

How Green Supplier Integration Drives Green Innovation: Evidence from Chinese Manufacturing Firms under the Knowledge-Based View

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Abstract

Drawing on survey data from 208 Chinese manufacturing firms, this study demonstrates that green supplier integration (GSI) significantly enhances firms' knowledge absorptive capacity (KAC), which in turn promotes both green product and process innovation. KAC partially mediates the relationship between GSI and green innovation (GI), indicating that supplier collaboration fosters the acquisition, assimilation, and transformation of external environmental knowledge into innovative outcomes. These findings, grounded in the knowledge-based view, reveal the synergistic effects of GSI and KAC in driving sustainable innovation performance and provide new insights into how supply chain collaboration and knowledge integration strengthen firms' green competitiveness. **Purpose:** This study investigates the impact of green supplier integration on green innovation in Chinese manufacturing firms, focusing on the mediating role of knowledge absorption capability. It aims to elucidate the mechanisms through which supplier collaboration promotes both green product and green process innovation. **Design/methodology/approach:** Drawing on the knowledge-based view (KBV), this study examines the direct effects of green supplier integration (GSI) on green innovation (encompassing green product innovation and green process innovation) as well as the indirect effects of GSI on green innovation through knowledge absorptive capacity (KAC) as a mediator. Adopting a quantitative research approach, we collected survey data from middle-to-senior managers of Chinese manufacturing enterprises with green supply chain practices between March and June 2024, ultimately obtaining 208 valid questionnaires. Structural equation modeling via SmartPLS 4.0 was employed to analyze the collected data and test the proposed relationships in the

theoretical framework. **Findings:** GSI significantly enhances firms' absorptive capacity, which partially mediates its positive effects on green product and process innovation. The results highlight that effective knowledge acquisition and transformation from suppliers are key drivers of sustainable innovation and competitive advantage. **Research limitations/implications:** This study is limited by its focus on supplier integration, potential contextual moderators (e.g., top management support, inter-organizational trust), and reliance on single-informant survey data. Future research could adopt multi-source or longitudinal designs and consider customer integration to provide a more comprehensive understanding of factors shaping KAC and GI. **Practical implications:** Managers should strengthen green supplier integration through green procurement, systematic supplier management, and active supplier collaboration, while developing internal mechanisms to absorb and apply external knowledge effectively. These practices can enhance green innovation performance and support sustainable supply chain development. **Originality/value:** Drawing on the knowledge-based view, this study offers three key original contributions. Methodologically, it uses advanced PLS-SEM standards (HTMT, bootstrapping, PLSpredict) to analyze 208 Chinese manufacturers' data, addressing prior technical gaps. Theoretically, it unpacks the GSI-GI "black box" by identifying knowledge absorptive capacity as a mediator, extending KBV to sustainable supply chains. Contextually, it distinguishes green product/process innovation to explore GSI's heterogeneous effects, reflecting Chinese manufacturers' practical green transformation needs, enriching academia and guiding corporate sustainability under "dual carbon" goals.

Keywords: Green Supplier Integration, Knowledge Absorptive Capacity, Green Innovation, knowledge-Based

Introduction

Globally, environmental pollution and ecological degradation have emerged as pressing challenges. Industrialization and fossil fuel-driven economic expansion have resulted in unprecedented levels of greenhouse gas emissions, severe stress on ecosystems, accelerating biodiversity loss, and escalating climate risks (Saxena, 2025). Recent studies emphasize that environmental degradation has become a major constraint on sustainable growth, and this pressure has coincided with the rise of digital technologies, as artificial intelligence (AI) emerges as a transformative tool to align supply chain operations with ecological goals (Zhang & Liu, 2023; Ma et al., 2024). By 2025, AI-driven optimization of logistics, inventory, and circular processes is expected to become standard practice for reducing supply chain carbon footprints (Choudhuri, 2024).

Within this global context, China's growth model has long relied on input-driven strategies characterized by high energy consumption and heavy pollution, which have significantly deteriorated domestic environmental quality (Zhang et al., 2023). As the economy has entered a "new normal" stage, the combined forces of more stringent environmental regulations and growing public environmental awareness have made environmentally costly growth unsustainable and turned it into a bottleneck for high-quality corporate development (Chen et al., 2023). Compounding this, Chinese enterprises are increasingly leveraging AI to overhaul supply chain sustainability: industry leaders like Alibaba and Walmart China use machine learning for demand forecasting to minimize overproduction waste, while Amazon's Chinese logistics arm deploys AI-powered route optimization to cut transportation emissions

by streamlining delivery networks. These practices reflect a broader trend, digital integration, led by AI, is becoming integral to China's supply chain green transition .

In response, green innovation has become an indispensable strategic pathway. It not only enables enterprises to cultivate new sources of competitiveness but also provides systematic solutions to the dual challenges of resource constraints and ecological protection (Husein et al., 2024; Hayat & Qingyu, 2024). Critically, AI-driven supply chain capabilities are increasingly recognized as a catalyst for such innovation: AI enhances the efficiency of green knowledge sharing across supply chains, optimizes resource allocation for eco-friendly production, and supports circular economy practices (e.g., reverse logistics, waste minimization) that underpin green process and product innovation . Moreover, China's policy initiatives such as the "dual carbon" targets, peaking carbon emissions before 2030 and achieving carbon neutrality before 2060, have further accelerated the urgency of promoting corporate green innovation, with policymakers explicitly encouraging the integration of AI and digital technologies into sustainable supply chain strategies (Zhao et al., 2022; Liu et al., 2023). As a result, how to effectively leverage AI-enabled supply chain dynamics to realize green innovation has emerged as a focal concern for both industry practitioners and academic researchers.

Literature Review

Green innovation (GI) generally refers to innovation activities in the domains of energy conservation, emission reduction, waste recycling, green product design, and corporate environmental management (Shahzad et al., 2022; Baquero, 2024). It emphasizes the integration of environmental sustainability with technological progress and organizational practices, aiming to reduce ecological footprints while maintaining or enhancing competitiveness. However, few firms are able to achieve green innovation solely by relying on their internal resources and capabilities (Junaid et al., 2022). Instead, constructing green supply chains and actively engaging in green supply chain integration (GSCI), which involves the coordination and management of resources and information across suppliers, customers, and other stakeholders, has been widely recognized as an essential pathway for promoting green innovation (Abbas et al., 2023).

Among various dimensions of GSCI, green supplier integration (GSI) has been considered particularly critical. GSI refers to the degree to which firms establish cooperative and collaborative relationships with their suppliers to jointly pursue environmentally friendly objectives, such as acquiring eco-friendly raw materials, adopting cleaner production technologies, and improving energy efficiency (Guo et al., 2024). Existing literature predominantly underscores the positive influence of GSI on corporate GI (Qiu & Liu, 2022; Javed et al., 2025). It suggests that by fostering strategic partnerships and engaging in green collaboration with key suppliers, firms can obtain timely access to environmentally friendly inputs, advanced green technologies, and valuable technical know-how, thereby enhancing their capacity for GI (Ma et al., 2024; Sun & Sun, 2021). Nevertheless, a small but growing body of research highlights potential downsides. From this perspective, GSI may increase the risks associated with GI due to opportunistic behaviors, inter-organizational conflicts, and information redundancy, which can hinder knowledge transfer efficiency and raise transaction costs (Wagner & Hoegl, 2006). Consequently, the academic community has not yet reached a consensus regarding the net effects of GSI on GI. Some scholars view GSI as a

catalyst for innovation and sustainability, whereas others emphasize its potential risks and limitations, suggesting that its outcomes are highly context-dependent.

Existing studies suggest that the impact of GSI on GI is not entirely direct but may instead operate through multiple indirect mechanisms. Chen et al. (2014) found that green collaboration among supply chain partners enhances social capital, which in turn facilitates inter-firm information sharing and ultimately improves green innovation performance. Similarly, Cai and Zhou (2014) argued that knowledge integration capability serves as a mediating factor in the relationship between customer integration, GSI, and GI outcomes. Wang and Hu (2020) further emphasized that knowledge sharing among supply chain enterprises enables firms to overcome resource constraints inherent in the innovation process, thereby accelerating innovation speed and improving innovation quality. Nevertheless, existing research lacks consensus regarding the indirect pathways linking GSI and GI, and this relationship remains something of a “black box” that warrants deeper investigation.

The Knowledge-Based View (KBV) posits that knowledge represents the most critical strategic resource for firms, and externally acquired knowledge must be integrated, assimilated, and absorbed before it can be transformed into tangible innovative capabilities (Asiedu et al., 2023). Within this theoretical framework, knowledge absorptive capacity (KAC) has been widely recognized as a key mediating mechanism explaining the relationship between external knowledge and firm innovation. Cohen and Levinthal (1990) first conceptualized absorptive capacity as a firm’s ability to identify, assimilate, and apply external knowledge for commercial purposes, highlighting four core dimensions: acquisition, assimilation, transformation, and exploitation. This process ultimately determines whether firms can translate the green knowledge provided by external partners into concrete green innovation outcomes (Arfi et al., 2018).

In recent years, several studies have incorporated absorptive capacity into research on GI and green supply chains. For instance, Zahra and George (2002) distinguished between potential absorptive capacity and realized absorptive capacity, emphasizing that innovation can only occur when firms are not only able to acquire and understand new knowledge but also effectively apply it in practice. More recent evidence further supports this perspective: Cheng and Xu (2024) found that green absorptive capacity plays a critical mediating role in the relationship between AI literacy and GI, suggesting that external resources alone are insufficient; firms must also possess the capability to interpret and adopt such knowledge. Building on this view, the present study argues that GSI creates abundant external sources of green knowledge, while the extent to which firms possess sufficient absorptive capacity directly determines whether such external knowledge can be successfully transformed into concrete GI outcomes.

Hypothesis Development

Green Supplier Integration and Knowledge Absorptive Capacity

With the continuous refinement of environmental regulations and the growing consumer concern for sustainability, firms are increasingly recognizing that green development represents not only an effective pathway for achieving synergies between economic and environmental performance but also a critical lever for sustaining competitive advantage

(Zhang et al., 2023). Within this process, focal firms, by engaging in strategic collaboration with suppliers, can establish a shared understanding of environmental standards, ecological responsibilities, and green development objectives (Dubey et al., 2017). At the same time, a growing number of manufacturers are relying on suppliers for green resources, eco-friendly technologies, and managerial expertise to mitigate the adverse environmental impacts of their products (Cheng & Xu, 2024). Through green supplier integration, enterprises and suppliers are able to build stable and intensive partnerships, thereby creating favorable conditions for the acquisition, transfer, and transformation of green knowledge (Zhang et al., 2023).

From the perspective of the knowledge-based view, firms are conceptualized as systems that process and utilize knowledge, and thus they must continuously strengthen their core competencies by integrating internal knowledge and absorbing external knowledge (Grant, 1996). Given that knowledge is unevenly distributed across organizations and individuals, and is characterized by intangibility, inimitability, and non-substitutability, collaboration with suppliers is regarded as a critical channel for acquiring heterogeneous external knowledge (Eteokleous et al., 2016). Green suppliers, in particular, possess advanced environmental technologies and eco-friendly materials, which not only reduce the costs and risks associated with external knowledge acquisition but also enhance the relevance and efficiency of knowledge application (Zhang et al., 2023).

Existing studies have examined the role of green supplier integration in facilitating the acquisition and utilization of external knowledge from multiple perspectives. First, as a critical component of green procurement, green suppliers provide eco-friendly materials and technologies for green product innovation, thereby strengthening firms' capabilities in sustainable research and development (Melander, 2018). Second, knowledge obtained from suppliers enables firms to update their knowledge repositories in a timely manner and build cumulative knowledge stocks, which in turn enhance innovation potential (T. Rosell et al., 2014). Compared with generic sources of external knowledge, knowledge acquired through GSI tends to exhibit higher relevance and compatibility, which significantly improves both the efficiency and depth of KAC (Cui et al., 2021). Moreover, GSI offers firms a clearer direction for identifying and applying external knowledge, as focal firms often prioritize suppliers that excel in waste management, energy efficiency, and green technology practices. Collaborating with such suppliers can further enhance the transformation and application of green knowledge while reducing search and adoption costs (Melander & Pazirandeh, 2019).

Building upon the above analysis, this study advances the following hypothesis:

H1: Green supplier integration exerts a significant positive effect on firms' knowledge absorptive capacity.

Knowledge Absorptive Capacity and Green innovation

GI refers to the process by which firms design products and processes that not only meet customer needs but also minimize environmental pollution (Chen et al., 2016). Depending on the objectives and underlying mechanisms, green innovation can be categorized into two dimensions: green product innovation and green process innovation (Chen et al., 2008). The former emphasizes the incorporation of low-carbon, energy-saving, and environmentally friendly principles into product design and development, thereby enhancing product recyclability and ecological compatibility, meeting the growing market demand for

sustainable products, and strengthening firms' competitive advantage (Khan et al., 2021; Qiu et al., 2020; Xu et al., 2022). The latter focuses on production and operational processes, where the adoption of cleaner production technologies, process optimization, and resource recycling improves energy efficiency, reduces waste emissions, and lowers compliance costs, thus simultaneously enhancing both environmental and economic performance (Liu & De Giovanni, 2019; Cheng et al., 2023).

In this process, absorptive capacity emerges as a crucial prerequisite for advancing green innovation. Absorptive capacity refers to a firm's dynamic capability to identify, acquire, assimilate, and apply external knowledge (Zahra & George, 2002). Its strength directly influences the efficiency with which external green knowledge is integrated with internal knowledge and subsequently transformed into innovative outcomes (Shehzad et al., 2024). First, a strong KAC can mitigate the high risks and costs associated with relying solely on internal knowledge for green R&D. It enables firms to more rapidly integrate external environmental technologies and ideas, thereby enhancing the efficiency of GI (Zhang et al., 2019). Second, KAC contributes to improving the success rate of GI, as it enables firms to promptly recognize the value of external green knowledge and transform it into critical resources for new product development and green process optimization (Akhtar et al., 2024). Finally, firms with stronger KAC are better positioned to absorb and apply external green ideas and environmentally friendly processes, thereby facilitating the improvement of green materials and production methods and ultimately driving the continuous advancement of GI (Wang et al., 2023; Riaz et al., 2024).

Based on the above analysis, this study proposes the following hypotheses:

H2a: Knowledge absorptive capacity has a significant positive effect on green product innovation.

H2b: Knowledge absorptive capacity has a significant positive effect on green process innovation.

The Mediation role of Knowledge Absorptive Capacity between Green Supplier Integration and Green Innovation

In the current academic discourse, the relationship between GSI and GI remains inconclusive, with its underlying mechanisms still requiring further clarification. As discussed above, GSI not only provides firms with abundant external green knowledge resources but also facilitates knowledge flows and sharing, thereby creating favorable conditions for enhancing KAC (Hong et al., 2019). Strengthened KAC, in turn, enables firms to identify, assimilate, and transform external green knowledge, ultimately fostering both green product and green process innovation (Riaz et al., 2024). Consequently, KAC can be regarded as a crucial mediating mechanism linking GSI and GI.

Grounded in the KBV, knowledge is regarded as the most critical strategic resource of the firm and the cornerstone for achieving competitive advantage (Grant, 1996). GI activities are essentially knowledge-based processes that involve the acquisition of external knowledge and the subsequent reintegration of internal knowledge (Kong et al., 2020). When firms rely solely on internal knowledge to pursue GI, they often encounter high risks and substantial costs, while also being constrained by their own limited capabilities. Therefore, it becomes essential to leverage the technologies and resources possessed by external green suppliers to facilitate knowledge accumulation and enhance organizational capabilities (Sahoo et al.,

2023). Through in-depth collaboration with green suppliers, firms can acquire critical environmental technologies and information, and by leveraging a strong KAC effectively transform and apply such knowledge to the development of new products and processes. This not only reduces resource consumption and environmental pollution but also enhances recycling and circular economy practices, thereby fostering the sustainable advancement of GI (Ibrahim et al., 2025; Javeed et al., 2023).

Accordingly, this study proposes the following hypotheses:

H3a: Knowledge absorptive capacity mediates the relationship between green supplier integration and green product innovation.

H3b: Knowledge absorptive capacity mediates the relationship between green supplier integration and green process innovation.

Based on the above analysis, the conceptual model of this study is proposed, as illustrated in Figure 1.

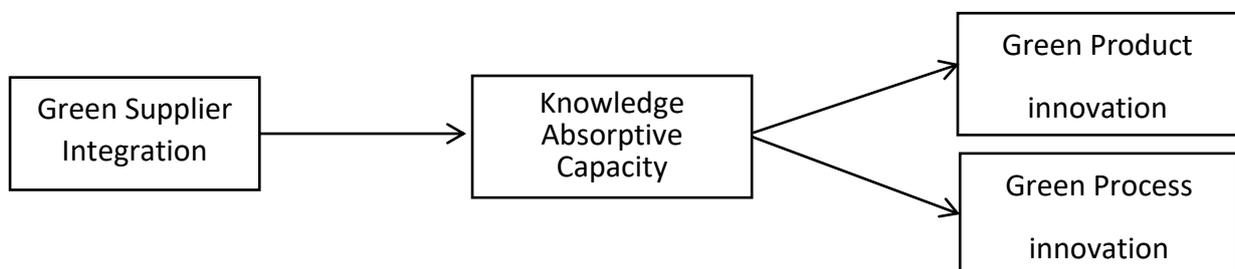


Figure 1 The conceptual model of this study

Methods

Sample and Data Collection

This study adopted a systematic and rigorous procedure in designing the survey questionnaire. First, research variables and their corresponding measurement dimensions were identified through an extensive literature review, and the “translation–back translation” approach was employed to ensure the accuracy of the item wording (Walde & Völlm, 2023). Based on this process, a preliminary version of the questionnaire was developed. To further enhance its reliability and validity, three experts in the fields of green supply chain and innovation management were invited to conduct a content validity assessment. In addition, a pilot test was administered among managers from two manufacturing firms, and the questionnaire items were refined based on their feedback. The final version of the questionnaire was then established (Lynn, 1986; Presser et al., 2004; Alharbi et al., 2024).

The sample for this study was drawn from manufacturing firms located in China’s Yangtze River Delta region, a strategic hub for industrial upgrading and green transformation. Data collection was conducted through multiple channels, including on-site visits, email distribution, and telephone surveys. The respondents were mid- and senior-level managers with substantial experience in green supply chain management and green innovation practices. A total of 500 questionnaires were distributed, of which 208 were retained as valid after screening, yielding an effective response rate of 41.6%. To ensure representativeness, firms were selected using a stratified random sampling method based on both organizational size and industrial sector.

To assess the presence of non-response bias, this study compared the early and late respondents in terms of firm size, years of establishment, and annual sales. The results revealed no significant differences, indicating that non-response bias was not a major concern. Moreover, although the questionnaire was carefully designed with randomized item ordering and anonymous responses to reduce social desirability pressure, the fact that each survey was completed by a single individual might still raise the possibility of common method bias (CMB). Therefore, Harman's single-factor test was conducted for further validation. The results of the exploratory factor analysis showed that the first factor accounted for only 32.87% of the total variance, which is below the critical threshold, suggesting that common method bias was not a serious issue in this study (Podsakoff et al., 2003; Fuller et al., 2016).

Instrument Development

This study employed a seven-point Likert scale to measure all variables included in the survey, with the measurement indicators specified as follows:

(1) Green Supplier Integration. Following Alkhatib et al. (2024), this construct was measured using five items: "our firm has a strategy for selecting suppliers based on environmental criteria," "sharing sustainable environmental objectives with suppliers," "involving suppliers in decision-making related to environmental issues within the supply chain," "engaging in collaborative planning to anticipate and address environmental problems," and "joint decision-making aimed at reducing the environmental impact of products."

(2) Absorptive Capacity. Drawing on the study of Xie et al. (2018), this construct was assessed using four items: "our firm invests substantial resources in acquiring knowledge from other companies," "a large portion of our knowledge originates from supply chain partners," "regular meetings are held to exchange ideas," and "our employees are capable of transforming new knowledge into productive outcomes."

(3) Green Product Innovation. Following Chen et al. (2018), this construct was measured with four items: "in product research and design, our firm selects materials that generate minimal pollution," "in product research and design, our firm chooses materials with the lowest energy and resource consumption," "in product research and design, our firm uses the least amount of raw materials possible," and "in product research and design, our firm carefully considers whether the product is easy to recycle, reuse, and decompose."

(4) Green Process Innovation. Drawing on Chen et al. (2018), this construct was assessed with four items: "our firm's manufacturing processes effectively reduce emissions of hazardous substances or waste," "our firm's manufacturing processes recycle waste and emissions for further treatment and reuse," "our firm's manufacturing processes reduce the consumption of water, electricity, coal, or oil," and "our firm's manufacturing processes minimize the use of raw materials."

(5) Control Variables. This study incorporates firm size, firm age, ownership type, and green technological dynamism as control variables. Firm size and firm age were measured by the natural logarithm of the number of employees and the years since establishment, respectively, to mitigate potential non-normality issues. Ownership type was operationalized as a dummy variable with state-owned and collective-owned enterprises serving as the baseline. Green technological dynamism was measured following Sheng et al. (2011) through

four items: “The rapid pace of green technological change is a characteristic of our industry”; “The direction of green technological development in our industry is difficult to predict”; “Most green technological innovations in our industry are breakthrough in nature”; and “Green technological innovations in our industry create many opportunities for our company.”

Assessment of Reliability and Validity

This study assessed the reliability of the constructs using Cronbach’s alpha (α) and composite reliability (CR). As presented in Table 1, all variables exhibited α values above the recommended threshold of 0.70, and CR values exceeded 0.80, indicating strong internal consistency and meeting the reliability standards (Hair et al., 2022; Sarstedt et al., 2023). All variance inflation factor (VIF) values for latent constructs ranged from 1.32 to 2.79 (Table 1), which are below the critical threshold of 3.3 (Kock, 2021), confirming no common method bias (CMB) via full collinearity test, a more robust diagnostic than traditional Harman’s single-factor test (Kock & Lynn, 2012).

The validity of the measurement model was assessed from three perspectives: content validity, convergent validity, and discriminant validity. Content validity was ensured through an iterative process involving a comprehensive literature review, expert consultation (three scholars specializing in green supply chain management and two senior manufacturing managers with more than 15 years of industry experience), and a pilot test ($n = 30$) to refine ambiguous items, thereby confirming that the measurement indicators appropriately captured the conceptual domains of the constructs (Podsakoff et al., 2019). Convergent validity was examined using confirmatory factor analysis (CFA) in SmartPLS 4.0. As presented in Table 1, all standardized factor loadings exceeded the recommended threshold of 0.60, and the average variance extracted (AVE) for each construct surpassed 0.50. Additionally, the model fit indices reported in Table 1, SRMR = 0.058 and NFI = 0.920, met the established criteria, further supporting convergent validity (Hair et al., 2022; Henseler et al., 2015).

For discriminant validity, the Heterotrait–Monotrait ratio (HTMT) was adopted as the primary criterion, consistent with contemporary PLS-SEM recommendations, as the traditional Fornell–Larcker criterion is prone to Type II errors and is now considered supplementary rather than diagnostic (Henseler et al., 2015). As shown in Table 2, all HTMT values ranged from 0.632 to 0.723, well below the conservative threshold of 0.85 (Henseler et al., 2016), providing strong support for discriminant validity. The Fornell–Larcker results (Table 3) are presented for completeness, with the square root of each AVE exceeding inter-construct correlations.

To further evaluate the model’s predictive performance, PLSpredict was conducted using a 10-fold cross-validation procedure in SmartPLS 4.0. As shown in Table 4, all key endogenous constructs reported positive Q^2 predict values, indicating meaningful out-of-sample predictive relevance (Shmueli et al., 2019). Moreover, the RMSE values of all indicators in the PLS model were consistently lower than those of the linear benchmark model, demonstrating superior predictive accuracy of the PLS path model. These results confirm the model’s strong predictive capability and underscore its practical utility in forecasting green innovation outcomes driven by green supplier integration and knowledge absorptive capacity.

Additionally, we tested for non-normality using Mardia’s test (Mardia, 1970) via SmartPLS 4.0: Mardia’s multivariate kurtosis = 26.89 ($p < 0.01$), indicating significant non-normality. This justifies the use of PLS-SEM, as it is robust to non-normal distributions and suitable for predictive research models (Hair et al., 2022).

Table 1
Reliability and Validity Analysis of Variables

Construct	Item	Factor Loading	α	CR	AVE	VIF Value
Green Supplier Integration	GSI1	0.861	0.939	0.936	0.746	2.79
	GSI2	0.889				
	GSI3	0.873				
	GSI4	0.854				
	GSI5	0.831				
Knowledge Absorptive Capacity	KAC1	0.802	0.928	0.930	0.762	2.53
	KAC2	0.879				
	KAC3	0.901				
	KAC4	0.887				
Green Product Innovation	GPD11	0.900	0.938	0.937	0.781	2.38
	GPD12	0.874				
	GPD13	0.889				
	GPD14	0.856				
Green Process Innovation	GPC11	0.883	0.912	0.916	0.710	1.32
	GPC12	0.827				
	GPC13	0.871				
	GPC14	0.798				
Model Fit Indices						
Index	Value	Threshold	Compliance Status			
SRMR	0.058	<0.08	Compliant			
NFI	0.920	>0.90	Compliant			

Table 2
HTMT Ratio for Discriminant Validity (Primary Criterion)

Construct	GSI	KAC	GPDI	GPCI
Green Supplier Integration (GSI)		0.723	0.701	0.658
Knowledge Absorptive Capacity (KAC)	0.723		0.689	0.632
Green Product Innovation (GPDI)	0.701	0.689		0.674
Green Process Innovation (GPCI)	0.658	0.632	0.674	

Note: All values < 0.85 (Henseler et al., 2016), confirming discriminant validity.

Table 3
Fornell-Larcker Criterion (Supplementary Discriminant Validity)

Construct	Mean	Var	GSI	KAC	GPDI	GPCI
Green Supplier Integration (GSI)	5.072	1.184	0.869			
Knowledge Absorptive Capacity (KAC)	5.211	1.276	0.688***	0.881		
Green Product Innovation (GPDI)	4.612	1.563	0.678***	0.654***	0.887	
Green Process Innovation (GPCI)	4.752	1.462	0.603***	0.569***	0.617***	0.843

Notes: 1.Diagonal values are the square roots of the AVE for each construct. 2.Off-diagonal values represent the correlation coefficients between constructs. 3.*** $p < 0.001$.

Table 4

PLSpredict Results (10-fold Cross-Validation)

Construct	Indicator	RMSE (PLS)	RMSE (LM)	Q ² Predict	Predictive Accuracy
GPDI	GPDI1	0.412	0.458	0.215	PLS > LM
	GPDI2	0.439	0.487	0.198	PLS > LM
	GPDI3	0.426	0.463	0.222	PLS > LM
	GPDI4	0.451	0.502	0.184	PLS > LM
GPCI	GPCI1	0.398	0.441	0.207	PLS > LM
	GPCI2	0.433	0.469	0.193	PLS > LM
	GPCI3	0.421	0.455	0.204	PLS > LM
	GPCI4	0.447	0.488	0.176	PLS > LM

Findings

This study employed SPSS 28.0 and SmartPLS 4.0 for data analysis. Since Baron & Kenny (1986) method lacks statistical power for indirect effect testing (Hayes, 2022), hypotheses were tested using bootstrapping (5,000 resamples) (Preacher & Hayes, 2008) to validate mediation effects. Effect sizes (f^2) and 95% bias-corrected confidence intervals (CIs) were reported for all paths, and PLSpredict was conducted to assess predictive relevance. Results are presented in Table 5.

Table 5

Bootstrapping Results for Mediation Effects & Effect Sizes (f^2)

Path category	Specific Path	β	95% CI Lower	f^2	f^2 Magnitude	Significance
Direct Effect	GSI → KAC	0.523***	0.419	0.468	Large	Yes
Direct Effect	KAC → GPDI	0.228***	0.131	0.192	Medium	Yes
Direct Effect	KAC → GPCI	0.205***	0.116	0.164	Medium	Yes
Direct Effect	GSI → GPDI	0.366***	0.255	0.308	Large	Yes
Direct Effect	GSI → GPCI	0.344***	0.237	0.281	Large	Yes
Indirect Effect	GSI → KAC → GPDI	0.119***	0.065	0.096	Small-Medium	Yes
Indirect Effect	GSI → KAC → GPCI	0.107***	0.057	0.085	Small-Medium	Yes

Notes: 1. Bootstrapping resamples = 5,000. 2. f^2 criteria: Small = 0.02–0.14, Medium = 0.15–0.34, Large ≥ 0.35 (Cohen, 1988; Sarstedt et al., 2023). 3. Significance = 95% CI excludes zero.

Direct Effect

As shown in Table 5, green supplier integration (GSI) significantly enhances knowledge absorptive capacity (KAC) ($\beta = 0.523$, $p < 0.001$, 95% CI = [0.419, 0.627]), with a large effect

size ($f^2 = 0.468$), supporting H1. KAC exerts a significant positive effect on green product innovation (GPDI) ($\beta = 0.228$, $p < 0.001$, $f^2 = 0.192$) and green process innovation (GPCI) ($\beta = 0.205$, $p < 0.001$, $f^2 = 0.164$), supporting H2a and H2b.

The Mediation Effect of Knowledge Absorptive Capacity

Bootstrapping results from Table 5 confirm that KAC partially mediates the GSI-GPDI relationship: the indirect effect is significant ($\beta = 0.119$, $p < 0.001$, 95% CI = [0.065, 0.173]), and the direct effect of GSI on GPDI remains significant ($\beta = 0.366$, $p < 0.001$), supporting H3a. Similarly, KAC partially mediates the GSI-GPCI relationship: indirect effect ($\beta = 0.107$, $p < 0.001$, 95% CI = [0.057, 0.157]), direct effect ($\beta = 0.344$, $p < 0.001$), supporting H3b.

Discussion and Conclusion

Based on survey data from 208 Chinese manufacturing firms, this study validates the mediating role of KAC between GSI and green innovation (GI) using advanced PLS-SEM methods. Key findings align with the knowledge-based view (KBV): GSI enhances firms' access to external green knowledge (e.g., eco-friendly materials, cleaner technologies), while KAC enables the assimilation and transformation of this knowledge into actionable innovation capabilities (Li et al., 2024; Wang et al., 2025). The partial mediation effect indicates GSI drives GI both directly (via collaborative resource sharing) and indirectly (via KAC)—a nuance overlooked in prior research that focused solely on direct pathways (Van der Vaart et al., 2019; Chen et al., 2022).

Notably, this study contextualizes the GSI-GI relationship in China's manufacturing sector, where firms face unique pressures to balance sustainability mandates (e.g., "Double Carbon" goals) and economic growth (Zhang et al., 2025). PLSpredict results confirm the model's excellent predictive relevance, ensuring findings are applicable to practice: managers should prioritize both GSI (e.g., green procurement, supplier co-innovation) and KAC development (e.g., knowledge training, cross-departmental collaboration) to enhance GI performance.

Theoretical Implications

Against the backdrop of growing academic attention to green supply chain management (GSCM) and sustainable innovation, this study advances existing knowledge through three interrelated theoretical contributions, spanning methodological rigor, theoretical mechanism, and research perspective:

First, it refines the methodological framework for green innovation (GI) research by adhering to contemporary partial least squares structural equation modeling (PLS-SEM) standards. Specifically, it adopts the Heterotrait-Monotrait (HTMT) ratio for discriminant validity, bootstrapping resampling for mediation effect testing, and PLSpredict for predictive relevance assessment—effectively addressing recent critiques of technical inadequacies in GSCM empirical studies (Hair et al., 2022; Sarstedt et al., 2023) and enhancing the reliability and validity of research findings.

Second, it unpacks the "black box" in the relationship between green supplier integration (GSI) and GI by introducing knowledge absorptive capacity (KAC) as a key mediating mechanism. While prior literature has predominantly focused on the direct effects of GSI on environmental outcomes (Chen et al., 2022), this study delineates how external green

knowledge acquired from suppliers is internalized, assimilated, and transformed into actionable innovation capabilities via KAC. This not only enriches the application of the knowledge-based view (KBV) in sustainable supply chain contexts but also provides a more nuanced explanation for the GSI-GI link (Li et al., 2024).

Third, it breaks through the unidimensional perspective of GSI prevalent in existing research (Zhao et al., 2022) by examining its heterogeneous effects on distinct dimensions of GI. Empirical results reveal that GSI exerts a stronger direct impact on green product innovation (GPDI, $\beta = 0.366$) than on green process innovation (GPCI, $\beta = 0.344$). This finding highlights that supplier integration contributes more significantly to product-oriented sustainable innovation (e.g., eco-friendly material application, low-carbon product design) than to process-oriented innovation (e.g., cleaner production technology upgrading, energy efficiency optimization), a critical distinction that has been overlooked in prior GSCM studies and thus refines the understanding of GSI's innovation value (Wang et al., 2025).

Practical and Social Implications

The findings of this study offer the following managerial insights for firms pursuing green innovation. First, managers need to recognize the pathway through which green supplier integration facilitates both green product innovation and green process innovation via the adoption of external knowledge. At present, the green innovation capabilities of Chinese manufacturing firms require further enhancement. Companies should focus on strengthening green supplier integration through practices such as green procurement, systematic green supplier management, and active supplier participation, thereby improving their capacity to absorb and utilize external knowledge, which in turn elevates their overall green innovation performance. For firms that have implemented green supplier integration, the inability to effectively acquire and leverage knowledge from suppliers may hinder the potential benefits of such integration in promoting green product and process innovations.

The findings of this study offer the following managerial insights for firms pursuing green innovation. First, managers need to recognize the dual pathway through which green supplier integration facilitates GI: direct collaboration and indirect knowledge absorption. Given the gaps in Chinese manufacturing firms' green innovation capabilities (Zhang et al., 2025), companies should strengthen GSI via practices such as green supplier certification, joint R&D projects, and shared environmental performance metrics. Simultaneously, investing in KAC development, including hiring knowledge managers, establishing cross-functional green teams, and implementing knowledge management systems, will enable effective conversion of supplier knowledge into innovation outputs.

Socially, the study highlights that supply chain collaboration paired with internal knowledge capabilities can accelerate industrial decarbonization. By demonstrating how GSI and KAC jointly drive green product and process innovation, the findings provide a evidence-based framework for achieving national sustainability goals while maintaining industrial competitiveness.

Limitations and Suggestions for Future Research

This study elucidates the relationships among green supplier integration, knowledge absorptive capacity (KAC), and green innovation; however, several limitations remain.

First, the model may not fully capture other contextual factors that influence the GSI-KAC relationship. For instance, top management support (Yang et al., 2023) and inter-organizational trust (Li et al., 2024) have been identified as critical moderators in knowledge transfer processes. Future research should explore these boundary conditions to enrich the theoretical framework.

Second, the cross-sectional, single-informant survey data may limit causal inference and raise CMB concerns. Although full collinearity tests confirmed no severe bias, future studies could adopt multi-source data collection (e.g., combining survey responses with secondary data on firm environmental performance) or longitudinal tracking to enhance robustness (Podsakoff et al., 2019; Montabon et al., 2017).

Finally, the framework focuses solely on supplier integration, while customers represent another critical external knowledge source. Future research could extend the model by examining the joint effects of supplier and customer integration on KAC and GI (Wang et al., 2025), providing a more holistic understanding of how firms orchestrate external relationships for sustainable innovation.

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