frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 24 November 2022
DOI 10.3389/fenvs.2022.1045414

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

RECEIVED 15 September 2022
ACCEPTED 11 November 2022
PUBLISHED 24 November 2022

CITATION
Zhang B, Zhao S, Fan X, Wang S and Shao D (2022), Green supply chain integration, supply chain agility and green innovation performance: Evidence from Chinese manufacturing enterprises. *Front. Environ. Sci.* 10:1045414. doi: 10.3389/fenvs.2022.1045414

Green supply chain integration, supply chain agility and green innovation performance: Evidence from Chinese manufacturing enterprises

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Despite widespread attention on the significance of green supply chain integration (GSCI), there is still limited research on how GSCI can improve firms' green innovation performance. From the perspective of the natural resource-based view and dynamic capability theory, based on the theoretical logic of "resource-capability-performance", this study aims to explore the relationship between GSCI and firms' green innovation performance and its intrinsic mechanism. In order to test the research model, this study collected survey data from 405 Chinese manufacturing firms and tested them by using hierarchical regression and bootstrap analysis. The results show that all three dimensions of GSCI, namely, green internal integration, green supplier integration, and green customer integration, have positive effects on supply chain agility. In addition, supply chain agility has a significant positive impact on green product and process innovation. This study also finds that supply chain agility plays a partially mediating role between all three dimensions of GSCI and green product and process innovation; that is, GSCI can further promote firms' green innovation performance by improving supply chain agility. The results of this study not only enrich the theoretical research on the driving factors of firms' green innovation but also provide policy implications for manufacturing firms and government policy-makers regarding the implementation and promotion of green innovation practices.

KEYWORDS

green internal integration, green supplier integration, green customer integration, green innovation, supply chain agility

1 Introduction

Currently, companies in various countries face many challenges brought about by environmental changes, such as global warming, energy consumption, and natural resources exhaustion, while promoting economic growth (Khan et al., 2022e; Wangsa et al., 2022). The economic growth approach, at the expense of the environment, has become a major bottleneck limiting the survival and growth of enterprises (Bildirici and Gökmenoğlu, 2017; Khan et al., 2022d). Additionally, with increasingly stringent government environmental regulations and rising awareness of environmental protection among consumers, providing green products and services in an environmentally friendly manner has become an important way for companies to gain competitive advantage (Khan et al., 2021b; Khan et al., 2022c). Therefore, seeking a sustainable development path has become a top priority. Green innovation, as the extension and promotion of traditional innovation, is regarded as a key force to balance the contradiction between economic growth and ecological environment development, and, eventually, to achieve sustainable development (Long et al., 2017). Therefore, exploring the path to improving corporate green innovation performance has become an important issue that needs to be addressed urgently.

According to the natural resource-based view (NRBV), the heterogeneous resources and unique capabilities accumulated by enterprises to respond to natural environmental challenges have a significant impact on green innovation (Hart, 1995). Due to increasing global competition and technological complexity, market competition has shifted from individual firms to supply chains (Yeh et al., 2020). It is difficult for firms to respond to the turbulent external environment by relying only on their resources, which leads to a series of challenges and risks for implementing firms' green innovation strategies (Huang and Li, 2017). Therefore, breaking through organizational boundaries and actively seeking cooperation with supply chain partners to access complementary resources has become a major means to improve firms' green innovation performance (Birasnav and Bienstock, 2019). In this context, there is a practical necessity and urgency to construct a green supply chain and implement green supply chain integration (GSCI) (Khan et al., 2021a; Mondal and Giri, 2022). GSCI refers to the extent to which companies and supply chain partners can improve resource utilization and achieve environmental goals through environmental cooperation and collaborative management of intra- and inter-organizational processes (Du et al., 2018). As an important strategy for enterprises, GSCI not only helps to enhance trust among supply chain members and promote the interaction and flow of information and knowledge resources but also helps to integrate multiple and scattered advantageous resources in the supply chain, thus compensating for the lack of corporate resources (Yang et al., 2020). Therefore, the implementation of GSCI will have an important impact on corporate green innovation performance. However, reviewing the existing literature, although the research around the theme of GSCI has attracted the attention of academic circles in recent years, scholars mainly focus on the impact of GSCI on firms' financial performance (Zhang et al., 2020) or environmental performance (Ji et al., 2020), while the impact of GSCI on green innovation performance has not received enough attention. Therefore, this study attempts to explore the relationship between GSCI and corporate green innovation performance.

In addition, although GSCI provides enterprises with access to resources (Yang et al., 2020), it is still unclear how enterprises can use acquired resources to guide their green innovation practice in a competitive and dynamic market environment (Lyu et al., 2021; Khan et al., 2022b). Therefore, to fully understand the relationship between GSCI and firms' green innovation performance, the "black box" between their relationships should be opened. In recent years, scholars have introduced dynamic capabilities from the perspective of the resource internalization process to explore the specific process by which resources act on firm performance (Parente et al., 2022). As a higher-order dynamic capability, supply chain agility helps companies quickly capture potential opportunities and risks in market competition and respond to turbulent environmental changes efficiently by rapidly arranging or coordinating organizational resources (Dubey et al., 2018), thus avoiding the negative impact of supply chain disruptions (Khan et al., 2022a; Khan and Ponce, 2022). Therefore, supply chain agility is helpful to dynamically match a company's resources with their environment to maximize their effectiveness, thus becoming an important guarantee for the effectiveness of GSCI (Shukor et al., 2021). Accordingly, this study intends to explore the role of supply chain agility in the relationship between GSCI and corporate green innovation performance from the perspective of dynamic capability to clarify the internal mechanism of the transformation from GSCI to corporate green innovation performance.

In summary, from the perspective of NRBV and DCT, based on the theoretical logic of "resource-capability-performance," this study aims to deeply explore the relationship between GSCI and corporate green innovation performance and its intrinsic mechanism by using the survey data of 405 Chinese manufacturing enterprises. In order to achieve this goal, this study tries to answer the following questions: 1) What impact of GSCI's three dimensions on supply chain agility? 2) What impact does supply chain agility have on corporate green product and process innovation? 3) Does supply chain agility mediate the relationship between GSCI's three dimensions and firms' green product and process innovation? Accordingly, this paper may have the following contributions. Firstly, this study discusses the influence of GSCI on supply chain agility and corporate green innovation performance, thus enriching the theoretical research

related to GSCI. Although the importance of GSCI has gradually gained the attention of scholars in recent years, tests on its effects are still limited. Most scholars focus on discussing the impact of GSCI on corporate financial performance (Zhang et al., 2020) or environmental performance (Ji et al., 2020), but pay less attention to its impact on green innovation performance, resulting in a lack of related research. Therefore, this study explores the impact of GSCI on supply chain agility and corporate green innovation performance through empirical research, thereby expanding its scope of application. Secondly, this study discusses the influencing factors of green innovation performance from the perspective of resources and capabilities, thus enriching the antecedent research on green innovation performance. Existing research mainly focused on the influence of external factors on green innovation performance, such as stakeholder pressure (Nguyen and Adomako, 2022) and institutional factors (Zhang et al., 2022), but lacked a discussion on the antecedents of green innovation performance in the context of the supply chain. This study innovatively takes the perspective of GSCI and supply chain agility to explore their impact on green innovation performance, thereby enriching the empirical research on the influencing factors of green innovation performance under the background of "double carbon", and also opening up new ideas for the existing literature. Thirdly, this paper discusses the mediating effect of supply chain agility on the relationship between GSCI and corporate green innovation performance, thus unveiling the "black box" of the relationship between GSCI and green innovation performance. Existing research lacks the exploration of the intrinsic mechanism between GSCI and corporate green innovation performance and thus fails to clearly understand the specific process by which GSCI affects green innovation performance. Based on the theoretical logic of "resource-capability-performance", this study examines the mediating role of supply chain agility between GSCI and green innovation performance from the perspective of dynamic capability, thus clarifying the potential mechanism of GSCI affecting green innovation performance and providing a theoretical reference and practical guidance for the management practice of manufacturing enterprises using GSCI to improve their green innovation performance.

2 Literature review and hypothesis development

2.1 Green supply chain integration

Supply chain integration refers to a manufacturing firm's strategic collaboration with supply chain partners and coordinated management of intra- and inter-organizational processes to provide maximum value to customers (Flynn et al., 2010; Donkor et al., 2021). As public awareness of the environment grows, GSCI is proposed, based on traditional supply chain integration, and is defined as the extent to which manufacturing companies and their supply chain partners can improve resource utilization and achieve environmental goals through environmental cooperation and the collaborative management of intra- and inter-organizational processes (Du et al., 2018). Like supply chain integration, GSCI can be divided into three dimensions: green internal integration, green supplier integration, and green customer integration (Lo et al., 2018). Green internal integration means that companies remove cross-functional barriers and enable different departments to collaborate environmentally in strategy, decision-making, and operations to respond promptly to potential environmental issues (Shah and Soomro, 2021). Green supplier and customer integration, often referred to as external green integration, reflect the degree of cooperation between companies and their supply chain partners in environmental protection (Guo et al., 2022). Green supplier integration helps companies and suppliers understand each other's environmental responsibilities and helps companies reduce pollutant emissions at the source by jointly setting environmental goals and sharing environmental plans (Ji et al., 2020). Green customer integration helps companies better understand the green needs of the market, enabling them to achieve the same environmental goals, for both supply and demand, through joint planning (Zhao et al., 2020). Owing to the importance of GSCI, it has become a hot topic in management research in recent years, and progress has been made in related research. Some scholars have explored the antecedents of GSCI from organizational internal and external perspectives. For example, Wang and Feng (2022) argued that ethical leadership helps to improve corporate image, which in turn contributes to the implementation of GSCI. Shafique et al. (2018) found that IoT capabilities can help companies quickly collect and process data information, thus ensuring efficient green collaboration among supply chain partners and then improving GSCI. Yang et al. (2021) indicated that suitable governance mechanisms not only clarify the responsibilities and obligations between partners but also increase the commitment and trust between them, thus reducing opportunistic behavior and contributing to the efficiency of green customer integration. In addition, some scholars have provided empirical evidence for the effects of GSCI through their studies. Most of them believe that there is a "bright side" to GSCI. For example, Kong et al. (2021) found that GSCI can help to promote organizational internal and external communication and cooperation, which improves firms' financial performance. Ji et al. (2020) argued that green supplier integration helps firms to acquire advanced green technologies from their suppliers, which contributes to developing the ability of firms to cope with the environment and achieving the improvement of environmental performance. However, some scholars have confirmed that there is a "dark side" to GSCI. For example, Shi et al. (2022) found that green customer integration is usually regarded as a firm-customer-specific investment, which leads to high switching

costs and increases the opportunistic behavior of partners; therefore, green customer integration may bring business risks to firms. Existing research has explored the antecedents and consequences of GSCI based on different perspectives, making an important contribution to the development of the field of GSCI and laying the foundation for subsequent research.

2.2 Green innovation performance

In recent years, with increasing environmental pollution, external pressure has forced companies to gradually improve their environmental awareness and produce green products to reduce the damage to the environment (Arroyave et al., 2020; Khan et al., 2021b); thus, green innovation was born. Green innovation, also known as environmental innovation, is defined as an innovative activity wherein companies adopt new or improved products, processes, and organizational management to reduce pollution emissions and realize the harmonious coexistence between man and nature. According to existing research, green innovation performance is usually classified into green product innovation and green process innovation (Wei et al., 2020). Green product innovation emphasizes the integration of environmental protection concepts in its life cycle to minimize the negative impact of new products on the environment (Wei et al., 2020). Green process innovation aims to reduce pollutant emissions and improve energy efficiency by improving or developing new processes (Xie et al., 2019). Unlike traditional innovation, green innovation emphasizes economic as well as environmental benefits; thus, it is considered an important way to achieve sustainable development (Long et al., 2017).

Despite a large number of studies confirming its important role, enterprises usually lack the willingness and motivation to undertake green innovation due to its double externality, characteristics of high investment and risk, and long cycle time (Bai et al., 2019). Therefore, how to efficiently promote corporate green innovation performance has become a key issue and has attracted widespread academic attention. In the existing literature, most scholars focus on the driving effects of organizational external factors on green innovation performance. For example, Zhang et al. (2022) argued that environmental regulations could stimulate firms' green innovation activities and promote continuous improvement of products and processes, thus producing an innovation compensation effect. Long and Liao (2021) pointed out that since green innovation requires a large amount of R&D investment, fiscal policy incentives can effectively compensate for the limitation of insufficient corporate funds, thus increasing firms' willingness to green innovation. Nguyen and Adomako (2022) found that the pressure from stakeholders can encourage firms to be proactive towards environmental responsibility, thus effectively promoting the implementation of corporate green innovation strategy. In addition, some scholars have shifted their research perspectives to organizational internal. For example, Zhao et al. (2021) found that executives with academic experience usually have a higher sense of social responsibility; therefore, they can better understand and take responsibility for environmental protection, which helps to improve firms' green innovation performance. Asiaei et al. (2022) confirmed that organizational intellectual capital is the intangible asset of firms, and thus it becomes a powerful driving force for firms' green innovation. Wang (2019) argued that organizational green culture helps to enhance employees' green organizational identity and enables them to better understand the company's green practices, thus promoting corporate green innovation activities. Although scholars have done a lot of research on the driving factors of green innovation performance and achieved fruitful results, the research on the impact of GSCI on green innovation performance has not received sufficient attention. In recent years, due to increasing market competition and technological changes, the development of green innovation places higher requirements on firms' knowledge structure and resource reserves, making it difficult for many enterprises to carry out green innovation independently because of talent, capital, and technology constraints (Huang and Li, 2017). In this context, GSCI, as an important strategy for enterprises, not only helps to reduce the risk of uncertainty in the process of green innovation but also integrates the multiple and scattered advantageous resources in the supply chain; this helps to realize resource sharing, complementation, and integration, and then compensates for the lack of corporate innovation resources (Yang et al., 2020; Kong et al., 2021). Therefore, it will be very effective in improving firms' green innovation performance. Based on this, this study explores the impact of GSCI's three dimensions on corporate green product and process innovation and its intrinsic mechanism, which is of strategic importance for effectively promoting and improving corporate green innovation performance.

2.3 Green supply chain integration and supply chain agility

The highly dynamic and competitive external environment has caused unprecedented pressure and challenges for companies; to survive and grow in fierce competition, the ability of companies to respond and adapt to changes quickly is particularly important (Yuan and Cao, 2022). As a higher-order dynamic capability, supply chain agility refers to a firm's ability to quickly respond to changes in a volatile environment by rapidly organizing and realigning operations and strategies within the supply chain (Dubey et al., 2018). Supply chain agility helps companies quickly capture threats and opportunities in the market environment; therefore, they can

prepare with the resources to respond to the development of new services (Cai et al., 2019). Consequently, an increasing number of companies are realizing the importance of supply chain agility. Existing research suggests that the dynamic capability of an enterprise is developed through a process of combining, renewing, and developing its unique resources (Abrudan et al., 2022). Therefore, firms must have sufficient resources to improve their dynamic capabilities (Kale et al., 2019). GSCI, as an important strategy for firms, helps integrate multiple and scattered resources in the supply chain (Yang et al., 2020). Therefore, in this study, we suggest that GSCI will have a significant influence on supply chain agility.

In many companies, information and communication are usually confined within departments, causing problems of untimely information transfer, and inaccurate communication and understanding between members of different departments, which affect the firm's agile response to unforeseen situations (Roscoe et al., 2020). Green internal integration breaks down departmental barriers within the organization, enhances communication and cooperation between different departments, and enables different departments to participate in and execute the operation plan of the enterprise as early as possible (Flynn et al., 2010; Shah and Soomro, 2021), which helps each department understand and grasp the firm's resources and capabilities, and optimize the firm's resources by cooperating. Therefore, it will help firms plan effectively to respond to dynamic market changes (Khanuja and Jain, 2021). At the same time, the collaborative atmosphere created by green internal integration enhances the emotional attachment and organizational commitment of employees (Shah and Soomro, 2021). This sense of identity, in turn, improves communication efficiency among cross-functional members, facilitating better and faster decision-making by sharing information about corporate production operations in real-time, thus speeding up problem-solving (Liu et al., 2018; Ramos et al., 2021). In addition, the breadth and richness of knowledge acquired by an enterprise is an important prerequisite for enhancing agility, that is, the richer the knowledge base of an enterprise, the stronger its ability to cope with and resolve uncertainties in the market environment (Ji et al., 2020; Parente et al., 2022). Green internal integration enhances the mutual understanding and common expectations of corporate environmental strategies within the enterprise, thus greatly reducing friction and hindrance in communication and cooperation, which helps to facilitate the flow of explicit and implicit knowledge among members within the enterprise. Moreover, in the process of continuous capital accumulation, the collision of different modes of thinking helps break the confinement of the inherent knowledge structure to employees, and realize the reorganization and creation of knowledge (Kong et al., 2020; Roscoe et al., 2020). New knowledge can effectively stimulate the potential of knowledge within the organization (Luo et al., 2018), which helps enterprises predict the trend of environmental changes more accurately and revisit the opportunities and challenges in the external environment, thus enhancing their ability to respond to changes and providing the possibility of improving supply chain agility (Cheng and Lu, 2017). Thus, we propose the following hypothesis:

H1: Green internal integration has a positive impact on supply chain agility.

Green external integration creates an atmosphere of mutual trust between enterprises, which allows them to share risks and benefits with supply chain partners, thus building a long-term and stable cooperation network between them (Guo et al., 2022). This stable partnership helps enhance mutual trust and dependence, thus reducing the risk of resource spillover and speculation in cooperation and mitigating the tendency of opportunistic behavior by supply chain members. This facilitates the interaction and flow of information and knowledge within the supply chain (Zhao et al., 2021), and further improves supply chain agility. Specifically, green supplier and customer integration improve the communication efficiency among supply chain members, facilitating high-quality information-sharing in all aspects of production planning, inventory levels, and demand forecasting, thus helping companies to develop more robust response strategies (Wong et al., 2020; Kong et al., 2021). For example, green supplier integration allows companies and suppliers to have a deeper understanding of each other's business and mutual needs, which facilitates suppliers to adjust their supply plans promptly, thus improving the company's ability to respond to supply market dynamics (Ji et al., 2020). Green customer integration helps in the timely acquisition of valuable market information, such as environmental demands, environmental policies, and competitor development, which helps companies grasp the overall market trends and take prompt actions to respond to dynamic changes in the environment, thus improving supply chain agility (Mao et al., 2017; Ramos et al., 2021).

Suppliers and customers are important sources of green knowledge for companies (Melander, 2018). Green external integration strengthens the continuous interaction between enterprises, suppliers, and customers, forming an embedded relationship network. This not only enriches the channels for enterprises to acquire knowledge, but also facilitates enterprises to carry out learning activities across organizational boundaries, thus expanding the scope of knowledge search and promoting enterprises to acquire diversified knowledge resources (Du et al., 2018; Yeh et al., 2020). Moreover, compared to general knowledge sources, the external knowledge acquired through green suppliers and customers has higher harmony and validity, which will help improve the efficiency of enterprises' adoption of external knowledge (Wei et al., 2020). The organic integration of internal and external knowledge helps improve the thinking of enterprises, encouraging them to think beyond convention, thus

providing more feasible solutions and countermeasures for enterprises, reducing the response time to environmental changes, and improving supply chain agility (Martínez-Ros and Kunapatarawong, 2019; Donbesuur et al., 2021). Thus, we propose the following hypotheses:

H2: Green supplier integration has a positive impact on supply chain agility.

H3: Green customer integration has a positive impact on supply chain agility.

2.4 Supply chain agility and corporate green innovation performance

According to the DCT, the ability of an enterprise to adjust organizational resources to adapt to changes in external environment will help the firm survive and thrive in a turbulent environment, thereby improving its green innovation performance (Teece, 2007). As an important part of dynamic capabilities, supply chain agility helps companies reconfigure and update their organizational resources to respond quickly to external environmental change (Dubey et al., 2018), which makes it a prerequisite for green innovation (Zhu and Gao, 2021).

Supply chain agility increases the flexibility of companies, making them sensitive to the dynamic changes of external environment (Cai et al., 2019) and also keep abreast of the government's environmental policy requirements and competitors' developments, which helps them fully grasp the green demand in the market and their own development direction (Zhou et al., 2018). This reduces the risk and uncertainty of exploring green innovation, thus improving corporate green innovation performance (Singh et al., 2022). In addition, supply chain agility helps companies identify potential market opportunities accurately, thereby gaining the time to innovate (Shahzad et al., 2020). When a company with higher agility identifies potential green opportunities in the market, it can quickly optimize its resources and fully mobilize them to invest heavily in green products or processes that are more compatible with the market (Yuan and Cao, 2022). This not only shortens the company's response time to new demands and increases the speed of new product development significantly (Hoonsopo and Puriwat, 2021), but also prepares resources for enterprises to implement green innovation strategy (Cai et al., 2019), thus promoting green product and process innovation. Simultaneously, good market performance increases stakeholders' confidence in the company, which in turn attracts more external resources to further support the firm's green innovation activities (Pan et al., 2021). In addition, supply chain agility alerts companies to potential risks of environmental changes, thereby increasing their sensitivity and risk resistance to the external environment (Riquelme-Medina et al., 2022). Agile enterprises can promptly handle unexpected crises, finding specific countermeasures to resolve problems, and actively adjusting the factors unfavorable to their development, thus reducing or avoiding the negative effects of supply chain disruption risks (Abdelilah et al., 2021; Khan et al., 2022a; Riquelme-Medina et al., 2022), this guarantees the smooth implementation of green innovation activities, and creates excellent green innovation performance. Thus, we propose the following hypotheses:

H4: Supply chain agility has a positive impact on green product innovation.

H5: Supply chain agility has a positive impact on green process innovation.

2.5 Mediating role of supply chain agility

Owing to the high risk and uncertainty of green innovation, it is difficult for firms to implement green innovation with their resources; thus, they need to cooperate with supply chain partners to obtain the required resources (Ocicka et al., 2022). Existing research suggests that firms' innovation resources may come from both inside and outside the organization (Kafouros et al., 2020). GSCI helps integrate multiple and scattered advantageous resources in the supply chain, thus providing access to resources for enterprises (Yang et al., 2020). However, it is difficult for firms to guarantee the smooth implementation of green innovation by only having abundant static resources, and enterprises need to have a certain dynamic ability to quickly adjust internal and external resources to dynamically match their environment and effectively improve green innovation (Du et al., 2018; Shukor et al., 2021). Therefore, this study argues that GSCI will impact corporate green innovation performance by improving supply chain agility. Specifically, GSCI builds a collaborative atmosphere of mutual sharing and joint participation, which enables the establishment of deep cooperation among different departments, suppliers, and customers, and effectively improves the level of information sharing among them (Kong et al., 2021). This close and continuous information sharing helps enterprises obtain high-quality green information and critical complementary environmental knowledge resources (Kong et al., 2020), thus improving supply chain agility. Higher agility helps enterprises quickly identify green opportunities in the market and develop response plans before competitors, thus preparing resources and activities for green innovation activities (Cai et al., 2019; Yuan and Cao, 2022). At the same time, this agility helps to improve corporate environmental perception, keeping them constantly alert to potential risks in unpredictable environments. This reduces the risk of supply chain disruptions (Abdelilah et al.,

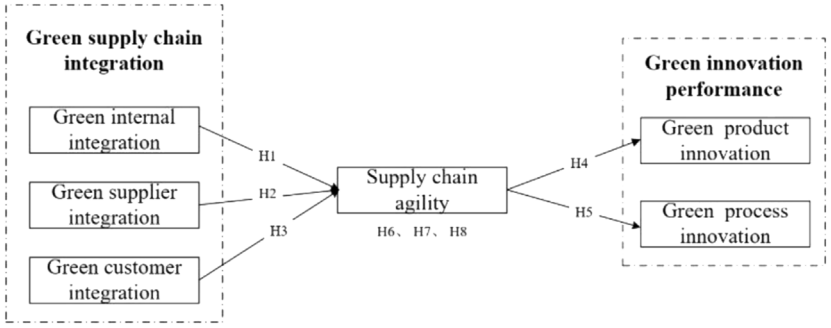

FIGURE 1
Conceptual model.

2021; Khan et al., 2022a; Riquelme-Medina et al., 2022) and guarantees the stable operation of the supply chain system, which ultimately improves corporate green innovation performance. Thus, we propose the following hypotheses:

H6: Supply chain agility positively moderates the relationship between green internal integration and (a) green product innovation and (b) green process innovation.

H7: Supply chain agility positively moderates the relationship between green supplier integration and (a) green product innovation, and (b) green process innovation.

H8: Supply chain agility positively moderates the relationship between green customer integration and (a) green product innovation, and (b) green process innovation.

Based on the above analysis, a conceptual model is proposed for this study, as shown in Figure 1.

3 Research methodology

3.1 Sampling and data collection

Manufacturing is an important driving force for China's boom economy and a major source of industrial pollution emissions. Chinese companies are facing increasingly stringent environmental regulations in the context of the "double carbon" target. Consequently, Chinese companies are placing great emphasis on investing in green innovation (Zhang et al., 2022). Moreover, firms in China are highly dependent on the network of relationships among supply chain members (Yanga and Linb, 2020); therefore, this provides an ideal research background for this study to explore the interactions between the variables. Based on this, this study collected relevant data from Chinese manufacturing firms by using a questionnaire survey. In this study, the measurement scales were derived from well-established scales in the existing literature. To ensure the accuracy of the data, we first followed the methods of translation and back translation to ensure accurate language expression and easy understanding of the semantic meaning. Second, we invited four experts with relevant research experience to evaluate the initial scale and selected senior managers for long-term cooperation with the subject group, for preliminary testing of the questionnaire before the formal research of the questionnaire, thereby modifying and improving it according to the pre-research and experts' feedback to form the final measurement scale. From April 2022 to July 2022, we distributed 860 questionnaires through the research team's network with the senior management of relevant enterprises and professional third-party research platforms. After excluding invalid questionnaires, 405 were obtained, with a usable response rate of 47.09%. The detailed distribution of sample characteristics is presented in Table 1.

3.2 Measures

In this study, the variables were measured on a seven-point Likert scale, with 1–7 indicating the degree of agreement with the description of the question. Among them, 1 means, "very non-conforming" and 7 means, "very conforming". (See Supplementary Appendix SA1).

3.2.1 Green innovation performance

Green innovation performance is an important indicator that can reflect the implementation of corporate green innovation strategy. Drawing on Wei et al. (2020), this study uses green product and process innovation to measure green innovation performance. The indicators of each dimension were measured with five items.

TABLE 1 Profile of sampled firms.

Characteristics of firms	Number	Percentage (%)
Firm age		
≤5	22	5.4
6–10	82	20.2
11–15	128	31.6
≥16	173	42.7
Ownership		
State-owned	96	23.7
Privately owned	274	67.7
Joint venture	26	6.4
Foreign owned	9	2.2
Number of employees		
≤100	42	10.4
101–300	101	24.9
301–500	77	19
501–1,000	80	19.8
1,001–2000	42	10.4
>2000	63	15.6
Industry		
Food products	57	14.1
Communication and computers related equipment	65	16
Pharmaceutical and medical	38	9.4
General equipment	69	17
Electrical machinery and equipment	60	14.8
Chemical products and petrochemical industry	13	3.2
Automobile and transport equipment	46	11.4
Textiles and apparel	22	5.4
Others	35	8.6
Total	405	

3.2.2 Green supply chain integration

Drawing on Kong et al. (2021), this study measures GSCI from three dimensions: green internal integration, green supplier integration, and green customer integration. The indicators of each dimension were measured with five items.

3.2.3 Supply chain agility

Supply chain agility usually reflects the ability of firms in the supply chain to perceive and respond to changes in the market environment (Zhu and Gao, 2021). Therefore, drawing on Altay et al. (2018) and Aslam et al. (2020), this study considers these two abilities as evaluation criteria for supply chain agility and uses six items to measure them.

3.2.4 Control variables

Based on previous studies (Ji et al., 2020), firm age, ownership, size, and industry type were selected as control variables to control for potential confounding impacts. Firm age and size were measured by the number of operational years and number of employees, respectively. Firm ownership was measured using a dummy variable with 1 = state-owned enterprise and 0 = otherwise. Firm industry type was measured using a dummy variable with 1 = highly polluting industry and 0 = otherwise.

3.3 Reliability and validity

To ensure the reliability and validity of the subsequent empirical analysis, this paper uses SPSS and AMOS software to test the reliability and validity of all variables, and Table 2 shows the test results. In terms of reliability, the Cronbach's α value of each measurement variable was greater than 0.70, and the composite reliability (CR) value of each measurement variable was above 0.70, indicating that the measurements in this study have good reliability. Validity includes both content and structural validity. In terms of content validity, the scales of

TABLE 2 Measurement reliability and validity.

Variables	Items	Factor loadings	Cronbach's α	CR	AVE
Green internal integration (GII)	GII1	0.773	0.885	0.886	0.608
	GII2	0.743			
	GII3	0.777			
	GII4	0.801			
	GII5	0.804			
Green supplier integration (GSI)	GSI1	0.795	0.884	0.885	0.606
	GSI2	0.740			
	GSI3	0.744			
	GSI4	0.782			
	GSI5	0.828			
Green customer integration (GCI)	GCI1	0.813	0.881	0.882	0.600
	GCI2	0.757			
	GCI3	0.771			
	GCI4	0.758			
	GCI5	0.770			
Supply chain agility (SCA)	SCA1	0.749	0.895	0.897	0.593
	SCA2	0.755			
	SCA3	0.775			
	SCA4	0.762			
	SCA5	0.784			
	SCA6	0.794			
Green product innovation (GPDI)	CP1	0.774	0.854	0.857	0.600
	CP2	0.775			
	CP3	0.766			
	CP4	0.782			
Green process innovation (GPCI)	LC1	0.853	0.913	0.914	0.726
	LC2	0.861			
	LC3	0.860			
	LC4	0.834			

Note: Model fit statistics: $\chi^2/df = 1.050$; RMSEA = 0.011; GFI=0.940; NFI=0.945; IFI = 0.997.

this study were all from the well-established scales in the existing literature and were modified after discussion and pre-testing by relevant experts and scholars, which ensured the content validity of the scales to a certain extent. Structural validity usually includes convergent and discriminant validity. As shown in Table 2, the standardized factor loading values of each measurement variable are greater than 0.70, and the average variance extracted (AVE) values of each measurement variable are greater than 0.50, indicating that the scale used in this study has good convergent validity. The square root of the AVE in Table 3 is higher than the correlation coefficient between the factors, indicating that the scale has good discriminant validity. In addition, the results of the validation factor analysis showed that the indices χ^2/df (<3.000), RMSEA (<0.080), GFI, NFI, and IFI (>0.900) were within a good range, indicating a good fit of the model. In conclusion, the measurements in this study have good reliability and validity.

3.4 Common method variance

Although the questionnaire was reasonably designed and refined before the survey data, and it was emphasized that the collected data were used only for academic research, as much as possible, the problem of common method variance may still arise because all the questions in the questionnaire were filled in by the same respondents. Therefore, this paper use Harman's single-factor test to test the common method variance. The results showed that the first factor explained 29.393% of the total variance, which was less than 40%, indicating that there was no serious common method variance.

TABLE 3 Summary and correlation of variables.

Variables	Mean	S.D.	Age	Ownership	Size	Industry	GII	GSI	GCI	SCA	GPDI	GPCI
Age	3.116	0.914	1									
Ownership	0.237	0.426	0.126*	1								
Size	3.415	1.585	0.445**	0.265**	1							
Industry	0.331	0.471	0.054	−0.022	−0.038	1						
GII	4.254	1.149	Measurement reliability and −0.066	−0.094	−0.028	−0.020	**0.780**					
GSI	4.072	1.175	0.045	−0.019	0.091	−0.010	0.114*	**0.778**				
GCI	4.410	1.102	0.000	0.053	0.019	−0.054	0.120*	0.136**	**0.774**			
SCA	4.011	0.910	0.082	0.012	0.045	−0.082	0.299**	0.382**	0.357**	**0.770**		
GPDI	4.219	0.983	−0.096	0.000	-0.042	0.009	0.280**	0.322**	0.274**	0.401**	**0.774**	
GPCI	4.249	1.154	0.030	−0.052	−0.023	−0.111*	0.272**	0.343**	0.277**	0.444**	0.372**	**0.852**

Note: The number in bold in the diagonal of the correlation matrix is the square root of the AVEs. *$p < 0.05$; **$p < 0.01$.

4 Analyses results

In this study, SPSS software was used to test the research hypotheses using hierarchical regression analysis. Before testing the research hypotheses, this study examined multicollinearity among the variables. As shown in Table 3, the means and standard deviations of the variables were within a reasonable range, and there was a correlation between the main variables. In addition, the correlation coefficients between the variables were all less than 0.7, and the variance inflation factor (VIF) values of each variable were all less than 2. This indicates that multicollinearity is not an issue, which meets the requirements for further regression analysis. The regression results are presented in Table 4 and Figure 2.

In Table 4, Model 1 is a regression model of control variables on supply chain agility, and Model 2 adds three dimensions of GSCI based on Model 1. The results show that green internal integration ($\beta = 0.236$, $p < 0.001$), green supplier integration ($\beta = 0.316$, $p < 0.001$), and green customer integration ($\beta = 0.282$, $p < 0.001$) have significant positive effects on supply chain agility. Meanwhile, compared to Model 1, the R^2 of Model 2 improved by 0.290 after including GSCI, and the F-test also reveals that ΔR^2 is significant. Hence, Hypotheses H1, H2, and H3 are supported.

Models 5 and 9 were used to test the impact of supply chain agility on green product and process innovation. Model 3 is the regression model of the control variables for green product innovation. Model 5 adds supply chain agility based on Model 3, and the results show that supply chain agility has a significant positive impact on green product innovation ($\beta = 0.416$, $p < 0.001$). Meanwhile, compared to Model 3, the R^2 of Model 5 improved by 0.170 after including supply chain agility, and the F-test also reveals that ΔR^2 is significant. Hence, H4 is supported. Model 7 is a regression model of the control variables on green process innovation, and Model 9 adds

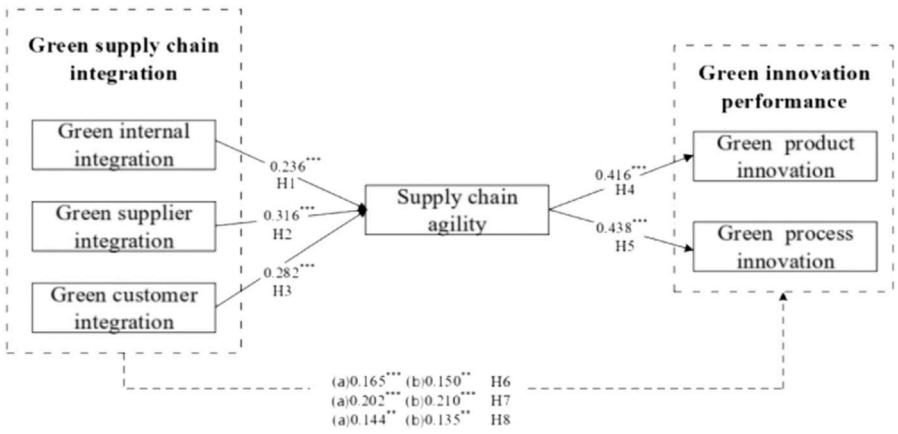

FIGURE 2
Regression model coefficients.

TABLE 4 Results of regression analysis.

Variables	SCA		GPDI				GPCI			
	Model1	Model2	Model3	Model4	Model5	Model6	Model7	Model8	Model9	Model10
Control variables										
Age	0.086	0.101*	−0.098†	−0.084†	−0.133**	−0.108*	0.061	0.074	0.024	0.048
Ownership	−0.001	0.021	0.013	0.036	0.014	0.031	−0.052	−0.029	−0.051	−0.034
Size	0.004	−0.036	−0.001	−0.036	−0.002	−0.027	−0.041	−0.077	−0.043	−0.068
Industry	−0.086	−0.065	0.015	0.032	0.051	0.047	−0.117*	−0.100*	−0.079†	−0.083
Independent variables										
GII		0.236***		0.221***		0.165***		0.212***		0.150**
GSI		0.316***		0.276***		0.202***		0.293***		0.210***
GCI		0.282***		0.211***		0.144**		0.210***		0.135**
Mediator										
SCA					0.416***	0.236***			0.438***	0.264***
R^2	0.014	0.304	0.010	0.219	0.180	0.257	0.018	0.233	0.208	0.281
F	1.445	24.790***	0.964	15.861***	17.510***	17.154***	1.878	17.238***	20.944***	19.392***
ΔR^2	0.014	0.290	0.010	0.209	0.170	0.039	0.018	0.215	0.189	0.048
ΔF	1.445	55.135***	0.964	35.392***	82.902***	20.696***	1.878	37.041***	95.433***	26.670***

Note: †$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

supply chain agility based on Model 7. The results show that supply chain agility has a significant positive effect on green process innovation ($\beta = 0.438$, $p < 0.001$). Meanwhile, compared to Model 7, the R^2 of Model 9 improved by 0.189 after including supply chain agility, and the F-test also reveals that ΔR^2 is significant. Hence, H5 is supported.

This study constructs model 4 and model 6 and uses the stepwise regression method to validate the mediating effect of supply chain agility on the relationship between the three dimensions of GSCI and green product innovation. In Table 4, Model 4 shows that green internal integration ($\beta = 0.221$, $p < 0.001$), green supplier integration ($\beta = 0.276$, $p < 0.001$), and green customer integration ($\beta = 0.211$, $p < 0.001$) have significant positive effects on green product innovation. Model 6 adds supply chain agility based on Model 4, and the results show that the positive effects of green internal integration ($\beta = 0.165$, $p < 0.001$), green supplier integration ($\beta = 0.202$, $p <$ 0 0.001) and green customer integration ($\beta = 0.144$, $p < 0.01$) on green product innovation become smaller, but are still significant, after including supply chain agility. Meanwhile, compared to Model 4, the R^2 of Model 6 improved by 0.039 after including supply chain agility, and the F-test also reveals that ΔR^2 is significant. Hence, supply chain agility partially mediates the relationship between all three dimensions of GSCI and green product innovation. In addition, Models 8 and 10 were constructed in this study to test the mediating effect of supply chain agility on the relationship between the three dimensions of GSCI and green process innovation. Model 8 in Table 4 shows that green internal integration ($\beta = 0.212$, $p < 0.001$), green supplier integration ($\beta = 0.293$, $p < 0.001$), and green customer integration ($\beta = 0.210$, $p < 0.001$) have significant positive effects on green process innovation. Model 10 adds supply chain agility based on Model 8, and the results show that the positive effects of green internal integration ($\beta = 0.150$, $p < 0.01$), green supplier integration ($\beta = 0.210$, $p < 0.001$), and green customer integration ($\beta = 0.135$, $p < 0.01$) on green process innovation become smaller, but are still significant, after including supply chain agility. Meanwhile, compared to Model 8, the R^2 of Model 10 improved by 0.048 after including supply chain agility, and the F-test also reveals that ΔR^2 is significant. Hence, supply chain agility partially mediates the relationship between all three dimensions of GSCI and green process innovation. In summary, Hypotheses H6, H7, and H8 are supported.

In addition, this study used bootstrap analyses (repeated sampling 5,000 times) to further examine and verify the mediating effect of supply chain agility. If the 95% bias-corrected confidence intervals do not include 0, the mediating effect is significant; the test results are shown in Table 5. In Table 5, the indirect effects of green internal integration, green supplier integration, and green customer integration on green product innovation through supply chain agility are 0.096, 0.108, and 0.115, respectively. The 95% bias-corrected confidence intervals [0.057, 0.141], [0.069, 0.152], and [0.073, 0.164] do not include 0, indicating that the mediating effect of supply chain agility is significant. In addition, the indirect effects of green internal integration, green supplier integration, and green customer integration on green process innovation, through

TABLE 5 Bootstrapped mediation results.

Model	Total effect		Direct effect		Indirect effect		
	Coefficient	t value	Coefficient	t value	Point estimate	Lower	Upper
GII→SCA→GPDI	0.041***	5.784	0.040***	3.525	0.096	0.057	0.141
GSI→SCA→GPDI	0.040***	6.992	0.040***	4.167	0.108	0.069	0.152
GCI→SCA→GPDI	0.043***	5.751	0.430**	3.062	0.115	0.073	0.164
GII→SCA→GPCI	0.048***	5.654	0.047**	3.247	0.121	0.077	0.170
GSI→SCA→GPCI	0.460***	7.399	0.047***	4.419	0.134	0.087	0.188
GCI→SCA→GPCI	0.050***	5.778	0.496**	2.917	0.145	0.094	0.201

Note(s): *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. 95% CI: Bias corrected bootstrap 95% confidence interval based on 5,000 bootstrap samples.

supply chain agility, are 0.121, 0.134, and 0.145, respectively. The 95% bias-corrected confidence intervals [0.077, 0.170], [0.087, 0.188], and [0.094, 0.201] do not include 0, indicating that the mediating effect of supply chain agility is significant. The results of this analysis further support H6, H7, and H8.

5 Discussion

Combining NRBV and DCT, based on the analytical logic of "resource-capability-performance", this study constructs a theoretical model of GSCI, supply chain agility, and corporate green innovation performance and aims to deeply explore the relationship between GSCI and corporate green innovation performance and its intrinsic mechanism. Based on this, this study uses hierarchical regression and bootstrap analysis to test the survey data of 405 Chinese manufacturing firms and draws the following conclusions.

Firstly, all three dimensions of GSCI have positive impacts on supply chain agility. Specifically, the close cooperation network built by GSCI promotes deep communication among supply chain members and helps enterprises to search and acquire a large number of valuable resources, such as information, technology, and knowledge (Yang et al., 2020), thus playing an important role in promoting supply chain agility. Among them, green internal integration enhances communication within the organization and helps enterprises achieve a centralized allocation of resources to respond to environmental changes (Flynn et al., 2010; Khanuja and Jain, 2021), thereby improving supply chain agility. Green supplier and customer integration build a cooperative atmosphere of mutual trust among supply chain members, which enhances the closeness of the mutual relationship and helps shorten the transmission time and path of complementary resources in cooperation (Du et al., 2018; Zhao et al., 2021). Consequently, it will accelerate the speed of multiple options and the response of enterprises to cope with environmental uncertainty (Martínez-Ros and Kunapatarawong, 2019; Donbesuur et al., 2021), thereby contributing to the cultivation and shaping of supply chain agility.

Secondly, supply chain agility improves firms' green innovation performance. Supply chain agility is a dynamic process whereby enterprises reconfigure and optimize their resources, which is an important prerequisite for the successful implementation of a firm's green innovation strategy (Dubey et al., 2018; Zhu and Gao, 2021). On the one hand, supply chain agility increases the flexibility and sensitivity of enterprises; therefore, they can discover potential green opportunities in the market before their competitors and fully mobilize internal and external resources of enterprises to invest in green innovation activities in line with market demand, thus gaining the time to innovate and contributing to the generation of new products and processes (Yuan and Cao, 2022). On the other hand, enterprises with higher supply chain agility can timely perceive the potential risks and threats in the environment and reduce the risk of supply chain disruption by quickly adjusting corporate strategy (Abdelilah et al., 2021; Khan et al., 2022a; Riquelme-Medina et al., 2022), which guarantees the smooth implementation of green innovation activities and thus improving green product and process innovation performance.

Thirdly, supply chain agility plays a partial mediating role in the relationship between all three dimensions of GSCI and corporate green innovation performance. This finding confirms the bridging role of supply chain agility in corporate green innovation activities; that is, the three dimensions of GSCI not only have a direct impact on corporate green innovation performance but can also indirectly promote them by improving supply chain agility. Specifically, GSCI helps form a strong relationship network among supply chain members, provides a channel for the interaction and flow of information and knowledge among enterprises (Yang et al., 2020), improves the knowledge system of enterprises, and provides more feasible options for enterprises to solve problems (Martínez-Ros and Kunapatarawong, 2019; Donbesuur et al., 2021), which, in turn, improves supply chain agility. This higher supply chain

agility enables enterprises to quickly perceive potential market opportunities and risks in a turbulent environment and effectively absorb, reorganize and transform the acquired information and technical resources by flexibly allocating and integrating internal and external resources (Dubey et al., 2018), thus laying a solid foundation for improving corporate green product and process innovation.

6 Conclusion

In the context of low-carbon economy, enterprises are faced with the double challenges of economic growth and environmental protection. Green innovation, as a new form of innovation from the perspective of ecological civilization, has become an inevitable choice for enterprises to achieve sustainable development (Long et al., 2017). Therefore, how to effectively improve corporate green innovation performance has become an important issue. However, due to increasing global competition and technological complexity, market competition has shifted from individual firms to supply chains (Yeh et al., 2020). It is difficult for firms to respond to the turbulent external environment by relying only on their own resources, which leads to a series of challenges for firms to implement green innovation strategies (Huang and Li, 2017). Therefore, enterprises need to seek collaboration with supply chain partners to obtain richer innovative resources (Birasnav and Bienstock, 2019). In recent years, GSCI has become one of the main ways for enterprises to acquire resources effectively. However, the research on the relationship between GSCI and green innovation performance in the existing literature has not received sufficient attention. Therefore, combining NRBV and DCT, based on the theoretical logic of "resources-capabilities-performance", this study examines the relationship between GSCI and green innovation performance and its intrinsic mechanism. Through the empirical research on the survey data of 405 Chinese manufacturing enterprises, this study finds that all three dimensions of GSCI, namely, green internal integration, green supplier integration, and green customer integration, have positive effects on supply chain agility. Supply chain agility can significantly improve corporate green product and process innovation. In addition, supply chain agility plays a partially mediating role in the relationship between all three dimensions of GSCI and corporate green product and process innovation. In summary, this paper shows that enterprises should actively implement GSCI to improve supply chain agility, thereby improving their green innovation performance.

6.1 Theoretical contributions

The research of this study is helpful to deeply understand the relationship between GSCI and firms' green innovation performance and its intrinsic mechanism, thus making the following theoretical contribution to existing research. Firstly, this study examines the impact of GSCI on supply chain agility and corporate green innovation performance, thus enriching and expanding theoretical research in the field of GSCI. In recent years, the importance of GSCI has been gradually recognized, and related research has made some progress. However, in general, the existing studies are limited in their testing of the effect of GSCI. Most scholars focus on the impact of GSCI on corporate financial performance (Zhang et al., 2020) or environmental performance (Ji et al., 2020), while the impact of GSCI on green innovation performance has not been clearly explained and tested. Therefore, this study explores the effect of GSCI on supply chain agility and two types of green innovation performance (i.e., green product innovation and green process innovation) through empirical research, thus expanding the scope of the effect of GSCI and enriching its research framework.

Secondly, this study explores the driving factors of corporate green innovation from the perspective of resources and capabilities, which enriches the antecedents of green innovation. Green innovation is regarded as an important way for enterprises to achieve sustainable development (Long et al., 2017), and it is especially important to clarify how to improve corporate green innovation performance in the context of the "double carbon". Previous studies mainly focused on the impact of external factors on green innovation, such as stakeholder pressure (Nguyen and Adomako, 2022) and institutional factors (Zhang et al., 2022), but lacked a discussion on the antecedents of green innovation performance in the context of the supply chain. This study innovatively explores their influence on green innovation performance from the perspective of GSCI and supply chain agility, thus enriching the research on the promotion path of firms' green innovation performance in the context of "double carbon" and providing new ideas and perspectives for theoretical research in the field of green innovation.

Thirdly, this study verifies the mediating role of supply chain agility on the relationship between GSCI and firms' green innovation performance, thus revealing the pathway through which GSCI influences firms' green innovation performance. Existing research lacks a discussion of the internal mechanism between GSCI and corporate green innovation performance, which prevents a clear understanding of the specific process by which GSCI affects green innovation performance. Based on the theoretical logic of "resource-capability-performance", this study integrates GSCI, supply chain agility, and corporate green innovation performance into the same framework and explores the mediating role of supply chain agility between GSCI and green innovation performance, thus opening the "black box" of the relationship between them from the perspective of dynamic capability, providing a micro knowledge base for the theoretical study of how GSCI can transform into corporate green innovation performance. Meanwhile, it also deepens the

theoretical understanding of the realization path to improve corporate green innovation performance.

6.2 Management insights

The findings of this study have important management insights for corporate green innovation practices and government policy formulation. Firstly, in the context of a low-carbon economy, GSCI provides an effective path for manufacturing enterprises to improve their green innovation performance. Therefore, enterprises need to cooperate deeply with their supply chain partners and establish a long-term relationship of information communication and resource sharing, thereby effectively improving their green innovation performance. On the one hand, enterprise managers should attach great importance to the role of GSCI, actively establish network connections with supply chain members, and integrate green concepts into every link of the supply chain, thereby continuously promoting the implementation of the GSCI strategy. Meanwhile, enterprises should enrich diversified participation channels so that they can integrate into more green supply chain network ecosystems, thus expanding the breadth and depth of GSCI and increasing the opportunities and channels to acquire diversified resources. On the other hand, enterprises should continuously improve their green supply chain management capabilities and create a good cooperation environment for supply chain members through effective communication and coordination to strengthen the cooperation among supply chain members and improve the quality of integration, thereby bringing into play the maximum effectiveness of GSCI and paving the way for their green innovation. Secondly, enterprise managers should fully recognize the important role of supply chain agility in the relationship between GSCI and green innovation performance. Therefore, in the process of GSCI, enterprises should incorporate supply chain agility into their long-term strategic planning and pay attention to the construction and improvement of supply chain agility. Specifically, enterprises should actively establish close network relationships with supply chain members to obtain more complementary resources. In addition, enterprises should further strengthen their information system construction and enhance information processing capability to guarantee the rapid and accurate flow of information within the organization to maximize supply chain agility, thereby giving full play to the role of GSCI and achieving the continuous improvement of green innovation performance. Finally, as an important regulator, the government should give full play to its guiding and coordinating role in GSCI. On the one hand, the government should strengthen contact with enterprise managers, make them establish good green values, and enhance their sense of environmental responsibility through various training methods, such as environmental education, technical exchange, and entrepreneurial forum, thereby effectively increasing the willingness of enterprises to implement GSCI. On the other hand, the government should establish a sharing platform and introduce encouraging policies to provide policy guidance and financial support for the formation of green supply chain networks and the selection of corporate partners, thus further improving the level of enterprises' implementation of GSCI, and then helping firms' green innovation practices.

6.3 Research limitations and future developments

Although some research results have been achieved in our study, there are still certain limitations which need to be improved in future research. Firstly, all data in this study were obtained through questionnaires. Although some methods were used to avoid common method variance, and the statistical test shows that they were within acceptable limits, future studies still need to further test the research through multiple sources of data to increase the robustness of the findings. Secondly, this study uses static cross-sectional data, which cannot clearly reflect the dynamic impact of GSCI on corporate green innovation performance. Future research can explore the dynamic changes in the relationship between GSCI and corporate green innovation performance through longitudinal or experimental research. Thirdly, this study focuses on the relationship and intrinsic mechanism between GSCI and corporate green innovation performance, ignoring the contextual factors that may affect this relationship. Future research can actively explore the boundary conditions of the relationship between GSCI and corporate green innovation performance, thereby further deepening the existing research. Finally, this study only investigates the data of Chinese manufacturing enterprises. Due to China's special cultural and economic backgrounds, this may lead to the fact that our findings may not be applicable to other countries. Therefore, future research can use more cross-country sample data to investigate the relationship and underlying mechanism between GSCI and corporate green innovation performance and compare whether the differences between different countries affect the relationship to obtain richer research findings.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

BZ: data curation, validation, visualization, writing–review, and editing. SZ: conceptualization, supervision, and writing—original draft. XF: methodology, formal analysis. SW: Software, writing—review, and editing. DS: writing—review and editing.

Funding

This study received funding from National Natural Science Foundation of China (NSFC) (Grant No. 72174073).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.1045414/full#supplementary-material

References

Abdelilah, B., Korchi, A. E., and Balambo, M. A. (2021). Agility as a combination of lean and supply chain integration: how to achieve a better performance. *Int. J. Logist. Res. Appl.*, 1–29. doi:10.1080/13675567.2021.1972949

Abrudan, D. B., Rafi, N., Daianu, D. C., and Kalyar, M. N. (2022). Linking green intellectual capital with green innovation: Examining the roles of green dynamic capabilities and 'motivation to achieve legitimacy. *Agric. Econ.* 68 (7), 250–258. doi:10.17221/97/2022-AGRICECON

Altay, N., Gunasekaran, A., Dubey, R., and Childe, S. J. (2018). Agility and resilience as antecedents of supply chain performance under moderating effects of organizational culture within the humanitarian setting: a dynamic capability view. *Prod. Plan. Control* 29 (14), 1158–1174. doi:10.1080/09537287.2018.1542174

Arroyave, J. J., Martínez, F. J. S., and González-Moreno, Á. (2020). Cooperation with universities in the development of eco-innovations and firms' performance. *Front. Psychol.* 11, 612465. doi:10.3389/fpsyg.2020.612465

Asiaei, K., O'Connor, N. G., Barani, O., and Joshi, M. (2022). Green intellectual capital and ambidextrous green innovation: The impact on environmental performance. *Bus. Strategy Environ.* 1–18. doi:10.1002/bse.3136

Aslam, H., Blome, C., Roscoe, S., and Azhar, T. M. (2020). Determining the antecedents of dynamic supply chain capabilities. *Supply Chain Manag.* 25 (4), 427–442. doi:10.1108/scm-02-2019-0074

Bai, Y., Song, S., Jiao, J., and Yang, R. (2019). The impacts of government R&D subsidies on green innovation: Evidence from Chinese energy-intensive firms. *J. Clean. Prod.* 233, 819–829. doi:10.1016/j.jclepro.2019.06.107

Bildirici, M. E., and Gökmenoğlu, S. M. (2017). Environmental pollution, hydropower energy consumption and economic growth: Evidence from G7 countries. *Renew. Sustain. Energy Rev.* 75, 68–85. doi:10.1016/j.rser.2016.10.052

Birasnav, M., and Bienstock, J. (2019). Supply chain integration, advanced manufacturing technology, and strategic leadership: An empirical study. *Comput. Ind. Eng.* 130, 142–157. doi:10.1016/j.cie.2019.01.021

Cai, Z., Liu, H., Huang, Q., and Liang, L. (2019). Developing organizational agility in product innovation: the roles of IT capability, KM capability, and innovative climate. *R&D Manag.* 49 (4), 421–438. doi:10.1111/radm.12305

Cheng, J. H., and Lu, K. L. (2017). Enhancing effects of supply chain resilience: insights from trajectory and resource-based perspectives. *Supply Chain Manag.* 22 (4), 329–340. doi:10.1108/SCM-06-2016-0190

Donbesuur, F., Zahoor, N., and Adomako, S. (2021). Postformation alliance capabilities and environmental innovation: The roles of environmental in-learning and relation-specific investments. *Bus. Strategy Environ.* 30 (7), 3330–3343. doi:10.1002/bse.2805

Donkor, F., Papadopoulos, T., and Spiegler, V. (2021). The supply chain integration-supply chain sustainability relationship in the UK and Ghana pharmaceutical industry: A stakeholder and contingency perspective. *Transp. Res. Part E Logist. Transp. Rev.* 155, 102477. doi:10.1016/j.tre.2021.102477

Du, L., Zhang, Z., and Feng, T. (2018). Linking green customer and supplier integration with green innovation performance: The role of internal integration. *Bus. Strategy Environ.* 27 (8), 1583–1595. doi:10.1002/bse.2223

Dubey, R., Altay, N., Gunasekaran, A., Blome, C., Papadopoulos, T., and Childe, S. J. (2018). Supply chain agility, adaptability and alignment Empirical evidence from the Indian auto components industry. *Int. J. Oper. Prod. Manage* 38 (1), 129–148. doi:10.1108/ijopm-04-2016-0173

Flynn, B., Huo, B., and Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *J. Operations Manag.* 28 (1), 58–71. doi:10.1016/j.jom.2009.06.001

Guo, X., Xia, W., Feng, T., and Sheng, H. (2022). Sustainable supply chain finance adoption and firm performance: Is green supply chain integration a missing link? *Sustain. Dev.* 1, 1135–1154. doi:10.1002/sd.2307

Hart, S. L. (1995). A natural-resource-based view of the firm. *Acad. Manage. Rev.* 20 (4), 986–1014. doi:10.5465/amr.1995.9512280033

Hoonsopo, D., and Puriwat, W. (2021). Organizational agility: Key to the success of new product development. *IEEE Trans. Eng. Manag.* 68 (6), 1722–1733. doi:10.1109/tem.2019.2929500

Huang, J., and Li, Y. (2017). Green innovation and performance: The view of organizational capability and social reciprocity. *J. Bus. Ethics* 145 (2), 309–324. doi:10.1007/s10551-015-2903-y

Ji, L., Yuan, C., Feng, T., and Wang, C. (2020). Achieving the environmental profits of green supplier integration: The roles of supply chain resilience and knowledge combination. *Sustain. Dev.* 28 (4), 978–989. doi:10.1002/sd.2050

Kafouros, M., Love, J. H., Ganotakis, P., and Konara, P. (2020). Experience in R&D collaborations, innovative performance and the moderating effect of different dimensions of absorptive capacity. *Technol. Forecast. Soc. Change* 150, 119757. doi:10.1016/j.techfore.2019.119757

Kale, E., Aknar, A., and Basar, O. (2019). Absorptive capacity and firm performance: The mediating role of strategic agility. *Int. J. Hosp. Manag.* 78, 276–283. doi:10.1016/j.ijhm.2018.09.010

Khan, S. A. R., and Ponce, P. (2022). Investigating the effects of the outbreak of COVID-19 on perishable food supply chains: an empirical study using PLS-SEM. *Int. J. Logist. Manag.* 33 (3), 773–795. doi:10.1108/IJLM-12-2020-0496

Khan, S. A. R., Godil, D. I., Jabbour, C. J. C., Shujaat, S., Razzaq, A., and Yu, Z. (2021a). Green data analytics, blockchain technology for sustainable development, and sustainable supply chain practices: evidence from small and medium enterprises. *Ann. Oper. Res.*, 1–25. doi:10.1007/s10479-021-04275-x

Khan, S. A. R., Yu, Z., and Sharif, A. (2021b). No silver bullet for de-carbonization: Preparing for tomorrow, today. *Resour. Policy* 71, 101942. doi:10.1016/j.resourpol.2020.101942

Khan, S. A. R., Razzaq, A., Yu, Z., Shah, A., Sharif, A., and Janjua, L. (2022a). Disruption in food supply chain and undernourishment challenges: An empirical study in the context of Asian countries. *Socioecon. Plann. Sci.* 82, 101033. doi:10.1016/j.seps.2021.101033

Khan, S. A. R., Yu, Z., and Farooq, K. (2022b). Green capabilities, green purchasing, and triple bottom line performance: Leading toward environmental sustainability. *Bus. Strategy Environ*. 1–13. doi:10.1002/bse.3234

Khan, S. A. R., Yu, Z., Umar, M., Jabbour, A., and Mor, R. S. (2022c). Tackling post-pandemic challenges with digital technologies: an empirical study. *J. Enterp. Inf. Manag.* 35 (1), 36–57. doi:10.1108/JEIM-01-2021-0040

Khan, S. A. R., Yu, Z., Umar, M., and Tanveer, M. (2022d). Green capabilities and green purchasing practices: A strategy striving towards sustainable operations. *Bus. Strategy Environ.* 31 (4), 1719–1729. doi:10.1002/bse.2979

Khan, S. A. R., Yu, Z., Umar, M., Zia-ul-haq, H. M., Tanveer, M., and Janjua, L. R. (2022e). Renewable energy and advanced logistical infrastructure: Carbon-free economic development. *Sustain. Dev.* 30 (4), 693–702. doi:10.1002/sd.2266

Khanuja, A., and Jain, R. K. (2021). The mediating effect of supply chain flexibility on the relationship between supply chain integration and supply chain performance. *J. Enterp. Inf. Manag.* doi:10.1108/jeim-11-2020-0449

Kong, T., Feng, T., Huang, Y., and Cai, J. (2020). How to convert green supply chain integration efforts into green innovation: A perspective of knowledge-based view. *Sustain. Dev.* 28 (5), 1106–1121. doi:10.1002/sd.2062

Kong, T., Feng, T., and Huo, B. (2021). Green supply chain integration and financial performance: A social contagion and information sharing perspective. *Bus. Strategy Environ.* 30 (5), 2255–2270. doi:10.1002/bse.2745

Liu, C.-L., Lee, M.-Y., Gammelgaard, B., Brent, D., Williams, J. R., Tokar, T., et al. (2018). Integration, supply chain resilience, and service performance in third-party logistics providers. *Int. J. Logist. Manag.* 31 (7-8), 543–554. doi:10.1016/j.jom.2013.09.003

Lo, S., Zhang, S., Wang, Z., and Zhao, X. (2018). The impact of relationship quality and supplier development on green supply chain integration: A mediation and moderation analysis. *J. Clean. Prod.* 202, 524–535. doi:10.1016/j.jclepro.2018.08.175

Long, S., and Liao, Z. (2021). Are fiscal policy incentives effective in stimulating firms' eco-product innovation? The moderating role of dynamic capabilities. *Bus. Strategy Environ.* 30 (7), 3095–3104. doi:10.1002/bse.2791

Long, X., Chen, Y., Du, J., Oh, K., and Han, I. (2017). Environmental innovation and its impact on economic and environmental performance: Evidence from Korean-owned firms in China. *Energy Policy* 107, 131–137. doi:10.1016/j.enpol.2017.04.044

Luo, B., Lui, S., Liu, C., and Zhang, R. (2018). Knowledge exploration and innovation: A review and an inverse S-curve proposition. *J. Manag. Organ.* 24 (6), 870–892. doi:10.1017/jmo.2016.39

Lyu, T., Zhao, Q., Lin, H., and Xu, Y. (2021). Understanding the sustainable competitive advantages of China's private manufacturing enterprises: An empirical study based on the dynamic capabilities of supply chain. *IEEE Access* 9, 130233–130246. doi:10.1109/access.2021.3112101

Mao, Z., Zhang, S., and Li, X. (2017). Low carbon supply chain firm integration and firm performance in China. *J. Clean. Prod.* 153 (1), 354–361. doi:10.1016/j.jclepro.2016.07.081

Martínez-Ros, E., and Kunapatarawong, R. (2019). Green innovation and knowledge: The role of size. *Bus. Strategy Environ.* 28 (6), 1045–1059. doi:10.1002/bse.2300

Melander, L. (2018). Customer and supplier collaboration in green product innovation: External and internal capabilities. *Bus. Strategy Environ.* 27 (6), 677–693. doi:10.1002/bse.2024

Mondal, C., and Giri, B. C. (2022). Investigating strategies of a green closed-loop supply chain for substitutable products under government subsidy. *J. Industrial Prod. Eng.* 39 (4), 253–276. doi:10.1080/21681015.2021.1974962

Nguyen, N. P., and Adomako, S. (2022). Stakeholder pressure for eco-friendly practices, international orientation, and eco-innovation: a study of small and medium-sized enterprises in vietnam. *Corp. Soc. Responsib. Environ. Manag.* 29 (1), 79–88. doi:10.1002/csr.2185

Ocicka, B., Baraniecka, A., and Jefmański, B. (2022). Exploring supply chain collaboration for green innovations: Evidence from the high-tech industry in Poland. *Energies* 15 (5), 1750. doi:10.3390/en15051750

Pan, X., Sinha, P., and Chen, X. (2021). Corporate social responsibility and eco-innovation: The triple bottom line perspective. *Corp. Soc. Responsib. Environ. Manag.* 28 (1), 214–228. doi:10.1002/csr.2043

Parente, R., Murray, J. Y., Zhao, Y., Kotabe, M., and Dias, R. (2022). Relational resources, tacit knowledge integration capability, and business performance. *J. Knowl. Manag.* 26 (4), 805–823. doi:10.1108/JKM-07-2020-0501

Ramos, E., Patrucco, A. S., and Chavez, M. (2021). Dynamic capabilities in the "new normal": a study of organizational flexibility, integration and agility in the Peruvian coffee supply chain. *Supply Chain Manag.* doi:10.1108/SCM-12-2020-0620

Riquelme-Medina, M., Stevenson, M., Barrales-Molina, V., and Llorens-Montes, F. J. (2022). Coopetition in business Ecosystems: The key role of absorptive capacity and supply chain agility. *J. Bus. Res.* 146, 464–476. doi:10.1016/j.jbusres.2022.03.071

Roscoe, S., Eckstein, D., Blome, C., and Goellner, M. (2020). Determining how internal and external process connectivity affect supply chain agility: a life-cycle theory perspective. *Prod. Plan. Control* 31 (1), 78–91. doi:10.1080/09537287.2019.1629704

Shafique, M., Rashid, A., Bajwa, I., Kazmi, R., Khurshid, M., and Tahir, W. (2018). Effect of IoT capabilities and energy consumption behavior on green supply chain integration. *Appl. Sci. (Basel).* 8 (12), 2481. doi:10.3390/app8122481

Shah, N., and Soomro, B. A. (2021). Internal green integration and environmental performance: The predictive power of proactive environmental strategy, greening the supplier, and environmental collaboration with the supplier. *Bus. Strategy Environ.* 30 (2), 1333–1344. doi:10.1002/bse.2687

Shahzad, M., Qu, Y., Zafar, A. U., Rehman, S. U., and Islam, T. (2020). Exploring the influence of knowledge management process on corporate sustainable performance through green innovation. *J. Knowl. Manag.* 24 (9), 2079–2106. doi:10.1108/jkm-11-2019-0624

Shi, H., Feng, T., and Li, Z. (2022). Too much is not always good: the inverted U-shaped link between green customer integration and opportunistic behavior. *Asia Pac. J. Mark. Logist.* 34 (5), 987–1009. doi:10.1108/apjml-01-2021-0062

Shukor, A. A. A., Newaz, M. S., Rahman, M. K., and Taha, A. Z. (2021). Supply chain integration and its impact on supply chain agility and organizational flexibility in manufacturing firms. *Int. J. Emerg. Mark.* 16 (8), 1721–1744. doi:10.1108/ijoem-04-2020-0418

Singh, S. K., Giudice, M. D., Jabbour, C. J. C., Latan, H., and Sohal, A. S. (2022). Stakeholder pressure, green innovation, and performance in small and medium-sized enterprises: The role of green dynamic capabilities. *Bus. Strategy Environ.* 31 (1), 500–514. doi:10.1002/bse.2906

Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strateg. Manag. J.* 28 (13), 1319–1350. doi:10.1002/smj.640

Wang, J., and Feng, T. (2022). Supply chain ethical leadership and green supply chain integration: a moderated mediation analysis. *Int. J. Logist. Res. Appl.*, 1–27. doi:10.1080/13675567.2021.2022640

Wang, C.-H. (2019). How organizational green culture influences green performance and competitive advantage. *J. Manuf. Technol. Manag.* 30, 666–683. doi:10.1108/jmtm-09-2018-0314

Wangsa, I. D., Vanany1Ca, I., and Siswanto1, N. (2022). An optimization model for fresh-food electronic commerce supply chain with carbon emissions and food waste. *J. Ind. Prod. Eng.*, 1–21. doi:10.1080/21681015.2022.2099473

Wei, L., Zhu, R., and Yuan, C. (2020). Embracing green innovation via green supply chain learning: The moderating role of green technology turbulence. *Sustain. Dev.* 28 (1), 155–168. doi:10.1002/sd.1979

Wong, C. Y., Wong, C. W. Y., and Boon-itt, S. (2020). Effects of green supply chain integration and green innovation on environmental and cost performance. *Int. J. Prod. Res.* 58 (15), 4589–4609. doi:10.1080/00207543.2020.1756510

Xie, X., Huo, J., and Zou, H. (2019). Green process innovation, green product innovation, and corporate financial performance: A content analysis method. *J. Bus. Res.* 101, 697–706. doi:10.1016/j.jbusres.2019.01.010

Yang, Q., Geng, R., and Feng, T. (2020). Does the configuration of macro- and micro-institutional environments affect the effectiveness of green supply chain integration? *Bus. Strategy Environ.* 29 (4), 1695–1713. doi:10.1002/bse.2462

Yang, Q., Geng, R., Jiang, Y., and Feng, T. (2021). Governance mechanisms and green customer integration in China: The joint effect of power and environmental

uncertainty. *Transp. Res. Part E Logist. Transp. Rev.* 149, 102307. doi:10.1016/j.tre.2021.102307

Yanga, Z., and Linb, Y. (2020). The effects of supply chain collaboration on green innovation performance:An interpretive structural modeling analysis. *Sustain. Prod. Consum.* 23, 1–10. doi:10.1016/j.spc.2020.03.010

Yeh, T., Pai, F., and Wu, L. (2020). Relationship stability and supply chain performance for smes: From internal, supplier, and customer integration perspectives. *Mathematics* 8 (11), 1902–1918. doi:10.3390/math8111902

Yuan, B., and Cao, X. (2022). Do corporate social responsibility practices contribute to green innovation? The mediating role of green dynamic capability. *Technol. Soc.* 68, 101868. doi:10.1016/j.techsoc.2022.101868

Zhang, Q., Pan, J., Jiang, Y., and Feng, T. (2020). The impact of green supplier integration on firm performance: The mediating role of social capital accumulation. *J. Purch. Supply Manag.* 26 (2), 100579. doi:10.1016/j.pursup.2019.100579

Zhang, Y., Hu, H., Zhu, G., and You, D. (2022). The impact of environmental regulation on enterprises' green innovation under the constraint of external financing: evidence from China's industrial firms. *Environ. Sci. Pollut. Res.* 1–22. doi:10.1007/s11356-022-18712-2

Zhao, Y., Zhang, N., Feng, T., Zhao, C., and Zhang, J. (2020). The green spillover effect of green customer integration: Does internal integration matter? *Corp. Soc. Responsib. Environ. Manag.* 27 (1), 325–338. doi:10.1002/csr.1808

Zhao, S., Zhang, B., Shao, D., and Wang, S. (2021a). Can top management teams' academic experience promote green innovation output: Evidence from Chinese enterprises. *Sustainability* 13 (11453), 11453. doi:10.3390/su132011453

Zhao, Y., Zhao, C., Guo, Y., Sheng, H., and Feng, T. (2021b). Green supplier integration and environmental innovation in Chinese firms: The joint effect of governance mechanism and trust. *Corp. Soc. Responsib. Environ. Manag.* 28 (1), 169–183. doi:10.1002/csr.2040

Zhou, Y., Hong, J., Zhu, K., Yang, Y., and Zhao, D. (2018). Dynamic capability matters: Uncovering its fundamental role in decision making of environmental innovation. *J. Clean. Prod.* 177 (4), 516–526. doi:10.1016/j.jclepro.2017.12.208

Zhu, M., and Gao, H. (2021). The antecedents of supply chain agility and their effect on business performance: an organizational strategy perspective. *Oper. Manag. Res.* 14 (1-2), 166–176. doi:10.1007/s12063-020-00174-9