasing responsibility)	62	44
Top management	7	5
Others	9	6
Missing	8	6
MIS title		
Section Manager/Manager/Assistant manager/Administrator/Consultant of MIS	31	22
Engineer of MIS	31	22
Management (with MIS responsibility)	49	35
Top management	3	2
Others	7	5
Missing	20	14

Table 3
Profile of the responding firms (N = 141).

	No.	%
Industry		
Automobile	13	9
Chemical	17	12
Computer and electronics	53	38
Food	6	4
Machine and tool	10	7
Metals and materials	25	18
Textile	6	4
Others	11	8
Number of employees		
30–50	6	4%
51–100	13	9%
101–150	21	15%
151–200	18	13%
201–250	15	11%
251–375	19	13%
376–500	8	6%
501–750	11	8%
751–1000	5	4%
1001–2000	11	8%
2001–4000	6	4%
> 4001	8	6%

standardized root mean square residual (SRMR) (Henseler et al., 2016).[1] Using the PLS algorithm, the SRMRs of the saturated model (SM) and the estimated model (EM) were 0.065 and 0.078, respectively, both below the cut-off value of 0.08 (Henseler et al., 2016), showing acceptable model fit. While the tests of SRMR using PLS algorithm did not pass the 95% (SM = 0.055; EM = 0.066) and 99% (SM = 0.059; EM = 0.073) bootstrap quantile, the tests using PLSc algorithm (SM = 0.065; EM = 0.075) did pass the 99% (SM = 0.066; EM = 0.076) bootstrap quantile. The rho_A, composite reliability (CR) and Cronbach's alpha estimates, reported in Table 4, were above 0.7 for all constructs, indicating good internal consistency and the reliability of the scales (Hair et al., 2017b; Henseler et al., 2016). We further assessed the convergent validity of our constructs based on average variance extracted (AVE). The AVE of each construct exceeded the minimum threshold value of 0.5 (Hair et al., 2017b; Henseler et al., 2016). The combined results demonstrated sufficient convergent validity of the constructs.

Discriminant validity is established when (1) items load more highly on the construct that they are intended to measure than on other constructs, (2) the square root of the AVE by each construct is larger than the inter-construct correlations (Hair et al., 2017b), and (3) the heterotrait-monotrait ratio of correlation (HTMT) is significantly smaller than 1. Cross-loadings were computed by calculating the correlations between a latent variable's component scores and the manifest indicators of other latent constructs (Hair et al., 2017b). Without exception, all items loaded more highly on their own construct than on other constructs (see Appendix B). As shown in Table 4, the square root of the AVE for each construct was greater than the correlations between the construct and other constructs, indicating that all the constructs shared more variances with their indicators than with other constructs. All HTMT values,

[1] The appropriateness or necessity of assessing model fit in PLS-SEM remains under debate (Hair et al., 2017a; Hair et al., 2017b). While Henseler et al. (2016) recommend using SRMR to test PLS-SEM model fit with SRMR, Hair et al. (2017a) and Hair et al. (2017b) do not suggest to assess model fit in PLS-SEM because the purpose of the PLS algorithm is to maximize prediction rather than model fit.

Table 4
Inter-construct correlations, reliability measures, and the heterotrait-monotrait ratio of correlation (HTMT) (N = 141).

Construct	Items	ρ_A	Cron. α	CR.	AVE	1	2	3	4	5
1. Manufacturer agility	9	0.94	0.94	0.95	0.66	**0.81**				
2. Operational flexibility	4	0.85	0.85	0.90	0.69	0.70 (0.79; 0.86)	**0.83**			
3. Relationship flexibility	3	0.91	0.87	0.92	0.80	0.57 (0.63; 0.72)	0.61 (0.69; 0.80)	**0.89**		
4. IOS integration	9	0.96	0.95	0.96	0.72	0.38 (0.41; 0.53)	0.43 (0.49; 0.60)	0.23 (0.26; 0.40)	**0.85**	
5. IOS-enabled analytic ability	3	0.93	0.92	0.95	0.86	0.29 (0.31; 0.44)	0.37 (0.42; 0.57)	0.21 (0.23; 0.39)	0.38 (0.40; 0.52)	**0.93**

Note: (1) Square roots of average variance extracted are shown on the diagonal in bold; (2) HTMT and their 95% CI are shown in parentheses (HTMT; the upper bounds of the 95% CI); (3) the 95% CI of HTMT are estimated by 4999 bias-corrected and accelerated bootstrapping with confidence intervals bias corrected (Henseler et al., 2016).

also shown in Table 4, were significantly smaller than 1 with 95% confidence interval (CI) (the upper bounds of CI were not larger than the value 1), indicating clear discriminant between two constructs. Thus, our measures exhibited sufficient discriminant validity.

Structural model

We first assessed multi-collinearity by examining each set of predictor constructs separately for each subpart of the research model (Hair et al., 2017b). In our model, all the variance inflation factors (VIF) of endogenous constructs are less than two which is well below the five threshold (Hair et al., 2017b), indicating no multi-collinearity problem in our model.

To assess the significance of the path coefficients in the inner model, SmartPLS was applied to generate 10,000 samples using a bootstrapping technique with the PLSc algorithm, no sign changes, connecting all latent variables for initial calculation, a path weighting scheme, and a percentile CI (Aguirre-Urreta and Rönkkö, 2018; Dijkstra and Henseler, 2015; Hair et al., 2017b). We applied the two-stage approach to create the interaction term with the standardized approach suggested by Hair et al. (2017b) for testing the moderating effects. The full model has an R^2 of 68.5% for manufacturer agility, 62.6% for operational flexibility, and 16.3% for IOS-enabled analytic ability. With omission distance equaling 5, all the cross-validated redundancy Q^2 values of endogenous constructs are larger than zero, indicating predictive relevance (Hair et al., 2017b). Fig. 3 shows the result of structural model estimation.

The results show that operational flexibility (H1: $p < 0.01$) has significant effect on manufacturer agility. Relationship flexibility positively influences operational flexibility ($p < 0.01$), supporting H2. IOS integration positively affects operational flexibility (H3a: $p < 0.01$) but does not positively moderate the relationship between relationship flexibility and operational flexibility (H3b: $p > 0.05$). By providing the needed data, IOS integration supports IOS-enabled analytic ability (H3c: $p < 0.01$). Our analysis reveals that IOS-enabled analytic ability positively moderates the relationship between operational flexibility and manufacturer agility (H4: $p < 0.05$). Finally, the effects of the control variables on manufacturer agility and operational flexibility are insignificant

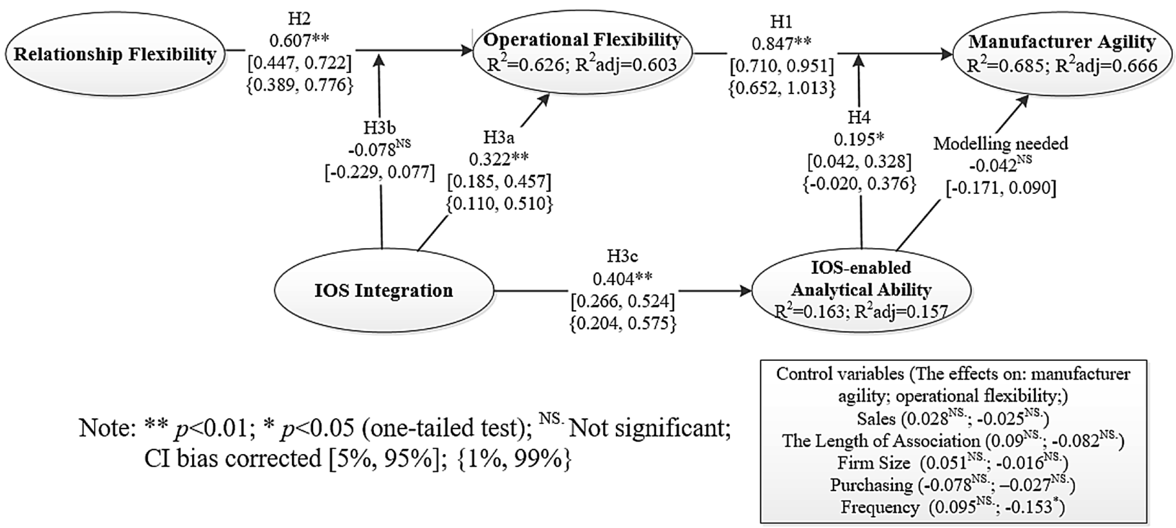

Fig. 3. Result of structural model.

except for the negative effect of frequency on operational flexibility ($p < 0.05$). Overall, we found support for five of six hypotheses in the research model. These findings are discussed below.

Summary of results

Consistent with prior studies that demonstrate the flexibility-agility association (Braunscheidel and Suresh, 2009; Swafford et al., 2006, 2008), we find support for the hypothesis that inter-firm operational flexibility can help a downstream manufacturing firm achieve greater agility (H1). We also find support for the effect of relationship flexibility on operational flexibility (H2). These results led us to further conduct a mediation test to examine the indirect effect of relationship flexibility on manufacturer agility through operational flexibility. We followed the guidelines suggested by Zhao et al. (2010). We first tested the total direct effect of relationship flexibility on manufacturer agility; the results show that relationship flexibility significantly influences manufacturer agility (path coefficient = 0.521; $p < 0.01$). We then tested our research model with an additional direct path from relationship flexibility to manufacturer agility. The result shows the direct path is insignificant (path coefficient = 0.118; $p > 0.5$). We also found very small f^2 (0.023; calculated by the comparison between included (R^2 for the agility = 69.2%) and excluded (R^2 for the agility = 68.5%) models). These results suggest that operational flexibility fully mediates the relationship between relationship flexibility and manufacturer agility. The results also indicate that flexibility-agility association may not always be direct but sometimes indirect because relationship modification takes time and agility may require responses faster than relationship modification can help. We further conducted the percentile bootstrap approach to test the indirect effect (Hayes et al., 2011). The result indicates that the indirect effect is significant at $p < 0.001$ level with 10,000 bootstraps (Sobel Z = 5.84; 99% CI: [0.18, 0.56]). Accordingly, our results reflect that operational flexibility is more directly relevant to enabling manufacturer agility as it is more related to daily inter-firm operations, while relationship flexibility should be more helpful in evolving their relationship to develop a greater capacity for providing operational flexibility. Thus, *operational flexibility is instrumental to the attainment of greater manufacturer agility while relationship flexibility is also important in that it provides a foundation for operational flexibility.*

This study shows that IOS integration enables operational flexibility (H3a). This result suggests that the essential capabilities of IOS integration, such as seamless digital linkages and bidirectional information accessing and sharing, can broaden product offerings with greater range and mobility. The result is consistent with the conceptual frameworks of Sambamurthy et al. (2003) and Overby et al. (2006). They propose that IT competences can help firms generate digital options, which in turn enable agility. In this study, we similarly identify IOS integration as a digital option generator and empirically demonstrate its effect on supporting the generation of operational options, leading to manufacturer agility. Although we do not find support for the moderating role of IOS integration on the relationship between relationship flexibility and operational flexibility (H3b), both the direct effects of IOS integration and relationship flexibility on operational flexibility are strongly supported (H3a and H2). Thus, both relationship flexibility and IOS integration are important ingredients in building operational flexibility. This result may also reflect what TOC called submodularity (also called sub-additive cost synergies), which suggests that the use of common resources across multiple units can create sub-additive cost synergies; coordinated investments in common resources would yield lower costs than uncoordinated investments (Lee et al., 2010; Tanriverdi, 2006). Accordingly, IOS integration and relationship flexibility, as the common resources and options of dyadic firms, can generate independent positive effects on operational flexibility (Tanriverdi, 2006). Finally, we find strong support for the association between IOS integration and IOS-enabled analytic ability (H3c). This reveals that rich data flow through IOS integration can provide the needed data for analytical tools and thereby enhance analytic ability. Overall, *IOS integration is instrumental in facilitating inter-firm operation-oriented flexibility through option and analytical mechanisms.*

Although the literature has shown that IT is an important driver of organizational agility and supply chain agility (Braunscheidel and Suresh, 2009; Fayezi et al., 2016; Lee et al., 2015; Lu and Ramamurthy, 2011; Ngai et al., 2011; Park et al., 2017; Swafford et al., 2008; Tallon and Pinsonneault, 2011), this research can add granularity to these findings and extend our understanding of the effects of inter-firm IT on MSF and manufacturer agility. We examined how IOS integration, a specific IT artefact, can support trading partners' operational capacity (H3a) and manufacturer agility. We also tested an indirect effect of IOS integration on manufacturer agility through operational flexibility. We first tested the total direct effect of IOS integration on manufacturer agility, and the result shows significance of the effect (path coefficient = 0.383; $p < 0.01$). We then tested the research model with an additional direct path from IOS integration to manufacturer agility, but the effect failed to be significant (path coefficient = −0.004; $p > 0.5$). We also found f^2 approaching 0 (R^2 for included model = 68.5% and R^2 for excluded model = 68.5%). These test results suggest that operational flexibility fully mediates the relationship between IOS integration and manufacturer agility in our model. We finally conducted the percentile bootstrap approach to test the indirect effect (Hayes et al., 2011), indicating the significant indirect effect at $p < 0.001$ level with 10,000 bootstraps (Sobel Z = 4.92; 99% CI: [0.15, 0.46]). These results suggest that *for IOS integration to enable manufacturer agility, we must first consider how well it supports inter-firm operation-oriented flexibility.*

Our result of H3b shows that the moderating effect of IOS integration on the relationship between relationship flexibility and operational flexibility is slightly negative with a coefficient of −0.078 ($p > 0.05$). While the result is not significant, we can offer possible competing arguments for H3b along the lines of the "darkside" of IT (Seo and La Paz, 2008) that might explain it. Although IOS integration can streamline and digitalize inter-firm practices and processes, it has also been known to discourage system modifications if the IT architecture is not flexible enough (Rai and Tang, 2010; Seo and La Paz, 2008; Trinh-Phuong et al., 2012). Some have argued that IOS integration indicates that dyadic firms are mutually entangled due to hard coded embedded inter-firm practices and processes, thereby reducing organizational learning and making modifications to the systems difficult (Lu and Ramamurthy, 2011; Seo and La Paz, 2008; Trinh-Phuong et al., 2012). It could also reflect resource constraints as more resources in modifications would result in less resources for implementing new add-on functionalities to expand their digitalized inter-firm practices and processes. Consequently, when the dyadic firms exercise relationship options to satisfy the changed demands in their inter-firm practices and processes, IOS integration may impede such changes, possibly offsetting the positive moderating effect or even resulting in a negative net moderating effect.

We conducted some post-hoc analyses to explore this issue further. According to TOC, IOS integration and relationship flexibility may reflect the so-called supermodularity (also called super-additive value synergies) if we adopt a different modelling approach (Tanriverdi, 2006). This approach can demonstrate the complementary effect between IOS integration and relationship flexibility on operational flexibility. Accordingly, we followed Tanriverdi (2006) and Tanriverdi and Venkatraman (2005) and used a two-dimensional second-order reflective construct to reflect the complementarity between IOS integration and relationship flexibility. We applied the procedures suggested by Hair et al. (2017c) to examine the effect of the second-order construct on operational flexibility. The results show that the second-order construct loadings are 0.471 ($p < 0.001$) for relationship flexibility and 0.967 ($p < 0.001$) for IOS integration; the values of AVE and CR for the second-order construct are 0.58 and 0.71 respectively; the path coefficient from the second-order construct to operational flexibility is 0.543 ($p < 0.001$); the values of R^2 are 22.2% for relationship flexibility, 93.5% for IOS integration, and 33.5% for operational flexibility. These results thus corroborate the complementarity modelling approach suggested by Tanriverdi (2006) and Tanriverdi and Venkatraman (2005). The result may not suggest a specific moderation direction (although the moderating modelling approach does not consider direction either) but the fit between IOS integration and relationship flexibility indeed can have positive effect on operational flexibility. These results suggest that *coordinated investments in relationship flexibility and IOS integration can generate supermodular returns on improving operational flexibility. However, firms should still be aware of the possible rigidity impacts of IOS, particularly when determining architectures of IOS and implementing new add-on functionalities.*

Finally, we find IOS-enabled analytic ability positively moderates the link between operational flexibility and manufacturer agility (H4). This finding suggests that using analytical tools to monitor and analyze inter-firm operations and extract patterns of customer and market information can provide directions for managers of manufacturing firms to better utilize their inter-firm operational capacity so as to allow the firms to respond to the market more rapidly and effectively. Accordingly, our results demonstrate *the ability of business analytics in enabling the managers of manufacturing firms to effectively exercise inter-firm operational options at the right time, thus achieving greater agility.*

Discussion

Implications for research

From a theoretical perspective, our research applies ROT in the inter-firm context, which offers a new perspective for explaining the association between inter-firm flexibility and firm's agility, as most prior studies have been largely based on the resource-based view (Braunscheidel and Suresh, 2009; Swafford et al., 2006, 2008). Specifically, we first develop our flexibility and agility constructs. The related concepts have been proposed in the field of production and operation management. Past studies in this field tend to develop these concepts with a production paradigm (or approach) and advocate various practices for supporting inter-firm (or supply chain) flexibility and agility (Agarwal et al., 2007; Christopher, 2000; Christopher and Towill, 2001; Christopher and Towill, 2000; Fayezi et al., 2016; Lummus et al., 2003; Yusuf et al., 2004; Yusuf et al., 1999). This approach, however, often lacks a clear distinction between flexibility and agility, making the studied constructs and cause-effect relationships ambiguous. In this study, we conceptualize flexibility at the inter-firm level with agility at the firm level, as it is the downstream partner firm who faces and responds to its markets. We however recognize the critical role of upstream suppliers in facilitating inter-firm flexibility and thereby enabling the downstream agility. We further theorize such a relationship based on ROT. We argue that flexibility reflects the capacity to change status within a pre-established range with mobility. The pre-establish range is developed by the investments of a variety of options available for doing things differently. By utilizing these options rapidly, manufacturing firms can meet changing demands, achieving agility. Our approach may mitigate the conceptual ambiguity associated with flexibility and agility and therefore contributes a different perspective to the literature.

Trigeorgis and Reuer (2017) reviewed the past studies of ROT in strategic management research and called for more studies to extend ROT to other organizational forms, such as partnerships, broadening the applications of ROT in research. They suggest that while early real options applications focused more on competitive strategy, future research could focus more on cooperative strategy. In line with these calls, this study extends real options applications from the firm context to an inter-firm context. The options related to relationship and operation are invested and held by a manufacturer and its key supplier, and they need to cooperate with each other to execute the options efficiently in order to achieve agility. This provides a new, cooperative perspective to ROT.

Moreover, in the IS literature, researchers have proposed that IT creates digital options for firms, allowing them to respond effectively to changing environments (Overby et al., 2006; Ravichandran, 2018; Sambamurthy et al., 2003). The core idea is that IT plays a central role in creating options for a series of chain reactions approaching agility. This study focuses more on the inter-firm context and proposes that the investment in IOS integration can generate digital options by possibly digitalizing dyadic firms' intra- and inter-firm work practices and manufacturing processes. Through a higher level of inter-firm operational flexibility, IOS integration can eventually lead to agility of the firm. In fact, such a perspective extends that of Sambamurthy et al. (2003); they argue that IT investments are option investments that directly generate digital options, reflected in process reach and richness. Our perspective, in the inter-firm context, proposes that dyadic firms need to first invest certain resources in building flexible inter-firm work practices and processes that can render certain operational flexibility. The investments in IOS integration by digitalizing existing practices and processes can serve as a generator or platform of new digital options that further enlarge inter-firm operational capacities and achieve greater inter-firm operational flexibility.

The study holds relationship flexibility and operational flexibility as the two critical foundations of the manufacturer's agility and identifies IOS integration and IOS-enabled analytic ability as their important drivers. Although prior research has indicated the important roles of IT in achieving organizational agility and supply chain agility, empirical examination on this issue remains limited (Agarwal et al., 2007; Braunscheidel and Suresh, 2009; Christopher, 2000; Christopher and Towill, 2001; Fayezi et al., 2016; Swafford et al., 2006, 2008; Trinh-Phuong et al., 2012). Whether specific inter-firm IT artefacts enable inter-firm flexibility and organizational agility still deserves further study (Lu and Ramamurthy, 2011; Tallon and Pinsonneault, 2011). This study empirically demonstrates that IOS integration can help manufacturers to achieve greater agility through operational flexibility. The study thus contributes to the IS literature by providing evidence that supports the enabling role of specific inter-firm IT on inter-firm flexibility and then organizational agility in the manufacturer-supplier context. Future research can explore how other specific inter-firm IT artefacts complement with other inter-firm organizational and managerial factors to enhance firm agility.

Although IOS integration plays a critical role in facilitating operational flexibility and then manufacturer agility, we cannot neglect the possible effect of relationship flexibility. Building up operational flexibility can come from both IOS integration and relationship flexibility and, more importantly, their possible complementarity. While many studies in IS field focus more on the role of IT artefact in enabling flexibility and agility (Felipe et al., 2016; Lee et al., 2015; Lu and Ramamurthy, 2011; Sambamurthy et al., 2003; Tallon and Pinsonneault, 2011), our study suggests that firms cannot abandon other possible competences and capacities for developing real options, especially those relationship related capacities. Future research can explore the possible effects of interaction between inter-firm IT artefacts and other competences on enabling flexibility and agility.

Finally, we show that IOS-enabled analytic ability is a key catalyst for making operational flexibility more effective in achieving manufacturer agility. Our results thus suggest that when integrated dyadic firms have high operational flexibility, business intelligence tools or business analytics can enable the manufacturer to be more responsive to market changes. This result provides a very important new insight, as most prior studies ignore the potential catalyst role of IT in the relationship between flexibility and agility (Braunscheidel and Suresh, 2009; Christopher, 2000; Christopher and Towill, 2001; Ngai et al., 2011; Swafford et al., 2006, 2008). A recent study also proposes that business analytics is a critical enabler for performance (Trkman et al., 2010). We however propose that business analytics play a facilitating role in providing quality information for decision-making (Park et al., 2017; Popovič et al., 2012), which enhances the value of flexibility, rather than a direct role that brings desirable outcomes. Overall, we suggest that business analytics can be a useful tool in supply chain management, but its effect may remain limited if existing operational capacity is not well built.

Implications for practice

From a practical perspective, our findings suggest that manufacturer agility can be facilitated through inter-firm operational flexibility prompted by relationship flexibility. Manufacturing firms and their suppliers would need to jointly invest resources in expanding operational capacity, while keeping their relationships flexible. Establishing IOS integration with suppliers enables real-time information sharing and efficient operations, reducing the time and cost of adapting inter-firm operations, wherein the information provided by analytic tools plays an enhancing role in providing product or service offerings flexibly to meet the market demands. IOS-enabled analytic ability is particularly useful for enhancing manufacturer agility when complemented with inter-firm operational flexibility. In practice, system vendors, such as SAP, have released various analytical tools as add-ons to the supply chain management system. Implementing those tools can help firms achieve greater agility when their operations with supply chain partners are sufficiently flexible. However, while we limited our assessment of analytical ability to tools, it is important to have personnel who are familiar with the tools and also have sufficient business knowledge to allow the firms to take full advantage of the business analytics.

Further, as suggested in the literature, IOS may in fact be an inhibitor of flexibility or agility (Gallagher and Worrell, 2008; Lu and Ramamurthy, 2011; van Oosterhout et al., 2006). For example, Allen and Boynton (1991) indicate that IS can be inflexible and thus be disablers of flexibility, and Rettig (2007) argues that enterprise systems may produce rigidity and unexpected barriers to change. Thus, although we suggest that IOS integration is critical to flexibility and agility association, our arguments are based on rich dyadic information flow and mutual commitment despite possible lock-in effects. Managers should still be aware of the functionality of IOS and any possible rigidity impacts of IOS (Seo and La Paz, 2008), particularly when determining architectures of IOS and implementing add-on functionalities in order to meet emerging needs.

Finally, firms may rely on market mechanisms and have multiple suppliers with short-term relationships in order to keep the manufacturer-supplier relationship flexible (Gosling et al., 2010; Young-Ybarra and Wiersema, 1999), and possibly increase exit flexibility (Young-Ybarra and Wiersema, 1999). This approach, however, may compromise inter-firm governance, incur higher transaction costs, and encourage supplier opportunism (Clemons et al., 1993; Williamson, 1981, 1985). Thus, maintaining flexible relationships with specific suppliers may be a good, low cost alternative for achieving inter-firm operational flexibility and thereby agility (Dyer and Singh, 1998; Fayezi et al., 2016), particularly when the partners remain capable of supplying needed products or services and are willing to continuously adjust with specific investments. Further, the enablement of manufacturer agility inevitably requires support from suppliers. Without accumulated relational assets (Dyer and Singh, 1998), new suppliers may be unable to support the firm with sufficient flexibility, speed and quality, which are critical for the manufacturer (Yusuf et al., 1999). New suppliers may also lack controllability that is essential for flexible inter-firm operations (De Leeuw and Volberda, 1996; Volberda, 1996).

Limitations

We should note that this study has several limitations. First, we have proposed the research constructs and arguments based on the dyadic relationships but we collected data only from the perspective of the manufacturers. We however asked the respondents to focus on the relationship with one key supplier when answering our survey. Future studies may collect data from both sides of a dyadic-relationship to further investigate our model. Further, we asked the respondents to focus on single supplier because our research constructs, such as IOS integration, relationship flexibility, and operational flexibility are likely to depend on individual relationships. Focusing on the dyad as our unit of analysis reduces the measurement difficulty while serving our research objectives but may still compromise generalizability. Future research may attempt to tackle this problem. Second, we used cross-sectional data to assess our model. Although the proposed research hypotheses were derived theoretically, the results still reflect associations rather than causality. Third, this study relies on perceptual measures, which may not accurately reflect the true relationships among the theoretical constructs we examined. But, because managers largely make their decisions and actions based on their perceptions, such a limitation may not be so severe after all. Fourth, the response rate of the survey appears low. This should be expected as we conducted a multiple informant approach for the survey in order to reduce common method bias and obtain data from more appropriate informants. Moreover, even though the possibility of non-response bias was checked and ruled out statistically, the representativeness of the sample, and thus the generalizability of the results, could still be a limitation. Finally, the respondents were asked to select a major supplier of their choice; this may incur some selection bias. By assuming that the choices were made randomly distributed across the sample, such an effect on our results could be minimal.

Conclusion

In this study, we developed and tested a research model that links relationship flexibility, operational flexibility, IOS integration, IOS-enabled analytic ability, and manufacturer agility based on real options theory and the concept of bounded rationality. The empirical results strongly support the model and the findings provide specific actionable guidance for practitioners to enhance manufacturer agility. This study departs from prior studies on agility in several ways. First, we conceptualize and validate an outside-in approach to enabling agility. That is, manufacturing firms have to collaborate with their suppliers to develop more flexible relationships and operations for greater agility. Second, though process-oriented IT, such as IOS integration, may not affect manufacturer agility directly, it could nevertheless produce an indirect effect on agility through enhancing the flexibility of inter-firm operations. Third, by utilizing IOS-enabled analytic ability, manufacturing firms can leverage operational flexibility to achieve greater manufacturer agility. Accordingly, this study contributes to the cumulative body of theoretical and practical knowledge in this research domain in following ways. First, this study applies ROT to detail the flexibility-agility association, wherein we extend the application of ROT from the firm context to the inter-firm context and from competitive strategy to cooperative strategy, responding to the call from the proponents of ROT. Second, although IOS integration can help manufacturers and their suppliers by generating more offering options to achieve greater agility, we cannot neglect the importance of inter-firm relationships and relationship flexibility. Such an insight is important particularly in the IS field as most studies in the field focus more on the role of IT. Third, this study demonstrates the important role of analytic ability in enhancing the flexibility-agility association. This approach provides a new theoretical insight to suggest that analytic ability can support managers to mitigate their bounded rationality. Such an ability has become increasingly important in the current big data era. Finally, this study provides rich practical insights for managers to better facilitate agility, such as implementing integrated IOS with continual function expansion, making good use of data analytical tools with sufficient business knowledge, and accumulating relational assets with specific relationships. Overall, we provide an important step toward better understanding the roles of inter-firm flexibility in enabling manufacturer agility and IOS technologies in driving inter-firm flexibility.

Acknowledgements

The authors thank the editor in chief, Guy Gable, and the two reviewers for their excellent guidance that greatly improved the manuscript. This research was supported in part by the Ministry of Science and Technology in Taiwan under contract number NSC 101-2410-H-008-010-MY3 and MOST 107-2410-H-415-036.

Appendix A. Measurement items

Scale indicators	Mean	S.D.
Manufacturer agility		
For the product related to this supplier,		
we are capable of forecast market demand effectively. (MA1)	5.40	0.94
we are capable of rapidly responding to real market demand. (MA2)	5.11	1.13
we are capable of rapidly improving our customer service. (MA3)	5.27	1.06
we are capable of rapidly improving our responsiveness to changing customer needs. (MA4)	5.18	0.99
we are capable of rapidly reducing order-to-delivery cycle time. (MA5)	5.40	1.05
we are capable of rapidly performing product customization. (MA6)	5.02	1.16
we are capable of rapidly reducing manufacturing lead times. (MA7)	5.20	1.05
we are capable of rapidly reducing product development cycle time. (MA8)	5.02	1.14
we are capable of rapidly increasing the frequency of new product introductions. (MA9)	4.87	1.14
Dropped item: We are able to respond to changes in demand without overstocks or lost sales.		
Manufacturer-supplier flexibility		
<u>*Operational flexibility*</u>		
For the product related to this supplier, when needed		
we are able to efficiently change demanded product volumes in conjunction with this supplier. (OF1)	5.42	0.84
we are able to efficiently alter deliver schedules to meet customer requirement in conjunction with this supplier. (OF2)	5.44	0.97
we are able to efficiently produce different combinations of products in conjunction with this supplier. (OF3)	5.16	1.19
we are able to efficiently phase out old products and introduce new ones in conjunction with this supplier. (OF4)	4.84	1.30
<u>*Relationship flexibility*</u>		
When business environment changes, we and this supplier are able to modify the agreement rather than hold each other to the original terms. (RF1)	5.12	1.15
Flexibility in response to requests for changes is a characteristic of the relationship between us and this supplier. (RF2)	5.22	1.08
Our company and this supplier expect to be make adjustments in the ongoing relationship to cope with changing circumstances. (RF3)	5.29	1.04
IOS integration		
Data are entered only once to be retrieved by this supplier's system. (IOSI1)	3.57	2.04
Our system can access data from this supplier's system. (IOSI2)	3.61	1.97
Our system can aggregate relevant information from this supplier's databases. (IOSI3)	3.52	1.97
Our company and this supplier share databases with each other. (IOSI4)	3.06	1.79
We have successfully integrated relevant applications of our system with this supplier's applications. (IOSI5)	3.28	1.88
Our applications work seamlessly with this supplier's applications. (IOSI6)	3.43	1.91
Our applications can share real time information with this supplier's applications. (IOSI7)	3.35	1.89
We have synchronized data formats and standards with this supplier. (IOSI8)	3.64	1.92
The data formats and standards used in the systems of our firm and this supplier are based on a common standard. (IOSI9)	3.74	1.95
*Dropped item: Definitions of key data elements (*e.g., *order and part numbers) are common between ours and this supplier's system.*		
IOS-enabled analytical ability		
Our systems offer various decision making tools (such as optimization, scenario analysis, etc.) that enable us to manage our relationship with this supplier. (AA1)	4.23	1.62
Our systems offer various tools that can enable us to examine trends in the data for managing our interaction with this supplier. (AA2)	4.38	1.54
Our systems offer various statistical tools that enable us to support our interactions with this supplier. (AA3)	4.61	1.52

Appendix B. Outer model loadings and cross loadings

Loadings and cross-loadings for the measurement (outer) model

Constructs	**1**	**2**	**3**	**4**	**5**
Manufacturer agility					
MA1	**0.81**	0.57	0.50	0.24	0.22
MA2	**0.76**	0.52	0.42	0.27	0.30
MA3	**0.83**	0.64	0.49	0.41	0.31
MA4	**0.86**	0.58	0.48	0.31	0.33
MA5	**0.80**	0.63	0.49	0.24	0.16
MA6	**0.80**	0.57	0.41	0.31	0.20
MA7	**0.86**	0.57	0.48	0.27	0.17
MA8	**0.83**	0.55	0.44	0.35	0.20
MA9	**0.77**	0.50	0.39	0.38	0.20
Operational flexibility					
OF1	0.62	**0.77**	0.49	0.32	0.35
OF2	0.57	**0.87**	0.66	0.35	0.34
OF3	0.55	**0.86**	0.40	0.38	0.25
OF4	0.58	**0.81**	0.43	0.39	0.28
Relationship flexibility					
RF1	0.44	0.54	**0.92**	0.22	0.19
RF2	0.57	0.62	**0.95**	0.20	0.21

RF3	0.51	0.43	**0.80**	0.18	0.15
IOS integration					
IOSI1	0.40	0.34	0.28	**0.72**	0.18
IOSI2	0.36	0.35	0.28	**0.78**	0.22
IOSI3	0.33	0.37	0.21	**0.82**	0.27
IOSI4	0.28	0.36	0.13	**0.88**	0.35
IOSI5	0.34	0.38	0.18	**0.92**	0.37
IOSI6	0.31	0.39	0.20	**0.91**	0.38
IOSI7	0.33	0.40	0.18	**0.90**	0.41
IOSI8	0.28	0.36	0.15	**0.85**	0.36
IOSI9	0.31	0.37	0.17	**0.84**	0.31
IOS-enabled analytical ability					
AA1	0.28	0.34	0.18	0.39	**0.94**
AA2	0.25	0.33	0.19	0.33	**0.96**
AA3	0.26	0.36	0.21	0.33	**0.89**

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