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Leveraging Open-standard Interorganizational Information Systems for Process Adaptability and Alignment: An Empirical Analysis

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Leveraging Open-standard Interorganizational Information Systems for Process Adaptability and Alignment: An Empirical Analysis

GE's Comments	Responses
1. Theory: 1(a). What is significant / special about this U-shape discovery? This needs further explanation in terms of linking the logic to relevant theory(ies) in the field of Operations and Supply Chain Management.	We appreciate your comment on theoretical contribution to the Operations and Supply Chain Management (OSCM) field, which helps us to better position this study. Based on this comment, we revised this manuscript to (1) explain how the U-shaped relationship enriches OSCM literature; (2) anchor our findings to OSCM theories; (3) illustrate the importance of this study to Industry 4.0; and (4) build this study based on previous work in International Journal of Operations and Production Management. Modifications were marked in red in the updated manuscript for your reference. Firstly, we referred to a stream of OSCM research which focuses on the value creation of OSIOS. By reviewing literature, it was found that there is insufficient guidance on how to effectively deploy OSIOS to garner the most benefits (Saeed *et al.*, 2011; Liu *et al.*, 2016). Conceivably, our attempt of investigating U-shaped relationships can further enrich the existing findings which share an assumption that the performance implication of OSIOS should be linear. Our empirical finding proved the hypotheses on non-linear relationships, which indicates the existence of the optimal deployment of OSIOS that facilitates the most supply chain adaptability and alignment. Therefore, knowledge on the value creation of OSIOS can be advanced by such a non-linear finding, which helps firms to identify the appropriate level of deploying OSIOS to maximize their operational gains. Based on above, we discussed the contribution and significance of the U-shaped effects in Introduction (Section 1) as follows: *"Apart from the knowledge gap in understanding the link between OSIOS deployment and supply chain integration, previous literature does not provide sufficient guidance on how to effectively deploy OSIOS to garner the most benefits (Saeed et al., 2011; Liu et al., 2016). Past research primarily employed linear models to investigate the performance impacts of OSIOS (Bala and Venkatesh, 2007; Malhotra et al., 2007; Saldanha et al., 2013), which may not adequately capture the complexity of OSIOS deployment and thus could not accurately reflect the exact nature of the relationship between OSIOS and supply chain performance. To fully exploit the potential of OSIOS and to the greatest extent facilitate supply chain integration, it is imperative to investigate the optimized strategy of deploying OSIOS by employing nonlinear models (Liu et al., 2016). Although electronic connections can improve supply chain performance through enhancing collaboration (Croom, 2005), it might possibly erode a firm's ability to make effective decisions and induce partner opportunisms when the level of collaboration reaches extremes. This calls for a better understanding of the conditions where OSIOS may positively (or negatively) affect supply chain operations*

	(Crosno and Dahlstrom, 2008; Villena et al., 2011). Our study thus aims to reveal the nonlinear impact of OSIOS deployment by suggesting the possibility of an inverted U-shape relationship between OSIOS deployment and adaptability. When OSIOS is deployed to digitalize inter-firm activities and relationships, it will contribute to process adaptability to a certain level, but beyond which a negative relationship will appear because system complexity and information redundancy become overwhelming for firms to manage and control, resulting in reduced process adaptability." Likewise, we highlighted the contributions of the U-shaped effects in Theoretical Implications (Section 6.1): *" Secondly, despite the critical role of OSIOS in determining the extent to which an organization can attain supply chain integration, there is little understanding of how OSIOS can be deployed effectively (Saeed et al., 2011; Liu et al., 2016). In order to fill this research gap, it is imperative to go beyond linear models to identify an ideal way of deploying OSIOS for supply chain collaboration (Liu et al., 2016). Therefore, a key contributions of this research is the examination of the curvilinear effects of OSIOS internal assimilation and external diffusion on enabling process adaptability and process alignment. This facilitates the identification of the optimal level of OSIOS deployment that will most effectively manage supply chain integration. Our study found that relationship between internal assimilation and OSIOS enabled process adaptability followed an inverted U-shaped pattern. The findings ascertain that by deploying OSIOS to support key supply chain activities, the utility of OSIOS to enhance process adaptability and alignment will drop after a certain degree. This could be due to that as more functions and processes are integrated in OSIOS, the whole system will become complicated to use and difficult to learn, which reduces the flexibility of the system and thus constrain the level of process adaptability OSIOS can enable. External diffusion only showed a positive linear relationship with process adaptability, which confirms with the network externalities of OSIOS, where once there are more supply chain partners using OSIOS, the value of OSIOS increases (Zhu et al., 2006a). This supports why OSIOS such as RosettaNet needs manufacturers in the industry to buy in into the technology and co-adopt it in order to maximize the collaboration and alignment in the supply chain. "* Reference: Saeed, K. A., Malhotra, M. K. and Grover, V. (2011) "Interorganizational system characteristics and supply chain integration: an empirical assessment", Decision Sciences, 42(1), pp. 7-42.

	Liu, H., Wei, S., Ke, W., Wei, K. K. and Hua, Z. (2016) "The configuration between supply chain integration and information technology competency: A resource orchestration perspective", Journal of Operations Management, 44(Supplement C), pp. 13-29.
1(b). You claimed you have extended previous studies conducted by scholars such as Gosain et al. (2004) and Malhotra et al. (2007) (1) by showing that the relationship between OSIOS deployment and OSIOS enabled process adaptability followed an inverted U-shaped pattern; (2) by concepualizing OSIOS implementation into internal assimilation and external diffusion, enhanced the knowledge about the post-adoption stages of OSIOS; 3) empirically confirmed that OSIOS can enable companies to enjoy interfirm integration by developing adaptability to continually restructure supply chain processes and respond to external changes – These are all fine, but you need to critically explain specifically what operations and supply chain management theory(ies) you have advanced and built from these? Cross discipline to information field is fine but advances from the home field (here in O&PM) is required.	Secondly, we repositioned this study to focus on OSCM literature to illustrate theoretical contributions. Apart from the contribution of finding U-shaped relationship in the value creation of OSIOS, another key contribution of this paper is to unveil the "black box" between OSIOS deployment and supply chain integration. It seems to be intuitive that OSOIS have the potential to promote integration and alignment in supply chains. However, this statement is challenged by inconsistent results of OSIOS deployment reported in the industry. There is a lack of research on the relationship between OSIOS deployment and supply chain integration in OSCM literature. To address this knowledge gap, our paper emphasizes that the key is to exploit the "plug-and-play" competency of OSIOS to generate process adaptability such that companies can reconfigure their IT resources and business processes. Process adaptability is identified as an intermediate value creation mechanism between OSIOS deployment and process alignment, which enhances the understanding of how to achieve an integrated supply chain. In addition, the current study provides OSCM literature with the insight on two different technology deployment focuses by distinguishing internal assimilation and external diffusion. This endeavor addresses the current research gap in OSCM literature where most studies neglected the difference between internal focus and external focus while using technologies to facilitate supply chain management, thereby generating insightful views on the value creation of technologies (Zhang *et al.*, 2011). The differentiation between internal assimilation and external diffusion can provide more nuanced understanding of the relationship between OSIOS and supply chain integration. To summarize, three key contributions of this paper to OSCM literature are concluded in Introduction: *"Our study contributes to extant literature on operations management and particularly towards the research of Industry 4.0 on three fronts: 1) we contribute to the research stream of supply chain integration by showing that process alignment can be enhanced by OSIOS through improving process adaptability to continuously adjust to external changes; 2) we advance the understanding of how to use OSIOS to generate the most benefits for supply*

	chain operations by exploring the U-shaped relationship between OSIOS deployment and process adaptability; 3) by categorizing OSIOS deployment into internal assimilation and external diffusion, we provide a nuanced lineation of the relationship between OSIOS deployment and process adaptability. " Reference: Zhang, X., Pieter van Donk, D. and van der Vaart, T. (2011) "Does ICT influence supply chain management and performance? A review of survey-based research", International Journal of Operations & Production Management, 31(11), pp. 1215-1247.
1(c). In addition, why this is so important for Industry 4.0 needs further discussion.	Thirdly, we reflected on the context of Industry 4.0 and elaborated the importance of this study in advancing the ongoing discussion of Industry 4.0. As illustrated in Introduction, one of the key challenges for companies to achieve Industry 4.0 is the difficulty to realize the goal of developing a "virtual single factory". In a virtual single factory, companies can vertically integrate their supply chain partners' systems to share information with each other. Therefore, the premise of Industry 4.0 is to develop integrated supply chains based on advanced technologies. However, it has always been challenging to achieve supply chain integration considering that most companies have undergone slow, struggling experiences, or even failures in this process. OSIOS have been widely recognized to have the potential to transform the concept of virtual single factory into reality because of the ability to help supply chain network partners achieve automation and decentralization of business processes. However, whether and to which extent OSIOS can facilitate the vision of Industry 4.0 remain to be settled. It is argued by some researchers that implementing OSIOS is too challenging because the current implementation roadmap and strategies are too simplistic, and the cost of OSIOS bears little return on investment. Investigating the value creation mechanisms of OSIOS thus is critical to enhance the understanding of how to facilitate the development of Industry 4.0 by implementing OSIOS. We illustrated our logic in Introduction: *"Industry 4.0 aims to address traditional manufacturers' supply chain deficiencies that have resulted in high costs and poor quality of product and service. One of the pillars to achieve Industry 4.0 is the interoperability and transparency of data which enables manufacturers to achieve supply chain integration, exchange timely and accurate data, and automate supply chains and smart factories (Lasi et al., 2014). Despite the recent advent in computing and in particular internet technologies, achieving Industry 4.0 is still some way off because of reported challenges faced by manufacturers (Gold, 2018). Notable among these challenges is the ability for*

	manufacturers to implement the concept of a "virtual single factory" that vertically integrates supply chain partners' systems to share information with each other (Kobusch, 2015). Despite the importance of supply chain integration for achieving Industry 4.0, organizations have undergone slow, struggling experiences, or even failures to develop an integrated supply chain (Mustafa Kamal and Irani, 2014; Vanpoucke et al., 2017). To transform the concept of virtual single factory into reality, open-standard inter-organizational information systems (OSIOS) have attracted increasing attention from both scholars and practitioners (Sodero et al., 2013)."
1(d). Although previous work such as in Journal of Operations Management, MISQ etc. have been referenced, it will be important to also build on the previous work in International Journal of Operations and Production Management.	Last but not least, we revised some arguments in the manuscript to make them derive from previous work in the International Journal of Operations & Production Management. Herein we provided some of the new liteature we used to support arguments: • Vanpoucke, E., Vereecke, A. and Muylle, S. (2017) "Leveraging the impact of supply chain integration through information technology", International Journal of Operations & Production Management, 37(4), pp. 510-530. • Zhang, X., Van Donk, D. P. and van der Vaart, T. (2016) "The different impact of inter-organizational and intra-organizational ICT on supply chain performance", International Journal of Operations & Production Management, 36(7), pp. 803-824. • Zhang, X., Pieter van Donk, D. and van der Vaart, T. (2011) "Does ICT influence supply chain management and performance? A review of survey-based research", International Journal of Operations & Production Management, 31(11), pp. 1215-1247. • Stevenson, M. and Spring, M. (2007) "Flexibility from a supply chain perspective: definition and review", International Journal of Operations & Production Management, 27(7), pp. 685-713. • Croom, S. R. (2005) "The impact of e-business on supply chain management: An empirical study of key developments", International Journal of Operations & Production Management, 25(1), pp. 55-73.
2. Comparison and examples: 2(a). The idea of open standards as suggested in OSIOS is interesting and well structured. However to what extent is OSIOS compared to other open (e.g. international) standards for Industry 4.0 for supply chain management? This needs further discussion including	Thank you for this valuable comment for improving our manuscript. We agree that more illustrative comparisons and examples can enhance the readability and clarity of this manuscript. Following your suggestion, we began with specifying the mechanisms of OSIOS based on the knowledge in OSCM field. Particularly, we highlighted the importance of OSIOS for supply chain management by interpreting how OSIOS facilitate digital integration and Industry 4.0. We used an example of the standards for product and engineering information and explained that these standards can support data exchanges between computer aided design (CAD) software from different vendors. OSIOS can support the interoperability among actors, sensors, and heterogeneous systems, which is an important to create Smart Factories because it can enable intelligent human-to-machine and machine-

explanation of their role in advancing / building relevant theory(ies) in the field of Operations and Supply Chain Management as well as comparison to other standards.	to-machine cooperation. In addition, the key for realizing smart manufacturing is supply chain agility. OSIOS can greatly promote agility in the supply chain by enhancing supply chain integration and flexibility. The elaboration on technical mechanisms of OSIOS and the example is incorporated in Section 2.1 as follows: *"In order to achieve digital transformation, data standardization is the key (Dallasega et al., 2018). A recent report by the U.S. National Institute of Standards and Technology (Lu et al., 2016) emphasized that standards are fundamental for achieving smart manufacturing systems. For example, standards for product and engineering information enable data exchanges between computer aided design (CAD) software from different vendors. The report also pointed out that one of the key attributes of smart manufacturing is the agility of supply chains. Such agile manufacturing relies heavily on supply chain integration and flexibility, which are enabled by interorganizational standards. Similarly, Grangel-González et al. (2017) stated that interoperability among actors, sensors, and heterogeneous systems is an important factor for realizing the Industry 4.0 vision, i.e., the creation of Smart Factories by enabling intelligent human-to-machine and machine-to-machine cooperation. In order to empower interoperability in Smart Factories, standards and reference architectures have been proposed by various organizations. Among these, OSIOS is an exemplary technology for enabling the modularized interoperability between supply chain partners (Bala and Venkatesh, 2007; Rai and Tang, 2010). "* We also made comparison to explain the uniqueness of OSIOS and its importance to Industry 4.0. Different from previously proprietary standards such as EDI, OSIOS represent open standards in general. We compared OSIOS with EDI which is traditional technological standard used to integrate supply chain processes. OSIOS define the content and structure of the information exchanged using a common agreed language. This is the key advantage of OSIOS over EDI because EDI only allows for one-to-one data exchange requiring customized interfaces. This quasi-open, multilateral nature of OSIOS can greatly facilitate the alignment of international standards and the harmonization of multi-platforms, which is vital for realizing smart manufacturing. Details of this comparison can be found in Section 2.1: *"Similar to information systems based on proprietary standards such as EDI, OSIOS enables the digital exchange of structured information between firms (Chong and Ooi, 2008). However, the key difference between EDI and OSIOS is that the latter defines the structure and content of e-exchanges based on a common agreed language. While EDI allows only for a*

	customized one-to-one exchange of information, the quasi-open, multilateral nature of OSIOS (e.g., open source development and access) allows for the alignment of international standards (Malhotra et al., 2007), which is the key to harmonize multi-platform transactions for realizing smart manufacturing."
2(b). For instance, does open standards in OSIOS address information security or enhance information asymmetry to harmonise multi-platform transactions required for Industry 4.0? If so, how? If not, why not? Give specific examples, like smart manufacturing or smart supply chain.	In this revised manuscript, we gave a specific example of RosettaNet, the OSIOS used my manufacturers, to interpret the role of OSIOS in Industry 4.0. Specifically, the technical properties of RosettaNet was described in details to demonstrate why and how OSIOS can support multi-planforms transactions and smart manufacturing. RosettaNet consists of three technical components which are PIP, RNIF and RosettaNet business and technical dictionaries. Each component defines and specifies business process choreography, data transfer, routing and security protocols, and information semantics, respectively. These components work together to support inter-organizational information transmission, business process integration, and automation of supply chain activities. Details on RosettaNet can be found in Section 2.1: *"An example of open standards would be RosettaNet which consists of three core components including the Partner Interface Processes (PIP), the RosettaNet implementation framework (RNIF), and the RosettaNet business and technical dictionaries. In a smart manufacturing environment involving different organizations and platforms, transactions will be conducted through a PIP connection. A PIP is a specialized system-to-system XML-based dialog that depicts the activities, decisions and interactions to fulfill business transactions among supply chain partners (Chong and Ooi, 2008). Each PIP specification contains a business document template and a diagram of the business process (Malakooty, 2005). The standardized PIP messages are then sent to the trading partners via network connections. In the meanwhile, the RNIF provides the exchange protocols for implementing RosettaNet standards such as the security, transfer and routing information. Once again, trading partners' transactions are harmonized through these standardized exchange protocols. The RosettaNet dictionaries specify the common vocabularies and semantics for conducting transactions, and therefore eliminates confusions that may occur in the trading process due to the idiosyncratic terminology by each organization (Chong and Ooi, 2008)."*

Leveraging Open-standard Interorganizational Information Systems for Process Adaptability and Alignment: An Empirical Analysis

Abstract

Purpose: This study aims to understand the value creation mechanisms of open-standard inter-organizational information systems (OSIOS), which is a key technology to achieve Industry 4.0. Specifically, this study investigates how the internal assimilation and external diffusion of OSIOS help manufactures facilitate process adaptability and alignment in supply chain network.

Design/methodology/approach: A survey instrument was designed and administrated to collect data for this research. Using three-stage least squares (3SLS) estimation, we empirically tested a number of hypothesized relationships based on a sample of 308 manufacturing firms in China.

Findings: Our results show that OSIOS can perform as value creation mechanisms to enable process adaptability and alignment. In addition, the impact of OSIOS internal assimilation is inversely U-shaped where the positive effect on process adaptability will become negative after an extremum point is reached.

Originality/value: This study contributes to existing literature by providing insights on how OSIOS can improve supply chain integration and thus to promote the achievement of industry 4.0. By revealing a U-shaped relationship between OSIOS assimilation and process adaptability, this study fills previous research gap by advancing the understanding on the value creation mechanisms of information systems deployment.

Keywords: inter-organizational information systems, open standards, Industry 4.0, supply chain integration, process adaptability

1 Introduction

The rapid growth and development in digital have provided great opportunities to evolve traditional businesses and industries. While most of the attention has been paid on the transformation of the digital economy, many of these advanced technologies are also re-shaping traditional manufacturers. Driven by the aforementioned new technologies, many have viewed the next phase of industry development to have higher levels of operational efficiency and productivity due to supply chain integration and automation (Lu, 2017). This new phase of industry development is coined as Industry 4.0, and is characterized by 1) digitization, optimization and production customization, 2) automation and adaptation, 3) human machine interaction, 4) value-added services and businesses, and 5) autonomous data exchange and communication (Posada *et al.*, 2015; Roblek *et al.*, 2016).

Industry 4.0 aims to address traditional manufacturers' supply chain deficiencies that have resulted in high costs and poor quality of product and service. One of the pillars to achieve Industry 4.0 is the interoperability and transparency of data which enables manufacturers to achieve supply chain integration, exchange timely and accurate data, and automate supply chains and smart factories (Lasi *et al.*, 2014). Despite the recent advent in computing and in particular internet technologies, achieving Industry 4.0 is still some way off because of reported challenges faced by manufacturers (Gold, 2018). Notable among these challenges is the ability for manufacturers to implement the concept of a "virtual single factory" that vertically integrates supply chain partners' systems to share information with each other (Kobusch, 2015). Despite the importance of supply chain integration for achieving Industry 4.0, organizations have undergone slow, struggling experiences, or even failures to develop an integrated supply chain (Mustafa Kamal and Irani, 2014; Vanpoucke *et al.*, 2017). To transform the concept of virtual single factory into reality, open-standard inter-organizational information systems (OSIOS) is attracting attentions from both scholars and practitioners (Sodero *et al.*, 2013). OSIOS refers to the kind of inter-organizational systems that use open standards which are the technical specifications to support, automate and coordinate the "interrelated, sequential tasks" such as inventory management, product development, and logistics (Bala and Venkatesh, 2007). These open standards are typically developed and approved by consortia of firms based on the negotiation, communication and coordination among the participants (Zhu *et al.*, 2006a), and are freely available for all potential adopters. Being used to create, sustain and develop inter-organizational relationships (Hagel and Brown, 2005), OSIOS provides the electronic enablement of extended enterprise by synchronizing and integrating inter-organizational relationships and processes (Dyer, 1997; Dyer and Singh, 1998).

Despite the optimistic attitude towards OSIOS in helping to achieve Industry 4.0, it remains an unsettled question that to which extent can supply chain integration be improved through deploying OSIOS. In the field of operations management, a large body of studies have made efforts to understand the factors facilitating OSIOS deployment (e.g., Nurmilaakso, 2008; Chong *et al.*, 2009; Liu *et al.*, 2010; Chan *et al.*, 2012; Sodero *et al.*, 2013). In these studies, they share a common assumption that OSIOS deployment will improve supply chain integration with very little chalenges. However, contradictory findings on the influence of OSIOS deployment have been reported (Saeed *et al.*, 2011), which suggests that the value creation mechanism of OSIOS requires careful studies driven by relevant theories in operations management. To unveil the "black box" between OSIOS deployment and supply chain integration (Liu *et al.*, 2016), our paper proposes that the key is to exploit the "plug-and-play" competency of OSIOS to generate process adaptability such that companies can reconfigure their IT resources and business processes (Gosain *et al.*, 2004; Rai and Tang, 2010). In volatile market environments, companies need to continuously restructure their supply chain procedures, processes, activities, and inter-organizational relationships to adapt to external changes. OSIOS permits the flexibility to tune the parameters related to business processes, which produces process adaptability to prevent existing business processes from being too rigid or even obsolete by dynamically adjusting and restructuring supply chain patterns (Gosain *et al.*, 2004; Malhotra *et al.*, 2007). Thus, companies can continually facilitate the coordination and joint optimization of activities with supply chain partners, making it possible to exploit process alignment. Therefore, although adaptability *per se* does not directly generate relational or operational value for companies (Saraf *et al.*, 2007), it serves as an intermediate value creation mechanism between OSIOS deployment and process alignment. To establish and test the important role of process adaptability in connecting OSIOS deployment and process alignment, our study will fill in the current knowledge gap in the operations management literature by enhancing the understanding of how to achieve an integrated supply chain.

Apart from the knowledge gap in understanding the link between OSIOS deployment and supply chain integration, previous literature does not provide sufficient guidance on how to effectively deploy OSIOS to garner the most benefits (Saeed *et al.*, 2011; Liu *et al.*, 2016). Past research primarily employed linear models to investigate the performance impacts of OSIOS (Bala and Venkatesh, 2007; Malhotra *et al.*, 2007;

Saldanha *et al.*, 2013), which may not adequately capture the complexity of OSIOS deployment and thus could not accurately reflect the exact nature of the relationship between OSIOS and supply chain performance. To fully exploit the potential of OSIOS and to the greatest extent facilitate supply chain integration, it is imperative to investigate the optimized strategy of deploying OSIOS by employing nonlinear models (Liu *et al.*, 2016). Although electronic connections can improve supply chain performance through enhancing collaboration (Croom, 2005), it might possibly erode a firm's ability to make effective decisions and induce partner opportunisms when the level of collaboration reaches extremes. This calls for a better understanding of the conditions where OSIOS may positively (or negatively) affect supply chain operations (Crosno and Dahlstrom, 2008; Villena *et al.*, 2011). Our study thus aims to reveal the nonlinear impact of OSIOS deployment by suggesting the possibility of an inverted U-shape relationship between OSIOS deployment and adaptability. When OSIOS is deployed to digitalize inter-firm activities and relationships, it will contribute to process adaptability to a certain level, but beyond which a negative relationship will appear because system complexity and information redundancy become overwhelming for firms to manage and control, resulting in reduced process adaptability.

Furthermore, OSIOS deployment requires a firm to make strategic decisions to determine how to assimilate OSIOS solutions internally across their supply chain activities and also, at the same time, diffuse them externally among the partners in the supply chain networks (Ranganathan *et al.*, 2004). However, scholars have pointed out that most studies neglected the differences between the use of technology for internal and external activities, thereby generating confounding results on this topic (Zhang *et al.*, 2011). To address this research gap, we distinguish internal assimilation and external diffusion as two focuses of technology use. *Internal assimilation* is defined as the extent to which OSIOS and related technological solutions have been deployed in the key supply activities to support inter-organizational relationships. *External diffusion* refers to the degree to which OSIOS and related technological solutions have been utilized to integrate supply chain partners and to conduct inter-firm transactions (Ranganathan *et al.*, 2004; Zhang and Dhaliwal, 2009). After implementation, a technology will be deployed to support organizational routines and activities as well as the exchange of knowledge and technology across organizational boundaries. Internal assimilation and external diffusion, therefore, work together to contribute to the infusion stage of the overall diffusion process for a typical OSIOS technology (Premkumar *et al.*, 1994; Ramamurthy and Premkumar, 1995). This research therefore attempts to answer the following research question: *How can the internal assimilation and external diffusion of OSIOS create values for manufacturers in achieving process adaptability and process alignment?*

Our study contributes to extant literature on operations management and particularly towards the research of Industry 4.0 on three fronts: 1) we contribute to the research stream of supply chain integration by showing that process alignment can be enhanced by OSIOS through improving process adaptability to continuously adjust to external changes; 2) we advance the understanding of how to use OSIOS to generate the most benefits for supply chain operations by exploring the U-shaped relationship between OSIOS deployment and process adaptability; 3) by categorizing OSIOS deployment into internal assimilation and external diffusion, we provide a nuanced lineation of the relationship between OSIOS deployment and process adaptability.

2 Research and Theoretical Background

2.1 Industry 4.0 and OSIOS

The 4th industrial revolution – Industry 4.0 – promotes changes in production systems and networks through IT advancement beyond industrial automation, so as to achieve greater potentials and values in operations management (Lasi *et al.*, 2014). In this new paradigm shift, digitalization is the key, fundamental requirement, and will be achieved through integrating internet technologies (incorporated with artificial intelligence, such as machine learning capability) and relevant objects (e.g., machines, products and humans) with associated production processes (Marr, 2016).

In order to achieve digital transformation, data standardization is the key (Dallasega *et al.*, 2018). A recent report by the U.S. National Institute of Standards and Technology (Lu *et al.*, 2016) emphasized that standards are fundamental for achieving smart manufacturing systems. For example, standards for product and engineering information enable data exchanges between computer aided design (CAD) software from different vendors. The report also pointed out that one of the key attributes of smart manufacturing is the agility of supply chains. Such agile manufacturing relies heavily on supply chain integration and flexibility, which are enabled by interorganizational standards. Similarly, Grangel-González *et al.* (2017) stated that interoperability among actors, sensors, and heterogeneous systems is an important factor for realizing the Industry 4.0 vision, i.e., the creation of Smart Factories by enabling intelligent human-to-machine and machine-to-machine cooperation. In order to empower interoperability in Smart Factories, standards and reference architectures have been proposed by various organizations. Among these, OSIOS is an exemplary technology for enabling the modularized interoperability between supply chain partners (Bala and Venkatesh, 2007; Rai and Tang, 2010).

Similar to information systems based on proprietary standards such as Electronic Data Interchange (EDI), OSIOS enables the digital exchange of structured information between firms (Chong and Ooi, 2008). However, the key difference between EDI and OSIOS is that the latter defines the structure and content of e-exchanges based on a common agreed language. While EDI allows only for a customized one-to-one exchange of information, the quasi-open, multilateral nature of OSIOS (e.g., open source development and access) allows for the alignment of international standards (Malhotra *et al.*, 2007), which is the key to harmonize multi-platform transactions for realizing smart manufacturing. An example of open standards would be RosettaNet which consists of three core components including the Partner Interface Processes (PIP), the RosettaNet implementation framework (RNIF), and the RosettaNet business and technical dictionaries. In a smart manufacturing environment involving different organizations and platforms, transactions will be conducted through a PIP connection. A PIP is a specialized system-to-system XML-based dialog that depicts the activities, decisions and interactions to fulfill business transactions among supply chain partners (Chong and Ooi, 2008). Each PIP specification contains a business document template and a diagram of the business process (Malakooty, 2005). The standardized PIP messages are then sent to the trading partners via network connections. The RNIF on the other hand provides the exchange protocols for implementing RosettaNet standards such as the security, transfer and routing information. Once again, trading partners' transactions are harmonized through these standardized exchange protocols. The RosettaNet dictionaries specify the common vocabularies and semantics for conducting transactions, and therefore eliminates confusions that may occur in the trading process due to the idiosyncratic terminology by each organization (Chong and Ooi, 2008).

Compared to the advances achieved in comprehending the technical properties of OSIOS, there is much less progress being made in recognizing the wider implications of OSIOS deployment. Due to a paucity of studies on the applications of OSIOS, researchers have debated much on the extent to which value can be appropriated from OSIOS. On one hand, there are researchers who regard OSIOS as the key technology that will pave the way for achieving Industry 4.0, centered on its ability to help supply chain network partners achieve automation and decentralization of business processes (Dallasega *et al.*, 2018). On the other hand, there are also researchers who claim that it is too challenging to implement OSIOS as the current implementation roadmap and strategies are too simplistic (Damodaran, 2005), and the cost of investing in the technology bears little return on investment (Chang and Shaw, 2009; Sodero *et al.*, 2013). To address the preceding knowledge gap, our study attempts to shed light on the value creation mechanism of internal assimilation and external diffusion of OSIOS.

2.2 Internal Assimilation and External Diffusion of OSIOS

Because OSIOS is deployed to support a wide spectrum of internal supply chain functions and cross-boundary processes, it is important to consider internal assimilation and external diffusion at the same time to provide a complete delineation of its permeation process. After a technology is adopted and adapted, it will progressively be integrated into supply chain processes to support activities and knowledge transfers within and beyond organizational boundaries (Ranganathan *et al.*, 2004). While internal assimilation concerns the intensity and scale of OSIOS assimilation, external diffusion concerns the diversity and scope of OSIOS diffusion (Zhang *et al.*, 2016a). These concepts can provide valuable insights about the post-adoption stages (Fichman, 2000), which have seldom been studied in current literature, as a majority of studies have focused on the single adoption stage, which essentially treated innovation diffusion process as a one-shot behavior (Zhu *et al.*, 2006b).

Internal assimilation refers to the extent to which the use of OSIOS permeates organizational processes and becomes routinized in the relevant activities (Chatterjee *et al.*, 2002; Ranganathan *et al.*, 2004). External diffusion refers to the extent to which OSIOS is used across organizational boundaries to integrate various trading partners (Ranganathan *et al.*, 2004; Wu and Chang, 2012). By aligning IT assets with internal and external resources, internal assimilation and external diffusion of OSIOS can fully leverage the technological value and improve and develop a firm’s capabilities (Nevo and Wade, 2010). However, the full value of OSIOS can only be leveraged when it is appropriately deployed to support internal and external processes (Zhang *et al.*, 2016a), which entails the importance to understand the risks and challenges involved in assimilation and diffusion processes to gain a more complete picture of the value creation mechanisms of OSIOS.

Although internal assimilation is the key to exploit the full business value of a technology (Liang *et al.*, 2007), very often practitioners may encounter difficulties in assimilating new technologies into their business processes, a phenomenon which is referred to as the “assimilation gap” (Fichman and Kemerer, 1999). To routinize a new technology within a firm after the initial adoption stage, a company needs to develop sufficient knowledge to leverage and adapt the technology to align it with relevant processes (Zhu *et al.*, 2006b). To bridge the assimilation gap for OSIOS will require a considerable amount of investment in the form of hardware, software, and personnel training. Moreover, relevant cross-boundary processes should be redesigned to satisfy the requirements of the new technical standards (Sodero *et al.*, 2013).

Weighing the business value and the substantial investment, the performance implication of internal assimilation of OSIOS remains undetermined.

By diffusing OSIOS to connect with supply chain partners, the focal firm can exploit network effects (Sodero *et al.*, 2013) with enhanced information processing capability and a larger knowledge base (Church and Gandal, 1992; Venkatesh and Bala, 2012). However, the diffusion process is complex, dynamic, and contingent on various technological and contextual factors, which entails a long time-lag before the full attainment of the benefits (Wu and Chang, 2012). Moreover, the widespread diffusion of technology might create inconsistency across different adopters regarding technical documents and managerial procedures due to discrepancies in understanding. Therefore, it remains challenging to conclude the influence of external diffusion of OSIOS.

Past studies investigating the outcomes of OSIOS deployment generally assume a linear relationship between them as one where increased assimilation and diffusion of OSIOS will indefinitely enhance the postulated benefits. For example, Venkatesh and Bala (2012) found that there is a negative linear relationship between OSIOS assimilation and cycle time; the study of Malhotra *et al.* (2007) suggested a positive association between OSIOS deployment and mutual adaptation. Although these studies expanded our knowledge frontier in understanding the performance outcomes of OSIOS adoption, they might have used an oversimplified lens by assuming an invariant, linear impact on a firm's capabilities and performance. This ignores the possibility of negative effects when OSIOS is assimilated or diffused to a certain level. Scholars also doubted this positive linear effect by claiming that the use of IT might hurt supply chain performance (e.g., ineffective decision-making) when a company collaborates too closely with its partners (Crosno and Dahlstrom, 2008; Villena *et al.*, 2011). Accordingly, our study proposes that to maximize the benefits enabled by OSIOS, there should be an appropriate level of OSIOS assimilation and diffusion such that an inflection point will be achieved where the users can benefit the most. Developing and testing non-linear models to study technology adoption and use has been suggested to be an important contribution to fill the research gap in current literature where over-simplified linear models have been essentially used to understand the phenomenon (Venkatesh and Goyal, 2010).

2.3 The Relational Mechanisms of OSIOS

The relational view of the firm, employing an inter-organizational theoretical lens, explains how relational resources and capabilities can form the foundation of strategic advantages (Kanter, 1994; Dyer and Singh, 1998). It is contended that a firm's critical resources will span across organizational boundaries and can be generated from inter-organizational processes and routines (Dyer and Singh, 1998). Therefore, this theoretical view extends beyond the resource-based view (RBV) which based only on a single firm's view, asserts that competitive advantages fully originate from the resources housed internally (Wernerfelt, 1984; Barney, 1991). With the evolution of inter-firm relationships from arm-length short-term transactions to collaborative partnerships over the last few decades (Corsten and Felde, 2005), increasingly, inter-organizational information systems (IOS) including OSIOS, are being used to create, sustain and develop inter-organizational relationships (Hagel and Brown, 2005). OSIOS could be the major source of competitive advantage as it is embedded in inter-organizational processes and routines to develop relational capabilities (Powell and Dent-Micallef, 1997; Bharadwaj, 2000). Therefore, following the logic of relational view, OSIOS, through promoting information sharing and inter-firm communication, can serve as an important embedding mechanism to generate relational rents that promote long-term success in supply chains (Paulraj *et al.*, 2008).

Relational rents are conceptualized as the economic rents generated from inter-organizational linkages when companies uniquely configure and combine the complementary relation-specific resources emerging from external partnerships (Dyer and Singh, 1998; Saraf *et al.*, 2007). The framework of Dyer and Singh (1998) identifies a wide range of determinants of relational rents (drivers of organizational performance), which provides the theoretical generalizability to study various inter-organizational relationships such as scientific alliances, marketing alliances, and supply chain collaborations (Malhotra *et al.*, 2005). In our study, some of the strategic determinants of relational rents such as complementary capabilities, effective governance mechanisms, partner scarcity, and institutional environment, however, are excluded because they are more relevant with joint ventures and R&D collaborations which are out of the scope of this study. In the context of digital supply chain relationships, this study will focus on relation-specific assets, knowledge exchange and joint learning, and interfirm assets interconnectedness identified by Dyer and Singh (1998) as the key sources of relational rents (Saraf *et al.*, 2007; Wang *et al.*, 2014). As a firm's core infrastructure to communicate and transact with supply chain partners, OSIOS can perform as a platform enabling the combination of these resources and to produce relational rents (Bensaou and Venkatraman, 1996; Bala and Venkatesh, 2007).

It is suggested that OSIOS could have a significant impact on an organization's process adaptability by transforming and shaping interfirm connectedness and knowledge exchanges (Malhotra *et al.*, 2007). Process adaptability connotes a firm's ability to accommodate new functions and reduce the costs associated with reconfiguring resources to support the emerging requirements to adapt supply chain activities and operational processes in inter-organizational relationships (Young-Ybarra and Wiersema, 1999; Gosain *et al.*, 2004; Rai and Tang, 2010), which can be enabled by OSIOS by developing flexible and responsive IT assets and processes. Based on modular interdependent processes, structured data connectivity and standardized interfaces (Gosain *et al.*, 2004), OSIOS allows a firm to quickly and economically adapt its IT assets to both the evolutionary and revolutionary changes in business requirements and processes (Kumar, 2004; Langdon, 2006). Users of OSIOS explicitly or implicitly agree on the common specifications at both syntactic and semantic levels, which not only improves multilateral information processing capability and knowledge exchange, but also resolves the interpretive differences in the information transmitted (Malhotra *et al.*, 2007). Supply chain partners thus can learn and adapt to the needs of each other better without the extensive coordination efforts in clarifying and conveying the uncertainty and ambiguity in the messages they send or receive (Gosain *et al.*, 2003). At the same time, the modular architecture of OSIOS allows for the disaggregation and reconfiguration of systems to accommodate new functions, which enables adaptation at system level (Rai and Tang, 2010). Therefore, the common templates and standardized interfaces of OSIOS will not constrain information diversity as the users are allowed to customize parameters to flexibly adapt to the requirements of partner-specific process (Malhotra *et al.*, 2007).

However, process adaptability *per se* does not create direct performance gains (Saraf *et al.*, 2007). Companies must develop process alignment that integrates, coordinates and jointly optimizes interfirm activities with partners (Rai and Tang, 2010). A major source of process alignment is suggested to be asset interconnectedness, which is created when supply chain partners closely link their business processes, and thereby increase relationship specificity (Dyer and Singh, 1998). Through process alignment, a focal firm can coordinate and interweave the interdependent supply chain activities with its business partners, which can ensure that business processes spanning across the supply chain network are operationally integrated (Saraf *et al.*, 2007; Rai and Tang, 2010). A company can achieve process alignment by deploying their IT assets to work as a "functional whole" with that of its partners (Saraf *et al.*, 2007, p. 324), which requires supply chain partners to resolve their differences at both the syntactic and semantic boundaries (Malhotra *et al.*, 2007). With the standardized interfaces of OSIOS, companies can quickly respond to the idiosyncrasies in the interfirm processes of their partners (Saraf *et al.*, 2007), enabling information sharing, activity coordination and process alignment (Grover and Saeed, 2007). In doing so, OSIOS provides firms with valuable bonding mechanisms that allow firms to transform from traditional weakly connected supply chains to closely aligned collaborative networks for joint success (Whipple and Russell, 2007).

3 Hypothesis Development

3.1 Curvilinear Relationships between OSIOS and Process Adaptability

Internal assimilation and external diffusion are the two underlying building blocks for the strategies to deploy OSIOS (Zhang and Dhaliwal, 2009). Internal assimilation of OSIOS provides companies with the ability to coordinate and synchronize interfirm processes (Bala and Venkatesh, 2007). When OSIOS is deployed to digitalize more supply chain processes, companies can standardize more information exchange, which can reduce the time and effort spent in interpreting and completing supply chain activities. By assimilating OSIOS with internal processes, the clarity of exchanged information is improved, which prevents information distortion and errors during information transfer (Venkatesh and Bala, 2012). This increased operational efficiency and information visibility will enhance a company's flexibility to adapt its business operations to external environments (Stevenson and Spring, 2007).

However, excessive internal assimilation of OSIOS may restrict the level of adaptability OSIOS can enable. To internally assimilate OSIOS, a company needs to spend a large amount of resources and make substantial adjustments to its supply chain processes (Venkatesh and Bala, 2012). Therefore, over-assimilation of OSIOS may present a major disruption in a company's existing processes that are already embedded in its operational routines (Porter, 2001), which will increase the difficulty to control interfirm processes, reducing a firm's ability to reconfigure current supply chain activities and adapt to the external environment. In addition, OSIOS may not be compatible with a firm's existing IT infrastructure, which requires specialized IT investment and personnel to support the operations of OSIOS (Gosain *et al.*, 2003). When OSIOS is deployed to complement too many supply chain activities, it will become increasingly challenging for a company to develop an adequate IT capability to maintain the systems and to adapt the systems and functions to the changing requirements. The discussion leads to the following hypothesis:

> *H1: An inverted U-shaped relationship exists between OSIOS internal assimilation and the level of process adaptability enabled by OSIOS, such that internal assimilation improves process adaptability at first and impedes process adaptability after reaching a certain level.*

When OSIOS is externally diffused to connect more partners, the users can exploit network effects that may expand the scope and range of information exchanged (Zhu *et al.*, 2006a). The more the partners are connected in the OSIOS network, the more diverse the knowledge a company can access and integrate, through which a company can absorb knowledge to enhance adaptability (Malhotra *et al.*, 2005). To adapt to the changes in the external environment, a company should develop knowledge of the environment, understand and improve their existing capabilities and skills, and restructure relevant business processes to build new capabilities. External diffusion of OSIOS generates a rich knowledge base by accessing diverse external knowledge sources, which enables companies to receive and respond to signals in the market, and adapt to the changes in the business environment by precisely capturing and fulfilling market needs (Malhotra *et al.*, 2005).

When OSIOS is excessively diffused and connected with too many external partners, the problem of information overload will be created (Hiltz and Turoff, 1985; Gulati *et al.*, 2012), which reduces a firm's ability to organize the information in the supply chain and also create obstacles for interfirm collaboration. The information flow might have a curvilinear relationship with the level of adaptability enabled by OSIOS, because there can be an inflection point at which it becomes overwhelming for an organization to deal with more information or coordinate with more partners (Huber, 1991). In the meantime, the information shared in the OSIOS network will become increasingly homogenous, as the number of partners increases, which diminishes the informational value accessed from OSIOS because the knowledge circulated among the partners will become increasingly redundant. This declined value of external knowledge might induce rigidity to deal with market changes (Gulati *et al.*, 2012). In addition, as the number of participants increases, free-riding behaviors and unexpected spillover effects are highly possible due to the misuse of proprietary information and resources (Wu, 2008). To deal with this threat, additional efforts of security control and institutional mechanisms should be implemented to manage OSIOS, which further complicates business processes and impedes the level of adaptability a company can attain from OSIOS (Lee and Lim, 2003; Valdés-Llaneza and García-Canal, 2006). Based on our discussion, we propose the following hypothesis:

> *H2: An inverted U-shaped relationship exists between OSIOS external diffusion and the level of process adaptability enabled by OSIOS, such that external diffusion improves process adaptability at first and impedes process adaptability after reaching a certain level.*

3.2 Process Adaptability and Process Alignment

To effectively manage supply chain relationships and leverage external resources, alignment and adaptability are highly correlated together (Bharadwaj, 2000; Langdon, 2006). However, researchers argue that there exists a trade-off between these two capabilities. To exploit benefits of alignment, a firm must forgo most of the benefits of adaptability (Kambil *et al.*, 1999; Saeed *et al.*, 2005). Therefore, it has been challenging for companies to maintain both process alignment and adaptability. This intuition is rooted in the context of traditional EDI where a firm must make chunky infrastructure investments, develop rigid and complex X12 formats, and create highly relation-specific EDI connections, which will result in a minimal level of flexibility to adjust and reconfigure IT assets (Hart and Estrin, 1991; Gosain *et al.*, 2004). Based on recent developments in open standards, modular design and extensible markups, OSIOS can resolve the contradictory requirements between alignment and adaptability (Zhu *et al.*, 2006a; Malhotra *et al.*, 2007; Saraf *et al.*, 2007). There is going to be a greater degree of IOS flexibility after the deployment of OSIOS, which in turn can enhance supply chain integration (Hagel and Brown, 2005).

Allowing firms to flexibly adjust their IT infrastructures and extend IT functionalities, OSIOS enables supply chain partners to rapidly respond to the changing needs in business processes and adapt to inter-organizational activities and plans (Rai and Tang, 2010), which can facilitate the dynamic alignment of processes with supply chain partners (Gosain *et al.*, 2004). Although in a stable environment, a firm can only choose to create highly partner-specific connections and invest in process-specific IT assets that forgo flexibility and adaptability, in a more dynamic environment a company must establish linkages and develop IT infrastructures that are more robust and reconfigurable. Otherwise, the company may develop sticky patterns with entrenched partners over time, resulting in resistance to change (Van Den Bosch *et al.*, 1999). Through obtaining process adaptability from OSIOS, firms can bridge the information gaps in markets and quickly respond to the changes in external environments using various strategies and actions (Gosain *et al.*, 2004), which can reduce of risk of the aforementioned "rigidity traps" and in the long-term, can promote the restructuring of supply chain processes and lead to greater process alignment (Bharadwaj, 2000). Therefore, we formulate the following hypothesis:

H3: OSIOS enabled process adaptability is positively associated with OSIOS enabled process alignment.

The overarching research model of this study is depicted in Figure 1.

<Figure 1 around here>

4 Methodology

To test the hypotheses, this study collected data from manufacturing companies operating in China using a self-report survey instrument which was carefully developed following existing guidelines and exemplars (Sethi and King, 1994). China is considered as an ideal environment to study IOS and supply chain management because of several reasons. Firstly, China is currently one of the foremost global manufacturing centers and is an attractive place for companies throughout the world to set up a manufacturing base (Flynn *et al.*, 2010). Secondly, the Chinese government has made significant efforts in the drive towards achieving Industry 4.0, with many resources being invested into areas such as smart and intelligent manufacturing (Zhong *et al.*, 2017). Lastly, the Chinese government also places great emphasis on their efforts to achieve the "Made in China 2025" project and as a result, there is growing efforts devoted by Chinese companies in deploying IOS to integrate partners within their global supply chains (Huo *et al.*, 2014; Liu *et al.*, 2016). To collect data from the existing adopters of OSIOS, the respondents were asked to identify the type of IOS their companies are implementing before they were provided with the questionnaire to fill in.

4.1 Measurement development

The survey instrument employed in this study was designed based on a comprehensive review of the literature on inter-organizational information systems, inter-organizational relationship management and supply chain management. Whenever possible, existing measurements in the literature were adapted from past studies to safeguard the content validity of the constructs and their fit in the research context, and to ensure that the overlap among the constructs was minimal (Cronbach, 1971).

The key variables in this study were operationalized as multi-item reflective and formative constructs. To decide whether a construct should be modeled as formative or reflective, four major criteria should be examined: (1) the direction of causality between constructs and their indicators, (2) the interchangeability of indicators, (3) the covariation among indicators, and (4) the nomological net of constructs (Jarvis *et al.*, 2003). A latent variable should be constructed as formative when the direction of causality is from the indicators to the constructs (i.e., the indicators create the constructs), the indicators are not inter-changeable and do not necessarily covary, and the nomological net of the indicators can differ (Chin, 1998). In contrast, reflective constructs should be created when the opposite conditions hold. Suggested by the decision rules, OSIOS enabled process alignment and internal assimilation, which were modeled as formative constructs; OSIOS enabled process adaptability and external diffusion, which were modeled as reflective constructs. The response formats and specific items for all measures are shown in Table 3.

Internal Assimilation measures the extent to which OSIOS has been used to support internal supply chain operation practices (Zhang *et al.*, 2016a). Following Zhu *et al.* (2006b), Zhang and Dhaliwal (2009) and Zhang *et al.* (2016a), a three-item formatively measured construct was adapted to assess the degree of OSIOS usage in different key up-stream supply chain activities: supplier selection, purchase-order processing, procurement from suppliers, and invoicing and payment processing.

External diffusion refers to the degree to which OSIOS has been used to facilitate inter-organizational activities with supply chain partners. Three reflective items were adapted from Premkumar *et al.* (1994), Premkumar and Ramamurthy (1995), Zhang *et al.* (2016a), and Zhang and Dhaliwal (2009) to measure the breadth and volume of the transactions that a firm has conducted through OSIOS (Zhu and Kraemer, 2002; Zhang and Dhaliwal, 2009; Zhang *et al.*, 2016a), which includes the number of partners a firm has been interacting with, the volume of transactions with partners, and the overall interactions with partners that have been handled via OSIOS.

OSIOS enabled process alignment measures the extent to which OSIOS enables the coordination and joint optimization of activities between a firm and its supply chain partners, and was measured with four formative items adopted from Tang and Rai (2012) and Rai and Tang (2010). The four items assessed the capabilities of OSIOS to enhance bonding among supply chain partners through coordinating interdependency, improving process visibility, optimizing supply chain processes, and handling operational exceptions and errors efficiently.

OSIOS enabled process adaptability was assessed with three reflective items adapted from Gibson and Birkinshaw (2004) and Im and Rai (2008), which measured the extent to which OSIOS promotes organizational responsiveness to adapt to the variations in the external environment through reconfiguring and adjusting supply chain relationships and activities.

4.2 Control Variables

To control for unobserved heterogeneity caused by industry effects in value creation analysis, following China's industrial classification guide (National Bureau of Statistics, 2017), eight industry dummies were created to represent the industries of the following: (1) automobiles and components, (2) electrical goods and electronics, (3) materials and chemicals, (4) energy, (5) healthcare and healthcare machinery, (6) machinery and equipment, (7) consumer durables and apparel, and (8) others. Ownership was also controlled by creating dummy variables to indicate whether a firm was state-owned, privately owned, or foreign-controlled. In addition, performance was also controlled for the influence of firm size by measuring the yearly turnover and the number of employees of a firm. Larger firms tend to enjoy more abundant resources to deploy OSIOS compared with smaller firms. We also controlled for the number of years a firm has been operating because the older a firm is, the more likely it has invested legacy systems that might not be compatible with OSIOS. In addition, we measured IT department size as the number of technical personnel hired to control for the IT capability of a firm. Two additional control variables – relationship duration and number of suppliers – were also accounted for the possible effects of supplier portfolio characteristics (Tang and Rai, 2012). Relationship duration measured the average relationship length (in years) between a firm and its major suppliers, which is consistent with Im and Rai (2008). Number of suppliers measures the number of major suppliers a firm has been routinely interacting with.

We further controlled for the effects of market and technological turbulence. Market turbulence describes the heterogeneity and the rapid variations in a firm's customer portfolio and the preferences of its customers (Kandemir *et al.*, 2006), which was assessed by three reflective items adapted from Calantone *et al.* (2003), Kandemir *et al.* (2006) and Trkman and McCormack (2009). Technology turbulence refers to the speed of changes in technology over time in the principal industry that a firm operates in and the consequences these changes induce to the industry (Chatterjee, 2004). Three reflective items adapted from Kandemir *et al.* (2006), Koo *et al.* (2006) and Trkman and McCormack (2009) were employed to measure technology turbulence.

4.3 Data Collection

To facilitate the data collection process, a survey research company specialized in helping researchers distribute survey in China was hired to collect data. The role of the data collection firm was to help distribute the survey as well as following up by phoning the companies and conversing with them in Chinese to remind them to fill in the questionnaire if they were willing to participate in our research. Employing data collection to distribute surveys has grown substantially in recent years across a variety of academic disciplines, but specific examples in supply chain operations and management research include Autry *et al.* (2010), Cai *et al.* (2010) and Schoenherr *et al.* (2015). Previous researchers have addressed the concerns with regards to the quality of data collected from survey research firms by confirming that the responses do not differ from those collected via random mail samples as long as the target population is knowledgeable regarding the subject matter (Autry *et al.*, 2010; Schoenherr *et al.*, 2015). It is argued that despite the potential challenges faced by survey research firm recruitment, employing them for data collection can provide a viable alternative to traditional self-administered surveys (Schoenherr *et al.*, 2015). In order to avoid potential bias in our data collection process, one of the co-authors of the research presented at the survey research company when the follow up phone calls were made to the respondents. We also followed the guidelines recommended by Schoenherr *et al.* (2015) to avoid potential bias in our data such as having clear procedures with the survey research company to ensure only qualified respondents took part in the survey, as well as having screening questions to provide assurance of reliability and validity of responses. In this study, the list of manufacturing firms with the Chinese Industrial Classification (CIC) codes 1311 – 4290 (National Bureau of Statistics, 2017) was decided to be the sampling frame to ensure the sample could span a comprehensive spectrum of manufacturing industries. Following Cai *et al.* (2010), the target companies were randomly selected based on the stratified probability proportional to sizes (PPS) method, which could ensure good representation of the sample in terms of industry, firm size and ownership. A list of 3,400 firms was selected as the target samples.

The surveys were conducted through computer-aided phone interviews by the employees of the professional research company. Based on standard practice (Flynn *et al.*, 2010; Zhou *et al.*, 2014; Liu *et al.*, 2016), our survey collected data from senior executives holding titles such as the chief executive officer, chief technology officer, and senior operations managers. These individuals were identified to be the key informants because they confirmed their involvement with supply chain technology as part of their job role, and they have strong knowledge about their companies' overall operational and IT capabilities. The data collection professionals first identified whether a firm has adopted OSIOS or not before administrating the questionnaire to the respondents. We screened our data by following the procedure by Schoenherr *et al.* (2015). We were able to monitor the time respondents took to complete the survey. Surveys that were answered in less than 15 minutes were eliminated. This 15-minute benchmark was the average completion time incurred by the authors when carefully reading and thoughtfully answering the survey. Following Schoenherr et al. (2015), we deemed these "speeders" as unreliable respondents. After discarding the responses with missing data, the final sample consisted of 308 valid responses from OSIOS current adopters. The sample demographic and respondent profile are shown in Table 1 respectively.

<Table 1 around here>

5 Data Analysis and Results

5.1 Measurement Validation

Confirmatory factor analysis was conducted to validate the measurement. Because reflectively measured constructs and formatively measured constructs are based on different concepts, they must be distinguished when evaluating the measurement models by using different assessment measures (Ringle *et al.*, 2009). Reflective constructs were assessed regarding their internal consistency reliability and construct validity following Hair *et al.* (2014), whereas formative constructs were evaluated following guidelines suggested by and Petter *et al.* (2007).

The internal consistency reliability of the reflective constructs was established by assessing composite reliabilities. The results in Table 2 showed that the composite reliabilities of all constructs were greater than the recommended benchmark of 0,70, suggesting satisfactory internal consistency of the reflective measurement model (Barclay *et al.*, 1995).

<Table 2 around here>

Construct validity assesses whether the items can actually capture the concepts that the constructs intend to measure (Bagozzi, 1980), which is evaluated by convergent and discriminant validity respectively. As shown in Table 2, the reflective measurement models exhibit sufficient indicator reliability because the standardized factors loadings ranged from 0.681 to 0.983 (Flynn *et al.*, 2010). Meanwhile, the average variance extracted (AVE) ranged from 0.577 to 0.949, greater than the suggested 0.50 threshold (Koufteros, 1999). These results thus provided strong evidence of convergent validity. To establish discriminant validity of the reflective measurements, the Fornell-Larcker criterion and cross-loadings were used as two measures. The Fornell-Larcker criterion (Fornell and Larcker, 1981) proposes that a construct should share more variance with its indicators than the variance shared with other constructs in the same model, which is statistically expressed as the rule suggesting that the square root of a construct's AVE should exceed the highest correlation it has with any other construct. As shown in Table 3, the square roots of the AVEs (figures on the diagonal) were all greater than the correlations among the constructs (figures off the diagonal), providing evidence for discriminant validity. In addition, the results in Table 4 demonstrate that no indicators loaded higher on other constructs than on their assigned constructs (Petter *et al.*, 2007), which further lends support for discriminant validity.

<Table 3 around here>

<Table 4 around here>

For OSIOS enabled process alignment and internal assimilation, which are formative measures, the statistical assessment criteria for reflective measurements such as composite reliability and AVE are not applicable. Content validity of formative measures, which ensures that all the formative indicators capture all, or at least a major part of, the facets of the construct domain (Nunnally, 1978), must be established before data collection and estimation. Because all of the measures for formative constructs were adapted directly from previous literature in prestigious IS and OM journals, the theoretical grounding of the indicators are well supported. In addition, as described in the data collection section, the questionnaire items were reviewed cautiously by a panel of eight academics and five practitioners to ensure the content validity of the formative indicators.

Similar to reflective measurements, cross-loadings of formative indicators are employed to evaluate their discriminant validity (Petter *et al.*, 2007). As shown in Table 4, no formative indicators loaded greater on the constructs they are not intended to measure, which provides support for discriminant validity of the formatively measured constructs.

5.2 Hypothesis Testing

Conventional analytical methods such as ordinary least squares (OLS) and general least squares (GLS) might not be appropriate for this study because the endogenous variables – OSIOS enabled process adaptability – is also specified as an explanatory variable in another equation in the system of equations (Hamilton and Nickerson, 2003). In addition, problems arising from correlated error terms due to the possible omission of variables that are correlated with the dependent variable and any of the independent variables in the model may arise (Zaefarian *et al.*, 2017). Correlation among error terms could also arise because each case is based on data obtained from a single respondent (Kuruzovich *et al.*, 2008). Therefore, the three-stage least squares (3SLS) estimation, which combines the features of two-stage least squares (2SLS) and seemingly unrelated regression estimation (SURE), was employed to analyze the data to simultaneously address the problems of dependent repressors and correlation of error terms (Kuruzovich *et al.*, 2008). In addition, 3SLS is recommended to be a more efficient approach (compared with OLS and GLS) to solve triangular structural models (Lahiri and Schmidt, 1978), just as the research model proposed in this study. When estimating models involving latent variables, 3SLS also has the advantage of being more robust to model specification errors, e.g., omitted paths or incorrect structures, compared with the commonly used maximum likelihood based structural equation modeling (SEM) method (Bollen *et al.*, 2007). Furthermore, because our research model involves quadratic effects, using 3SLS can cater for interacting variables more easily compared with SEM. The following system of equations was developed to test the proposed hypotheses:

$$Process\ Adaptability_i = \beta_0 + \beta_1 ExternalDiffusion_i + \beta_2 InternalAssimilation_i + + \beta_3 ExternalDiffusion_i^2 + \beta_4 InternalAssimilation_i^2 + \beta_5 Market\ Turbulence_i + \beta_6\ TechnologicalTurbulence + \beta_7 Turnover + \beta_8 Employee + \beta_9 IT\ Department + + \beta_{10}\ OperationYears + \beta_{11-12} OwnershipDummies + \beta_{13-19} IndustryDummies + e_i \quad (1)$$

$$Process\ Alignment_i = \gamma_0 + \gamma_1 Process\ Adaptability_i + \gamma_2 No.\ of\ Suppliers_i + \gamma_3 RelationshipDuration_i + \gamma_4 Market\ Turbulence_i + \gamma_5 TechnologicalTurbulence + \gamma_6\ Turnover + \gamma_7 Employee + \gamma_8 IT\ Department + + \gamma_9 OperationYears + \gamma_{10-11}\ OwnershipDummies + \gamma_{12-18} IndustryDummies + \upsilon_i \quad (2)$$

As specified in the equations, we controlled the effects market and technological turbulence on process adaptability. In addition, relationship duration and number of suppliers, as two network properties, were included as control variables for process alignment in the model.

5.3 Results

Table 5 details the main estimation result of the system of equations, wherein, Models (1), (2) and (3) list estimate for the various specifications of Equation (1) while Models (4) and (5) detail the result for Equation (2). Among the control variables, it was found that the effect of number of suppliers was negative on process alignment, which reflects the difficulty in managing a wide variety of inter-organizational relationships. A company is constrained to attained high levels of process alignment when there are many partnerships to cater for (Madhok, 2002). Relationship duration, on the other hand, was positively associated with process alignment, which lends support to the notion that tie strength can facilitate supply chain integration (Tang and Rai, 2012).

<Table 5 around here>

In Model (1), the main linear effects of both OSIOS deployment constructs were entered. Consistent with our earlier discussion that OSIOS can provide relational mechanism to enable process adaptability, results showed that external diffusion (β_1 = 0.265, p < .01) and internal assimilation (β_2 = 0.241, p < .01) were predictive for the creation of process adaptability. In Model (2), quadratic terms of the two OSIOS deployment constructs were entered. Only the nonlinear term of internal assimilation was significant predictive for process adaptability (β_3 = -0.075, p < .01), which lent support for Hypothesis 1. However, Hypothesis 2 was not supported as the nonlinear effect of external diffusion was not significant (β_4 = -0.06, ns). External diffusion thus only had positive linear effect on OSIOS enabled process adaptability. To corroborate the nonlinear effect in the case of internal assimilation, Figures 2 illustrates the graph of the quadratic relation. Hypothesis 3 posits that OSIOS enabled process adaptability positively affects OSIOS enabled process alignment. Model (3) represents the corresponding result: the positive effect of process adaptability was statistically significant (γ_1 = 0.501, p < .01), offering support to Hypothesis3.

<Figure 2 around here>

Although not explicitly suggested in the hypotheses, the research model implies a mediation effect of process adaptability on the relationship between OSIOS deployment and process alignment. Because external diffusion was shown to have no significant relationship with process adaptability, we only tested the mediating role of process adaptability. Due to the involvement of nonlinear effect, we performed a bootstrapping test (n = 5000) following the procedure of Hayes and Preacher's (2010) to calculate the instantaneous indirect effects of internal assimilation on process alignment through process adaptability at different values of internal assimilation (i.e., mean and mean +- SD). The instantaneous indirect effect was significant at low internal assimilation ($\theta_{x=-1.04}$ = 0.288, bias-corrected bootstrap 95% CI = [0.167, 0.397], not including zero), mean ($\theta_{x=-0.11}$ = 0.227, bias-corrected bootstrap 95% CI = [0.145, 0.307], not including zero), and higher ($\theta_{x=0.82}$= 0.167, bias-corrected bootstrap 95% CI = [0.085, 0.259], not including zero). The result provides evidence that increasing internal assimilation can enable more process alignment through the effect on OSIOS enabled process adaptability. However, the return from internal assimilation is diminishing as its marginal effect on process alignment is larger for companies low in internal assimilation compared with those have moderate or high levels of internal assimilation.

As OSIOS internal assimilation and external diffusion could be endogenously affected by the level of process adaptability, the results might be biased and inconsistent (Guide and Ketokivi, 2015). We conducted a two-stage least squares (2SLS) regression with instrumental variables and a Durbin–Wu–Hausman postestimation test of endogeneity (Davidson and MacKinnon, 1993) to deal with the potential endogeneity concern (Liu *et al.*, 2016). The results (see Appendix I) showed that the findings in our original model were unlikely to be unduly influenced by endogeneity.

Several additional tests were conducted to check the robustness of our results. We tested our hypotheses using Structural Equation Modeling with FIML estimation to estimate simultaneously the effect of OSIOS adoption on process adaptability and process alignment. The model leads to the same statistical conclusions as 3SLS (see Appendix II, Table A). Additionally, a 2SLS analysis with LIML estimation was performed, which also showed consistent results with 3SLS (see Appendix II, Table B). 2SLS recommended for system of equations where there might be endogeneity due to potential reverse causality between the independent and dependent variable (Baron and Kenny, 1986). The consistent results from 2SLS thus minimize concerns about endogeneity.

6 Discussion and Implications

OSIOS technology is an important fundamental IT artifact to help achieve Industry 4.0. It has the potential to provide the standards for business processes and data exchanges that can create an autonomous, decentralized supply chain network, thus helping firms to achieve better supply chain integration. As found in Flynn *et al.* (2010), supply chain integrations can be described in three dimensions, namely internal, customer and supplier integration. OSIOS technology is important in helping firms improve their supply chain integration (Chong and Ooi, 2008). However, OSIOS deployment is still in its infancy stage given that the technology is still elusive to most manufacturers. Most manufacturers understand the potential values of OSIOS, but at the same time they are taking a cautious approach in investing in OSIOS. Our research advances contemporary knowledge of the values brought by the assimilation and diffusion of OSIOS. Drawing on the theoretical lens of the relational view of the firm, we examined how manufacturers can achieve process adaptability and alignment by deploying OSIOS. Through collecting surveys from a large group of manufacturers, we were able to examine the non-linear impact of OSIOS assimilation and diffusion on process adaptability and alignment, and, therefore, shed light on how manufacturers should optimize their deployment of OSIOS to achieve the best outcomes. As such, our research bears significant implications for both theory and practice.

6.1 Implications for Theory

By conducting an empirical examination on the research model proposed, this research contributes to extant literature on three fronts.

Firstly, supply chain alignment and integration is one of the most important topics studied by the scholars of operation management. In particular, the success of Industry 4.0 is very much dependent on achieving integration and alignment in supply chains. Our study extends extant literature on the topic by focusing on an important enabler of supply chain integration and alignment – OSIOS. Although the importance of supply chain integration is widely recognized, it remains a considerable challenge for organizations to reap the benefits of an integrated supply chain because of the complexities in SCM strategies (Mustafa Kamal and Irani, 2014; Vanpoucke *et al.*, 2017). Given the inconsistent results of OSIOS deployment in different industry (Saeed *et al.*, 2011), the relationship between OSIOS deployment and supply chain integration remains a black box (Liu *et al.*, 2016). Our study thus enriches this stream of research by exploring the relationship between OSIOS deployment and process alignment. Through enabling process adaptability, OSIOS can indirectly generate process alignment to integrate inter-firm supply chain processes and activities. This finding is of particular interest and importance to achieve Industry 4.0 given that OSIOS has the ability to address the potential tradeoffs between OSIOS integration and flexibility (Saraf *et al.*, 2007; Rai and Tang, 2010). Without process adaptability, even though a company achieves process alignment, it will not be able to reconfigure its supply chain activities to adapt to the changing environments. The company will end up facing the risks of rigidity such that the existing business processes that were once aligned will become obsolete or misaligned when relevant supply chain activities or relationships change. This rigidity has been pertinent in the application of EDI because of its inflexibility and costs which have restrained its ability to transform inter-organizational relationships (Hart and Estrin, 1991). OSIOS overcomes the disadvantages of EDI by affording companies with the flexibility to tune the parameters related to business processes, thus allowing them to adapt to the emerging alignment requirement (Malhotra *et al.*, 2007; Saraf *et al.*, 2007). Therefore, our research empirically confirmed that OSIOS enables companies to enjoy close coordination and inter-firm integration and to pursue higher-order performance by developing adaptability to continually restructure supply chain processes and respond to external changes.

Secondly, despite the critical role of OSIOS in determining the extent to which an organization can attain supply chain integration, there is little understanding of how OSIOS can be deployed effectively (Saeed *et al.*, 2011; Liu *et al.*, 2016). In order to fill this research gap, it is imperative to go beyond linear models to identify an ideal way of deploying OSIOS for supply chain collaboration (Liu *et al.*, 2016). Therefore, a key contributions of this research is the examination of the curvilinear effects of OSIOS internal assimilation and external diffusion on enabling process adaptability and process alignment. This facilitates the identification of the optimal level of OSIOS deployment that will most effectively manage supply chain integration. Our study found that relationship between internal assimilation and OSIOS enabled process adaptability followed an inverted U-shaped pattern. The findings ascertain that by deploying OSIOS to support key supply chain activities, the utility of OSIOS to enhance process adaptability and alignment will drop after a certain degree. This could be due to that as more functions and processes are integrated in OSIOS, the whole system will become complicated to use and difficult to learn, which reduces the flexibility of the system and thus constrain the level of process adaptability OSIOS can enable. External diffusion only showed a positive linear relationship with process adaptability, which confirms with the network externalities of OSIOS, where once there are more supply chain partners using OSIOS, the value of OSIOS increases (Zhu *et al.*, 2006a). This supports why OSIOS such as RosettaNet needs manufacturers in the industry to buy in into the technology and co-adopt it in order to maximize the collaboration and alignment in the supply chain.

Lastly, this study further contributes to the supply chain management literature by categorizing OSIOS deployment into internal assimilation and external diffusion, which provides a nuanced understanding about the linkage between OSIOS deployment and supply chain performance. This endeavor echoes the call in the operations management literature to investigate the influencing mechanisms exerted by different approaches of implementing information systems (Zhang *et al.*, 2011). Distinguishing internal assimilation and external diffusion of OSIOS can enhance the assessment of the operational improvement generated by OSIOS deployment (Zhang *et al.*, 2016b). The different impact mechanisms between internal assimilation and external diffusion explored by this research thus provide valuable insights to understand how IT can create value when deployed to support different integration needs.

6.2 Implications for Practice

Our research informs practice in two ways. Firstly, even though Industry 4.0 provides numerous opportunities for many countries to digitalize manufacturing industries, contemporary applications of Industry 4.0 technologies still exist at an experimental stage. This study offers an overview of how OSIOS can be deployed to help create value to supply chain processes. Furthermore, we separate deployment of OSIOS into internal assimilation and external diffusion, thus offering a richer understanding of how applying OSIOS within a firm's business process and its integration with its partners can help create values to a manufacturer. In this sense, our study informs practitioners who are planning or in the process of deploying OSIOS, to gain a comprehensive view of the value offered by OSIOS.

Secondly, given that organizations may have limited resources to invest in OSIOS, our study provides valuable insights into how to deploy IT assets internally and externally to maximize the relational outcomes from OSIOS. In particular, we showed that manufacturers should not blindly increase assimilation of OSIOS into their business processes, as more does not necessarily mean better in our U-shaped result. Manufacturers should instead focus on key business processes to implement OSIOS, while other business processes internally can function using existing systems. On the other hand, within the supply chain network, manufacturers should ensure that the business processes that have assimilated OSIOS should be fully integrated with their supply chain partners, as this is shown to increase the process adaptability of manufacturers.

7 Limitations and Future Research

Despite the contributions of this study in both theory and practice, there are several limitations. Firstly, this study could not show the value creation of OSIOS over time. Future studies can consider the dynamism of time when evaluating the relationship between OSIOS and relational capabilities. This study used cross-sectional data, which might be subject to the risk that the influence of OSIOS on organizational outcomes is only temporal. The quasi-open attribute of OSIOS makes imitation easy, which will reduce the uniqueness of OSIOS and erode a firm's competitive advantage overtime. It is important to ensure that performance gains from OSIOS can be sustained in the long-term. Future study can conduct longitudinal research to understand whether and how OSIOS deployment can promote long-term advantages. The use of cross-sectional data also restricts us from exploring whether the capabilities developed from OSIOS deployment, in the long run, will in turn affect the extent to which OSIOS are deployed. With improved adaptability and alignment, a firm might be more capable of assimilating and diffusing OSIOS to support inter-firm activities.

Although our research model in terms of OSIOS enabled process adaptability and alignment has the advantage of parsimony, the explanatory breath and richness can be improved. Future study thus can include other outcomes of OSIOS such as relationship flexibility (Rai and Tang, 2010), or even first order value such as operational and financial performance that could potentially yield from OSIOS deployment. In addition, the moderation effects of inter-organizational relationships e.g., trust and information sharing can be explored in the future. In addition, we also acknowledge the limitation of measuring internal assimilation as the extent to which OSIOS are deployed to support internal activities. Due to the differences in downstream and upstream supply chain activities, assimilation of IT to integrate customers and suppliers should be measured as separate variables (Frohlich, 2002). Future research can investigate internal assimilation of OSIOS in downstream activities to provide more insights into the phenomenon.

Furthermore, the data was collected from China where there is a collectivist cultural environment and therefore the respondents may have a tendency to agree regardless of the content of the questions (Liu *et al.*, 2010). Thus there might be a slight chance of acquiescence bias in our data. Despite these limitations, we believe that this study provides compelling evidence showing that OSIOS can be leveraged as importance value creation mechanisms to lead to the roadmap of Industry 4.0.

References

Autry, C. W., Grawe, S. J., Daugherty, P. J. and Richey, R. G. (2010) "The effects of technological turbulence and breadth on supply chain technology acceptance and adoption", *Journal of Operations Management,* 28(6), pp. 522-536.

Bagozzi, R. P. (1980) *Causal Models in Marketing. Theories in marketing series* New York: John Wiley & Sons Inc.

Bala, H. and Venkatesh, V. (2007) "Assimilation of interorganizational business process standards", *Information Systems Research,* 18(3), pp. 340-362.

Barclay, D., Higgins, C. and Thompson, R. (1995) "The partial least squares (PLS) approach to casual modeling: Personal computer adoption ans use as an illustration", *technology Studies,* 2, pp. 285-309.

Barney, J. (1991) "Firm resources and sustained competitive advantage", *Journal of Management,* 17(1), pp. 99-120.

Baron, R. M. and Kenny, D. A. (1986) "The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations", *Journal of personality and social psychology,* 51(6), pp. 1173.

Bensaou, M. and Venkatraman, N. (1996) "Inter-organizational relationships and information technology: a conceptual synthesis and a research framework", *European Journal of Information Systems,* 5(2), pp. 84-91.

Bharadwaj, A. S. (2000) "A Resource-Based Perspective on Information Technology Capability and Firm Performance: An Empirical Investigation", *MIS Quarterly,* 24(1), pp. 169-196.

Bollen, K. A., Kirby, J. B., Curran, P. J., Paxton, P. M. and Chen, F. (2007) "Latent Variable Models Under Misspecification: Two-Stage Least Squares (2SLS) and Maximum Likelihood (ML) Estimators", *Sociological Methods & Research,* 36(1), pp. 48-86.

Cai, S., Jun, M. and Yang, Z. (2010) "Implementing supply chain information integration in China: The role of institutional forces and trust", *Journal of Operations Management,* 28(3), pp. 257-268.

Calantone, R., Garcia, R. and Dröge, C. (2003) "The Effects of Environmental Turbulence on New Product Development Strategy Planning", *Journal of Product Innovation Management,* 20(2), pp. 90-103.

Chan, F. T. S., Chong, A. Y.-L. and Zhou, L. (2012) "An Empirical Investigation of Factors Affecting E-Collaboration Diffusion in SMEs", *International Journal of Production Economics,* 138(2), pp. 329-344.

Chang, H.-L. and Shaw, M. J. (2009) "The Business Value of Process Sharing in Supply Chains: A Study of RosettaNet", *International Journal of Electronic Commerce,* 14(1), pp. 115-146.

Chatterjee, D., Grewal, R. and Sambamurthy, V. (2002) "Shaping up for e-commerce: institutional enablers of the organizational assimilation of web technologies", *MIS Quarterly,* 26(2), pp. 65-89.

Chatterjee, P. (2004) "Interfirm alliances in online retailing", *Journal of Business Research,* 57(7), pp. 714-723.

Chin, W. W. (1998) 'The partial least squares approach to structural equation modeling', in Marcoulides, G.A. (ed.) *Modern methods for business research*. Mahwah, NJ: Lawrence Erbaum Associates, pp. 295-336.

Chong, A. Y.-L. and Ooi, K.-B. (2008) "Adoption of Interorganizational System Standards in Supply Chains: An Empirical Analysis of Rosettanet Standards", *Industrial Management & Data Systems,* 108(4), pp. 529-547.

Chong, A. Y.-L., Ooi, K.-B. and Sohal, A. (2009) "The Relationship Between Supply Chain Factors and Adoption of E-Collaboration Tools: An Empirical Examination", *International Journal of Production Economics,* 122(1), pp. 150-160.

Church, J. and Gandal, N. (1992) "Network effects, software provision, and standardization", *The Journal of Industrial Economics,* 40(1), pp. 85-103.

Corsten, D. and Felde, J. (2005) "Exploring the performance effects of key-supplier collaboration: An empirical investigation into Swiss buyer-supplier relationships", *International Journal of Physical Distribution & Logistics Management,* 35(6), pp. 445-461.

Cronbach, L. J. (1971) 'Test Validation', in Thorndike, R. (ed.) *Educational Measurement.* 2nd ed. Washington, DC: merican Council on Education, pp. 443-507.

Croom, S. R. (2005) "The impact of e-business on supply chain management: An empirical study of key developments", *International Journal of Operations & Production Management,* 25(1), pp. 55-73.

Crosno, J. L. and Dahlstrom, R. (2008) "A meta-analytic review of opportunism in exchange relationships", *Journal of the Academy of Marketing Science,* 36(2), pp. 191-201.

Dallasega, P., Rauch, E. and Linder, C. (2018) "Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review", *Computers in industry,* 99, pp. 205-225.

Damodaran, S. 'RosettaNet: Adoption brings new problems, new solutions', *The XML 2005 Conference*, Atlanta, GA, November 14-18, 1-14.

Davidson, R. and MacKinnon, J. (1993) *Estimation and Inference in Econometrics.* OUP Catalogue, Oxford University Press.

Dyer, J. H. (1997) "Effective Interfirm Collaboration: How Firms Minimize Transaction Costs and Maximize Transaction Value", *Strategic Management Journal,* 18(7), pp. 535-556.

Dyer, J. H. and Singh, H. (1998) "The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage", *Academy of Management Review,* 23(4), pp. 660-679.

Fichman, R. (2000) 'The Diffusion and Assimilation of Information Technology Innovations', in Zmud, R.W. (ed.) *Framing the Domains of IT Management: Projecting the Future through the Past*. Cleveland, OH: Pinnaflex Publishing, pp. 105–127.

Fichman, R. G. and Kemerer, C. F. (1999) "The illusory diffusion of innovation: An examination of assimilation gaps", *Information systems research,* 10(3), pp. 255-275.

Flynn, B. B., Huo, B. and Zhao, X. (2010) "The impact of supply chain integration on performance: A contingency and configuration approach", *Journal of Operations Management,* 28(1), pp. 58-71.

Fornell, C. and Larcker, D. F. (1981) "Evaluating Structural Equation Models with Unobservable Variables and Measurement Error", *Journal of Marketing Research,* 18(1), pp. 39-50.

Frohlich, M. T. (2002) "e-Integration in the Supply Chain: Barriers and Performance*", *Decision Sciences,* 33(4), pp. 537-556.

Gibson, C. B. and Birkinshaw, J. (2004) "The Antecedents, Consequences, and Mediating Role of Organizational Ambidexterity", *The Academy of Management Journal,* 47(2), pp. 209-226.

Gold, S. (2018) *Manufacturers are Behind in Industry 4.0—and for Good Reason*: Industry Week. Available at: https://www.industryweek.com/leadership/manufacturers-are-behind-industry-40-and-good-reason (Accessed: Dec 02 2018).

Gosain, S., Malhotra, A. and El Sawy, O. A. (2004) "Coordinating for flexibility in e-business supply chains", *Journal of Management Information Systems,* 21(3), pp. 7-45.

Gosain, S., Malhotra, A., Sawy, O. A. E. and Chehade, F. (2003) "The Impact of Common E-Business Interfaces", *Communications of the ACM,* 46(12), pp. 186-195.

Grangel-González, I., Baptista, P., Halilaj, L., Lohmann, S., Vidal, M.-E., Mader, C. and Auer, S. "The industry 4.0 standards landscape from a semantic integration perspective". *2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, Limassol, Cyprus: IEEE, 1-8.

Grover, V. and Saeed, K. A. (2007) "The impact of product, market, and relationship characteristics on interorganizational system integration in manufacturer-supplier dyads", *Journal of Management Information Systems,* 23(4), pp. 185-216.

Guide, V. D. R. and Ketokivi, M. (2015) "Notes from the Editors: Redefining some methodological criteria for the journal", *Journal of Operations Management,* 37(1), pp. v-viii.

Gulati, R., Sytch, M. and Tatarynowicz, A. (2012) "The Rise and Fall of Small Worlds: Exploring the Dynamics of Social Structure", *Organization Science,* 23(2), pp. 449-471.

Hagel, J. and Brown, J. S. (2005) *The only sustainable edge: Why business strategy depends on productive friction and dynamic specialization.* Boston, MA: Harvard Business Press.

Hair, J. F., Hult, G. T. M., Ringle, C. and Sarstedt, M. (2014) *A primer on partial least squares structural equation modeling (PLS-SEM).* Thousand Oaks, CA: Sage Publications.

Hamilton, B. H. and Nickerson, J. A. (2003) "Correcting for Endogeneity in Strategic Management Research", *Strategic Organization,* 1(1), pp. 51-78.

Hart, P. and Estrin, D. (1991) "Inter-organization networks, computer integration, and shifts in interdependence: the case of the semiconductor industry", *ACM Trans. Inf. Syst.,* 9(4), pp. 370-398.

Hiltz, S. R. and Turoff, M. J. C. o. t. A. (1985) "Structuring computer-mediated communication systems to avoid information overload", 28(7), pp. 680-689.

Huber, G. P. (1991) "Organizational Learning: The Contributing Processes and the Literatures", *Organization science,* 2(1), pp. 88-115.

Huo, B., Zhao, X. and Zhou, H. (2014) "The Effects of Competitive Environment on Supply Chain Information Sharing and Performance: An Empirical Study in China", *Production and Operations Management,* 23(4), pp. 552-569.

Im, G. and Rai, A. (2008) "Knowledge Sharing Ambidexterity in Long-Term Interorganizational Relationships", *Management Science,* 54(7), pp. 1281-1296.

Jarvis, C. B., MacKenzie, S. B. and Podsakoff, P. M. (2003) "A Critical Review of Construct Indicators and Measurement Model Misspecification in Marketing and Consumer Research", *Journal of Consumer Research,* 30(2), pp. 199-218.

Kambil, A., Nunes, P. F. and Wilson, D. (1999) "Transforming the Marketspace with All-in-One Markets", *International Journal of Electronic Commerce,* 3(4), pp. 11-28.

Kandemir, D., Yaprak, A. and Cavusgil, S. T. (2006) "Alliance Orientation: Conceptualization, Measurement, and Impact on Market Performance", *Journal of the Academy of Marketing Science,* 34(3), pp. 324-340.

Kanter, R. M. (1994) "Collaborative advantage", *Harvard business review,* 72(4), pp. 96-108.

Kobusch, I. (2015) *Industrie 4.0 Vision Versus Semiconductor Manufacturing Status Quo (Part 2)*: IBM Industry Insights. Available at: https://www.ibm.com/blogs/insights-on-business/electronics/industrie-4-0-vision-versus-semiconductor-manufacturing-status-quo-part-2/ (Accessed: Dec 02 2018).

Koo, C., Song, J., Kim, Y. J. and Nam, K. (2006) "Do e-business strategies matter? The antecedents and relationship with firm performance", *Information Systems Frontiers,* 9(2), pp. 283.

Koufteros, X. A. (1999) "Testing a model of pull production: a paradigm for manufacturing research using structural equation modeling", *Journal of Operations Management,* 17(4), pp. 467-488.

Kumar, R. L. (2004) "A framework for assessing the business value of information technology infrastructures", *Journal of Management Information Systems,* 21(2), pp. 11-32.

Kuruzovich, J., Viswanathan, S., Agarwal, R., Gosain, S. and Weitzman, S. (2008) "Marketspace or marketplace? Online information search and channel outcomes in auto retailing", *Information Systems Research,* 19(2), pp. 182-201.

Lahiri, K. and Schmidt, P. (1978) "On the Estimation of Triangular Structural Systems", *Econometrica,* 46(5), pp. 1217-1221.

Langdon, C. S. (2006) "Designing information systems capabilities to create business value: A theoretical conceptualization of the role of flexibility and integration", *Journal of Database Management,* 17(3), pp. 1.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T. and Hoffmann, M. (2014) "Industry 4.0", *Business & Information Systems Engineering,* 6(4), pp. 239-242.

Lee, S. and Lim, G. G. (2003) "The impact of partnership attributes on EDI implementation success", *Information & Management,* 41(2), pp. 135-148.

Liang, H., Saraf, N., Hu, Q. and Xue, Y. (2007) "Assimilation of enterprise systems: the effect of institutional pressures and the mediating role of top management", *MIS Quarterly,* 31(1), pp. 59-87.

Liu, H., Ke, W., Wei, K. K., Gu, J. and Chen, H. (2010) "The Role of Institutional Pressures and Organizational Culture in the Firm's Intention to Adopt Internet-Enabled Supply Chain Management Systems", *Journal of Operations Management,* 28(5), pp. 372-384.

Liu, H., Wei, S., Ke, W., Wei, K. K. and Hua, Z. (2016) "The configuration between supply chain integration and information technology competency: A resource orchestration perspective", *Journal of Operations Management,* 44(Supplement C), pp. 13-29.

Lu, Y. (2017) "Industry 4.0: A survey on technologies, applications and open research issues", *Journal of Industrial Information Integration,* 6, pp. 1-10.

Lu, Y., Morris, K. and Frechette, S. (2016) *Current Standards Landscape for Smart Manufacturing Systems*: National Institute of Standards and Technology. Available at: http://dx.doi.org/10/6028/NIST.IR.8107.

Madhok, A. (2002) "Reassessing the fundamentals and beyond: Ronald Coase, the transaction cost and resource-based theories of the firm and the institutional structure of production", *Strategic Management Journal,* 23(6), pp. 535-550.

Malakooty, N. (2005) *RosettaNet: The organization and the system*: UC Irvine: Center for Research on Information Technology and Organizations. Available at: https://escholarship.org/uc/item/13h666zb.

Malhotra, A., Gosain, S. and El Sawy, O. A. (2007) "Leveraging standard electronic business interfaces to enable adaptive supply chain partnerships", *Information Systems Research,* 18(3), pp. 260-279.

Malhotra, A., Gosain, S. and Sawy, O. A. E. (2005) "Absorptive Capacity Configurations in Supply Chains: Gearing for Partner-Enabled Market Knowledge Creation", *MIS Quarterly,* 29(1), pp. 145-187.

Marr, B. (2016) *What Everyone Must Know About Industry 4.0*: Forbes. Available at: https://www.forbes.com/sites/bernardmarr/2016/06/20/what-everyone-must-know-about-industry-4-0/#703acc87795f (Accessed: Dec 03 2018).

Mustafa Kamal, M. and Irani, Z. (2014) "Analysing supply chain integration through a systematic literature review: a normative perspective", *Supply Chain Management: An International Journal,* 19(5/6), pp. 523-557.

National Bureau of Statistics, China, S.A.o.t.P.s.R.o. (2017) *Industrial classification for national economic activities*.

Nevo, S. and Wade, M. R. (2010) "The formation and value of IT-enabled resources: Antecedents and consequences of synergistic relationships", *MIS quarterly,* 34(1), pp. 163-183.

Nunnally, J. C. (1978) *Psychometric Theory.* 2nd edn. New York, NY: McGraw-Hill.

Nurmilaakso, J.-M. (2008) "Adoption of e-business functions and migration from EDI-based to XML-based e-business frameworks in supply chain integration", *International Journal of Production Economics,* 113(2), pp. 721-733.

Paulraj, A., Lado, A. A. and Chen, I. J. (2008) "Inter-organizational communication as a relational competency: Antecedents and performance outcomes in collaborative buyer–supplier relationships", *Journal of Operations Management,* 26(1), pp. 45-64.

Petter, S., Straub, D. and Rai, A. (2007) "Specifying Formative Constructs in Information Systems Research", *MIS Quarterly,* 31(4), pp. 623-656.

Porter, P. (2001) "Deciphering RosettaNet", *CIO Insight*.

Posada, J., Toro, C., Barandiaran, I., Oyarzun, D., Stricker, D., Amicis, R. d., Pinto, E. B., Eisert, P., Döllner, J. and Vallarino, I. (2015) "Visual Computing as a Key Enabling Technology for Industrie 4.0 and Industrial Internet", *IEEE Computer Graphics and Applications,* 35(2), pp. 26-40.

Powell, T. C. and Dent-Micallef, A. (1997) "Information technology as competitive advantage: The role of human, business, and technology resources", *Strategic management journal,* 18(5), pp. 375-405.

Premkumar, G. and Ramamurthy, K. (1995) "The Role of Interorganizational and Organizational Factors on the Decision Mode for Adoption of Interorganizational Systems*", *Decision Sciences,* 26(3), pp. 303-336.

Premkumar, G., Ramamurthy, K. and Nilakanta, S. (1994) "Implementation of Electronic Data Interchange: An Innovation Diffusion Perspective", *Journal of Management Information Systems,* 11(2), pp. 157-186.

Rai, A. and Tang, X. (2010) "Leveraging IT Capabilities and Competitive Process Capabilities for the Management of Interorganizational Relationship Portfolios", *Information Systems Research,* 21(3), pp. 516-542.

Ramamurthy, K. and Premkumar, G. (1995) "Determinants and outcomes of EDI diffusion", *IEEE Transactions on Engineering Management,* 42(4), pp. 332-351.

Ranganathan, C., Dhaliwal, J. S. and Teo, T. S. H. (2004) "Assimilation and Diffusion of Web Technologies in Supply-Chain Management: An Examination of Key Drivers and Performance Impacts", *International Journal of Electronic Commerce,* 9(1), pp. 127-161.

Ringle, C. M., Sinkovics, R. R. and Henseler, J. (2009) 'The use of partial least squares path modeling in international marketing', in Sinkovics, R.R. and Ghauri, P.N. (eds.) *New Challenges to International Marketing: Vol. 20 Advances in International Marketing*. Bingley, UK: Emerald Group Publishing Limited, pp. 277-319.

Roblek, V., Meško, M. and Krapež, A. (2016) "A Complex View of Industry 4.0", *SAGE Open,* 6(2), pp. 1-11.

Saeed, K. A., Malhotra, M. K. and Grover, V. (2005) "Examining the Impact of Interorganizational Systems on Process Efficiency and Sourcing Leverage in Buyer–Supplier Dyads", *Decision Sciences,* 36(3), pp. 365-396.

Saeed, K. A., Malhotra, M. K. and Grover, V. (2011) "Interorganizational system characteristics and supply chain integration: an empirical assessment", *Decision Sciences,* 42(1), pp. 7-42.

Saldanha, T. J. V., Melville, N. P., Ramirez, R. and Richardson, V. J. (2013) "Information systems for collaborating versus transacting: Impact on manufacturing plant performance in the presence of demand volatility", *Journal of Operations Management,* 31(6), pp. 313-329.

Saraf, N., Langdon, C. S. and Gosain, S. (2007) "IS application capabilities and relational value in interfirm partnerships", *Information systems research,* 18(3), pp. 320-339.

Schoenherr, T., Ellram, L. M. and Tate, W. L. (2015) "A Note on the Use of Survey Research Firms to Enable Empirical Data Collection", *Journal of Business Logistics,* 36(3), pp. 288-300.

Sethi, V. and King, W. R. (1994) "Development of Measures to Assess the Extent to Which an Information Technology Application Provides Competitive Advantage", *Management Science,* 40(12), pp. 1601-1627.

Sodero, A. C., Rabinovich, E. and Sinha, R. K. (2013) "Drivers and outcomes of open-standard interorganizational information systems assimilation in high-technology supply chains", *Journal of Operations Management,* 31(6), pp. 330-344.

Stevenson, M. and Spring, M. (2007) "Flexibility from a supply chain perspective: definition and review", *International Journal of Operations & Production Management,* 27(7), pp. 685-713.

Tang, X. and Rai, A. (2012) "The Moderating Effects of Supplier Portfolio Characteristics on the Competitive Performance Impacts of Supplier-Facing Process Capabilities", *Journal of Operations Management,* 30(1), pp. 85-98.

Trkman, P. and McCormack, K. (2009) "Supply chain risk in turbulent environments—A conceptual model for managing supply chain network risk", *International Journal of Production Economics,* 119(2), pp. 247-258.

Valdés-Llaneza, A. and García-Canal, E. J. M. I. R. (2006) "Direct competition, number of partners and the longevity of stakes in joint ventures", 46(3), pp. 307-326.

Van Den Bosch, F. A., Volberda, H. W. and De Boer, M. (1999) "Coevolution of firm absorptive capacity and knowledge environment: Organizational forms and combinative capabilities", *Organization Science,* 10(5), pp. 551-568.

Vanpoucke, E., Vereecke, A. and Muylle, S. (2017) "Leveraging the impact of supply chain integration through information technology", *International Journal of Operations & Production Management,* 37(4), pp. 510-530.

Venkatesh, V. and Bala, H. (2012) "Adoption and Impacts of Interorganizational Business Process Standards: Role of Partnering Synergy", *Information Systems Research,* 23(4), pp. 1131-1157.

Venkatesh, V. and Goyal, S. (2010) "Expectation Disconfirmation and Technology Adoption: Polynomial Modeling and Response Surface Analysis", *MIS Quarterly,* 34(2), pp. 281-303.

Villena, V. H., Revilla, E. and Choi, T. Y. (2011) "The dark side of buyer–supplier relationships: A social capital perspective", *Journal of Operations Management,* 29(6), pp. 561-576.

Wang, E. T. G., Chou, F. K. Y., Lee, N. C. A. and Lai, S. Z. (2014) "Can intrafirm IT skills benefit interfirm integration and performance?", *Information & Management,* 51(7), pp. 924-938.

Wernerfelt, B. (1984) "A resource-based view of the firm", *Strategic Management Journal,* 5(2), pp. 171-180.

Whipple, J. M. and Russell, D. (2007) "Building supply chain collaboration: a typology of collaborative approaches", *The International Journal of Logistics Management,* 18(2), pp. 174-196.

Wu, I.-L. and Chang, C.-H. (2012) "Using the balanced scorecard in assessing the performance of e-SCM diffusion: A multi-stage perspective", *Decision Support Systems,* 52(2), pp. 474-485.

Wu, W. p. (2008) "Dimensions of social capital and firm competitiveness improvement: The mediating role of information sharing", *Journal of Management Studies,* 45(1), pp. 122-146.

Young-Ybarra, C. and Wiersema, M. (1999) "Strategic Flexibility in Information Technology Alliances: The Influence of Transaction Cost Economics and Social Exchange Theory", *Organization Science,* 10(4), pp. 439-459.

Zaefarian, G., Kadile, V., Henneberg, S. C. and Leischnig, A. (2017) "Endogeneity bias in marketing research: Problem, causes and remedies", *Industrial Marketing Management,* 65(Supplement C), pp. 39-46.

Zhang, C. and Dhaliwal, J. (2009) "An investigation of resource-based and institutional theoretic factors in technology adoption for operations and supply chain management", *International Journal of Production Economics,* 120(1), pp. 252-269.

Zhang, C., Xue, L. and Dhaliwal, J. (2016a) "Alignments between the depth and breadth of inter-organizational systems deployment and their impact on firm performance", *Information & Management,* 53(1), pp. 79-90.

Zhang, X., Pieter van Donk, D. and van der Vaart, T. (2011) "Does ICT influence supply chain management and performance? A review of survey-based research", *International Journal of Operations & Production Management,* 31(11), pp. 1215-1247.

Zhang, X., Van Donk, D. P. and van der Vaart, T. (2016b) "The different impact of inter-organizational and intra-organizational ICT on supply chain performance", *International Journal of Operations & Production Management,* 36(7), pp. 803-824.

Zhong, R. Y., Xu, X., Klotz, E. and Newman, S. T. (2017) "Intelligent Manufacturing in the Context of Industry 4.0: A Review", *Engineering,* 3(5), pp. 616-630.

Zhou, K. Z., Zhang, Q., Sheng, S., Xie, E. and Bao, Y. (2014) "Are relational ties always good for knowledge acquisition? Buyer–supplier exchanges in China", *Journal of Operations Management,* 32(3), pp. 88-98.

Zhu, K. and Kraemer, K. L. (2002) "e-Commerce Metrics for Net-Enhanced Organizations: Assessing the Value of e-Commerce to Firm Performance in the Manufacturing Sector", *Information Systems Research,* 13(3), pp. 275-295.

Zhu, K., Kraemer, K. L., Gurbaxani, V. and Xu, S. X. (2006a) "Migration to Open-Standard Interorganizational Systems: Network Effects, Switching Costs, and Path Dependency", *Mis Quarterly,* 30(Special Issue on Standard Making), pp. 515-539.

Zhu, K., Kraemer, K. L. and Xu, S. (2006b) "The Process of Innovation Assimilation by Firms in Different Countries: A Technology Diffusion Perspective on E-Business", *Management Science,* 52(10), pp. 1557-1576.

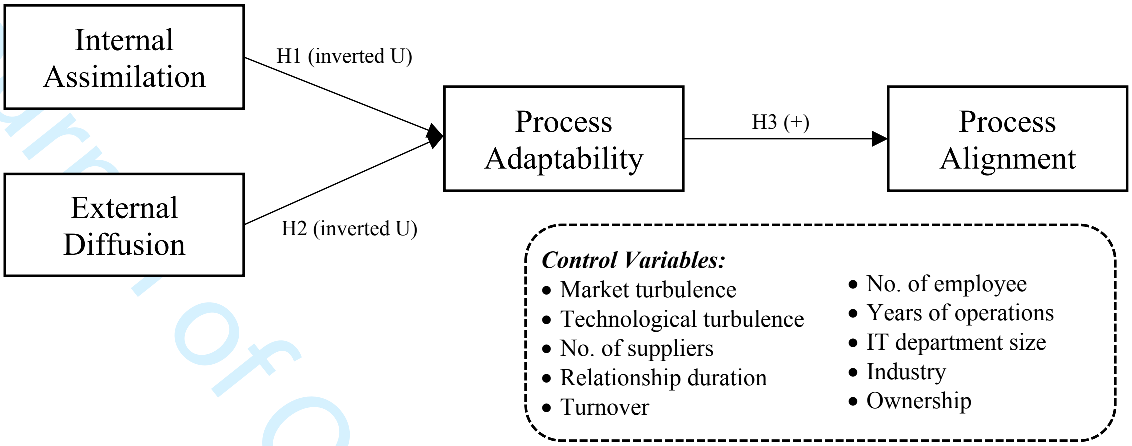

Figure 1. Research Model

Table 1. Sample Demographics and Respondent Profile (N = 308)

Sample Demographics					
	Frequency	Percentage		Frequency	Percentage
Industry			**Turnover**		
Automobiles & Components	21	6.82%	< 25 Million	32	10.39%
Electronical & Electronics	71	23.05%	25–100 Million	72	23.38%
Materials/Metals/Chemicals	93	30.19%	100-300 Million	63	20.45%
Energy	13	4.22%	> 300 Million	141	45.78%
Health Care	28	9.09%	**Employee**		
Equipment & Machinery	46	14.94%	<160	34	11.04%
Consumer Durables & Apparel	22	7.14%	160-1000	161	52.27%
Others	14	4.55%	> 1000	113	36.69%
Years of Operation			**Operation Scope**		
≦ 5 Years	15	4.87%	Multinational Organization	94	43.12%
6-10 Years	127	41.23%	Non-multinational Organization	214	98.17%
≧ 10 Years	166	53.90%			
Organization Type (Ownership)			**Size of IT Department**		
State-owned (fully/partly owned)	36	11.69%	≦ 5	58	18.83%
Privately-owned	145	47.08%	6 – 10	90	29.22%
Foreign Controlled	127	41.23%	11– 15	93	30.19%
			≧ 16	67	21.75%

Respondent Profile					
	Frequency	Percentage		Frequency	Percentage
Position			**Years of Working**		
CEO/President	3	0.97%	≦5 Years	89	28.90%
Senior executive/Vice President	122	39.61%	6-10 Years	210	68.18%
IT Manager/CIO/CTO	72	23.38%	≧ 11 Years	9	2.92%
Supply Chain/Operations Manager/ COO	111	36.04%			

Table 2. Questionnaire Items and Confirmatory Factor Analysis

Construct and items		Standardized loadings	Composite Reliability	AVE
OSIOS Enabled Process Alignment (ALM)* *Adapted from Tang and Rai (2012) and Rai and Tang (2010)*				
Through implementing OSIOS…				
ALM1	we can closely coordinate interdependent processes with specific partners.	0.851		
ALM2	we can make interdependent operating procedures and routines (e.g., manufacturing, bar coding, packaging, shipping, etc.) to be highly visible among specific partners and us.	0.688	-	-
ALM3	we can jointly optimize related operating processes with specific partners. ALM4	0.714		
ALM1	we can closely coordinate interdependent processes with specific partners.	0.866		
OSIOS Enabled Process Adaptability (ADP) *Adapted from Gibson and Birkinshaw (2004) and Im and Rai (2008)*				
Through implementing OSIOS…				
ADP1	we can adapt current supply chain relationships to respond quickly to changes in our markets.	0.838		
ADP2	we can adapt existing business processes rapidly to respond to shifts in our business priorities.	0.821	0.868	0.686
ADP3	we can facilitate reconfiguration of activities to respond to changes in the external environments.	0.827		
Internal Assimilation (INT)* *Adapted from Zhu et al. (2006b), Zhang and Dhaliwal (2009) and Zhang et al. (2016a)*				
Please rate the extent to which your firm has been using OSIOS to conduct the following supply chain activities…				
INT1	Supplier selection (getting quotes, bid etc.)	0.928		
INT2	Purchase order processing	0.907	-	-
INT3	Procurement from suppliers (distribution, warehouse, shipping, logistics etc.)	0.944		
External Diffusion (EXT) *Adapted from Premkumar et al. (1994), Premkumar and Ramamurthy (1995), Zhang et al. (2016a), and Zhang and Dhaliwal (2009)*				
Please indicate the percentage of total transactions or inter-firm interactions that your firm has performed through OSIOS…				
EXT1	Percent of total supply chain partners who interact with your organization through the system	0.968		
EXT2	Percent of total supply chain partner transactions done through the system	0.983	0.983	0.949
EXT3	Percent of overall interactions with supply chain partners carried out through the system	0.973		
Market Turbulence (MT) *Adapted from Calantone et al. (2003), Kandemir et al. (2006) and Trkman and McCormack (2009)*				
Please indicate the extent to which you agree with the following statements regarding the principal market your company is operating in…				
MT1	We continuously cater too many new customers.	0.804		
MT2	Our customers tend to look for new products all the time.	0.681	0.803	0.577
MT3	New customers tend to have product-related needs that differ from our existing customers.	0.788		
Technological Turbulence (TT) *Adapted from Kandemir et al. (2006), Koo et al. (2006) and Trkman and McCormack (2009)*				
Please indicate the extent to which you agree with the following statements regarding the principal market your company is operating in…				
TT1	It is very difficult to forecast where the technology in our industry will be in the next 2–3 years.	0.883		
TT2	In our principal industry the modes of production and service often change.	0.887	0.876	0.704
TT3	The rate of product/service obsolescence in our industry is very high.	0.737		

* Formative Constructs

Table 3. Discriminant Validity, Means, Standard Deviations, and Correlations

	Mean	SD	1	2	3	4	5	6	7	8	9	10
1. Process Alignment	4.698	0.780	-									
2. Process Adaptability	4.925	0.758	0.695**	**0.828**								
3. Internal Assimilation	3.961	0.980	0.577**	0.532**	-							
4. External Diffusion	4.518	1.800	0.638**	0.532**	0.691**	**0.974**						
5. Market Turbulence	5.190	0.645	0.439**	0.303**	0.363**	0.453**	**0.760**					
6. Technological Turbulence	5.447	0.647	0.407**	0.281**	0.322**	0.486**	0.711**	**0.839**				
7. Number of Suppliers	119.344	119.350	0.062	0.034	0.161**	0.217**	-0.118*	-0.092	-			
8. Relationship Duration	6.107	2.653	0.258**	0.208**	0.271**	0.289**	-0.017	0.005	0.342**	-		
9. Turnover	NA	NA	0.388**	0.287**	0.375**	0.454**	0.077	0.008	0.376**	0.423**	-	
10. Ownership	NA	NA	0.105	0.096	0.191**	0.285**	0.113*	0.045	-0.201**	-0.003	0.042	-
11. Industry	NA	NA	-0.056	-0.060	-0.100	-0.145*	-0.006	-0.033	-0.094	-0.190**	-0.146*	-0.001

* $p < 0.05$, ** $p < 0.01$

Note: The square roots of the AVEs were shown as figures on the diagonal

Table 4. Cross Loadings

	ADP	ALM	EXT	INT	TT	MT
ADP1	**0.838**	0.578	0.487	0.456	0.331	0.388
ADP2	**0.821**	0.561	0.394	0.465	0.199	0.327
ADP3	**0.827**	0.556	0.442	0.403	0.086	0.252
ALM1	0.621	**0.851**	0.602	0.497	0.361	0.502
ALM2	0.593	**0.688**	0.457	0.549	0.120	0.324
ALM3	0.482	**0.714**	0.478	0.452	0.246	0.480
ALM4	0.538	**0.866**	0.516	0.365	0.442	0.613
EXT1	0.483	0.575	**0.968**	0.660	0.414	0.507
EXT2	0.540	0.653	**0.983**	0.670	0.424	0.535
EXT3	0.532	0.663	**0.973**	0.664	0.392	0.548
INT1	0.495	0.522	0.706	**0.928**	0.238	0.423
INT2	0.484	0.483	0.631	**0.907**	0.286	0.435
INT3	0.503	0.479	0.577	**0.944**	0.199	0.397
TT1	0.199	0.390	0.451	0.294	**0.883**	0.577
TT2	0.263	0.438	0.360	0.232	**0.887**	0.510
TT3	0.138	0.187	0.174	0.012	**0.737**	0.271
MT1	0.380	0.600	0.459	0.395	0.237	**0.804**
MT2	0.254	0.360	0.324	0.284	0.679	**0.681**
MT3	0.235	0.469	0.438	0.323	0.517	**0.788**

Table 5. Results of Hypothesis Testing

	Process Adaptability			**Process Alignment**	
	(1)	(2)	(3)	(4)	(5)
Market Turbulence	0.033	0.046	0.066	0.201**	0.168**
	(0.62)	(0.88)	(1.25)	(4.69)	(4.17)
Technological Turbulence	0.036	0.054	-0.012	0.019	0.070
	(0.65)	(0.96)	(-0.21)	(0.44)	(1.70)
Internal Assimilation	0.265**	0.236**	0.317**		
	(5.11)	(4.44)	(5.25)		
External Diffusion	0.241**	0.248**	0.215**		
	(5.06)	(5.14)	(4.17)		
Internal Assimilation^2		**-0.079****	**-0.076****		
		(-3.00)	(-2.79)		
External Diffusion^2`		-0.006	-0.013		
		(-0.12)	(-0.26)		
Process Adaptability				**0.574****	**0.501****
				(18.17)	**(16.29)**
No. of Suppliers			-0.126**		-0.048
			(-2.68)		(-1.36)
Relationship Duration			0.0333		0.098**
			(0.71)		(2.75)
Turnover			-0.0619		0.148**
			(-1.06)		(3.39)
No. of Employee			0.0320		-0.120*
			(0.52)		(-2.51)
IT Department Size			0.0419		0.0729
			(0.71)		(1.59)
Years of Operation			0.028		0.005
			(0.69)		(0.16)
Ownership (State)			0.0529		0.119
			(0.42)		(1.24)
Ownership (Private)			0.212*		0.011
			(2.49)		(0.19)
IND1[c]			0.327		-0.188
			(1.71)		(-1.26)
IND2			0.055		-0.008
			(0.75)		(-0.14)
IND3			0.031		-0.00141
			(0.64)		(-0.04)
IND4			0.011		-0.091*
			(0.21)		(-2.18)
IND5			0.056		0.0231
			(1.32)		(0.71)
IND6			-0.017		0.024
			(-0.57)		(1.09)
IND7			0.0122		-0.0267
			(0.54)		(-1.53)
Constant	4.981**	5.054**	4.845**	4.707**	4.740**
	(140.01)	(84.21)	(34.35)	(161.11)	(46.43)
R^2	0.333	0.340	0.380	0.557	0.640
F	43.72**	31.69**	9.83**	168.5**	35.86**

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$

[b] For ownership dummies, foreign-controlled firms served as the base group relative to the effects other dummies.

[c] IND1 = automobiles and components industry; IND2 = electrical and electronics; IND3 = materials and chemicals industry; IND4 = energy industry, IND5 = healthcare and healthcare machinery industry; IND6 = machinery and equipment industry, IND7 = consumer durables and apparel industry. Others served as the base group relative to the effects other industry dummies.

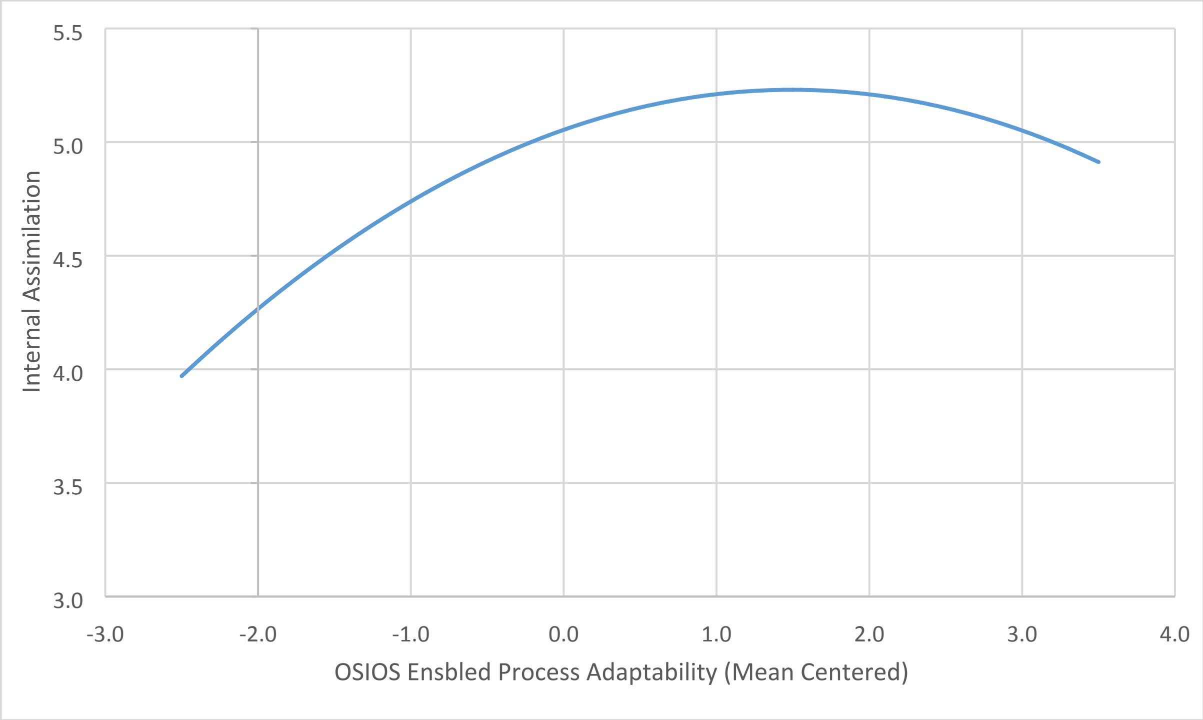

Figure 2. Curvilinear Relationship Between Internal Assimilation and Process Adaptability

Appendix I. Endogeneity Test

It is possible that OSIOS deployment, i.e., internal assimilation and external diffusion, is endogenously affected by the level of process adaptability, which may cause biased and inconsistent results (Greene, 2003; Guide and Ketokivi, 2015). A two-stage least squares (2SLS) regression with instrumental variables was used to deal with the potential endogeneity concern (Liu *et al.*, 2016). The variables that were not significantly associated with process adaptability (i.e., market turbulence, technological turbulence, relationship duration, turnover, number of employees, IT department size, and years of operations) (see Table 6) were identified as the instrumental variables for internal assimilation and external diffusion (Bellamy *et al.*, 2014; Liu *et al.*, 2016). To conduct 2SLS estimation, internal assimilation and external diffusion should be regressed on all the instrumental variables and control variables at the first stage. The R^2 for internal assimilation and external diffusion are 0.342 (Model 1) and 0.570 (Model 2) respectively. These values are significantly higher than the R^2 of the regressions with only the control variables ($R^2_{\text{Internal Assimilation}}$ =0.072, $R^2_{\text{External Diffusion}}$ = 0.175), which lends support for using the aforementioned variables as effectives instrumental variables (Liu *et al.*, 2016). At the second step, the predicted values of internal assimilation and external diffusion were applied to test the relationship between them and process adaptability. As shown in Model 3 and 4, the effects of the predicted values of internal assimilation (β = 0.260, p <0.01) and external diffusion assimilation (β = 0.642, p <0.01) were significantly positive.

After performing the 2SLS, a Durbin–Wu–Hausman postestimation test of endogeneity (Davidson and MacKinnon, 1993) was conducted by testing an augmented regression which included additional error terms of internal assimilation and diffusion obtained from the first stage of 2SLS. The coefficients of the error terms ($\beta_{Internal\ Assimilation}$ =0.051, p =0.746; $\beta_{External\ Diffusion}$ = -0.054, p =0.385) were shown to be insignificantly related to process adaptability. The result suggests that the endogeneity test associated with internal assimilation and external diffusion was insignificant. Thus the null hypothesis that internal assimilation and external diffusion are exogenous cannot be rejected (Bellamy *et al.*, 2014; Liu *et al.*, 2016). Therefore, we can conclude that the findings in our original model were unlikely to be unduly influenced by endogeneity.

Table A1. 2SLS Model Testing for Endogeneity

	Internal Assimilation	External Diffusion	OSIOS enabled Adaptability	
	Model 1 (OLS)	Model 2 (OSLS)	Model 3 (2SLS)	Model 4 (2SLS)
Ownership (State)	-0.276*	-0.864**	-0.0369	-0.126
	(-2.07)	(-3.51)	(-0.27)	(-0.91)
Ownership (Private)	-0.124	-0.992**	0.171	-0.0137
	(-1.47)	(-6.31)	(1.75)	(-0.15)
IND1	-0.0252	-0.0480	0.364	0.376
	(-0.12)	(-0.12)	(1.68)	(1.70)
IND2	-0.0728	-0.134	0.0675	0.0654
	(-0.90)	(-0.90)	(0.81)	(0.77)
IND3	-0.0327	-0.0147	0.0350	0.0403
	(-0.62)	(-0.15)	(0.64)	(0.73)
IND4	-0.102	-0.167	0.0211	0.0180
	(-1.73)	(-1.54)	(0.35)	(0.29)
IND5	0.0301	-0.161	0.0707	0.0133
	(0.66)	(-1.90)	(1.50)	(0.27)
IND6	-0.0320	0.0193	-0.0166	-0.00455
	(-1.02)	(0.33)	(-0.51)	(-0.14)
IND7	-0.020	-0.061	0.0159	0.0119
	(-0.82)	(-1.33)	(0.61)	(0.45)
No. of Employee[a]	0.078	0.201		
	(1.19)	(1.66)		
IT department size[a]	0.105	0.172		
	(1.64)	(1.45)		
Years of Operation[a]	-0.067	-0.087		
	(-1.52)	(-1.07)		
Market Turbulence[a]	0.103	0.248*		
	(1.81)	(2.36)		
Technological Turbulence[a]	0.017	0.707**		
	(0.29)	(6.62)		
Relationship Duration[a]	0.201**	0.239*		
	(4.04)	(2.58)		
Turnover[a]	0.183**	0.428**		
	(2.98)	(3.76)		
Internal Assimilation[a]				0.642**
				(6.57)
External Diffusion			0.260**	
			(7.51)	
R^2	0.342	0.570	0.210	0.179
F	9.445**	24.050**	7.885**	6.477**

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$

Appendix II. Robustness Test

Table A2. Structural Equation Modelling with FIML Estimation

	Process Adaptability			Process Alignment	
	(1)	(2)	(3)	(4)	(5)
Market Turbulence	0.042	0.052	0.065	0.220**	0.180**
	(0.80)	(0.99)	(1.23)	(5.12)	(4.46)
Technological Turbulence	0.042	0.053	-0.007	0.030	0.081*
	(0.76)	(0.95)	(-0.13)	(0.70)	(1.98)
Internal Assimilation	0.242**	0.218**	0.295**		
	(4.59)	(4.00)	(4.84)		
External Diffusion	0.228**	0.235**	0.207**		
	(4.70)	(4.75)	(3.96)		
Internal Assimilation^2		**-0.056***	**-0.056***		
		(-2.07)	**(-2.01)**		
External Diffusion^2		0.012	0.005		
		(0.22)	(0.09)		
Process Adaptability				**0.485****	**0.423****
				(15.16)	**(13.59)**
No. of Suppliers			-0.127**		-0.055
			(-2.70)		(-1.56)
Relationship Duration			0.0371		0.110**
			(0.79)		(3.08)
Turnover			-0.047		0.157**
			(-0.81)		(3.59)
No. of Employee			0.034		-0.114*
			(0.55)		(-2.37)
IT department size			0.042		0.0806
			(0.72)		(1.76)
Years of Operation			0.026		0.00395
			(0.64)		(0.13)
Ownership (State)			0.022		0.0946
			(0.17)		(0.99)
Ownership (Private)			0.183*		0.006
			(2.14)		(0.09)
IND1			0.334		-0.155
			(1.74)		(-1.04)
IND2			0.054		-0.005
			(0.74)		(-0.10)
IND3			0.03		0.001
			(0.65)		(0.02)
IND4			0.010		-0.094*
			(0.19)		(-2.27)
IND5			0.054		0.0261
			(1.28)		(0.81)
IND6			-0.017		0.023
			(-0.58)		(1.01)
IND7			0.011		-0.027
			(0.51)		(-1.54)
Constant	4.977**	5.013**	4.827**	4.707**	4.740**
	(139.87)	(82.16)	(34.16)	(161.11)	(46.43)
R^2	0.334	0.343	0.381	0.568	0.647

Table A3. 2SLS analysis with LIML Estimation

	Process Adaptability			Process Alignment	
	(1)	(2)	(3)	(4)	(5)
Market Turbulence	0.042	0.052	0.064	0.146**	0.107
	(0.75)	(0.96)	(1.22)	(2.79)	(1.91)
Technological Turbulence	0.042	0.052	-0.008	-0.0142	0.00875
	(0.82)	(1.00)	(-0.13)	(-0.27)	(0.15)
Internal Assimilation	0.242**	0.218**	0.295**		
	(5.27)	(4.51)	(5.57)		
External Diffusion	0.228**	0.235**	0.207**		
	(4.96)	(4.87)	(3.89)		
Internal Assimilation^2		**-0.056***	**-0.056**†		
		(-2.03)	**(-1.93)**		
External Diffusion^2`		0.011	0.005		
		(0.22)	(0.09)		
Process Adaptability				**0.838****	**0.918****
				(11.27)	**(8.99)**
No. of Suppliers			-0.127**		-0.010
			(-2.66)		(-0.21)
Relationship Duration			0.0371		0.0356
			(0.83)		(0.71)
Turnover			-0.0471		0.100
			(-0.85)		(1.68)
No. of Employee			0.0339		-0.154*
			(0.65)		(-2.37)
IT department size			0.042		0.032
			(0.71)		(0.51)
Years of Operation			0.026		0.010
			(0.65)		(0.24)
Ownership (State)			0.0221		0.248
			(0.15)		(1.88)
Ownership (Private)			0.183		0.0418
			(1.91)		(0.51)
IND1			0.334		-0.366
			(1.90)		(-1.78)
IND2			0.0543		-0.0189
			(0.84)		(-0.24)
IND3			0.0310		-0.0128
			(0.75)		(-0.26)
IND4			0.0103		-0.0722
			(0.20)		(-1.28)
IND5			0.0538		0.00739
			(1.28)		(0.17)
IND6			-0.0166		0.0339
			(-0.65)		(1.12)
IND7			0.0116		-0.0258
			(0.62)		(-1.09)
Constant	4.711**	4.713**	4.728**	4.711**	4.728**
	(136.59)	(126.19)	(34.27)	(136.59)	(34.27)
R^2	0.334	0.343	0.381	0.399	0.356
adj. R^2	0.325	0.330	0.336	0.393	0.316

References

Bellamy, M. A., Ghosh, S. and Hora, M. (2014) "The influence of supply network structure on firm innovation", *Journal of Operations Management,* 32(6), pp. 357-373.

Davidson, R. and MacKinnon, J. (1993) *Estimation and Inference in Econometrics.* OUP Catalogue, Oxford University Press.

Greene, W. H. (2003) *Econometric Analysis.* New Jersey: Prentice Hall.

Guide, V. D. R. and Ketokivi, M. (2015) "Notes from the Editors: Redefining some methodological criteria for the journal", *Journal of Operations Management,* 37(1), pp. v-viii.

Liu, H., Wei, S., Ke, W., Wei, K. K. and Hua, Z. (2016) "The configuration between supply chain integration and information technology competency: A resource orchestration perspective", *Journal of Operations Management,* 44(Supplement C), pp. 13-29.