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The impact of product complexity and variety on supply chain integration

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Abstract

Purpose – The purpose of this paper is to examine the antecedents of supply chain integration (SCI) at the product level. More specifically, it aims to show the relationship between product-level characteristics (i.e. product complexity and product variety) and different dimensions of SCI (i.e. internal, supplier and customer integration).

Design/methodology/approach – A survey-based research design is developed to measure different dimensions of SCI, product complexity and product variety. The authors use structural equation modelling to test the related hypotheses.

Findings – This research shows that internal integration is an enabler to supplier and customer integration. The results also show that under high product complexity, firms tend to implement internal and supplier integration, while product complexity does not have a direct impact on customer integration. Product variety is confirmed to be positively related to all dimensions of SCI.

Originality/value – This paper contributes to the SCI literature by first, providing empirical evidence which supports the study of the product design-supply chain interface; and second, exploring the relationships between product complexity, variety and internal, supplier and customer integration based on a governance view.

Keywords Product complexity, Structural equation modelling, Supply chain integration, Internal integration, Supplier integration, Customer integration, Product variety

Paper type Research paper

Introduction

Supply chain integration (SCI), which can be divided into internal, supplier and customer integration, has attracted growing attention from both academic researchers and practitioners due to its strategic importance to the competitiveness of organizations. Recent studies have confirmed the positive effects of SCI on operational performance (e.g. manufacturing costs, quality, delivery and flexibility) and business performance (e.g. financial and market performance) (Ellinger *et al.*, 2000; Germain and Iyer, 2006; Flynn *et al.*, 2010; Leuschner *et al.*, 2013; Mackelprang *et al.*, 2014). However, it has been observed that supply chain practices differ between organizations; each enterprise does not necessarily implement all the SCI dimensions of internal, customer, and supplier integration. Van Donk and Van der Vaart (2004) point out that few studies attempt to explore "what it is

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exactly that explains the differences in integrative practices in the supply chain" (p. 108). Chen *et al.* (2009) also call for "research on integration drivers or antecedents" (p. 75).

This paper seeks to explore the key antecedents that drive the implementation of internal, supplier and customer integration at the product level, in response to these calls from Van Donk and Van der Vaart (2004) and Chen *et al.* (2009). Prior studies have recognized the relationship between product design and supply chain practices. For example, Fisher (1997) advocates: "before devising a supply chain, consider the nature of the demand for your products" (p. 106). Fine (2000) and Ellram *et al.* (2007) focus on the integration of supply chain design into product and process design, referred to as three-dimensional (i.e. product-process-supply chain) concurrent engineering. Since product design is directly associated with supply chain risk (Khan *et al.*, 2008; Lin and Zhou, 2011), it is recommended that firms consider product characteristics in the development of supply chain strategies. Khan and Creazza (2009) also emphasize the impact of product design on supply chain management which arises from the modern shift from a supplier-driven to a demand-driven supply chain; these authors propose approaches for managing the product design-supply chain interface using case studies and cross-case analysis. In the IJPDLM 45th Anniversary Issue, Stevens and Johnson (2016) summarize substantial changes of SCI from past to present and point out that market and product dynamics is one main driver for the change. However, empirical evidence for the relationship between product design and SCI remains very limited.

Particularly in today's business environment, manufacturers are faced with trends toward innovation, globalization of markets, increasingly demanding customers and technological advancement. Firms are encouraged to provide a growing mix of products tailored to customers' individual needs (Perona and Miragliotta, 2004), and this implies a need for a wider product variety. However, the difficulties of manufacturing these products tend to increase due to the large number of product components and the extensive interactions among these components, and this gives rise to a high degree of product complexity (Novak and Eppinger, 2001). The product variety and complexity in manufacturing has created numerous new challenges for supply chain management which aims to improve flexibility and responsiveness to customer demands in a timely and cost efficient manner (Randall and Ulrich, 2001; Perona and Miragliotta, 2004; Khan and Creazza, 2009; Inman and Blumenfeld, 2014; Bode and Wagner, 2015). This study therefore focuses on these two aspects of product design, i.e., product complexity and variety, and uses an empirical approach to examine their effects on the three dimensions of SCI.

To proceed further, this paper discusses the relationship between product complexity and variety and the internal, supplier and customer aspects of integration from the perspective of governance theory, complemented with a knowledge-based view (KBV). Drawing upon transaction cost theory (Williamson, 1981, 1985), several studies have discussed the governance view of SCI (Das *et al.*, 2006; Richey *et al.*, 2010; Cao and Zhang, 2011; Danese and Bortolotti, 2014). As one type of hybrid governance structure, SCI can aid in reducing the "costs of running the system" (Das *et al.*, 2006) such as negotiation, coordination and monitoring costs, and can thus achieve the same advantages as vertical integration (Danese and Bortolotti, 2014) in safeguarding specific assets, processing complex information, and adapting to uncertainty through familiarity and trust among supply chain partners. Especially in the case of products with a high degree of complexity and variety, transaction and coordination costs across the whole supply chain increase with supply chain risk, which may demand integration among internal functional departments and external suppliers and customers. Additionally, product complexity and variety call for the integration of diversified knowledge. Prior work using KBV has noted that an integrative structure can facilitate the transfer and creation of knowledge within and across organizations (Kogut and Zander, 1992). The use of governance theory complemented with

KBV provides the necessary theoretical underpinnings to fully understand how product complexity and variety influence firms' decisions on SCI.

Overall, we aim to investigate the impacts of product complexity and variety on the three dimensions of SCI, which can provide empirical knowledge on why firms implement internal, supplier and customer integration based on product characteristics. This study contributes to the existing literature regarding the product design-supply chain interface and provides insights for managers to enhance internal, suppliers and customer integration under conditions of high levels of product complexity and variety. In the following section, we develop a theoretical framework, which is then tested using a data set collected from 843 manufacturers. Finally, we discuss the major findings and implications of this study and draw conclusions.

Theoretical background and hypotheses development

The governance view of SCI

The term "integration," in Webster's Third New International Dictionary, is defined as "the unified control of a number of successive or similar economic or especially industrial processes formerly carried on independently" (William, 1966), and this shows that the essence of integration is governance. Drawing upon transaction cost theory, governance structure such as market, hybrid and hierarchy indicates the institutional arrangements for specific transactional relations (Williamson, 1985; Ebers and Oerlemans, 2013). Particularly when using a hybrid structure, the firm needs to employ both formal contracts and informal relational mechanisms to mitigate opportunistic behavior and foster continuance of the exchange (Poppo and Zenger, 2002). As Ménard (2004) notes, external hybrids comprise "a great diversity of agreements among legally autonomous entities doing business together, mutually adjusting with little help from the price system, and sharing or exchanging technologies, capital, products, and services, but without a unified ownership" (p. 348). In the context of supply chains, integration enables manufactures, customers and suppliers within the supply chain network to operate as a single unified and cohesive entity even in the absence of ownership (Bagchi and Skjoett-Larsen, 2002). We therefore argue that SCI forms a type of hybrid governance structure which is dominated by the manufacturing firm in order to coordinate and control relationships with internal functions and external suppliers and customers, through formal or informal governance arrangements (e.g. incentive mechanisms, specific investment, administrative control and adaptation to contingencies).

Meanwhile, Barki and Pinsonneault (2005) find that integration "essentially represents a structural and relational characteristic of a given organization or between organizations" (p. 166). This structural characteristic of integration aligns with the "interaction" philosophy proposed by Kahn and Mentzer (1996), which indicates formal communication and exchange of information. The relational characteristic corresponds to another philosophy referred to as "collaboration" by Kahn and Mentzer (1996), which suggests that partners actively participate in an information exchange based on mutual benefit, joint action and collaborative attitudes. Using a combination of these structural and relational characteristics, most scholars recognize information sharing, collaborative approaches, joint decision making and system coupling as the four main elements of SCI (Ellinger *et al.*, 2000; Narasimhan and Kim, 2002; Gimenez and Ventura, 2005; Flynn *et al.*, 2010).

In the current study, the governance view of SCI is explored in order to generate a new perspective on these four primary elements. In other words, we attempt to explain theoretically the reasons for supply chain partners exhibiting integration behaviors such as information sharing, collaboration, joint decision making and system coupling under an integrative structure, and thereby aim to provide a theoretical foundation for the measurement of SCI.

Information sharing. "Information sharing is described as the heart, lifeblood, nerve center, essential ingredient, key requirement, and foundation" of integration in the supply chain management literature (Cao and Zhang, 2011, p. 166). Koufteros *et al.* (2005) view integration as a structural mechanism for dealing with information processing and coordinating requirements. Through the unified control of internal and external processes, manufacturers can build the administrative structure, rules, regulations, procedures and technologies necessary to promote the collection, processing, exchange and distribution of information (Daft and Lengel, 1986). Meanwhile, the relational mechanisms of the integration structure such as mutual benefits and shared values (Cao and Zhang, 2011) improve the willingness of firms to share information.

Collaborative approaches. In the context of SCI, although external partners maintain autonomy, they are highly interdependent. Kahn and Mentzer (1998) assert that interaction and collaboration are two primary components of integration. Based on a mutually acceptable goal, the separate members of the chain work together in a collaborative manner (Pagell, 2004). A relationship is built for SCI which cannot be exactly imitated or substituted (Mentzer *et al.*, 2001), and this constitutes the competitive advantage. Additionally, in order to strengthen the commitment to the relationship, the payment structure is shifted from a predetermined contractual price to a cost and revenue sharing arrangement. According to Mayer and Teece (2008), traditional chain members are paid a specific price per unit produced after delivery, while partners in the integration structure should agree on an up-front investment cost and share the loss or revenue of the products together. This kind of cost and revenue sharing arrangement serves as a mechanism for aligning incentives among supply chain partners (Cao and Zhang, 2011) and motivates them to participate in the relationship.

Joint decision making. This characteristic overlaps to some degree with collaborative approaches; both emphasize joint actions, although joint decision making focuses more on the allocation of decision rights, especially when contingencies arise. In the supply chain context, we describe contingencies as the modification of products and processes. In view of bounded rationality, supply chain members cannot specify all possible contingencies in the contracts, resulting in ongoing negotiations on specifications and prices (Grover and Malhotra, 2003). Transaction cost theory holds that adaptations to contingencies are supported by relational contract law in the hybrid structure, which means that partners' behaviors are based on mutual agreements rather than litigation in order to achieve greater flexibility (Williamson, 1981). Joint decision making is one such mutual agreement through which the different departments within manufacturing firms and their partners express their willingness to engage in inter-organizational collaboration.

System coupling. To facilitate integration, specific investments in human and physical assets should be made in order to align the manufacturing and management processes across suppliers and customers. Kim and Lee (2010) note that the premise for information sharing and collaboration on forecasting and planning is to make communication systems compatible with each other. In addition, the integration of physical flows also requires a close coupling of production systems such as just-in-time (JIT), Kanban, and continuous replenishment between manufacturers and their external partners (Cagliano *et al.*, 2006). Subramani and Venkatraman (2003) show that suppliers using JIT systems need to make significant changes to their own production planning and manufacturing processes in order to deliver the precise lot sizes of components required by automobile assemblers. This kind of relation-specific investment in system coupling cannot only facilitate the integration of information flows and physical flows, but also enhance the trust and commitment between partners and hence increase cooperative behavior (Lui *et al.*, 2009).

Internal integration and external integration

As the three dimensions of SCI, internal, supplier and customer integration have been widely discussed in previous literature (Flynn *et al.*, 2010; Wong *et al.*, 2011; Zhao *et al.*, 2011;

Schoenherr and Swink, 2012). While internal integration refers to the unified control of product design, procurement, production, sales and distribution functions within the firm (Germain and Iyer, 2006) by breaking down functional barriers, the aspects of supplier and customer integration emphasize collaboration with the upstream and downstream partners (Wong *et al.*, 2011) through the overcoming of organizational barriers. Both internal and external integration have been shown to have positive effects on performance in terms of cost, delivery, quality and flexibility (Leuschner *et al.*, 2013; Mackelprang *et al.*, 2014).

From a governance view, internal integration can facilitate functional cooperation through ownership. We recognize internal integration as a sign of a firm's governance capability in terms of processing complex information, making rational decisions, and guarding against external exchange hazards. With regard to external integration, prior researchers have acknowledged its positive influences, but insufficient attention has been paid to the related barriers or hazards. The governance theory suggests that exchanges with external partners are always accompanied by transaction risks and coordination difficulties due to information asymmetry, bounded rationality, and opportunistic behavior, which may result in the breakdown of close relationships (Grover and Malhotra, 2003; Perols *et al.*, 2013). It is conjectured here that internal integration is a prerequisite for and the foundation of better coordination and control of the behaviors and resources of external partners in the integration processes.

First, transaction cost theory indicates that most external exchanges with supply chain members are characterized by incomplete, imperfect or asymmetric information whereby parties tend to be opportunistic (Williamson, 1985; Hobbs, 1996). It can be inferred that insufficient information on suppliers and customers impedes manufacturers' decisions on external integration practices. In manufacturing firms, the sales and purchasing departments hold information on customers and suppliers, respectively, which can be viewed as a bridge between focal firms and their customers and suppliers. Internal integration across these different functional departments helps the organization to come to a better understanding of both customers and suppliers, thus improving the situation of information asymmetry to a certain extent. In addition, "internal integration extends the bounded rationality with which decisions are made, as it enables a wider range of personnel to participate in joint evaluations and planning for the use of knowledge content" (Schoenherr and Swink, 2012, p. 102). Since opportunism is one direct factor in relationship breakdown, firms can strengthen control over external partners through internal integration. As a result, a higher level of internal integration is associated with a higher capability of accessing and managing complex transactional information with customers and suppliers, which aids in reducing exchange hazards and facilitates external integration.

Second, while contingencies are inevitable in long-term exchanges with suppliers and customers, they may adversely affect the integrative relationship if improperly handled. Knowledgeable decision-makers or negotiators are essential in directing behaviors, preventing disputes and maintaining an excellent long-term relationship. Internal integration improves the "bounded rationality" of firms through the exchange and integration of knowledge and information across different functional departments, which helps in dealing with potential contingencies, disputes, and conflicts with their suppliers and customers. Information sharing and cooperation across a firm's internal functions enables the identification of critical issues with regard to suppliers and customers (Zhao *et al.*, 2011). Meanwhile, joint decision making between manufacturing, purchasing, and sales departments improves the efficiency and quality of decisions when contingencies arise. Therefore, internal integration serves as a coordination and adaptation mechanism which facilitates a manufacturer's external exchanges.

Third, in order to implement external integration, both the focal firm and its external partners are required to reconfigure their internal operational processes and adjust internal production systems to achieve compatibility (Chen *et al.*, 2009), which can be regarded as their specific investments according to transaction cost theory. The exchange relationship of JIT is a good example of this. On the one hand, it directly indicates that external integration depends on internal integration (Frazier *et al.*, 1988). On the other hand, highly specific investments are needed to satisfy the requirements of the JIT system. Although from governance theory, unilateral specific investments in physical and human assets are expected to exacerbate opportunistic behavior (Handley and Benton, 2012). Lui *et al.* (2009) have shown that mutual asset specificity in fact leads to higher levels of commitment and more cooperative behaviors. As the foundation of collaboration, investments by the focal firm in internal integration enhance the quality of the relationship with their partners and therefore enhance the implementation of external integration.

Based on the above arguments, the following hypotheses are proposed:

H1a. Internal integration is positively related to supplier integration.

H1b. Internal integration is positively related to customer integration.

Product complexity and SCI

Within the area of operations management, the concept of product complexity has been associated with "the number of parts or components needed to build the product" (Inman and Blumenfeld, 2014, p. 1957). Lucchetta *et al.* (2005) and Kaufmann and Carter (2006) also define complexity from a technical perspective, as the difficulty of generating or manufacturing parts or components. Bode and Wagner (2015) have summarized these different definitions in terms of two aspects: structural complexity (number and variety of elements) and operational complexity (interactions between elements). The current study adopts this definition of Bode and Wagner (2015), since structural and operational dimensions present a more comprehensive view of product complexity. Inman and Blumenfeld (2014) consider product complexity as one of the critical risk factors which further influence supply chain strategy. Similarly, this study assumes that manufacturers of complex products need to strengthen SCI implementation in order to govern risk factors incurred by product complexity.

Internal integration is encouraged in manufacturing firms with high levels of product complexity (Kotha and Orne, 1989). One reason for this is that complex products with multiple components are strongly associated with difficulties in design and production (Salvador *et al.*, 2014), and therefore increase transaction and coordination costs between the functional departments. In this case, the purchasing, manufacturing and marketing departments within the firm must work closely together in order to support concurrent engineering and design for manufacturing (Swink, 1998). Moreover, in environments with high product complexity, manufacturers are also required to deal with component inventory and capacity problems (Closs *et al.*, 2010), which results in greater coordination and collaboration between the manufacturing and purchasing departments.

While most researchers have acknowledged the significant effects of product complexity on the internal manufacturing strategy of the firm, few discuss its specific impacts on the external supply chain strategy. A higher level of product complexity is related to higher levels of supply chain risks and disruptions (Inman and Blumenfeld, 2014; Bode and Wagner, 2015), which increase difficulties in coordinating supply and demand. A complex product may contain components or parts which each have different technical specifications and lead times (Lu *et al.*, 2003). The more complex the final product is, the more difficult it is to specify all specifications and production schedules (Kaufmann and Carter, 2006). If the production and delivery of a particular component of a complex product experiences difficulties or delays, this is likely to substantially increase costs. Malucci (2006) has reported that losses to an automotive manufacturer may reach $20,000 per minute if an automotive assembly line is shut down for the lack of a single part. In general, a dual or even multiple sourcing strategy or a buffering policy are recommended for dealing with these disruption risks (Yu *et al.*, 2009). However, for complex products, these approaches will also increase the complexity of the supply chain network as a whole, since they require high levels of coordination with greater numbers of suppliers, and involve more customer approval processes for using the sourced components in production. We therefore infer that for high levels of product complexity, transaction and coordination costs in the exchanges between manufacturers and their external supply chain partners increase, which calls for a close and collaborative relationship.

Specifically, integration which includes information sharing, adequate coordination and collaboration with key external partners is regarded as being effective in preventing and eliminating the uncertainty and supply chain risks arising from product complexity (Narasimhan and Talluri, 2009; Speier *et al.*, 2011). Customer integration enables manufacturers to attain more accurate information on demand in order to specify the quality and quantity requirements of products in more detail (Flynn *et al.*, 2010). Manufacturers also transmit this information to suppliers, which improves the suppliers' understanding and anticipation of the manufacturer's needs (Flynn *et al.*, 2010). The sharing of demand information is also beneficial for suppliers in terms of arranging production and inventory of the parts or components. Therefore, integration with customers and suppliers increases the transparency of the complex information about the product and the production process in the supply chain. Moreover, collaborative approaches such as the sharing of benefits and risks increase the willingness of supply chain partners to exchange critical information and knowledge, thus guaranteeing delivery of components. We conclude that external integration with suppliers and customers through the breaking down of organizational walls is necessary to cope with the negative effects of product complexity.

Furthermore, a KBV supports the governance view in the selection of an integrative structure for firms manufacturing complex products. Kaufmann and Carter (2006) point out that product complexity requires close cooperation between manufacturers and their external partners to achieve the benefits of joint actions, especially in the early stages of development. The KBV suggests that the frequencies and values of knowledge transfer and creation are both much higher in the context of solving a complex problem (Nickerson and Zenger, 2004). Despite the difficulty of knowledge transfer across organizational boundaries (Kogut and Zander, 1992), manufacturers can build a set of organizational structures, rules, principles, routines, channels and procedures through the unified control of supply chain processes and activities to promote the transfer, convergence and creation of knowledge from multiple organizations. When a manufacturing firm achieves this level of integration with its external partners, the supply chain acts as a social community "in which individual and social expertise is transformed into economically useful products and services by the application of a set of higher-order organizing principles" (Kogut and Zander, 1992, p. 384).

We therefore hypothesize that product complexity demands internal, supplier and customer integration, as follows:

H2a. The higher the product complexity, the more likely that manufacturing firms promote internal integration.

H2b. The higher the product complexity, the more likely that manufacturing firms promote supplier integration.

H2c. The higher the product complexity, the more likely that manufacturing firms promote customer integration.

Product variety and SCI

Product variety is defined by Fisher *et al.* (1999) as "the breadth of products that a firm offers at a given time" (p. 197). Randall and Ulrich (2001) refer to this as "the number of different versions of a product offered by a firm at a single point in time" (p. 1588). The definition of Fisher *et al.* (1999) is applied here, since the current research focuses on the variety of product portfolios in the manufacturing firm. Several scholars have associated product variety with product innovations or new product development activities by firms. Indeed, "increasing product variety implies that new products are introduced" (Wan *et al.*, 2012, p. 318). In this study, we posit that SCI is encouraged by a manufacturer with a variety of product portfolios.

It can be inferred that a high level of product variety gives rise to a wide spread of product and production information in the supply chain. For example, for a manufacturer providing automotive products, product variety implies the existence of various models of an automobile (e.g. a Honda Accord vs a Honda Civic) and various options offered for the same model (e.g. engine, satellite navigation and electronic stability control) (Al Zu'Bi and Tsinopoulos, 2012). An excess of product information may result in selection confusion (variety fatigue) for customers and lead to forecasting difficulty for manufacturers (Thompson *et al.*, 2005; Wan *et al.*, 2012). Meanwhile, variations in product configuration present great difficulties for the manufacturer in terms of coordinating suppliers. In this case, the manufacturer not only needs to process large amounts of product design information to cater to customers' changing needs, but also needs to manage the production information for various components and modules in order to coordinate the upstream supply, and this greatly increases transaction and coordination costs. We argue that there is a greater need for SCI for the effective implementation of a strategy of product variety.

Specifically, internal integration facilitates the transfer and recombination of ideas, knowledge, and information which are dispersed across functional departments, and this is beneficial for the firm in building product portfolios that are robust against environmental changes (Patel and Jayaram, 2014). The firm can also improve its information processing capability through internal integration (Wong *et al.*, 2011). Integration with customers has the potential to enrich manufacturers' knowledge of product demands, requirements and market trends (Flynn *et al.*, 2010), which helps manufacturers to grasp opportunities and develop competitive strengths. Additionally, the difficulties in scheduling production which result from product variety also call for information sharing and coordinated actions with suppliers (Randall and Ulrich, 2001; Wan *et al.*, 2012). Extensive supplier integration is encouraged to ensure that suppliers deliver components or modules in a timely and accurate manner. Moreover, since suppliers often control vitally important new technology or knowledge about components or materials for certain types of products (Rothaermel *et al.*, 2006; Kim *et al.*, 2012), integration offers a more efficient way to access this knowledge than traditional market relationships.

The KBV can also be used to explain why a firm implements an integrative structure for high levels of product variety. In order to continuously introduce new products, a product diversification strategy requires the integration of both internal and external complementary knowledge (and especially implicit knowledge) across the different value chain activities and organizations (Rothaermel *et al.*, 2006; Al Zu'Bi and Tsinopoulos, 2012) to improve the firm's innovation capability. The KBV suggests that the efficiency of transferring complementary knowledge depends on the level of authority in directing others' actions (Conner and Prahalad, 1996) and the formation of a shared language and identity (Kogut and Zander, 1996), which motivates firms to engage in collaborative arrangements within and across organizations (Nicholls-Nixon and Woo, 2003; Grant and Baden-Fuller, 2004). As Schoenherr and Swink (2012) note, "to develop such organizational skills (to acquire and exploit unique knowledge), a firm typically must work on creating effective communication protocols, shared understandings and languages, and shared collaborative values with supply chain partners" (p. 101).

We therefore propose the third hypothesis as follows:

H3a. The higher the level of product variety, the more likely that manufacturing firms promote internal integration.

H3b. The higher the level of product variety, the more likely that manufacturing firms promote supplier integration.

H3c. The higher the level of product variety, the more likely that manufacturing firms promote customer integration.

Research methods

Sample

To test the theoretical hypotheses developed above, data collected from the sixth round of the International Manufacturing Strategy Survey (IMSS) were used. The IMSS is an international survey executed by a research consortium of operations management academics from universities across the world. The sixth round of the IMSS was carried out in 2013. The research group involved developed a standard English questionnaire which was then translated into the local language by academic research coordinators using a reliable method (either double parallel translation or back-translation). Most of the coordinators were full-time university staff in the areas of operations and supply chain management.

All participating companies were manufacturers with more than 50 employees. Only companies with an ISIC Rev. 4 code of between 25 and 30 were surveyed, using random sampling. Specifically, the types of industry included: (25) manufacture of fabricated metal products, excluding machinery and equipment; (26) manufacture of computer, electronic and optical products; (27) manufacture of electrical equipment; (28) manufacture of machinery and equipment not elsewhere classified; (29) manufacture of motor vehicles, trailers and semi-trailers; and (30) manufacture of other transport equipment. Plant managers were contacted and the questionnaire was sent to them by ordinary mail, fax or e-mail. The common process for administration of the questionnaire ensured the consistency of the survey across different countries. In total, 2,586 questionnaires were distributed in 22 countries, including both developing and developed regions worldwide, thus ensuring the representativeness of the sample. After deleting samples with numerous errors or which were missing over 60 percent of the data, a total of 931 valid samples were released. The overall response rate was 36 percent.

For this study, a further 88 samples were dropped due to missing data in related items, resulting in 843 usable samples, as shown in Table I. Independent sample *t*-tests using firm size, market share and return on sales (ROS) were conducted to ensure that there were no systematic differences between this subset of 843 samples and the overall IMSS data set. The results of Levene's test for equality of variance indicate that the variances in firm size ($p = 0.826$; $F = 0.048$), market share ($p = 0.848$; $F = 0.037$) and ROS ($p = 0.733$; $F = 0.116$) are not significantly different. Furthermore, results of *t*-tests indicate that mean scores do not differ for firm size ($p = 0.890$; $t = 0.139$), market share ($p = 0.932$; $t = 0.085$) and ROS ($p = 0.859$; $t = 0.178$).

Non-response bias, late-response bias and common method bias

In order to test for non-response bias and late-response bias, most of the local researchers could access a secondary data set of the public firms in their country, which were used to reveal any significant differences between respondents and non-respondents and between the early and late respondents in terms of their size, industry, sales or proprietary structure (Yang *et al.*, 2016). If local researchers could not access such databases, non-response bias

Demographic dimensions	Frequency (*n*)	%
Region		
Asia	321	38.08
China	116	
India	88	
Japan	78	
Malaysia	13	
Taiwan	26	
Europe	431	51.13
Belgium	27	
Denmark	34	
Finland	31	
Germany	13	
Hungary	52	
Italy	45	
The Netherlands	46	
Norway	24	
Portugal	30	
Romania	38	
Slovenia	17	
Spain	23	
Sweden	30	
Switzerland	21	
America	91	10.79
Canada	24	
USA	39	
Brazil	28	
Total	843	100
Firm size (personnel employed)		
1-50	37	4.39
51-250	357	42.35
251-1,000	244	28.94
1,001-10,000	156	18.51
10,000-50,000	41	4.86
>50,000	8	0.95
Total	843	100

Table I.
Sample overview

and late-response bias were then checked using questionnaire items such as size, industry and operational performance. No evidence of non-response bias or late-response bias was found in either case.

Harman's one-factor test (Podsakoff and Organ, 1986) was conducted in order to assess the possibility of common method variance. This analysis revealed four distinct factors with eigenvalues above 1.0, explaining 65.48 percent of the total variance. The first factor explained 36.76 percent of the total variance, i.e. less than 40 percent, and therefore was not the majority of the total variance. These results suggest that a common method bias is not a serious concern in this research. We also conducted Harman's single factor test using confirmatory factor analysis (CFA). The fit indices of this model of $\chi^2/\mathrm{df} = 22.62$, NFI = 0.606, TLI = 0.565, IFI = 0.617 and CFI = 0.616 were unacceptable. This suggests that a single factor model does not fit the data well. Following Lindell and Whitney (2001), the tenure of respondents was further used as a marker variable which was theoretically unrelated to other variables. As shown in Table III, the tenure of respondents is not significantly related to the other five variables, providing further evidence that common method variance is not a concern in this study.

Measures

The IMSS survey includes several items related to product-level characteristics and integration practices using a list of five-point Likert scales. As shown in Table II, all measures for product complexity, product variety and SCI align with the existing literature.

Two independent variables, product complexity and product variety, are considered in this research. The three items of integrated design, complexity of bill of material and number of operational steps required to build the plant's products are used to measure product complexity (Lucchetta *et al.*, 2005; Inman and Blumenfeld, 2014). Product variety is defined as the range of products offered by the plants (Fisher *et al.*, 1999). In general, firms diversify product versions by frequently introducing innovative products (Miller and Roth, 1994; Cagliano *et al.*, 2005; Wan *et al.*, 2012). Therefore, respondents were required to assess the attributes of variety with regard to a wider product range (Fisher *et al.*, 1999), offering new products more frequently (Wan *et al.*, 2012) and offering more innovative products (Miller and Roth, 1994; Cagliano *et al.*, 2005).

This study characterizes external integration in terms of collaborative approaches, information sharing, joint decision making on contingencies and system coupling (Spekman, 1988; Ellinger *et al.*, 2000; Narasimhan and Kim, 2002; Gimenez and Ventura, 2005; Flynn *et al.*, 2010). As shown in Table II, customer and supplier integration were each measured

Latent variable	Observed variables	Factor loading	SE	*t*-value	Reliability and validity
Product complexity					Cronbach's $\alpha = 0.677$; composite
	Integrated product design	0.459	0.044	11.941	reliability = 0.702; AVE = 0.454
	Many parts/materials, complex bill of material	0.663	0.046	16.611	
	Many steps/operations required	0.844	0.044	19.652	
Product variety					Cronbach's $\alpha = 0.757$; composite
	Wider product range	0.595	0.034	17.088	reliability = 0.770; AVE = 0.533
	Offer new products more frequently	0.868	0.038	24.968	
	Offer products that are more innovative	0.701	0.036	20.166	
Internal integration					Cronbach's $\alpha = 0.887$; composite
	Sharing information with purchasing department	0.753	0.030	21.884	reliability = 0.887; AVE = 0.664
	Joint decision making with purchasing department	0.784	0.031	23.609	
	Sharing information with sales department	0.855	0.028	30.736	
	Joint decision making with sales department	0.862	0.030	31.492	
Supplier integration					Cronbach's $\alpha = 0.842$; composite
	Sharing information	0.768	0.030	24.996	reliability = 0.850; AVE = 0.587
	Developing collaborative approaches	0.822	0.030	27.752	
	Joint decision making	0.789	0.032	26.171	
	System coupling	0.677	0.037	21.143	
Customer integration					Cronbach's $\alpha = 0.881$; composite
	Sharing information	0.853	0.032	29.818	reliability = 0.884; AVE = 0.657
	Developing collaborative approaches	0.854	0.033	29.864	
	Joint decision making	0.753	0.034	24.792	
	System coupling	0.776	0.037	25.817	

Table II. Survey items and confirmatory factor analysis results using four items ranging from one (none) to five (high) indicating the current level of implementation. As for internal integration, information sharing and joint decision making are recognized by Ellinger *et al.* (2000), Narasimhan and Kim (2002), and Huo *et al.* (2015) and as being important for internal integration in order to coordinate production and inventory management and ensure customer service. In this study, internal integration was therefore measured in terms of joint decision making and information sharing between purchasing and sales departments.

In addition to the product-level characteristics which may influence a firm's decision on SCI, we control for firm size in terms of the natural log of the total number of employees. Firm size is often used as a control variable for two reasons, one of which is that larger firms tend to have more resources and capabilities for carrying out activities (Kimberly, 1976); the other is that larger firms can "take advantages of economies of scale in their business activities" (Kim and Lee, 2010, p. 964).

Reliability and validity

To evaluate the focal constructs, exploratory factor analysis (EFA) was first carried out using SPSS 19.0. A principal component analysis with varimax rotation was conducted to test the unidimensionality of each construct and Cronbach's α was calculated to assess the internal consistency of the construct (Cronbach, 1951). The EFA results revealed that all items had strong loadings on the construct that they were intended to measure and lower loadings on other irrelevant constructs, thus confirming construct unidimensionality. As recommended by Nunnally *et al.* (1978) and Fornell and Larcker (1981), Cronbach's α for each construct was greater than 0.60, and values ranged between 0.68 and 0.89. The reliability of the five constructs is therefore ensured.

CFA with the maximum likelihood method was used to examine convergent validity and discriminant validity. The ratio of χ^2 to the degree of freedom (χ^2/df) was 3.873, and was thus somewhat larger than 3 and smaller than 5. Since "a large sample size may cause the rejection of almost any model, even for models that explain most of the variance in the data" (O'Leary-Kelly and Vokurka, 1998, p. 403), other fit indices should therefore be examined for thoroughness of discussion. According to Hu and Bentler (1999), the fit indices of RMSEA = 0.058, SRMR = 0.046, CFI = 0.953, GFI = 0.940, IFI = 0.953 and TLI = 0.942 indicate a reasonably high level of fit for the model. As summarized in Table II, most of the factor loadings in the CFA model, except for that of the item "integrated product design" (0.459), are greater than 0.50, with the smallest *t*-value being 11.941. Nonetheless, this item is retained since "integrated product design" is used to describe the operational dimension (i.e. interactions between the elements) of product complexity (Lucchetta *et al.*, 2005; Inman and Blumenfeld, 2014). In addition, the EFA results show that the item "integrated product design" has a factor loading of greater than 0.50 (0.683), and is significantly loaded on the product complexity measure. The item of product complexity has a relatively low factor loading, which leads to a relatively low average variance extracted (AVE = 0.45). Values for AVE for the other four constructs are all higher than 0.50, and the composite reliability for all five constructs are greater than 0.70; this demonstrates the reliability of the measurement scales (Fornell and Larcker, 1981; O'Leary-Kelly and Vokurka, 1998). From these results, convergent validity is deemed to be ensured.

Referring to Fornell and Larcker (1981), the measures have good discriminant validity when the square root of the AVE for each construct is greater than its correlation with other constructs. The results presented in Table III verify a satisfactory level of discriminant validity. We also test the discriminant validity by comparing the unconstrained model (with the two constructs allowed to vary freely) and the constrained model (with the correlations between two constructs constrained to 1) (Bagozzi *et al.*, 1991; O'Leary-Kelly and Vokurka, 1998). Significant differences in χ^2 provide further evidence for discriminant validity.

Since cross-country data were used in this study, cultural effects were controlled for by testing measurement equivalence across Asia, Europe and America. A multi-group analysis was conducted to investigate the similarity of the measurement models across these three groups (Byrne, 2006). The indices for the baseline model (in which the factor loadings varied freely across the three groups) were $\chi^2 = 832.36$, RMSEA = 0.038, IFI = 0.941, NNFI = 0.926 and CFI = 0.940, whereas the indices for the constrained model (in which the factor loadings were constrained to be equal across the three groups) were $\chi^2 = 904.31$, RMSEA = 0.038, IFI = 0.936, NNFI = 0.928 and CFI = 0.936. This indicates that the data from the different continents fit the model well. Measurement invariance may be demonstrated by the difference in χ^2 between the baseline model and the constrained model. However, Byrne (2006) points out that the value of $\Delta\chi^2$ may not be a practical measure since it is sensitive to sample size and non-normality. Vanpoucke *et al.* (2014) point out that the negligible change in CFI value (ΔCFI) between the baseline model and the constrained model can be used as an indicator. In this study, the value of ΔCFI is 0.004, which is negligible. Overall, measurement invariance can be confirmed across three continents.

Analyses and results

A widely used technique for simultaneous testing of the complex, multi-stage relationships between variables (Lomax and Schumacker, 2012), structural equation modeling was used with the maximum likelihood estimation method to test the proposed hypotheses in the present research. The goodness of fit indices for our model are χ^2/df = 3.667, RMSEA = 0.056, 90 percent confidence interval for RMSEA = (0.051; 0.062), GFI = 0.940, NFI = 0.935, NNFI (TLI) = 0.940, IFI = 0.952, CFI = 0.952, RFI = 0.920, standardized RMR = 0.045, AGFI = 0.917, PGFI = 0.683. These indices are all better than the recommended threshold (Hu and Bentler, 1999), which indicates that the overall fits of the model are good. Figure 1 and Table IV show the fit indices and the results of hypothesis testing.

The results presented in Table IV suggest support for *H1*. The standardized path coefficients for *H1a* (supplier integration) and *H1b* (customer integration) are 0.540 with *t*-value 13.196, and 0.468 with *t*-value 11.283, respectively, which are both statistically significant at the level of 0.001. These results confirm the positive impacts of internal integration on supplier integration and customer integration.

H2 examines the relationship between product complexity and (*H2a*) internal integration, (*H2b*) supplier integration and (*H2c*) customer integration. *H2a* is supported with a path coefficient of 0.190 ($t = 4.468$), which is statistically significant at the level of 0.001. The path coefficient for *H2b* supplier integration is 0.104 ($t = 2.816$), which is statistically significant at the level of 0.01. These results confirm that product complexity has significant, positive, and direct impacts on internal integration and supplier integration. However, the path coefficient for *H2c* (customer integration) is not statistically significant, with a value of 0.021 ($t = 0.564$). *H2c* therefore cannot be confirmed.

	(1)	(2)	(3)	(4)	(5)
Product complexity (1)	0.674				
Product variety (2)	0.199***	0.730			
Internal integration (3)	0.228***	0.233***	0.815		
Supplier integration (4)	0.284***	0.345***	0.641***	0.766	
Customer integration (5)	0.187***	0.340***	0.531***	0.746***	0.810
Tenure of respondent (marker variable) (6)	−0.019	0.080	0.050	−0.011	−0.027

Notes: Value on the diagonal is the square root of AVE. ***$p < 0.001$

Table III. Correlations of the constructs

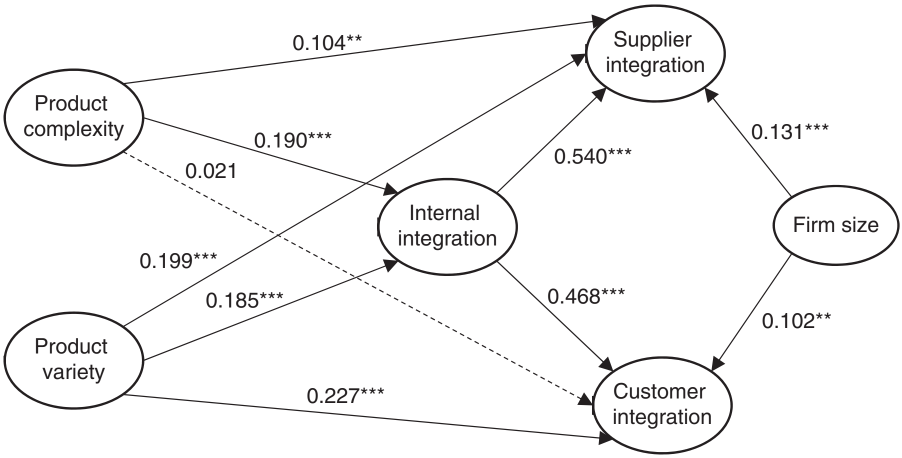

Figure 1. Estimated structural equation model

Notes: χ^2/df = 3.667; RMSEA = 0.056; SRMR = 0.045; CFI = 0.952; NNFI (TLI) = 0.940. ——►, Significant path; ----------►, non-significant path. ***p < 0.001; **p < 0.01

Table IV. SEM path analysis

Structural paths	Standardized estimates	SE	p-value	t-value
H1a: internal integration → supplier integration	0.540***	0.052	0.000	13.196
H1b: internal integration → customer integration	0.468***	0.053	0.000	11.283
H2a: product complexity → internal integration	0.190***	0.032	0.000	4.468
H2b: product complexity → supplier integration	0.104**	0.035	0.005	2.816
H2c: product complexity → customer integration	0.021	0.037	0.574	0.564
H3a: product variety → internal integration	0.185***	0.037	0.000	4.467
H3b: product variety → supplier integration	0.199***	0.041	0.000	5.502
H3c: product variety → customer integration	0.227***	0.044	0.000	6.011

Notes: **p < 0.01; ***p < 0.001

H3 predicts that product variety is positively associated with internal integration, supplier integration and customer integration. The standardized path coefficients are 0.185 (t = 4.467), 0.199 (t = 5.502) and 0.227 (t = 6.011), respectively. The coefficients for *H3* are all statistically significant at the level of 0.001, which indicates that product variety has significant, positive, and direct effects on internal integration, supplier integration and customer integration. Thus, *H3* is supported.

Furthermore, we calculate the indirect effects of product complexity and variety on SCI to determine whether internal integration carries the effects of product complexity and variety to external integration. By multiplying the path coefficients from product complexity/variety to internal integration and from internal integration to customer/supplier integration, the indirect effect of product complexity on customer integration is shown to be $0.190 \times 0.468 = 0.089$, that of product complexity on supplier integration is $0.190 \times 0.540 = 0.103$, that of product variety on customer integration is $0.185 \times 0.468 = 0.087$, and that of product variety on supplier integration is $0.185 \times 0.540 = 0.100$. To test the significance of these indirect effects, Sobel's Z-test was conducted, and the resultant Z-values for the above indirect effects are 4.219 (p = 0.000), 4.291 (p = 0.000), 4.117 (p = 0.000) and 4.184 (p = 0.000), respectively. These results indicate that internal integration is a mediating factor between product complexity/variety and supplier/customer integration.

Discussion and implications

Theoretical implications

The results suggest that internal integration is an important enabler for achieving external integration. This finding is consistent with those of Stank *et al.* (2001), Chen *et al.* (2009), Koufteros *et al.* (2010) and Zhao *et al.* (2011). Prior studies have recognized that internal and external integration are two completely different supply chain practices (Chen *et al.*, 2009) due to the differences in organizational ownership, structure, policies and values. Furthermore, this study discusses the differences and relationship between internal and external integration from a governance view. While internal integration enhances the organization's governance capability through the unified ownership, external integration is recognized as another kind of governance arrangement through mutual benefit and dependence, joint decision making, and system coupling with external partners. However, since external exchanges are accompanied with transactional hazards and coordination difficulties, the implementation of external integration demands the safeguards of internal integration. The governance view aids in extending the understanding of these two completely different kinds of integration practice and supports the relationship between internal and external integration.

The results also confirm that product complexity has direct and positive effects on internal integration and supplier integration; there is also a direct and positive relationship between product variety and internal, supplier and customer integration. Meanwhile, product complexity and variety indirectly influence supplier and customer integration through internal integration. First, the results help answer the question of why a manufacturer implements internal integration, supplier integration and customer integration at the product level; these results are presented in response to the call made by Van Donk and Van der Vaart (2004) and Chen *et al.* (2009) for further research on the antecedents of SCI. Using a governance view and a KBV, we conclude that product complexity and variety give rise to a need for SCI in order to mitigate transactional hazards and facilitate knowledge transfer. Second, prior studies have pointed out the effects of product design on supply chain practices through literature review (Ellram *et al.*, 2007) and case studies (Khan *et al.*, 2008; Khan and Creazza, 2009; Lin and Zhou, 2011). The current study analyzes the ways in which product complexity and variety influence the different dimensions of SCI and provides further empirical evidence which extends the existing knowledge of the product design-supply chain interface.

Managerial implications

The results offer some guidelines for managers in the direction of their SCI practices. First, the study suggests that internal and external supplier and customer integration should be treated as different practices. The firm should pay attention to the sequential ordering of the implementation of internal and external integration. More specifically, our results indicate that the firm should give strategic priority to the implementation of internal integration in order not only to improve functional collaboration within the organization, but also to facilitate external integration with their suppliers and customers. Particularly when the firm is characterized by a high degree of product complexity and variety, relationships with supply chain partners may involve exchange hazards and coordination difficulties. In this case, the implementation of external integration will be difficult unless the firm can enhance its governance capability through internal integration.

Second, it is recommended that firms should enhance their internal, supplier and customer integration when offering complex and diverse products. For a manufacturer offering highly complex products, information sharing and collaboration are needed across functional departments and supply chain partners in order to promote production coordination and problem solving (Nickerson and Zenger, 2004; Kaufmann and Carter, 2006). Similarly, a firm with high levels of product variety is driven to integrate within the organization and with external partners by means of information sharing, collaboration, joint decision making and system coupling, in order to facilitate product development (Rothaermel *et al.*, 2006) and to improve the production efficiency of suppliers (Al Zu'Bi and Tsinopoulos, 2012). Meanwhile, it is also suggested that product complexity/variety should be designed according to the current capability of SCI. If the level of a firm's SCI is relatively low, the firm may have poor capability in terms of the management of product complexity and variety. In short, the product complexity/variety and the level of SCI should be well matched and balanced.

Conclusion, limitations and future research

In summary, this research focuses on the impacts of product characteristics on the implementation of internal, supplier and customer integration from a governance view. The statistical results show that internal integration is an enabler for external integration and that product complexity and variety are two critical antecedents for implementation of SCI. This research extends the literature on SCI and contributes to discussions of product design-supply chain interface in the governance view. For managers, we suggest that internal integration should be implemented before integration with suppliers and customers. We also find that firms have a particular need to conduct SCI in the case of high product complexity and variety.

Although this research offers new insights into SCI literature and practice, there are some limitations to this study. First, cross-sectional data was used to test the proposed hypotheses. Since firms with high levels of SCI may have advantages in offering complex and diverse products, longitudinal studies will be fruitful in revealing the evolutional patterns of product design and SCI. Second, this study controlled only for the effects of firm size. Future studies should further investigate and compare the relationships between product characteristics and SCI for different types of firms, and possibly for different industries and countries. Third, further scrutiny of supply chain complexity is required. In this study, only complexity and variety at the product level were considered. It therefore would be valuable for future research to investigate the impacts of other potential sources of supply chain complexity on SCI. Finally, this study focused solely on the antecedents of SCI at the product level. Since SCI plays an important role in handling product complexity and variety and in facilitating knowledge transfer and creation, a further examination of the ways in which SCI influences product innovation performance in the context of product complexity and variety would be valuable.

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