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Green innovations, supply chain integration and green information system: A model of moderation

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ABSTRACT

Building on the theory of information processing, this study investigates the moderation effect of green information system in shaping the impacts of supplier integration and customer orientation on green innovation. This study uses survey data (231 sample firms) to empirically test the proposed conceptual model. The results from the structural equation modeling estimation confirm the important role of supply chain integration in improving organizational green innovations. More importantly, the positive effects of supply chain integration, i.e., supplier integration and customer orientation, are more significant when aligned with an effective green information system. This study contributes to the literature by studying the moderation effect of green information system in improving the effect of supply chain integration on green innovations and provides a guideline for practitioners to invest in green information systems to facilitate smooth communication and information sharing across the supply chain for green innovations.

1. Introduction

The growing concerns for the environment have been imposing great pressures on companies to implement new models focusing on environmental sustainability rather than traditional models that focus on efficiency and profit only. This major strategic change urges companies to find a win–win solution to mitigate the conflicts between environmental management and economic performance (Chang, 2011). Green innovation has been suggested by researchers as a strategic tool to maintain sustainable development while achieving competitive advantages (Liu, 2020). Green innovation is regarded as a promising way to achieve economic development and sustainability simultaneously because of its emphasis on product differentiation, new-market entry strategies, cost-saving techniques, and high-level management capabilities (Porter and van der Linde, 1995). Green innovations can improve resource productivity by enhancing product value which offsets the extra costs of environmental investments (Porter and van der Linde, 1995). In today's business environment, it is critical for companies to embrace green innovation in order to prosper financially and environmentally as well. However, research dealing with the inherent drivers or antecedents of green innovation is rare. Many studies have focused on external factors as the drivers in improving green innovation, such as government regulations, stakeholders' pressures, etc. (Provasnek et al., 2017; Yu et al., 2017).

Literature in strategic management and organizational learning indicates that innovation is a process of actively obtaining new knowledge and information, properly managing and integrating diverse knowledge from different sources, and successfully applying the knowledge to new products or production processes for value creation (DeCarolis and Deeds, 1999; Eliasson, 1997; Miller et al., 2007). Therefore, a high level of complexity with high-volume knowledge and information is integral to green innovations. Moreover, due to the uniqueness of green innovations, high-level external uncertainties exist, such as technology changes, market uncertainties, and policy & regulation risks, etc. These uncertainties must be weighed when evaluating the implementation of green innovations. Information-processing theory (IPT) sheds light on this issue, suggesting companies should expand their capacity to effectively and efficiently process associated knowledge and information involved in green innovations to reduce uncertainties and enhance performance. To deal with the high-volume knowledge and information as well as high-level uncertainties involved in green innovations, a company's information-processing capacity can be enhanced by attaching external information-processing units (Galbraith, 1973).

Recently, the incorporation of environmental factors in operations

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requires properly managing the flow of products, materials, and services in the context of sustainability. Extra pressure is imposed on supply chain management (SCM) to achieve profitability and sustainability simultaneously. This newly emerging green element in SCM has been triggering a lot of studies in rethinking and reassessing various factors involved in supply chain integration (SCI) such as theoretical assumptions and explanations regarding its impact on green innovations and the interactions of different parties across the whole supply chain. (Chen et al., 2006; Chen and Hung, 2014; De Marchi, 2012; Geyer and Jackson, 2004; Zhu and Sarkis, 2004). Although many studies have identified that green SCI is positively associated with green innovations (Aslinda Abu Seman et al., 2019; Chen, 2008; Chen and Chang, 2013; Chien and Shih, 2007; Du et al., 2018; Seman et al., 2012; Wong et al., 2020; Zhu et al., 2010), the relationship between green SCI and a company's green innovation capabilities is still inconclusive (Chiou et al., 2011; Eltayeb and Zailani, 2009; Gollagher et al., 2010; Large and Thomsen, 2011; Sharma et al., 2017; Zailani et al., 2015).

Moreover, the rapid advancement of IT technologies has facilitated a wider application of green practices for more technology-driven green initiatives (Chiabai et al., 2013; Liu et al., 2018). The fast-growing digital technology has been driving major changes in promoting sustainable development (Liu et al., 2020). The establishment of a green information system (GIS) can support a company's operations for sustainable development by expanding its information-processing capacity and promote the flow of information across the whole supply chain (Dedrick, 2010). An effective GIS plays a great supporting role for sustainable supply chains by connecting suppliers and customers (Dao et al., 2011; Green et al., 2012) and provides an effective platform to enhance a company's green innovation capability (Leenders et al., 2003; Liu et al., 2018; Wei and Wang, 2011).

Regarding earlier studies of SCI, most studies focus on the impacts of SCI on different aspects of performance such as customer service, financial performance, innovations, etc. We summarize some representative studies in Table 1 below. The critical roles of information systems have also been recognized in facilitating the information intra- and inter-organizations in improving organizational performance thereafter (Legarth, 2001; Darnall et al., 2008). Please refer to the studies found in the literature shown in Table 1.

Although there are many studies in SCM and information system that have articulated the constructs of SCI and information systems in improving organizational performance from various perspectives, most of them focus on the antecedents in improving SCI or information system and the direct effect of SCI or information system on performance. Limited attentions have been paid to the alignment of SCI and information system on innovations. Also, majority studies pay attention to the construct of innovation as a whole without identifying the two different aspects of innovation, process innovation and production innovation.

Compared with traditional innovations, more information and knowledge are involved in green innovations due to the environmental factors such as resources & energy conservation, waste & pollution prevention, waste recycling & reuse, etc. (Chen et al., 2006; Li et al., 2019), requiring more connections and communications across supply chains in terms of procurements, productions, distributions, recyclings and reuses (Barve and Muduli, 2013). Therefore, green innovations may require much more supports, corporations as well as collaborations from internal and external stakeholders, leading a greater volume of information transfer and sharing.

The incorporation of environmental factors in operations requires properly managing the flow of products, materials, and services in the context of sustainability. Extra pressures are imposed on SCM to achieve profitability and sustainability simultaneously. This newly emerging green element in SCM has been triggering a lot of studies in reassessing various factors involved in SCI such as theoretical assumptions and explanations regarding its impacts on green innovations and the interactions of different parties across the whole supply chain. "As more information is shared across a supply chain, the complexity and cost of both the required infrastructure and the follow-up analysis grow exponentially" (Chopra and Meindl, 2016). The information-intensive feature of green innovations may require the necessity of rethinking and re-evaluating the theoretical assumptions and explanations of SCI under the scenario of green collaborations across different parties of supply chains.

Furthermore, compared with the traditional supportive role of an information system, a green information system (GIS) can provide more direct supports for green innovations and corporate sustainability (Chofreh et al., 2014) by facilitating the process of procurements, productions, distributions as well as waste recycling and reuse for sustainable operations, strategies, customer outreach, and supplier cooperation, etc. (Loos et al., 2011). Aligning a well-built GIS with SCI

Table 1
Summary of representative related empirical literature.

Study	*Explanatory variables*		Outcome variables
	SCI	Information System	
Wong et al. (2013)	Internal & external SCI		Product innovation
Lii and Kuo, 2016	Customer integration, supplier integration, internal integration		Competitive capabilities, financial performance
Wu (2013)	Green SCI, environmental uncertainty		Green innovation
Wong et al. (2013)	SCI, green innovation		Environmental & cost performance
Kumar et al. (2020)	Operations Strategy, SCI		Innovation performance
Khan and Wisner (2019)	SCI, learning, agility		Performance
Song et al. (2018); Sun and Sun (2021)	SCI		Green Innovations
Du et al. (2018)	Customer integration, supplier integration		Green innovation
Melander (2018)	Collaboration with Customer & supplier		Green product innovation
Liao (2018)	Market orientation		Environmental innovation
Feng et al. (2018)	Internal & external environmental orientation		Green product & process innovation
Leal-Millán et al. (2016)		IT, Relationship learning	Green innovation performance
Yang et al. (2020)		Green information system	Environmental performance, economic performance
Gholami et al. (2013)		Green information system	Environmental performance
Liu et al. (2018)		Green information system	Environmental performance
Yang et al. (2017)		Green information system	Green image, environmental performance
Chuang & Huang (2018)		Green information technology	Environmental performance, business competitiveness
Our Study	The alignment between SCI and green information system		Green Process Innovation Green Product Innovation

may facilitate the efficiency of collaboration in improving green innovations.

Therefore, by testing how the fit between SCI and GIS in improving green process innovations as well as product innovations, this study fills in the gap and supplements previous literature by examining how the structure setting between SCI and GIS impacts green innovations. Second, this research contributes to green SCI and green-innovation literature by revealing the contingencies under which the alignment between SCI and GIS is effective in shaping the two aspects of green innovations and provides useful managerial references for practitioners. Third, this study validates the conceptual framework proposed theoretically and empirically by using information-processing theory and survey data.

The purpose of this research is to propose a conceptual framework and empirically study the fit between the two aspects of green SCI (namely, supplier integration and customer orientation) and GIS in terms of the underlying rationales and consequences. Drawing on IPT, this research proposes that both supplier integration and customer orientation can increase green innovations in the aspects of products as well as processes and that an effective GIS can reinforce the positive impacts of supplier integration and customer orientation on green innovations. The rest of the paper is structured as follows: Section 2 describes the theoretical foundation and discusses green innovations. Section 3 presents the conceptual framework and hypotheses. Section 4 discusses the research methodology, data collection, as well as scale validation. Section 5 describes the model estimations and outcomes. Section 6 discusses the results of this study, contributions, and limitations. Section 7 draws the conclusions of this study in the end.

2. Theoretical foundation

2.1. Information-processing theory

IPT was developed to cognitively describe people's mental learning process regarding sensory information transitions (Shiffrin and Schneider, 1977). IPT was later used to address the dynamic process of organizational learning (Galbraith, 1973; Grah et al., 2016). From the perspective of IPT, each organization is regarded as an information-processing system with a certain level of processing capacity (Galbraith, 1973; Tushman and Nadler, 1978). To achieve high-level performance, organizations need to carry certain information-processing capacity that matches with the volume and intensity of information they face so as to facilitate effective information collection, storage, and transformation (Egelhoff, 1991; Galbraith, 1977). Risks and uncertainties are inevitable in this process. And the level of risks and uncertainties are positively associated with the volume and intensity of information (Galbraith, 1974). Generally speaking, simple and routine jobs can only incur a small volume of information, which requires a simple organizational structure with low information-processing capacity. More complex jobs will incur a larger amount of information and uncertainties with greater exceptions, which requires external vertical or lateral information-processing entities added to expand an organization's information-processing capacity in order to avoid information overload and achieve effective information processing (Galbraith, 1973).

For this study, the information-processing requirement is determined by the characteristics of green innovations, such as complexities and uncertainties. As indicated earlier, high-volume knowledge and information are involved in green operations with great complexity. Meanwhile, the dynamic and fast-changing green market imposes great challenges in precisely predicting customer demand as well as preferences for green products. (Corrocher and Zirulia, 2010; Freel, 2005; Gilbert and Cvsa, 2003). Moreover, intense competition resulted from globalization also imposes extra pressures on a company's green innovations (Banerjee and Chatterjee, 2010). Therefore, a company must expand its information-processing capacity to align with all the complexities and uncertainties involved in green innovations. IPT sheds rich light on how a company expands its information-processing capacity to effectively handle the information and associated uncertainties and improve its green innovation without incurring extra costs.

2.2. Green innovation

Green innovation is viewed as the development of green processes or green products with less adverse environmental impacts with the goal of resources and energy conservation as well as waste and pollution prevention, recycling, and reuse, etc. (Chen et al., 2006; Li et al., 2019). Green innovation can effectively address the growing environmental concerns and requirements for sustainability. In this study, to fully capture a company's green initiatives and operations, we partition the construct of green innovation into two aspects, green product innovation and process innovation (Amores-Salvadó et al., 2014). Green product innovation is defined as a radical innovation regarding new product development aiming at promoting sustainability and reducing damages to the environment such as new product development or designs regarding energy-saving, pollution prevention, reuse & recycling, toxicity reduction, etc. (Chen et al., 2006; Lin et al., 2013). Life cycle analysis is adopted in green product innovation by focusing on all the activities related to the products, including raw materials, production processes, distribution, consumption, disposal, and reuse/recycling, in other words, a "cradle to grave" approach (Noci and Verganti, 1999). Compared with green product innovation, the scope of green process innovation is narrower, typically restricted to the lifecycle of one certain product. Green process innovation focuses on partially modifying the designs of existing products or production processes in order to reduce the adverse effects on the environment (Klassen and Whybark, 1999). Specifically, green process innovation includes reducing energy consumption, mitigating wastes and emissions, increasing reuse and recycling options, as well as increasing production efficiency with less input and higher quality (Johne, 1999; Tseng et al., 2013).

As discussed previously, successful implementation of green innovations requires companies to effectively reduce uncertainties related to the change of green technologies, market demands, customer preferences, policies, and regulations, etc. Therefore, great efforts are needed to closely track, monitor, and process vast quantities of information, such as resource and energy consumption, waste disposal and reuse, emission and toxicity prevention, etc. The great volume of information and high-level uncertainty may impose significant challenges to companies with limited information-processing capacities. IPT offers significant insights regarding inter-organizational design across SCM to specify the relationships between a company with its suppliers and customers to increase its information-processing capacity. Based on IPT, the vertical or lateral integration of external information-processing systems (such as supplies and customers) can improve a company's information-processing capacity and efficiency. This type of inter-organizational structure will promote various direct contacts in the levels of individuals, teams, organizations, which will lead to effective information processing and uncertainty reduction (Egelhoff, 1991; Galbraith, 1973). Literature has demonstrated the importance of SCI in improving performance (Koufteros et al., 2007; Narayanan et al., 2011; Zhao et al., 2008; Zhu and Sarkis, 2016). Thus, the high-level supplier integration and customer orientation can increase a company's information-processing capacity so as to effectively process the great amount of information and uncertainties associated with green innovations. Moreover, a company's information-processing capacity can be greatly expanded with a well-developed GIS. GIS provides a platform for easy collaborations and smooth communications among various functional units both within the company and with its suppliers and customers.

3. Hypothesis development

Literature in SCM confirms the important role of integration among members in improving performance (Koufteros et al., 2007; Marquez et al., 2004; Rosenzweig et al., 2003). Early SCM studies focused on the flows of physical products and materials. Recently, research put more and more efforts into emphasizing, collaborations, operation alignments, information sharings, and the flows of other intangible resources across a supply chains (Balsmeier and Voisin, 1996). The social capital theory indicates the critical role of good relationships with partners across a supply chain regarding information acquisition as well as inter-firm cooperations and collaborations (Zhou and Poppo, 2010). For example, Gmelin and Seuring (2014a) indicates in their study that information and product data exchanges among different companies across the supply chain are important to develop sustainable products successfully. Research has indicated that companies can obtain great benefits by closely integrating with their partners across the supply chains in improving new product development (Brown and Eisenhardt, 1995; Das et al., 2006).

As indicated earlier, great challenges are caused by a great deal of complexities and uncertainties associated with green innovations. It is hard for companies to conduct the entire green initiatives independently (Mentzer, 2004). The interactions with suppliers and customers for joint efforts in R&D will improve a company's environmental performance (Gold et al., 2010; Takeishi, 2001; Zhu et al., 2007). The high-level SCI will expand a company's information-processing capacity for effective information processing and creative green initiatives.

3.1. Supplier integration

Supplier integration is a process of linking with key suppliers to work jointly on common business processes and problem solvings for competitive advantages (Monczka et al., 2016). Studies in SCM demonstrate the positive effect of collaborating with suppliers on a company's innovation capability (Ragatz et al., 2002; Un et al., 2010). Suppliers contribute greatly for green innovations (Gmelin and Seuring, 2014b). Information sharing and collaboration are the key practices of supplier integration (Van Donk and Van Der Vaart, 2005). As indicated earlier, other than stewarding the movement of raw materials and parts, the flow of information is critical for all different units across the whole supply chain. This information exchange allows companies to avoid potential supply interruption in the process of procurement and achieve an efficient flow of materials and reliable delivery (Singh et al., 2005; Lau et al., 2010). The close integration of suppliers can greatly reduce uncertainties and risks and enable a company to develop and move products to new markets quickly.

As discussed earlier, green innovations require vast quantities of information and involve a great deal of uncertainties. Companies must employ high-capacity information processing systems to track, monitor, and manage intensive operation-related information (i.e., resource and energy consumption, waste disposal and reuse, emission, and toxicity prevention, etc.) as well as non-operation-related information (i.e., the change of green technologies, market demand, customer preferences, policies, and regulations, etc.). Therefore, companies need to help their suppliers become greener by providing helpful guidance and advice and sharing their skills and knowledge (Chiou et al., 2011). This type of inter-organizational structure will promote various direct contacts in the levels of individuals, teams, organizations, which will lead to effective information processing and uncertainty reduction (Egelhoff, 1991; Galbraith, 1973). Based on IPT, close integration with major suppliers can increase a company's information-processing capacity and efficiency by adding extra information-processing units outside of the company and prevent information overload. This synthesis can incorporate the suppliers' complementary knowledge and expertise regarding the parts and components to improve green innovations (Bonaccorsi and Lipparini, 1994). Therefore, high-level supplier integration can expand information-processing capacity so that the company can effectively handle the intensive information involved in green product and process innovation, and successfully implement those strategies. So, we can make the following two hypotheses,

H1. High-level supplier integration can help improve green product innovation.

H2. High-level supplier integration can help improve green process innovation.

3.2. Customer orientation

Customer orientation is one type of organizational culture that requires a company to actively monitor and satisfy the changing needs and preferences of its current and potential customers (Narver and Slater, 1990). As an important component of market orientation, a customer-oriented company puts the customers' needs at its top (Deshpande and Farley, 1998; Kohli and Jaworski, 1990). As stated by Narver and Slater (1990), "Customer orientation requires that a seller understand a buyer's entire value chain, not only as it is today but also as it will evolve over time subject to internal and market dynamics". Therefore, to achieve high-level customer orientation, a company has to put more efforts into obtaining related information regarding its customers. As one of a company's most important capabilities, customer orientation requires companies to respond promptly to the dynamic changes of customer requirements in order to provide high-level customer satisfaction (Day, 1994; Kohli and Jaworski, 1990; Narver and Slater, 1990). Literature has indicated customer orientation as one of the important antecedents for new product success (Wong and Tong, 2012). A customer-oriented green innovation can translate customer's aspirations to reflect their concerns over environmental issues (Banerjee et al., 2003).

From the perspective of IPT, it is difficult for a company with a limited information-processing capacity to effectively processing a great volume of customer-related information and reducing uncertainties during its green innovation. To expand its information-processing capacity, the company can connect with its customers closely to reduce information asymmetry and mitigate the information-processing burden. High-level customer orientation enables a company to closely interact and communicate with its customers and avoid misunderstanding regarding customers' environmental preferences and needs. Today's consumers are more environmentally conscious than in previous decades, forcing companies to redesign products and processes which means that customer orientation data is a valuable tool for companies' innovation strategy (Kautish and Sharma, 2020; Yenipazarli et al., 2020). In order to achieve successful green innovation, customer-oriented companies must prioritize communication with consumers and concentrate on effectively processing information to satisfy their unique requirements. The high-level customer orientation can increase a company's information-processing capacity for effective information processing to reduce uncertainties associated with green innovations. Therefore, we can hypothesize as follows,

H3. High-level customer orientation can help improve green product innovation.

H4. High-level customer orientation can help improve green process innovation.

3.3. Green information system

GIS indicates a type of information system that enables an organization to sustainably manage its operational activities, sustainable initiatives and interactions with supply chain partners (Seidel et al., 2017; Siegler and Gaughan, 2008; Watts, 2016). An effective GIS can help an organization track, analyze, and reduce adverse environmental impacts from various business activities by actively monitoring energy usage, resource consumption, emissions, etc. (Carberry et al., 2019). GIS can also help achieve optimal supply chains with efficient distribution networks (Carberry et al., 2019; Jenkin et al., 2011). Specifically, an effective GIS is able to track, monitor, store, and synthesize various environmental factors and information regarding energy and resource consumption, waste generation, emissions, and pollution. It also includes tools to support environmental management activities (i.e., carbon footprint analysis, emission reduction, resource optimization, cost reduction, etc.) across the supply chain for green SCM. For example, members across the supply chain can promptly share information for efficient coordinations and collaborations regarding green innovations through videoconferencing, desktop virtualization, and other virtual inter-organizational softwares (Olson, 2008).

Therefore, GIS provides direct support to companies in enhancing their environmental effectiveness of business routines (Chofreh et al., 2014). GIS is a practical tool that can help a company to promote sustainable activities including setting up green plans, facilitating smooth communications between different functional departments, and improving operation efficiency and management capabilities (Liu et al., 2018). Grant et al. (2010) indicates that GIS is very helpful in building industrial symbiosis to minimize adverse environmental impacts by achieving a self-sustainable system with mutualistic reuse of energy and wastes among different industries.

Based on the discussion above, GIS serves as the foundation of environmental management activities and offers an overarching platform to guide the behaviors of green innovation for all members across supply chains (El-Gayar and Fritz, 2006). GIS facilitates the coordinations and integrations with suppliers and customers regarding eco-product design, production, packaging, transportation, etc. (Chandra et al., 2007; Liu et al., 2018). Through this platform, a company can quickly and easily share information with its suppliers and customers to avoid information asymmetry and achieve seamless collaborations with them for green innovations. From the perspective of IPT, an effective GIS can greatly expand a company's information-processing capacity by providing a platform for easy knowledge sharing and smooth communications among various functional units within the company and between the company and its suppliers and customers. A well-developed GIS can greatly facilitate a company's supplier integration as well as customer orientation. This type of alignment between GIS and SCI enhances a company's information-processing capacity to properly deal with the high level of uncertainty and complexity involved in green innovations without incurring extra costs, which contributes to green innovations in the end. So, the existence of a well-developed GIS will enhance the impacts of supplier integration and customer orientation on both green product and process innovation.

H5. GIS positively moderates the impacts of supplier integration on (a) green product innovation and (b) green process innovation.

H6. GIS positively moderates the impacts of customer orientation on (a) green product innovation and (b) green process innovation.

3.4. Control variables

In addition to the proposed relationships and constructs, two control variables are included here. The first one is the size of the company for the reason that large companies usually carry more resources and very like to achieve economies of scale (Pfeffer and Salacik, 1978). Second, we control the education level of employees. Companies with well-educated employees may be more cutting-edge when it comes to current trends and be more equipped to effectively integrate knowledge within the organization.

In Fig. 1, we graphically illustrate the conceptual framework regarding the relationships among supplier integration, customer orientation, green information systems, and the two aspects of green innovation: green product innovation and green process innovation.

4. Methodology

4.1. Survey instrument design and validation

The data used in this study were collected by surveying the senior managers of companies in Shandong Province, China. We developed the questionnaire by using a deductive procedure suggested by Hinkin (1998). One member of our research team interviewed top managers of various companies to obtain information regarding green initiatives, green practices, and other environmental-related issues. The conversations focused on managerial issues regarding green operations and performance as well as relationships between parties across the supply chains. We surveyed the literature for the measurement of constructs proposed in the proposed conceptual model. The initial questionnaire was developed after the completion of field visits and an extensive literature review. We then had a pre-test with the help of several CEOs and operations managers. Based on this pre-test feedback, we made modifications to the questionnaire and tested it again by another five company managers for clarity and specificity. Table 2 below shows the modifications based on the pre-test results.

Next, we established face validity by discussing the questionnaire with CEOs and operations managers to eliminate potential ambiguity or difficulty and customizing to the companies in China, by conducting face-to-face talks with CEOs and operations managers regarding possible ambiguities or difficulties when answering items in the survey

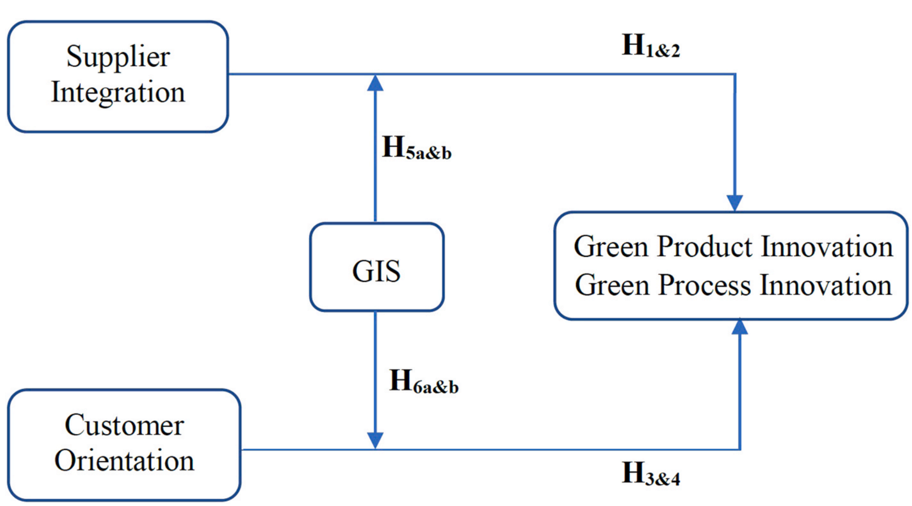

Fig. 1. Conceptual framework.

Table 2
Modifications made based on pre-testing.

Changes made	Reasons for change or deletion
Item d for *Green Information System*. "We formally track the environmental performance within our company" changed to "We formally track and report the environmental performance within our company"	• For completeness because most pre-test participants believed that report needed for the awareness of top management team
Item c for *Green Process Innovation*, "Preference for green products in purchasing, was added" was added	• For specificity because most pre-test participants indicated this as one of the important steps involved in their green production.
Item b for *Green Process Innovation*, "optimizing materials exploitation" is added	• For completeness because most pre-test participants indicated the material exploitation as a major aspect of green process innovation.

questionnaire. Based on their suggestions and feedback, we then made some minor modifications in the questionnaire. Moreover, we asked two academic experts to critically evaluate each item regarding its specificity, clarity, and representativeness. The questionnaire was revised based on their feedback accordingly. Finally, five senior managers were asked to complete the questionnaire. After these extensive revisions and checks, we had very minimal concerns about the questionnaire. The measurements of constructs are attached in the appendix.

4.2. Data collection and construct validation

We develop a list of the first 1000 largest companies from the Shandong Statistical Yearbook because large and small firms benefit differently from sustainable operations and innovations. Normally large firms will benefit more from sustainable activities for the reason that they usually receive more attention from the public than small firms (Dixon–Fowler et al., 2012). Therefore, large firms would be more likely to increase their green innovations to enhance the reputation and benefit from it. Moreover, large firms usually carry more resources than small firms so that they can devote more to green innovations and enjoy the economies of scale in their operations (D'Amboise and Muldowney, 1988; Eden et al., 1997; Woo and Cooper, 1981). The questionnaires were mailed out with a prepaid return envelope to those 1000 companies. To deal with potential privacy concerns and mitigate the issue of potential bias in self-reported data, we assured all respondents anonymity and confidentiality regarding their responses with results reported only in aggregate format. After two months we received 112 responses, we sent out a reminder which yielded 27 more responses. To increase the response rate, we hired local university students to travel to nearby companies for another 126 responses. In total, we collected 265 responses including 34 incomplete responses. This yielded a total of 231 useable questionnaires.

Because of the single respondent in each of our observations, we further adopt extra steps to evaluate the risk of common method variance (CMV) (Podsakoff and Organ, 1986). First of all, each questionnaire was completed by either the CEO or other senior manager. Normally, high-level executives understand their companies very well regarding operations and innovations, which reduces the risk of CMV problem (Miller and Roth, 1994). Second, when designing the questionnaire, we intentionally intersperse dependent variables among those independent variables. This approach will limit the potential cues inferred by those managers when they answered the questions in our questionnaire. This helps to further reduce the CMV risk. Thirdly, Harman's single factor test is employed in this study to further evaluate the risk of CMV. The fit indices from the single-factor test are as follows, RMSEA = 0.206, χ^2 = 1547.69 (d.f. = 648), CFI = 0.401 and SRMR = 0.247. These results are not as favorable or reliable as those obtained from the Confirmatory Factor Analysis model presented below.

4.3. Validation for measurement instrument

A five-point Likert scale is used in our measurement for all items. The descriptive statistics for all items of measurement are displayed in Table 3 below. We employ confirmatory factor analysis (CFA) to analyze the unidimensionality for all constructs included in our conceptual framework. The fit index of RMSEA is 0.041 with χ^2 = 657.8 (df = 543). Thus, RMSEA is much less than the suggested threshold value of 0.08 and the ratio of χ^2 to the degree of freedom is also much lower than the suggested cutoff value of 2 in the literature (Browne and Cudeck, 1993; Segars and Grover, 1993). Combined with other fit indices such as CFI = 0.971, TLI = 0.962, a good fit of our measurement model is indicated.

Furthermore, we calculate Cronbach's Alpha to evaluate the measurement reliability of each construct with the results shown in Table 4 below. We can confirm the internal consistency of those indicators for each construct. To evaluate convergent validity regarding the measurement of each construct, AVE is obtained by calculating the average value of all the squared "completely standardized" loadings for each construct (Fornell and Larcker, 1981). As shown in Table 4 below, all of our latent constructs have larger AVE values than the indicated threshold value in literature, i.e. 0.5, indicating that most variance of the latent construct is captured by the indicators. Lastly, discriminant validity is examined by comparing the square root of the AVE for each construct with its associated correlation coefficients of each construct with all others. The square roots of the AVEs are in bold shown along the diagonal in Table 4. Therefore, a reasonable conclusion can be made that each of the latent constructs used in this study shares less variance with any other constructs than with its own indicators.

Table 3
CFA results.

Constructs	Item Code	Completely Standardized Loadings	t-value	Item Mean	S.D.
Supplier Integration (SI)	SI1	0.754	Fixed	2.688	0.837
	SI2	0.763	10.74	2.813	0.845
	SI3	0.757	10.52	3.063	0.981
	SI4	0.774	11.06	2.813	0.839
	SI5	0.785	11.42	3.000	0.873
Customer Orientation (CO)	CO1	0.773	Fixed	3.336	0.752
	CO2	0.742	10.54	3.412	0.843
	CO3	0.751	10.73	3.543	0.763
	CO4	0.764	10.97	3.621	0.821
	CO5	0.801	11.030	3.334	0.783
Green Information System (GIS)	GIS1	0.783	Fixed	3.321	0.724
	GIS2	0.807	11.82	3.292	0.856
	GIS3	0.798	11.32	3.575	0.832
	GIS4	0.821	11.87	3.284	0.865
	GIS5	0.768	10.76	3.426	0.854
	GIS6	0.823	11.98	3.473	0.829
Green Product Innovation (GPDI)	GPDI1	0.708	Fixed	3.615	0.743
	GPDI2	0.635	8.082	3.629	0.766
	GPDI3	0.796	13.555	3.380	0.799
	GPDI4	0.697	8.788	3.654	0.755
	GPDI5	0.677	8.728	3.668	0.719
		0.708	8.911	3.534	0.782
	GPDI6	0.708	8.911	3.534	0.782
Green Process Innovation (GPCI)	GPCI1	0.641	Fixed	3.639	0.765
	GPCI2	0.681	7.928	3.610	0.769
	GPCI3	0.753	9.042	3.229	0.774
	GPCI4	0.768	12.859	3.415	0.834
	GPCI5	0.794	8.787	3.629	0.700
	GPCI6	0.799	8.813	3.561	0.695

Fit indices: χ^2 = 657.8; d.f. = 543; CFI = 0.971; TLI = 0.962; SRMR = 0.047; RMSEA = 0.041; sample size (n) = 231.

Table 4
Correlation & reliability.

	SI	CO	GIS	GPD	GPP
SI	**0.767**				
CO	0.105	**0.766**			
GIS	0.117	0.138	**0.800**		
GPDI	0.342	0.302	0.205	**0.705**	
GPCI	0.298	0.322	0.193	0.347	**0.742**
Reliability	*0.877*	*0.877*	*0.914*	*0.855*	*0.879*

Note: Numbers in bold indicates the square root of Average Variance Extracted (AVE).

5. Results and analyses

This study employs a structural equation model (SEM) to analyze the proposed relationships specified in our conceptual framework (Fig. 1). SEM is a statistical methodology including factor analysis (i.e., measurement model) and path analysis (i.e., structural model). SEM can be used to study the relationships among latent constructs that are indicated by multiple measures. SEM has the ability to incorporate latent variables into the analysis and accounts for measurement errors in the estimation process. SEM allows to model and test complex patterns of relationships, including a multitude of hypotheses simultaneously with multiple dependent variables. Fig. 2 below illustrates the diagram of estimated relationships among those constructs discussed in this study and their corresponding measurement items.

Mplus 8 was used to estimate the SEM with the maximum-likelihood estimation. Table 5 below displays the outcomes with the fit indices of the estimation. In this process, a hierarchical estimation process is used by estimating the direct effects of supplier integration (SI) and customer orientation (CO) on green product innovation (GPDI) and green process innovation (GPCI) first in model 1. Then the moderation effect of green information system (GIS) is estimated by adding GIS and its interactions with SI and CO in model 2. Compared with a big aggregate structure of analysis with all information involved, the hierarchical structure allows adding extra information easily to confirm the relationship of interest. The hierarchical model will largely eliminate the potential of collinearity incurred by adding too many explanatory variables at one time while confirming the focal relationships step by step. The results are shown in Table 5 below.

Based on the results in Table 5, a good fit is indicated by those fit indices of both models such as RMSEA below the suggested threshold

Table 5
Results of hierarchical estimation.

	Model 1	Model 2
SI→GPDI	.205 (2.544)**	.198 (2.421)**
SI→GPCI	.232 (2.732)**	.229 (2.711)**
CO→GPDI	.173 (2.229)*	.169 (2.116)*
CO→GPCI	.269 (3.376)**	.263 (3.312)**
GIS→GPDI		.174 (2.126)*
GIS→GPCI		.162 (2.115)*
SI*GIS→GPDI		.178 (2.194)*
SI*GIS→GPCI		.189 (2.235)*
CO*GIS→GPDI		.132 (1.651)
CO*GIS→GPCI		.197 (2.654)**
Firm Size →GPDI	.185 (2.207)*	.179 (2.179)*
Firm Size →GPCI	.179 (2.163)*	.172 (2.123)*
Education →GPDI	.175 (2.207)*	.171 (2.153)*
Education →GPCI	.168 (2.135)*	.165 (2.118)*
	$\chi^2 = 778.728$	$\chi^2 = 1096.354$
	df = 724	df = 895
Fit Indices	CFI = .957	CFI = .945
(Sample size = 231)	TLI = .951	TLI = .941
	RMSEA = .038	RMSEA = .042
	SRMR = .085	SRMR = .092

Note: ** 1% level, * 5% level.

0.08 (Browne and Cudeck, 1993) and values of CFI over 0.945. The satisfied RMSEA and CFI values indicate significant improvement in fitting the proposed relationships specified in our conceptual model when compared with the null model. A good fit is indicated by the ratio of chi-square to the degrees of freedom that is lower than the suggested threshold value of 2 (Segars and Grover, 1993).

5.1. Main effects

Supplier Integration (H1 & H2): In model 1, the path coefficient from supplier integration (SI) to green product innovation (GPDI) is significantly positive (0.205, $p < 0.01$, Table 5), and the coefficient from supplier integration (SI) to green process innovation (GPCI) is also significantly positive (0.232, $p < 0.01$, Table 5). Both hypotheses H1 and H2 are supported. These positive impacts confirm the proposed relationships in our conceptual framework that supplier integration can improve a firm's green innovation in product and process aspects. High-level supplier integration can improve a company's information-processing capacity and incorporate the suppliers' complementary knowledge and expertise so that the company can successfully develop

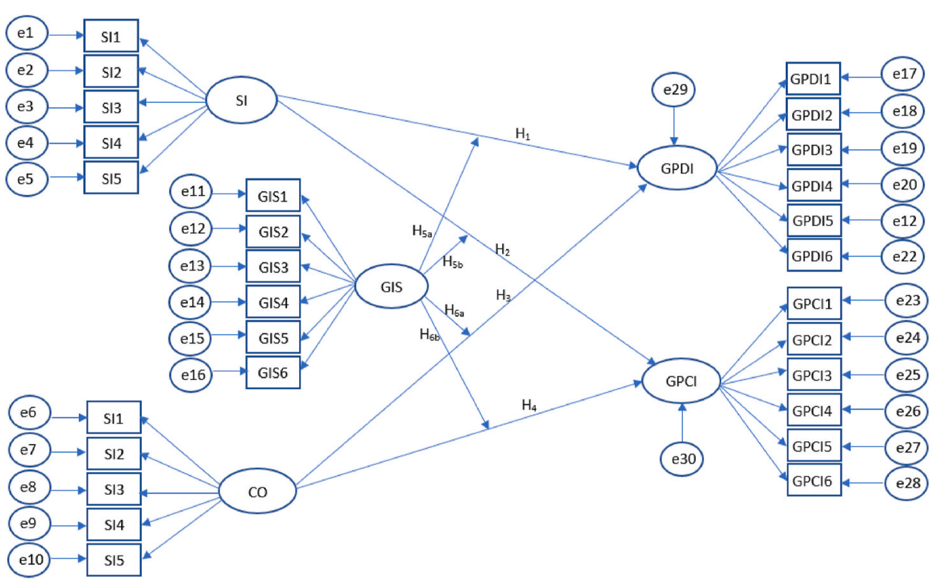

Fig. 2. Diagrammatic illustration of the estimated relationships in SEM.

new green initiatives and innovations.

Customer orientation (H3 & H4): the path coefficient from customer orientation (CO) to green product innovation (GPDI) is significantly positive (0.173, $p < 0.05$, Table 5), and the coefficient from customer orientation (CO) to green process innovation (GPCI) is also significantly positive (0.269, $p < 0.01$, Table 5). Both hypotheses H3 and H4 are supported. These positive impacts confirm the proposed relationships in our conceptual framework that customer orientation can also help improve a firm's green product and process innovation. High-level customer orientation can enable a company to closely monitor and satisfy its customers' environmental preferences and needs by developing new green products or production processes.

The results of the main effects confirm the effect of coordination and collaboration, i.e., integration, across the supply chain in improving performance (Koufteros et al., 2007; Marquez et al., 2004; Rosenzweig et al., 2003). This study shows that integrating suppliers into a company's operations in order to serve the customers' green needs can improve green product and process innovations. Therefore, it is important for companies to communicate smoothly, work closely, and integrate seamlessly with their upstream suppliers and downstream customers to increase innovative capabilities and achieve environmental goals. This type of integration & orientation may generate more opportunities to increase competitive advantages in the global market. Based on the main-effect results, companies should therefore engage in substantial efforts along with their suppliers and customers to improve green innovations and address environmental issues. Practically, to promote supplier integration, companies can provide training and assistance to help their suppliers improve environmental awareness and technical capabilities. To enhance customer orientation, it is important to understand customers' environmental concerns and requirements through active market information collection and effective inter-organizational communication.

5.2. Moderation effects of GIS

Model 2 tests the moderation effect of green information systems on the main effects discussed above. The coefficient of the interaction between GIS and supplier integration (GIS*SI) on green product innovation is significantly positive (0.178, $p < 0.05$, Table 5), indicating that a well-developed GIS can help improve a company's connections with its suppliers and strengthen the positive impact of supplier integration on green product innovation (Fig. 3a). Similarly, the coefficient of the interaction between GIS and supplier integration (GIS*SI) on green process innovation is also significantly positive (0.189, $p < 0.05$, Table 5), which means that a well-developed GIS can also strengthen the positive impact of supplier integration on green process innovation (Fig. 3b), possibly due to suppliers that are actively involved in collaboratiosn with their buyers through GIS. Therefore, both hypotheses H5a and H5b are supported, confirming our previous argument that a well-developed GIS facilitates the active involvement of suppliers towards green initiative and production.

As to the moderation effects of GIS on the relationships between customer orientation and green innovations, the coefficient of the interaction between GIS and customer orientation (GIS*CO) on green process innovation is significantly positive (0.197, $p < 0.01$, Table 5), indicating that a well-developed GIS can help firms obtain customer requirements and other types of information effectively so as to increase the positive impact of customer orientation on green process innovation (Fig. 3c). So hypothesis H6b is supported; however, the coefficient of the interaction between GIS and customer orientation (GIS*CO) on green product innovation is not significant (0.132, $p < 0.1$) at the 5% level of significance, which means that GIS may not have effect in improving the impact of customer orientation on green product innovation based on the data used in this study.

The positive moderation effects of GIS indicate the importance and necessity of building GIS for companies that are engaged in green innovations. GIS will provide an effective infrastructure facilitating a company to communicate and share information with its suppliers and

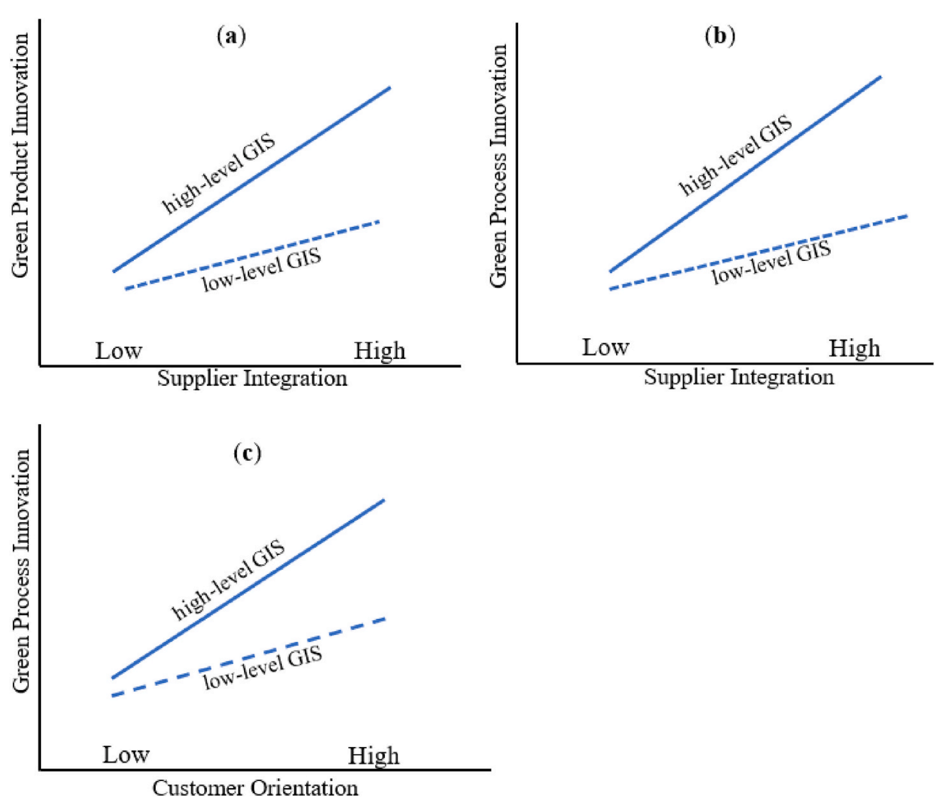

Fig. 3. Results of GIS moderation effects.

customers smoothly. Therefore, GIS offers an overarching platform to guide the behaviors of green innovation for all members across the supply chain to achieve effective environmental management activities (El-Gayar and Fritz, 2006). Specifically, efficient GIS enables seamless supplier integration to support a company's innovative activities, which will be helpful in identifying opportunities of green innovation for less adverse environmental impacts, conservation of resources and energy, waste and pollution prevention, recycling, and reuse, etc. (Chen et al., 2006; Li et al., 2019).

As to GIS's moderation effect on the link between customer orientation and green innovations, an effective GIS enables a company to track, monitor, and collect various customer-related information regarding their green preferences & choices associated with energy and resource consumption, waste generation, emissions, and pollution, etc. So, companies will improve their decision-making capabilities in satisfying customers' green requirements to reduce wastes and emissions, and optimize resource utilization for small carbon footprints. The analysis results in this study indicate that GIS strengthens the positive impact of customer orientation on green process innovation, which confirms the previous argument in this study. However, the moderation effect of GIS on the relationship between customer orientation and green product innovation is insignificant at the 5% level of significance with a *p*-value of more than 0.05 but less than 0.1. There are two possible reasons for this insignificant moderation effect on the link between customer orientation and green product innovation. The first one could be due to customers' lack of expertise in providing break-through green ideas for green product innovation. Compared with suppliers, customers have limited knowledge or information regarding the production process, materials usage, energy and resource consumption, etc. So through GIS, companies can only collect a narrow scope of customer-related knowledge and information, limiting the positive effect of GIS. The second possible reason could be due to the data used in this study. Even though the moderation effect of GIS on the link between customer orientation and green product innovation is not significant at the 5% level of significance, the direction of the estimation is positive with a *p*-value of less than 10%. The moderation effect could be significant for another dataset with a larger sample size by reducing type II error and increasing the power of our test.

Control variables: For the results of the two control variables included in this study (Table 5), both coefficients are significantly positive, indicating that higher-level green innovation for larger companies possibly due to economies of scale and companies with high-level education employees possibly due to high learning capabilities.

6. Discussions

The results of this study shed some light on the role played by GIS in green SCM to improve green innovations. Green SCM and GIS have been articulated in literature respectively regarding their roles in improving organizational green innovations and environmental performance. However, the alignment between them in impacting green innovations has been barely studied. Building on information-processing theory, we suggest that GIS is an exogenous decision requiring an appropriate alignment with supplier integration and customer orientation in enhancing organizational green innovations. We developed the logic in the following four steps: (1) green innovations increase project complexity and uncertainty and thus information-processing requirements; (2) organizations will manage such requirements by expanding information-processing capabilities through supply chain integration; (3) an effective supply chain integration is achieved only if the great deal of information associated with green innovations can be processed efficiently without incurring excessive information-processing cost; and (4) GIS provide an overarching platform for easy information sharing and smooth communication among different parties across supply chains.

This study extends the extant literature by analyzing how GIS can properly align with green SCM in improving green innovations. The findings in this study provide the basis for some theoretical and managerial insights regarding green innovations in an inter-organizational setting across supply chains.

6.1. Theoretical implications

This study essentially addresses the issue of aligning an effective GIS with green SCI to improve organizational green innovations, which has been largely omitted in the SCM research community. A conceptual framework is developed to identify the moderation effect of GIS in shaping the relationships between supply chain integration (i.e. supplier integration and customer orientation) and green performance in green product process innovation, Although this study does not aim to design an overarching inter-organizational framework, future inquiries may still reference this study in finding contingencies in shaping the effects inter-organizational relationships across SCM on innovations. The above findings suggest that the effect of SCI cannot be isolated from its contexts, and should be instead be coupled with contingent factors to achieve expected benefits.

Besides, this study presents the application of information-processing logic to inter-organizational design in the SCI setting. Complexity and uncertainty involved in green innovations determine the need for information-processing capacity for proper information processing without extra cost. The findings in this study provide useful references for future research in identifying factors that improve green innovations under a green supply chain scenario. The arguments and theoretical model presented in this study provide a valuable reference for academicians interested in green innovation, green SCM, sustainability, and GIS.

6.2. Managerial implications

Green innovations have been widely used by companies as a strategic tool to address the growing environmental concerns of sustainable development while achieving a competitive advantage. However, risks and uncertainty are high when conducting green innovations. Supplier integration, as well as customer orientation, may expand a company's information-processing capacity to satisfy the requirement for the high-level complexity and uncertainty associated with green innovations. An effective GIS can provide an overarching platform that guides smooth information sharing and communication across the supply chain. Green SCI and GIS work together to enhance high-quality communication and collaboration among different parties, which in turn generates considerable benefits for all parties with successful innovations.

Practitioners for green innovations should realize the importance of aligning GIS with green SCI in increasing the organizational capability of green innovations. An effective and well-design GIS is a steppingstone to successful innovation and customer satisfaction. This study provides a potential direction for practitioners when investing resources to enhance green innovations. The empirical outcomes of this study show that GIS significantly intensifies the impact of supplier integration on the green product and process innovation, as well as strengthens the effect of customer orientation on green process innovation. Faced with the pressure of sustainability from various stakeholders, manufacturers need to get their suppliers closely involved in their green product and process innovation and satisfy the requirements of their customers. GIS plays an important role in this process, effectively facilitating supplier integration and customer orientation. The results of this study provide great opportunities for the top management team of a company to justify their investment in GIS, actively connect with other parties along the supply chain, and eventually develop innovation capability, improving their green performance.

6.3. Limits and future research

As with any study, this study also has several limitations. First of all, a self-reported dataset is used in this study. Although the test results of various measures indicate that little concern exists for the risk of common method bias, the outcomes and findings of this study still need to be considered with reservation. Moreover, single-region and cross-sectional data are used here. Longitudinal or multi-regional data from other areas can be used in the future to analyze the relationships specified here and push this study forward. Third, this study only specifies and analyzes the two aspects of SCI, supplier integration, and customer orientation, in improving green innovation. However, the antecedents of these two aspects are not touched here. One direction for future study is to identify the antecedents or factors that can enhance supplier integration and customer orientation and indirectly improve a company's green innovations. Another direction for further research is to focus on identifying factors and different dimensions of GIS so that a company can develop an effective GIS to expand information-processing capacity and achieve high-level green supply chain integration. Finally, identifying proper governance mechanisms well-aligned with the inter-organizational relationship for effective supply chain integration is another promising direction for future research.

7. Conclusion

In response to the increasing concerns from various stakeholders regarding the adverse effects of business activities on the environment, companies adopt green process innovation and production innovation by working with its partners across their supply chains to address these concerns and gain competitive advantages. The GIS may play a critical role in helping companies to succeed by helping address this type of challenges. This study develops a theoretical framework to investigate two aspects of the benefits of GIS. The first aspect concerns how GIS can facilitate the green capabilities of suppliers to assist in the development of green processes and products. The second focuses on how GIS can help firms determine customer requirements and incorporate them into the development of green product and process innovation.

Overall, a company's supplier integration and customer orientation are important drivers for both green product and process innovation. This finding is consistent with SCM literature related to supply chain integration in general, suggesting green product and process innovations might be successfully implemented through inter-organizational collaborations by integrating suppliers' and customers' capabilities. Moreover, the implementation of GIS may help facilitate information sharing for effectively improving the green product and process innovation. A well-developed GIS strengthens the impact of a company's supplier integration and customer orientation on its green innovations. The empirical results suggest that to increase green innovations, it is important for a company to devote substantial efforts in building a well-developed GIS so that it can closely collaborate with suppliers and understand customers' green requirements accurately and timely. Therefore, GIS can help increase green integration across all members throughout the whole supply chain and expand a company's information-processing capacity for a higher level of green innovative capabilities.

CRediT authorship contribution statement

Kejin Qu: Conceptualization, questionnaire design, data collection, Writing – original draft. **Zuoming Liu:** data preparation, Formal analysis, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Scale items for latent constructs used in this study

For each of the following five constructs, the respondents indicated their agreements with the statement on a 1 to 5 scale. (1) indicated very low and (5) indicated very high.

Supplier Integration (SI)

a. We closely monitor and assess our suppliers' green practices
b. We communicate with our suppliers regarding green practices
c. Our suppliers' green practices are helpful in building our competitive advantage
d. We develop our business objectives based on our suppliers' green practices
e. We get our suppliers involved in and consider their suggestion regarding our green practices

Customer Orientation (CO)

a. We closely monitor our level of serving customers' needs in green practices
b. Business strategies are driven by the goal of increasing customer value of green operations
c. We frequently measure customer satisfaction regarding sustainable operations
d. Our business objectives are driven by customer satisfaction with green operations
e. We pay close attention to after-sales service in satisfying customers' green requirements

Green Information System (GIS)

a. Our company has a formal system regarding environment improvement in operation
b. We have formal departments that is responsible for environmental affairs
c. The practices and steps in the system regarding green practices are widely available
d. We formally track and report the environmental performance within our company
e. We regularly track, monitor, and share environmental information within company
f. Firm has a well-developed database to track and monitor environmental issues

Green Product Innovation (GPDI)

a. Product design focused on reducing resource consumption and waste generation
b. Products are designed for disassembly, reusability and recyclability
c. Products are designed to avoid or reduce the use of hazardous of materials
d. Products are designed for to produce less byproducts and waste
e. Products are designed for easy storage and handle during transportation
f. Products are designed to use less energy and resource in production

Green Process Innovation (GPCI)

a. Emission filters and end-of-pipe controls
b. Production process based on reducing waste and optimizing materials exploitation
c. Preference for green products in purchasing
d. Ecological materials for primary packaging

e. Recuperation and recycling systems
f. Responsible disposal of waste and residues

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