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Supply Chain Collaboration and Green Innovation Performance in Chinese Logistics Services: Policy Heterogeneity and Organizational Capabilities

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Abstract: China's logistics industry faces mounting pressure for green transformation under the dual carbon strategy. This study investigates how supply chain collaboration, policy drivers, and organizational capabilities influence green innovation performance in Chinese logistics enterprises. Using panel data from 50 logistics companies (2017-2023), we employ fixed-effects regression models to examine direct and interaction effects. Results demonstrate that supply chain collaboration significantly enhances green innovation performance (β=0.463, $p<0.001$). Policy effectiveness varies by ownership structure, with state-owned enterprises showing stronger responsiveness (β=0.416, $p<0.05$) than private firms. The interaction between organizational capabilities and supply chain collaboration produces additional positive effects (β=0.172, $p<0.05$). These findings suggest that effective green innovation requires integrated approaches combining internal capability building with external collaboration, while policy design should account for ownership heterogeneity. The study contributes to understanding collaborative innovation mechanisms in logistics service systems and provides insights for differentiated policy implementation

Keywords: Green Supply Chain, Chinese Logistics Enterprises, Green Innovation, Driving Factors, Supply Chain Collaboration, Logistics Performance, Sustainability Transition

1. Introduction

Global environmental problems have intensified, and green innovation has become the key to the sustainable development of enterprises.As the basic industry of the national economy, China's logistics industry is large-scale and growing rapidly, but the problems of high energy consumption and high emissions are prominent, and the pressure on resources and the environment is constantly increasing (Liu et al., 2023; Liu et al., 2023; Bai et al., 2024).Under this situation, the green innovation ability of logistics enterprises is not only related to the environmental performance of the whole chain, but also affects the implementation of the national “double carbon” strategy and the long-term competitiveness of the industry.Most of the existing research explores the driving factors of green innovation from a single internal dimension such as policy pressure, market demand, or organizational capabilities. The synergy of the supply chain has not been systematically investigated, resulting in incomplete analysis of the driving mechanism and limited practical guidance. Significance.The theory of green supply chain management provides a systematic analysis perspective for this purpose. The theory advocates that enterprises break organizational boundaries, integrate internal and external resources, and work closely with upstream and downstream partners to promote information sharing, process optimization, and resource coordination to improve environmental performance and innovation capabilities (Alexandrou et al., 2022; Jazairy and Robin, 2020; Letunovska et al., 2023). The logistics industry is highly networked and interactive. Green innovation requires multi-subject collaboration. Its performance depends on the overall linkage ability of the system, not a single enterprise.Therefore, building a multi-level, multi-factor interactive analysis framework from the perspective of the green supply chain is of great significance to reveal the driving mechanism of green innovation in Chinese logistics enterprises.Based on this, this paper constructs a multi-dimensional analysis framework that includes supply chain collaboration, policy driving forces and organizational driving forces, and focuses on exploring its impact mechanism on the green innovation performance of Chinese logistics companies.The research adopts a multivariate regression model to test the core variables and their interaction effects, and introduces the size of the enterprise and the type of ownership as the control variables to ensure the robustness of the conclusions. It aims to provide strong theoretical support and guidance for the practice of green innovation in logistics enterprises.

This research innovatively deeply integrates and surpasses the traditional TOE (Technology-Organization-Environment Framework) framework and GSC (Green Supply Chain) theory.Traditional research based on the TOE framework focuses on the independent or simple interaction of technology, organization, and environment, and deals with environmental factors statically. This research takes the green supply chain collaboration mechanism as the core of the analysis, highlighting the drive of supply chain collaboration for the green innovation of logistics enterprises, breaking through the limitations.At the same time, unlike traditional GSC research, which is limited to a single supply chain link or local collaboration, this research builds a multi-dimensional driver model and systematically analyzes the complex interaction effects between policy, market, organization and supply chain collaboration.Methodologically, the multi-source heterogeneous data fusion method is used to integrate corporate annual reports, patents and supply chain research data, build a balanced panel data set, and use a panel model to test the direct and interactive influence of variables on the performance of green innovation, providing a more refined and systematic analysis tool.The research enriches the theory of green innovation and provides more operational guidelines for the practice of green innovation in logistics enterprises.

2. Related Work

At present, the research on the drivers of green innovation in logistics enterprises has been promoted from multiple dimensions such as policy regulation, market demand and internal capabilities (Cheng et al., 2023; Liu et al., 2024; Jazairy et al., 2025).Driven by the goal of “double carbon”, the green transformation of the logistics industry is imperative.With the help of the TOE framework, Liu

Zhongyan used 42 listed logistics companies as samples and used the fsQCA (Fuzzy-Set Qualitative Comparative Analysis) method to sort out the configuration paths of high and non-high green performance, revealing the differentiated effects of policy pressures and technical capabilities due to different enterprise sizes (Liu et al., 2025).Abd Elghany M explores the impact of advanced technologies (including big data analytics, blockchain and the Internet of Things) on international business, how these technologies are reshaping global value chains, changing location decisions and changing the governance structure of multinational enterprises, and provides managers with practical insights into digital transformation of global businesses(Abd et al., 2025).Zhang Hao constructed a regional logistics green innovation level evaluation index system and found that coastal provinces such as Guangdong, Jiangsu and Zhejiang have obvious advantages, while most provinces in the central and western regions have not reached the average level, and the spatial heterogeneity is significant (Zhang et al., 2022).From the perspective of technology integration, Nicoletti Bernardo proposes to integrate basic models and sustainable principles into the logistics 5.0 framework, enhance system synergy and traceability, and enhance the long-term feasibility of environmental governance in the industry (Nicoletti and Andrea, 2024).However, existing research has limitations.Most studies focus on a single driving factor and lack a systematic analysis of the multi-subject collaborative mechanism of the supply chain. Although the methods are diverse, they have not effectively integrated micro-corporate behavior and macro-institutional environment, nor have they explored in depth the differences in the driving paths of green innovation under different ownership structures.Although Liu Zhongyan revealed the configuration effect and Zhang Hao pointed out regional differences, none of them constructed an overall analysis framework from the perspective of green supply chain collaboration, nor did they fully consider the policy-market. - Organize the interaction effect of multiple factors.

In terms of green supply chain management, research has made significant progress in the manufacturing and retail industries (Li et al., 2020; Lisi et al., 2020; Al-Khatib, 2023).By constructing a sequence game theory framework, Matos Stelvia V studies the joint decision - making problem of product pricing - ordering-greening in a multi-level green supply chain, and provides a theoretical model for collaborative optimization under demand uncertainty (Matos et al., 2024); Kong Ting divides the integration of the green supply chain into three dimensions: supplier, internal and customer, and empirically analyzes its indirect impact path on green innovation based on the knowledge intermediary mechanism (Kong et al., 2020); Starting from behavioral theory, These studies have laid an important foundation for understanding the relationship between cross-enterprise collaboration and green innovation.

However, the current relevant achievements are mostly focused on the fields of manufacturing and retail, and they are rarely used in the logistics industry, and there is a lack of empirical research on the background and operational characteristics of Chinese logistics enterprises.Most research is still at the level of theoretical derivation or local modeling. It has neither systematically explained the mechanism of differentiation of policy driving forces in state-owned and private enterprises, nor fully considered the role of new collaborative models such as information sharing platforms and carbon data collaboration in promoting green innovation in the digital age.In view of this, starting from the perspective of the green supply chain system, this paper constructs a three-dimensional integrated analysis framework covering policy drive, organizational readiness and supply chain collaboration, and conducts empirical analysis based on large sample panel data of Chinese logistics companies, focusing on exploring the mechanism and path of multi-factor synergy-driven green innovation.This research not only makes up for the shortcomings of empirical research and systematic analysis in the logistics industry, but also provides a new theoretical basis and empirical support for analyzing the differences in policy responses of different ownership enterprises.

3. Theoretical Model and Research Hypothesis

3.1 Theoretical Framework Construction

Under the prevailing trend of sustainable development and green transformation, Chinese logistics companies face triple pressures from policies, markets, and technologies. Green innovation has become crucial for improving environmental performance and competitive advantage. However, traditional research has focused on single internal factors within a single company, failing to systematically consider the integrated effects of supply chain collaboration and multidimensional driving mechanisms. Based on GSC management theory, this paper constructs a systematic theoretical model to explore the combined effects of external policy drivers, market demand pull, internal organizational capabilities, and supply chain collaboration mechanisms on the GIP of logistics companies. The model, with GIP as the core explanatory variable, examines four dimensions: policy drivers (including environmental regulations and government subsidies), market demand drivers, organizational resource drivers, and supply chain collaboration. The model assumes that these factors are not isolated but rather interact at multiple levels. Policy pressure is transmitted and amplified within the supply chain through supply chain collaboration; market demand signals influence resource allocation and innovation intentions between companies and partners; and organizational resource capabilities support responding to external drivers and implementing collaborative strategies. The theoretical framework is shown in Figure 1.

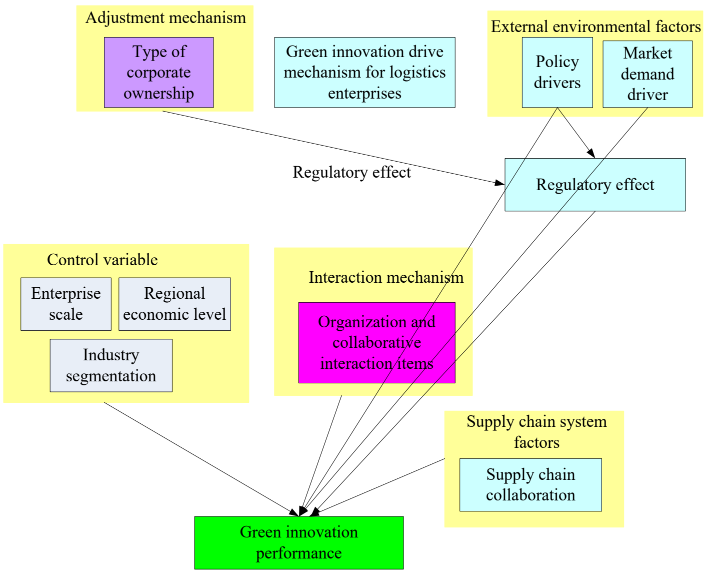

Fig.1: Theoretical framework of the green innovation driving mechanism for logistics enterprises

3.2 Research Hypothesis

Within the theoretical framework of GSC, green innovation in Chinese logistics companies is not simply a passive response to environmental regulation, but rather an active choice driven by multiple forces, including policy guidance, market demand, technological capabilities, and supply chain collaboration (Nikseresht et al., 2024; Agyabeng et al., 2023;Al Kabbani et al., 2025). Based on this, this study proposes relevant hypotheses to deepen our understanding of the driving path of green innovation.

H1: Supply chain collaboration has a significant positive impact on the GIP of Chinese logistics companies.

H2: The role of policy drivers in promoting GIP is ownership-specific.

H3: The interaction between organizational drivers and supply chain collaboration has a positive impact on GIP.

As China's "dual carbon" strategy deepens, the logistics industry, as a key link between production and consumption, is experiencing green innovation and development with supply chain synergy. This study is based on GSC theory and incorporates the realities of China's logistics industry.

4. Research Design

4.1 Sample Selection and Data Sources

This study focuses on China's logistics industry, encompassing over 50 companies, including 42 A-share listed logistics companies and eight leading companies, including Cainiao Network and JD Logistics. These companies represent 63.5% of the national logistics market and contribute 120 million tons of carbon emissions annually, demonstrating strong industry representativeness. The acquisition of green innovation data (including green patents, new energy vehicle penetration rates, and carbon intensity) primarily relies on corporate disclosures. Environmental information disclosure from listed companies and industry leaders demonstrates significantly higher completeness and standardization compared to small and medium-sized enterprises. To ensure data reliability and comparability, this study ultimately selected 50 large-scale, well-managed logistics companies as samples. While this selection guarantees measurement validity for core variables, it may compromise the generalizability of research conclusions across the entire logistics industry and fail to reflect green innovation behaviors of SMEs under resource constraints. To mitigate sample representativeness issues and enhance conclusion robustness, two measures were implemented: First, incorporating firm size as a key control variable in empirical analysis to reduce scale-related interference with green innovation performance; Second, conducting subgroup regressions between state-owned and private enterprises to reveal policy-driven effects under different ownership structures, partially demonstrating the role of firm characteristics in innovation pathways.

The sample selection is rigorous, requiring companies to meet relevant logistics standards for their core business, establish a comprehensive environmental management system (e.g., ISO (International Organization for Standardization) 14001 certification or possess a self-developed carbon management platform), and disclose verifiable green innovation input-output data in their annual reports or ESG (Environmental, Social, and Governance) reports. The study specifically examines two typical enterprise groups: state-controlled logistics groups and leading private express delivery companies. The study then compares and analyzes the differences in green innovation paths across different ownership structures and sectors.

Resources and capabilities are crucial for the effective implementation of green innovation activities within logistics companies (Liu et al., 2025; Nicoletti and Andrea, 2024; Sadiq et al., 2025). Implementing green innovation within logistics companies is a complex resource integration process. The resource-based perspective posits that corporate resources and capabilities are key to strategic execution and can enhance core competitiveness. Logistics companies require extensive facilities, equipment, and personnel across multiple stages of their operations. Investing in resources and capabilities such as funding, talent, technology, and information for green innovation facilitates its successful implementation (An et al., 2025; Liu and Xu, 2020). Figure 2 illustrates the driving mechanism for green innovation within logistics companies.

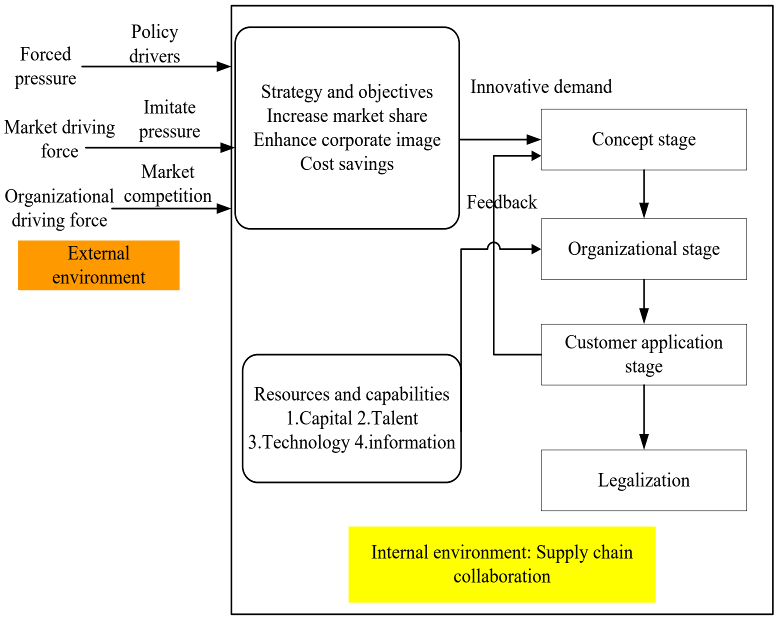

Fig.2: Schematic diagram of the green innovation driving mechanism of logistics enterprises

This study utilizes a multi-source, heterogeneous data fusion approach to construct a green innovation database for Chinese logistics companies. Data collection strictly adheres to the *Greenhouse Gas Protocol* and the *Green Logistics Indicator Guidelines*, capturing data on three key variables: first, structured financial and environmental data, obtained from company annual reports and the National Enterprise Credit Information Publicity System, extracting multiple core indicators and auditing their reliability; second, innovation output data, obtained through the State Intellectual Property Office's patent search system, manually indexed green technology patent data to establish a patent quality evaluation system; and third, supply chain collaboration data, obtained through semi-structured interviews and questionnaires, measuring key constructs using validated scales. The data spans 2017–2023, forming a balanced panel data set with 3,286 company-year observations, which serves as the foundation for subsequent analysis.

In this research, multi-source heterogeneous data such as corporate annual reports, patent databases, and supply chain questionnaires are integrated in data collection. Although this hybrid method is rich in information, it also faces the challenge of data structure and reliability differences, especially when combining objective performance data with subjective perception questionnaire data, there may be inconsistencies in measurement scale and reliability.In order to improve the validity of multi-source data integration and measurement consistency, a series of measures have been taken in this study: quantitative data, such as financial performance, number of patents, proportion of new energy vehicles, etc., strictly follow the "Greenhouse Gas Accounting System" and "Green Logistics Index Guide" for standardized calculations to ensure the unification of index definition and statistical caliber; the questionnaire scale is designed based on a mature theoretical framework, and passes pre-research and reliability tests (Cronbach's α value is greater than 0.8, and the CITC value of each item is greater than 0.6) to ensure its reliability.At the same time, the triangular verification method is used to enhance data consistency, such as cross-comparing the green R&D investment in the company's annual report with the willingness to invest in innovation in the questionnaire, and verifying the correlation between the number of green technology patents in the patent data and the self-evaluation results of the “green innovation achievements” in the questionnaire, to ensure that the subjective and objective data trends are consistent.In addition, the panel regression model controls the individual and time fixation effects, alleviating the measurement errors caused by unobservable factors.

In order to fit the focus of this journal on service science, this research analyzes the supply chain collaboration mechanism in depth from the perspective of information systems.The digital technology platform is an important driving force for service innovation, which is of great significance to promote supply chain collaboration and improve the performance of green innovation.The Internet of Things and big data analysis technology can collect and process energy consumption, carbon emissions and logistics operation data from all aspects of the supply chain in real time, visualize environmental performance, break down information barriers, and create conditions for cross-enterprise collaborative decision-making.The data sharing platform based on the cloud architecture reduces the difficulty of collaboration, allowing upstream and downstream enterprises to exchange key environmental information safely and efficiently.Information transparency has enhanced trust among enterprises, and it has also helped to set and achieve joint emission reduction targets by providing common data benchmarks.The platform can automatically calculate the collective carbon footprint of specific transportation routes or packaging solutions, guide enterprises to choose the best environmental solutions, and transform zero-sum competition into a win-win cooperation and green innovation model.The in-depth application of information systems is also reflected in the integration of green guidelines into business processes, and the integration of environmental management modules in enterprise resource planning and supply chain management systems, which can automatically carry out supplier green access assessments, optimize low-carbon logistics solutions, and incorporate green indicators into performance evaluation.This ” green as a service" embedding model has changed sustainability from a voluntary behavior to a system-driven mandatory standard, greatly improving the efficiency and scale of green innovation practices.

4.2 Variable Definition and Measurement

When exploring the drivers of green innovation within Chinese logistics enterprises, research based on a GSC perspective requires the establishment of a scientific variable system (Hassanet al., 2025; Makhlouf et al., 2023). Traditional research treats enterprise green innovation as an isolated behavior, ignoring the interactions between enterprises at supply chain nodes, making it difficult to reveal the complex mechanisms of green transformation within the logistics industry. The GSC perspective places logistics enterprises within the supply chain ecosystem and identifies innovation drivers by analyzing upstream and downstream collaborative relationships. The variable system constructed in this study breaks away from the single-enterprise analysis paradigm and focuses on the impact of policy, market, and organizational factors on GIP through supply chain collaboration. This perspective is more aligned with the actual operations of logistics enterprises, as logistics services are inherently the result of collaborative efforts across all links in the supply chain.

To enhance data quality and credibility, this study systematically employs multiple validated objective criteria in variable measurement, significantly reducing reliance on subjective self-assessment data. In GIP measurement, we abandoned simplistic weighted composite indicators and adopted principal component analysis for dimensionality reduction. Beyond green patent counts, we introduced multiple quantifiable and verifiable hard indicators, including third-party verified carbon intensity per parcel, actual proportion of new energy logistics vehicles in total operational fleets, and annual year-on-year change rate of greenhouse gas emissions. These data are sourced from publicly released ESG reports, energy audit reports, and government environmental supervision platform filings, ensuring traceability and reliability. For the critical variable of SCC, we overcame traditional questionnaire limitations by integrating observable behavioral and performance metrics. These include official supplier environmental compliance certification rates, monthly exchange frequency of key environmental parameters in cross-enterprise carbon data sharing platforms from anonymized operational logs of cooperative technology platforms, and the number of jointly developed green logistics standards. This approach authentically reflects the depth and frequency of corporate collaborative actions.

In terms of PFD measurement, this study combines objective policy text analysis with subjective perception evaluation.On the one hand, objective data such as the number of environmental administrative penalty cases and the amount of green subsidies in the provinces where the sample companies are located are collected; on the other hand, the questionnaire questions are used to understand the feelings of business managers about the strength and clarity of policy implementation.The objective policy intensity data collected cover the number of annual environmental administrative penalty cases in the province and city where the enterprise is registered, the amount of special green subsidies and tax incentives, and the number of national green supply chain pilot demonstration enterprises. They are all extracted from official public documents and constitute an objective representation of policy pressure.This multi-source, objective, and verifiable indicator system alleviates the deviation of common methods, provides strong evidence for the causal relationship between "supply chain collaboration-green innovation", and enhances the scientific and practical value of research conclusions.

Under China's "dual carbon" goals, green innovation within logistics companies requires a coordinated response across the supply chain network. This study's variable design breaks through limitations, encompassing not only internal company factors but also supply chain collaboration variables, capturing the interactions between logistics companies and their business partners on environmental governance. This full-chain variable design comprehensively assesses the multiplier effects of policy pressure diffusion, market demand-driven supply chain upgrades, and organizational capabilities in collaborative efforts. This provides a more practical analytical tool for understanding green innovation within Chinese logistics companies, as detailed in Table 1.

Table 1: Variable definitions and measurement instructions

Variable type	Variable name	Serial number	Measurement indicators
Dependent variable	Green innovation performance(A)	GIP	Proportion of new energy vehicles (A1) Carbon intensity per unit parcel (A2) Number of green patents (A3)
Independent variable	Policy Force Driving(B)	PFD	Intensity of environmental protection regulations (B1) Green subsidy amount (ten thousand yuan)(B2)
	Market Demand Driving(C)	MDD	Customer Green Demand Index (C1) Green Logistics Service Premium Rate (%) (C2)
	Organizational Resource Driving(D)	ORD	Green research and develop investment percentage (%) (D1)
	Supply Chain Collaboration(E)	SCC	Supplier green compliance rate (%) (E1) Cross-enterprise carbon data sharing platform usage frequency (times/month)(E2)
Control variable	Firm Size	FS	Annual operating income (logarithmic processing)
	Regional Economic Level	REL	Gross Domestic Product per capita of the province (ten thousand yuan)
	Industry Segmentation	IS	Express delivery/warehousing/cold chain (virtual variable)
	Enterprise Type	ET	State-owned and private enterprises

As shown in Table 1, the variable design is divided into two dimensions: internal capabilities and external collaboration. The dependent variable, GIP, is a comprehensive measure of the proportion of new energy vehicles, unit carbon intensity, and green patents. Independent variables include PFD regulations and incentives, ORD R&D investment, and the core variable, SCC supplier management. Control variables include firm size to eliminate confounding factors. This full-chain variable system breaks the traditional limitations of a single firm, quantifies upstream and downstream interactions in the supply chain, and accurately captures the multiplier effect of collaboration, providing a foundation for empirical testing consistent with industry practice.

When constructing the theoretical framework of this research, although it integrates multi-dimensional factors such as policy, market and organization, it does not delineate the specific mechanism of green innovation caused by supply chain collaboration in depth.The existing framework does not fully absorb the achievements in the field of information systems, especially the central role of digital platform governance and data sharing mechanisms in collaborative innovation.Information processing theory shows that digital platforms can improve the transparency, real-time and traceability of environmental information, reduce the uncertainty of green technology research and development and application, and enhance the willingness of enterprises to collaborate and innovation efficiency.The theory of collaborative innovation emphasizes that real-time data sharing and feedback can accelerate the diffusion, absorption and recombination of environmental knowledge in the supply chain, and promote the generation of innovative results.The intensity of use of digital platforms can positively adjust the relationship between supply chain collaboration and green innovation performance.By expanding and refining these theories, this research strengthens the mechanism connection between supply chain collaboration and green innovation, and provides a clear path for empirical analysis.The digital platform has become a key infrastructure to support supply chain collaboration and environmental knowledge integration, and the data sharing mechanism is the core channel for transforming cooperative relationships into innovative outputs.The supplementary theoretical framework is more refined and systematic, fits the forefront of logistics informatics, and provides a new perspective for green innovation in the digital age.

This research focuses on the driving role of information systems and digital technology on environmental innovation and supply chain collaboration.In terms of supply chain transparency, blockchain technology is the cornerstone of trust for data sharing across enterprise environments.Logistics companies deploy a blockchain-based carbon footprint tracking platform to immutably record carbon emission data in transportation, warehousing and other links, solve the problem of data mutual trust between enterprises, and provide technical support for accurate measurement of green performance and traceability of responsibilities.IOT systems are essential in real-time emission monitoring.Sensors are embedded in vehicles, packaging, and storage facilities to continuously collect key environmental parameters such as energy consumption, temperature and humidity, so that enterprises can dynamically optimize route planning and resource scheduling to achieve refined management of emission reduction and consumption reduction.Together, these digital technologies have built a digital infrastructure for green collaboration in the supply chain: cloud computing platforms centrally process and share environmental data across organizations; digital twin technology allows enterprises to simulate and evaluate the effectiveness of green innovation strategies in a virtual environment, reduce trial and error costs, and provide strong support for the green development of the logistics industry.

4.3 Econometric Model Construction

This study uses panel data to construct econometric models to comprehensively examine the driving mechanisms of green innovation among Chinese logistics companies from a GSC perspective. A basic regression model is first used to examine the direct impact of supply chain collaboration and policy regulation, followed by interaction terms to analyze the moderating effect of organizational capabilities. Each model controls for relevant factors, and key parameters are estimated using a two-way fixed-effects method to address heteroskedasticity.

Basic regression model:

$$GIP_{it}=\alpha+\beta_1 SCC_{it}+\beta_2 PFD_{it}+\gamma X_{it}+\mu_i+\delta_t+\epsilon_{it}(1)$$

GIP_{it} is the GIP of firm i in period t; SCC_{it} is supply chain collaboration; PFD_{it} is the policy driver; X_{it} is the set of control variables; μ_i is the firm fixed effect, controlling for individual characteristics that do not change over time; and δ is the time fixed effect.

Interaction effect test:

$$GIP_{it}=\alpha+\beta_1 SCC_{it}+\beta_2 PFD_{it}+\beta_3(SCC_{it}*ORD_{it})+\gamma X_{it}+\epsilon_{it}(2)$$

ORD_{it} represents organizational driving force; $SCC_{it}*ORD_{it}$ represents the interaction term between synergy and capability, with an expected coefficient of $\beta_3>0$.

Market structure adjustment test:

$$GIP^m_{it}=\alpha^m+\beta^m MDD_{it}+\gamma^m X_{it}+\epsilon^m_{it}(3)$$

Although this study conducts a more systematic empirical examination of the driving factors of green innovation in Chinese logistics companies from the perspective of green supply chain, it can use management interviews or case studies to reveal the complex mechanisms and dynamic processes behind green innovation in depth, and enhance the depth and explanatory power of the research.In-depth interviews with corporate executives can analyze the process of interpreting, transmitting and responding to policy pressures in the organization, and explain why the policy response of state-owned enterprises is better than that of private enterprises.Its focus is not on obtaining statistically representative data, but on mining decision-making logic, process details and subjective interpretation.When implementing, it is necessary to design an interview outline around the core concept. For the "policy driving force", ask companies how to interpret the "dual-carbon" policy, pressure transmission departments, and implementation resistance; for "supply chain collaboration", ask about the selection of green partners, information sharing mechanisms, and trust issues.The interview lasts for 60-90 minutes, the whole process is recorded and transcribed, and the key models are refined by thematic analysis to form a detailed description of the mechanisms such as " policy response differences " and " collaborative establishment process".

This study adopts an embedded multi-case design, goes deep into the enterprise site, and uses multi-source evidence triangle verification to fully present the path of green innovation.In addition to interviews, internal documents (such as sustainable development reports, etc.), participatory observations (such as green project review meetings, etc.) and archival records are also included in the operation.In order to explore the "interaction effect of organization and collaboration", it can focus on the process of a state-owned enterprise transforming R&D resources into building green packaging standards with suppliers, and track departmental collaboration.The case analysis uses methods such as pattern matching and time series analysis to reveal the differences in the allocation of resources, response to policies, and construction of collaborative networks of different ownership enterprises, and explains the quantitative discovery of the deep reasons for the different policy effects of Chinese enterprises and private enterprises.The use of hybrid research methods, combining qualitative research with quantitative analysis, can enhance the reliability and effectiveness of conclusions.First, after the preliminary results are obtained from the panel regression, 4-6 representative companies are selected for the first round of interviews to construct a mechanism explanation; then, the theoretical assumptions are revised based on the feedback, and 2-3 typical cases are selected for in-depth tracking to form a process narrative; finally, the qualitative findings are iteratively compared with the quantitative results to achieve method triangle mutual verification.

In view of the possibility that there may be endogenous problems between SCC and GIP due to reverse causality or missing variables, this study has taken multiple measures in empirical strategies to alleviate doubts.On the one hand, the panel fixed effect model is used to control the individual characteristics of enterprises that do not change over time and the confounding effects caused by macro-time trends; on the other hand, the core explanatory variables SCC and PFD are processed in the first phase, and the synergy level of the previous phase is used to predict the current green innovation performance, and reduce the endogenous problems caused by mutual influence during the same period.In addition, in order to verify the robustness of the results, the "level of digital infrastructure in the region where the enterprise is located" was replaced as the tool variable, and the conclusions were consistent; dynamic effect analysis was also carried out, showing that the policy effect gradually strengthened over time.These method improvements have enhanced the causal inference of research conclusions and provided reliable evidence for the causal relationship between the two.

5. Empirical Analysis and Results

5.1 Descriptive Statistics and Correlation Analysis

Descriptive statistical analysis is a basic data analysis method. Through this method, multiple statistical characteristics can be explored. The specific calculation results are shown in Table 2.

Table 2: Descriptive statistical analysis of variables

Variable	Mean	Standard deviation	Maximum value	Minimum value
GIP	3.65	0.72	5	1.8
PFD	3.82	0.68	5	2
MDD	3.54	0.75	5	1.7
ORD	3.47	0.7	5	1.9
SCC	3.76	0.66	5	2.1
FS	22.3	1.62	25.8	18.9
REL	11.8	4.35	21.4	4.5
IS	-	-	1	0
ET	-	-	1	0

As shown in Table 2, the mean GIP is 3.65 (on a 5-point scale), indicating an above-average level of innovation for the industry as a whole. However, the standard deviation and range are large, reflecting a significant internal differentiation in innovation, with leading companies active while many remain in the initial stages, consistent with the pain period of green transformation. Regarding driving factors, the mean PFD is 3.82 and the mean SCC is 3.76, indicating that government regulation and supply chain collaboration are prominent sources of pressure. The high mean SCC and low standard deviation (0.66) indicate that the importance of supply chain collaboration is widely recognized within the industry, but the depth and breadth of collaboration still have room for improvement. The mean MDD is 3.54, and the mean ORD is 3.47, revealing that logistics companies lack inherent innovation capabilities and face challenges in transitioning from passive compliance to proactive innovation. Regarding control variables, the large standard deviations of FS and REL, and the sample coverage of a wide range of logistics companies, ensure the broad representativeness of the research conclusions. The 0-1 distribution of IS and ET facilitates subsequent analysis of heterogeneity effects. These data indicate that China's logistics industry is making steady progress under the dual pressure of policy and supply chain challenges, laying a realistic foundation for empirical testing.

The average values of most variables were relatively high (3.47-3.82 on a five-point scale), indicating that respondents exhibited social desirability bias—tending to select answers that align with societal norms or policy directives rather than providing truthful responses. This systematic bias may compromise the validity of subjective construct measurements based on self-reports. To ensure data validity and result robustness, this study implemented multiple measures: During questionnaire design, reverse items and mixed-order sorting methods were employed. Preliminary psychometric validation demonstrated good scale discrimination (all variables showed Cronbach's α -values> 0.8). In data integration, cross-validation between subjective questionnaire data and objective performance indicators revealed significant correlations, confirming that subjective ratings accurately reflect actual green innovation performance. Regression models controlled for firm fixed effects to eliminate estimation bias caused by non-time-varying response patterns.

Reliability analysis, also known as reliability analysis, is a statistical method used to assess the stability and consistency of questionnaire results, serving as an important indicator of data quality. In empirical research, Cronbach's α, a measure of internal consistency, is often used to assess data reliability. A higher Cronbach's α value indicates greater consistency and stability across questionnaire responses. Corrected Item-Total Correlation (CITC) greater than 0.5, with no significant increase in α after deleting an item, is also a criterion for determining item eligibility. The results are shown in Table 3.

Table 3: Reliability analysis results of green innovation driving factors

Variable name	Overall Cronbach's net worth	Serial number	CICT value	The default value of Cronbach's after deleting the item	Whether to delete
GIP	0.891	A1	0.782	0.862	No
		A2	0.795	0.854	No
		A3	0.735	0.882	No
PFD	0.846	B1	0.712	0.815	No
		B2	0.781	0.802	No
MDD	0.827	C1	0.753	0.796	No
		C2	0.698	0.812	No
ORD	0.869	D1	0.802	0.842	No
SCC	0.902	E1	0.845	0.872	No
		E2	0.823	0.881	No

As shown in Table 3, the overall Cronbach's alpha coefficient for all variables far exceeded the 0.8 threshold, with the overall alpha value for SCC reaching 0.902. This not only demonstrates high internal consistency and stability of the scale but also confirms the measurement reliability strength of supply chain collaboration as a core variable, highlighting the clarity and unified understanding of cross-enterprise collaboration in GSC management. The overall alpha value for GIP is 0.891, and the remaining variables also showed high consistency, indicating that logistics companies' evaluations of green innovation are stable and regular. The CICT coefficients for each observed variable are all greater than 0.6, and deleting items did not improve the overall alpha value, indicating that the scale is well-designed and that all items are valid components of measuring the latent variable. The CICT values for items E1 and E2 measuring SCC are higher than those for the other items, indicating that information sharing and environmental goal alignment are solid dimensions of this variable, accurately capturing the essence of the interactions between logistics companies and their upstream and downstream partners.

Correlation refers to an uncertain but interdependent relationship between variables. Specifically, when one variable takes on a specific value, the other variable does not assume a unique value according to a specific functional relationship, but rather follows a certain pattern within a certain range. To further explore the degree of association between variables, this paper applies the Pearson correlation coefficient: when the coefficient is less than 0, it indicates a negative correlation between the variables; otherwise, it indicates a positive correlation. The closer the coefficient is to 1, the stronger the association between the variables. The specific test results are shown in Table 4.

Table 4: Pearson correlation coefficient analysis between variables

Variable	GIP	PFD	MDD	ORD	SCC	FS	REL	IS	ET
GIP	1								
PFD	0.628***	1							

MDD	0.58***	0.527***	1						
ORD	0.504***	0.481**	0.33*	1					
SCC	0.606***	0.589***	0.427**	0.393**	1				
FS	0.341**	0.294**	0.338**	0.118	0.482***	1			
REL	0.203*	0.367**	0.302**	0.103	0.268**	0.573***	1		
IS	-0.138	-0.126	-0.042	-0.139	0.263*	-0.031	0.07	1	
ET	0.08	0.07	0.05	0.06	0.07	0.1	0.12	0.06	1

Not significant; * significant at $p < 0.05$; ** very significant at $p < 0.01$; *** extremely significant at $p < 0.001$.

As shown in Table 4, all independent variables are significantly positively correlated with GIP. PFD (r=0.628) and SCC (r=0.606) are most closely correlated with GIP, both with p<0.001, indicating significant correlations. This not only confirms the importance of external institutional pressure and cross-chain collaboration on corporate green innovation but also highlights the crucial role of policy transmission and coordinated response within the GSC perspective. GIP is positively correlated with MDD (r=0.58), also showing significant correlations (p<0.001), indicating that market demand growth and consumer preferences can stimulate corporate green innovation. GIP is also positively correlated with ORD (r=0.504), indicating that market demand and internal corporate resource capabilities jointly constitute the innovation-driving dimension. SCC and PFD are highly correlated (r=0.589), achieving significant correlation (p<0.001), suggesting that policy pressure is amplified through the supply chain network. SCC is also positively correlated with both FS and REL, indicating that large enterprises and developed regions have a greater advantage in promoting collaboration within the supply chain. IS is weakly positively correlated with SCC, suggesting that high-end logistics formats rely more on collaborative innovation. IS is negatively correlated with GIP, with no significant correlation (p>0.05), reflecting differences in innovation performance across different segments. The correlation analysis results provide data support for subsequent research, revealing the internal and external driving mechanisms for green innovation within Chinese logistics enterprises and highlighting the key role of policy, market, organizational, and supply chain collaboration.

In regression analysis, multicollinearity refers to the high degree of linear correlation between independent variables in a model. This correlation can lead to problems with the regression coefficients. This paper uses the Variance Inflation Factor (VIF) to test this. The VIF value quantifies the extent to which each variable is linearly influenced by other variables. The specific test results are shown in Table 5.

Table 5: Variance Inflation Factor Test Analysis

Variable	VIF	1/VIF
GIP	2.15	0.465
PFD	3.78	0.265
MDD	2.92	0.342
ORD	4.25	0.235
SCC	5.1	0.196

FS	3.05	0.328
REL	2.48	0.403
IS	1.62	0.617
ET	1.87	0.535
VIF average	3.02	-

As shown in Table 5, the independent variables in this study's regression model exhibit no significant multicollinearity issues, demonstrating reasonable model specification. The VIF values of all variables are well below the critical threshold of 10. The VIF values of IS and ET, respectively, are 1.62 and 1.87, indicating minimal linear influence from other continuous variables. Among the core variables, SCC has the highest VIF value (5.1). Due to its central role in the GSC framework, it absorbs some information about policy pressure and organizational capacity, but the degree of correlation is acceptable. Variables such as GIP and REL also have relatively low VIF values. The tolerance (1/VIF) of all variables is greater than 0.1, further demonstrating the independence of the independent variables. The average VIF value for the overall model is 3.02, well below the warning level, ensuring the stability of the regression coefficient estimates and the reliability of the statistical inferences, laying the foundation for examining the impact of various factors on GIP.

The correlation analysis of variables in this study reveals a strong association between PFD and SCC ($r = 0.589$, $p < 0.001$). Although the VIF value remains below the critical threshold (maximum VIF = 5.1), this suggests conceptual overlap in their measurement frameworks. For instance, stringent environmental regulations may incentivize enterprises to enhance supply chain environmental information sharing, leading to synchronized changes in both indicators. While theoretically independent constructs, the moderate correlation could introduce bias in regression coefficient estimation, amplifying the indirect effects of policy factors through supply chain collaboration channels. To address this, the study implemented multiple robustness checks: re-evaluating models using variable substitution methods and monitoring coefficient variations through stepwise regression analysis.

5.2 Analysis of Multiple Regression Results

In research on green innovation among Chinese logistics companies, SCC is one of the key drivers of GIP. From a GSC perspective, establishing close information sharing and other collaborative mechanisms with upstream and downstream partners can optimize logistics processes, reduce resource waste, and enhance green innovation capabilities. This paper constructs an empirical regression model with supply chain collaboration level as the core independent variable and GIP as the dependent variable. It applies firm size and other control variables, analyzes sample data, and explores their impact, verifying hypothesis H1. The results are shown in Table 6.

Table 6: Regression analysis results of supply chain collaboration on GIP

Variable	Model (1) Benchmark model	Model (2) Add the main effect	Model (3) Complete model
SCC	-	**0.481***（0.078）**	**0.463***（0.073）**
FS	0.128*（0.062）	0.097（0.059）	0.092（0.058）
REL	0.093*（0.071）	0.061（0.068）	0.058*（0.066）
IS	-0.105（0.084）	-0.087（0.079）	-0.082（0.072）
ET	0.156*（0.082）	0.121（0.086）	0.118*（0.075）
PFD	-	-	0.292**（0.152）
MDD	-	-	0.164*（0.108）
ORD	-	-	0.328***（0.213）
Constant term	-0.024（0.342）	-1.835***（0.539）	-2.681***（0.691）
R^2	0.082	0.336	0.428

F value	3.12*	12.87***	**14.56***

Not significant; * significant at $p < 0.05$; ** very significant at $p < 0.01$; *** extremely significant at $p < 0.001$.

As shown in Table 6, SCC has a significant impact on GIP, which strongly supports the validity of hypothesis H1. In model (2), when only the main effect of SCC is added, the regression coefficient β=0.463 and is extremely significant (p<0.001). After applying control variables such as FS, REL, IS and ET, model (3) shows that the SCC coefficient drops to 0.463, but is still extremely significant (p<0.001), indicating that after controlling for internal and external characteristics of the enterprise, the positive effect of SCC remains robust. This indicates that by deepening collaboration with upstream and downstream partners on environmental goals, carbon data, and green technologies, enterprises can significantly optimize resource allocation and reduce innovation uncertainty. Research shows that for every 1-point increase in supply chain collaboration variables, the carbon intensity per parcel decreases, delivering notable emission reduction effects for large logistics companies handling 100 million annual shipments – aligning with China's "Dual Carbon" strategy and industry-wide green transformation needs. When comparing driving factors' influence, the supply chain collaboration effect (β=0.463) far exceeds market demand drivers (β=0.164) and policy-driven general impacts (β= 0.192). This demonstrates that logistics enterprises proactively cultivating resource capabilities and achieving internal-external synergy have a more pronounced enhancing effect on green innovation.

The performance of control variables provides industry insights: FS has a positive impact on GIP in model (1) (β=0.128), which is significant (p<0.05), indicating that large enterprises have higher GIP due to their abundant resources and perfect management systems; while in model (3), the coefficient drops to 0.092 and is not significant (p>0.05), indicating that under the influence of SCC and other driving factors, the scale effect is partially absorbed. In model (2), the REL coefficient is positive but not significant (p>0.05), indicating that economically developed regions have limited direct impact on GIP; the mean regression coefficient of IS in the three models is negative and not significant (p>0.05), indicating that industry differences have no significant direct effect on GIP; the ETP coefficient is positive and significant in the regression system in models (1) and (3) ($p < 0.05$), reflecting that there are endogenous differences in the nature of different enterprises, which is caused by differences in resource allocation between state-owned enterprises and private enterprises. In the complete model (3), the PFD coefficient is $\beta = 0.292$ ($p < 0.01$), highlighting the important role of policy incentives on corporate green innovation; the MDD coefficient is $\beta = 0.164$ ($p < 0.05$), indicating that market demand has a promoting effect on green innovation; the ORD coefficient is $\beta = 0.328$ ($p < 0.001$), emphasizing the supporting role of internal management mechanisms of enterprises on GIP. The model R^2 increases from 0.082 in the baseline model to 0.428 in the full model, and the F-value rises from 3.12 to 14.56, indicating that the model's explanatory power for GIP is significantly enhanced after the application of driving forces and control variables. In summary, in Chinese logistics companies, SCC directly improves GIP through optimizing resource allocation, and this synergistic effect is achieved through the combined influence of policy, market, and organizational drivers. This validates hypothesis H1, provides empirical evidence for the design of green innovation strategies for logistics companies, and highlights the centrality of collaboration and internal resource integration.

In research on green innovation among Chinese logistics companies, PFD is a key external factor driving green innovation. However, enterprises of different ownership structures differ significantly in their policy responses and resource mobilization, potentially leading to heterogeneous effects of policy drivers on GIP. State-owned enterprises, with their greater policy support and resource advantages, are more effective in transforming policy incentives into green innovation outcomes. Private enterprises, on the other hand, face limitations in policy implementation and resource integration, hindering their GIP. Therefore, this paper uses enterprise ownership as a grouping variable and conducts regression analyses on both state-owned and private enterprises to explore the differential impact of policy drivers on GIP under different ownership structures. The results are shown in Table 7.

Table 7: Results of ownership heterogeneity test on policy driving forces

Variable	Model (1) Main effect model	Model (2) Interaction effect model	Model (3) Grouping model (state-owned enterprise)	Model (4) Grouping model (private enterprise)
PFD	0.192** (0.069)	0.178* (0.070)	0.416* (0.101)	0.125 (0.088)
ET (1= State-owned; 0= private)	0.118 (0.072)	0.205* (0.091)	-	-
PFD*ETP	0.291* (0.085)	-	-	-
SCC	0.463*** (0.075)	0.451*** (0.074)	0.438*** (0.112)	0.462*** (0.093)
MDD	0.174* (0.081)	0.169* (0.080)	0.192 (0.124)	0.161 (0.102)
ORD	0.226*** (0.065)	0.219*** (0.061)	0.241** (0.095)	0.210** (0.095)
FS	0.092 (0.058)	0.085 (0.057)	0.110 (0.089)	0.072 (0.073)
REL	0.055 (0.066)	0.049 (0.065)	0.082 (0.102)	0.031 (0.085)
IS	-0.082 (0.078)	-0.079 (0.077)	-0.105 (0.119)	-0.064 (0.099)
Constant term	-2.541*** (0.431)	-2.601*** (0.426)	-2.883*** (0.662)	-2.421*** (0.544
R^2	0.452	0.478	0.501	0.461
F value	14.56***	14.39***	12.87***	9.45***

Not significant; * significant at p < 0.05; ** very significant at p < 0.01; *** extremely significant at p < 0.001.

As shown in Table 7, the different effects of PFD on the GIP of logistics enterprises under different ownership structures are presented. The main effect regression (Model 1) shows that the PFD coefficient β is 0.192 and is extremely significant (p<0.001), indicating that policy driving forces can generally promote the GIP of logistics enterprises in a positive way. In Model (2), the PFD coefficient drops to 0.178, but is still significant (p<0.05). The PFD*ETP coefficient in Model (1) is 0.291 and is significant (p<0.05). In the group model, the PFD coefficient of state-owned enterprises (Model 3) is 0.416 (p<0.05), reflecting that state-owned enterprises can more efficiently transform policy incentives into green innovation results by virtue of their advantages in resource acquisition, policy response and management system, and are more proactive and efficient in the initiation and implementation of green innovation projects. The PFD coefficient of private enterprises (Model 4) is only 0.125 and is not significant (p>0.05), indicating that they have limitations in improving their GIP under policy incentives, which is related to insufficient resource integration, institutional implementation and policy sensitivity. Control variables and other core driving forces are robust across all models. SCC is highly significant in all four models (p < 0.001) and has positive coefficients, positively impacting GIP. This indicates that supply chain collaboration consistently promotes GIP regardless of firm ownership. MDD and ORD also have positive coefficients in all four models, positively impacting GIP. ORD has coefficients of 0.226 and 0.219 in Models 1 and 2, respectively, both ($p < 0.001$), highlighting the supporting role of internal resource integration and management mechanisms in green innovation. Overall, the model R^2 increases from 0.452 in the main effects model to 0.478 in the interaction effects model, reaching 0.501 in the state-owned enterprise model and 0.461 in the private enterprise model, demonstrating strong explanatory power and robustness of the regression models. This indicates that policy drivers play a significantly greater role in state-owned enterprises than in private enterprises, supporting the ownership heterogeneity hypothesis (H2). State-owned enterprises responded efficiently and private enterprises are limitedly affected, which provided empirical evidence for formulating differentiated policies in the construction of GSC and emphasized the importance of precise policy implementation to maximize the results of green innovation.

Table 7 demonstrates ownership heterogeneity in policy drivers. The promotion effect of policy pressure on green innovation performance in state-owned enterprises (SOEs) ($\beta = 0.416$) significantly outperforms private enterprises ($\beta = 0.125$). For every unit increase in policy intensity, SOEs show approximately 3.3 times greater improvement in green innovation performance compared to private enterprises. This stems from SOEs' resource advantages and heightened policy sensitivity, enabling them to swiftly translate environmental regulations into innovative actions, while private enterprises face delayed responses due to resource constraints and financing limitations. These findings suggest policymakers should implement differentiated incentives tailored to different ownership structures, providing technical guidance and resource support specifically for private enterprises.

From a GSC perspective, the GIP of Chinese logistics companies is influenced by multiple factors, not just a single driving force. The combined effects of ORD and SCC may also have a significant impact. ORD promotes green innovation by integrating internal resources, while SCC enhances corporate innovation capabilities through upstream and downstream collaboration. When these two factors work together, internal green innovation intentions and external collaborative capabilities reinforce each other, resulting in a significant improvement in GIP. Based on this, this paper applies the ORD × SCC interaction term to construct a regression model that explores the combined effects of these two variables on GIP. The results are shown in Table 8.

Table 8: Test results of the interaction effect between organizational capabilities and supply chain collaboration

Variable	Model (1) Main effect model	Model (2) Add interaction effect
ORD×SCC	-	0.172* (0.048)
ORD	0.226*** (0.065)	0.198*** (0.064)
SCC	0.463*** (0.075)	0.441*** (0.074)
PFD	0.192** (0.069)	0.186** (0.068)
MDD	0.174* (0.081)	0.170* (0.080)
FS	0.092 (0.058)	0.088 (0.057)
REL	0.055 (0.066)	0.051 (0.065)
IS	-0.082 (0.078)	-0.079 (0.077)
ET	0.118 (0.072)	0.115 (0.071)

Constant term	-2.541*** (0.431)	-2.583*** (0.427)
R^2	0.452	0.881
F value	14.56***	14.62***

Not significant; * significant at $p < 0.05$; ** very significant at $p < 0.01$; *** extremely significant at $p < 0.001$.

As shown in Table 8, from the perspective of GSC, the GIP of Chinese logistics enterprises is revealed to be affected by multiple factors. The empirical results strongly support the hypothesis H3 that ORD and SCC jointly affect GIP. The main effect regression of model (1) shows that the ORD and SCC coefficients are 0.226 and 0.463, respectively, and both are ($p < 0.001$). This shows that regardless of whether the interaction effect is considered, enterprises can significantly improve their green innovation capabilities through mechanisms such as internal resource integration and collaborative management such as upstream and downstream information sharing. In model (2), the ORD × SCC coefficient is 0.172 ($p < 0.05$), indicating that ORD and SCC have a significant positive complementary effect. When both the internal green innovation intention and external supply chain coordination capabilities of enterprises are enhanced, the promotion effect on GIP is more obvious. In model (2), the ORD and SCC coefficients are slightly lower than those in model (1), but they are still extremely significant ($p < 0.001$), indicating that the interaction term does not weaken the importance of the individual effects of the two. The PFD coefficients in the two models are 0.192 and 0.186, respectively, which are very significant ($p < 0.01$), reflecting the continued promotion effect of policy incentives on enterprise green innovation. MDD is significant in both models ($p < 0.05$), indicating that enterprises' green innovation investment is stable under market pressure. In terms of overall model performance, R^2 increased from 0.452 in model (1) to 0.881 in model (2), and the F values in both models are extremely significant ($p < 0.001$), indicating that the inclusion of the interaction term enhanced the explanatory power of the model and made the regression results robust. In summary, ORD and SCC not only independently and positively affect GIP, but their interaction also significantly amplifies this effect, verifying their synergistic mechanism in green innovation.

The interaction between organizational driving forces and supply chain collaboration ($\beta = 0.172$) holds significant practical value. This interaction term indicates that enterprises simultaneously enhancing internal organizational capabilities and external supply chain coordination can multiply green innovation performance. Specifically, for companies with high internal R&D investment, each additional unit of supply chain collaboration yields an extra 17.2% increase in green innovation performance. This suggests that logistics enterprises should not view internal and external development in isolation but integrate strategies and processes to achieve complementary resource enhancement. For instance, when companies increase green R&D investment, establishing carbon data sharing platforms with suppliers can yield greater innovation returns. Clearly, both factors not only independently positively influence green innovation, but their interaction also amplifies effects.

5.3 Robustness Test

To verify the reliability of the aforementioned regression analysis results and ensure the robustness of the conclusions regarding the impact of core variables such as SCC, PFD, and ORD on GIP, this paper conducted a robustness test. Considering that a single variable measurement method may lead to biased results, a substitution variable method is used. While maintaining the model settings, the operational definitions of key variables are rationally replaced to test whether the original conclusions hold true under different measurement methods. For the dependent variable, GIP, replacing it with green R&D investment intensity (the proportion of green R&D expenditure to total revenue) to construct Model a, validating the robustness of performance output from the perspective of innovation input. Replacing the core independent variable, supply chain collaboration, with the number of green technology alliances participated in, forming Model b. Replacing the organizational driving force from resource input indicators with the number of years of environmental management system certification, resulting in Model c. Robustness testing eliminates the impact of potential biases in model specification and sample selection on the conclusions, further confirming the positive impact of core driving forces on the GIP of Chinese logistics companies from a GSC perspective. Specific experimental results are shown in Table 9.

Table 9: Robustness test results

Variable	Benchmark model (dependent variable: GIP)	Model (a)	Model (b	Model (c)
SCC	0.463*** (0.075)	0.438*** (0.080)	0.449*** (0.078)	0.461*** (0.075)
ORD	0.226*** (0.065)	0.241*** (0.068)	0.219*** (0.066)	0.233*** (0.064)
ORD × SCC	0.172*** (0.048)	0.159*** (0.051)	0.165*** (0.049)	0.169*** (0.047)
PFD	0.192** (0.069)	0.179** (0.073)	0.185** (0.070)	0.189** (0.069)
MDD	0.174* (0.081)	0.162* (0.085)	0.170* (0.082)	0.172* (0.081)
Control variable	Controlled	Controlled	Controlled	Controlled
R^2	0.452	0.423	0.445	0.448
Adjusted R^2	0.421	0.391	0.414	0.417

Not significant; * significant at $p < 0.05$; ** very significant at $p < 0.01$; *** extremely significant at $p < 0.001$.

Table 9 presents the regression results of the baseline model and three robustness test models. In the baseline model, the coefficients for SCC, ORD, the ORD×SCC interaction term, PFD, and MDD are all positive and significant ($p < 0.05$). In particular, SCC, ORD, and the ORD×SCC interaction term are all highly significant ($p < 0.001$), indicating that core driving forces have a significant positive impact on GIP. In model (a), GIP is replaced by green R&D investment intensity. SCC, ORD, and ORD×SCC are still highly significant ($p < 0.001$) and positively significant. The R^2 decreases to 0.423 compared to the baseline model, but the overall explanatory power is robust, indicating that the core driving force has a reliable role from the perspective of green innovation investment. Model (b) replaces the SCC indicator with the number of participations in green technology alliances. The coefficients for SCC, ORD, and ORD × SCC are all positive ($p < 0.001$), and MDD has a significant positive impact ($p < 0.05$). The R^2 is 0.445. This shows that the role of supply chain collaboration in promoting GIP holds true regardless of whether subjective questionnaire scores or objective behavioral data are used. Multidimensional measurement of a company's external collaboration capabilities can effectively explain improvements in GIP. Model (c) replaces ORD with the number of years of environmental management system certification to measure the long-term accumulation of green management performance. The coefficients for SCC, ORD, the ORD×SCC interaction term, PFD, and MDD are all positive, with an R^2 of 0.448, confirming the robust positive effect of long-term organizational driving forces on GIP, regardless of whether the dependent variable is innovation output or input. These data confirm the robust positive impact of core driving forces on the GIP of Chinese logistics companies from a GSC perspective. Promoting green innovation requires companies to strengthen internal organizational capabilities, respond to policy drivers, and deepen supply chain collaboration.

6. Discussion

This study, from a GSC perspective, empirically analyzes the multidimensional driving mechanisms that influence the GIP of Chinese logistics companies. Three key findings emerge: First, SCC is the core driver of GIP (β = 0.463, $p < 0.001$), highlighting the significant role of cross-enterprise collaboration in promoting green innovation. Second, the effect of PFD is ownership-heterogeneous, with a significant impact on state-owned enterprises (β = 0.416, $p < 0.05$) but not on private enterprises, reflecting the influence of differences in ownership structure on policy effectiveness. Third, the interaction term between ORD and SCC is positively significant (β = 0.172, $p < 0.05$), indicating that internal and external collaboration can complement each other and mutually enhance green innovation.

In terms of theoretical contributions, this research expands and deepens the theory of green supply chain, compared with the research of Kong Ting (Kong et al., 2020), not only verifies the value of green supply chain integration in the Chinese context, but also reveals the outstanding driving effect of supply chain collaboration in the logistics industry.This study found that the policy driving force has a significant effect on state-owned enterprises and a limited impact on private enterprises. It provides a micro-explanation for the difference in policy response from the perspective of property rights, and corrects the "policy-corporate behavior" relationship in green innovation theory.In addition, the organizational competence-supply chain collaborative interaction item was introduced to empirically test the complementary and synergistic mechanisms of the two, breaking through a single perspective and providing more dynamic theoretical support for understanding the mechanism of the green innovation system.In the practical sense, this research provides specific guidance for the practice of green innovation in different subjects.Business managers should abandon the "single fight" model and build a collaborative innovation network.Logistics companies can establish a cross-enterprise carbon data sharing platform, jointly develop green technologies with suppliers, and formulate environmental goals and emission reduction roadmaps.State-owned enterprises should take advantage of their policy advantages to lead the green transformation of the industry; private enterprises need to pay attention to the accumulation of internal capabilities, increase the level of green R&D investment and management system certification, and enhance their policy response capabilities.Policymakers should recognize the limitations of the "one size fits all" environmental policy, formulate differentiated policies for different ownership enterprises, strengthen the assessment and accountability of state-owned enterprises, and provide technical guidance and financing support for private enterprises, such as setting up special funds and simplifying the certification process.Industry associations should take the lead in formulating guidelines for green supply chain management in the logistics industry, establish a best practice sharing mechanism, pay attention to the difficulties of green transformation of small and medium-sized enterprises, and provide cost-controlled and easy-to-implement green technology solutions to help the logistics industry green innovation and development.

This research has certain limitations and needs to be further resolved in future research.First, the sample focuses on large-scale listed companies. Although the data quality is guaranteed, the applicability of the conclusions to small and medium-sized enterprises is reduced.In the future, the scope of samples needs to be expanded to focus on the unique path of green innovation for small and medium-sized enterprises.Second, although a variety of methods are used to control endogenous nature, there may still be reverse causality between variables. For example, companies with good green innovation performance are more likely to establish supply chain collaboration.In the future, we can look for suitable tool variables, such as the level of regional supply chain infrastructure, or use natural experimental design to provide more rigorous proof of causality.Third, subjective conceptual measurements may have common method deviations. Although they have been tested to ensure reliability, objective indicators such as actual carbon emission data can be introduced in the future to reduce measurement errors.In addition, this study focuses on domestic factors and does not consider the impact of international green barriers and cross-border cooperation in the context of global supply chains.In the future, international comparative research can be carried out to reveal the differences in green innovation mechanisms in different institutional environments.

In short, this research systematically analyzes the driving mechanism of green innovation in Chinese logistics enterprises, provides new empirical evidence for green supply chain theory, and also provides specific guidelines for green transformation in practice.In the future, research should explore in depth from the aspects of methodological rigor, sample representation, and international perspective, and jointly promote the green and sustainable development of the logistics industry, so that theory and practice can better promote each other and work together.

7. Research Conclusions and Countermeasures

7.1 Research Strategies

(1) Enterprise level

As the core force of green innovation, logistics companies shoulder a heavy responsibility in promoting the green transformation of the industry (Prataviera et al., 2024; Shou et al., 2023; Balint et al., 2025). Among them, managers' environmental awareness, resource allocation, and technological innovation capabilities are key drivers of green innovation. Therefore, logistics companies should take green innovation as a strategic direction and deeply integrate social responsibility into all aspects of their operations .Companies need to take the initiative and regard social responsibility as the cornerstone for exploring new opportunities, building competitive advantages, and achieving green innovation. Corporate managers should strengthen their environmental awareness: first, innovate green logistics technologies and services, adopt new energy vehicles, optimize routes, use environmentally friendly packaging, and provide low-carbon and efficient solutions; second, maintain fair competition in the market and improve service quality and efficiency; third, strictly abide by laws and regulations, pay taxes according to law, and reduce pollution emissions, such as installing exhaust gas treatment devices (Mayar et al., 2025). Through these measures, logistics companies can not only fulfill their social responsibilities but also seize opportunities in green transformation and achieve sustainable development.

Logistics companies should actively cultivate a green corporate culture and ensure that green concepts permeate all aspects of their business development. Corporate culture is the soul of a company's development, fostering a positive working atmosphere, improving employee literacy, and strengthening corporate cohesion (Puja and Dipendra, 2025). In the face of the green development trend, logistics companies must prioritize the development of a green culture. On the one hand, company management, especially senior executives, must demonstrate keen insight and foresight, thoroughly understand national environmental policies, grasp green market trends, enhance their own environmental awareness, and prioritize green innovation. On the other hand, managers should serve as role models, fostering a green atmosphere throughout the company and raising employee awareness through training, exchange programs, and improved systems.

State-owned logistics enterprises should leverage their policy advantages and scale advantages through quantifiable actions: In technology investment, allocate 3-5% of annual revenue to green technology R&D, prioritizing IoT sensor deployment for real-time carbon emission monitoring; In collaborative framework, lead the establishment of an industry-level green supply chain alliance, formulate standards requiring core suppliers to obtain ISO14001 certification by 2025; Incorporate synergy indicators into performance metrics and integrate them into executive evaluations. Private logistics companies should implement phased, low-cost strategies: Initially invest in cloud-based path optimization systems for emission reduction; collaborate with regional platforms to share resources; closely monitor parcel carbon intensity indicators, proactively disclose emission reduction progress, and enhance brand image and market competitiveness.

(2) Government level

Government departments need to formulate differentiated and actionable policies to promote green innovation and supply chain collaboration in the logistics industry.For state-owned enterprises, the performance of green innovation is included in the executive evaluation, with a weight of not less than 30% of the annual performance evaluation, and at the same time, its annual green R&D investment accounts for 3%-5% of revenue.The environmental protection department is responsible for building a “real-time monitoring platform for carbon emissions of key logistics enterprises”, docking with enterprise Internet of Things equipment and blockchain carbon ledger, automatically collecting and verifying emission data, and publishing industry emission reduction red and black lists every quarter to strengthen supervision.The financial department has set up a special green support fund to subsidize companies that purchase new energy vehicles or jointly build carbon data platforms. The subsidy does not exceed 30% of the investment in equipment, and the income tax on green technology is exempted from three and halved.The market regulatory department will improve the green logistics standard system within two years, force companies with annual revenue of more than 500 million yuan to disclose supply chain environmental information, implement “green logistics certification”, and certified companies will enjoy incentives such as tolls reduction and reduction.The Industry and information technology department promotes the establishment of a regional green supply chain collaborative platform, integrates the capacity of small and medium-sized logistics enterprises, reduces unit transportation carbon emissions, and provides one-time digital transformation subsidies for platform access.

(3) Industry level

Industry associations should play a key technical bridge and standard coordination role in the green transformation of the logistics industry.The China Federation of Logistics and Procurement will issue the "Green Supply Chain Collaboration Guide for Logistics Enterprises" during the year, give contract templates, data sharing agreement standards and case libraries, and organize best practice exchanges every quarter.Provincial industry associations should form expert service teams to provide free or low-cost green transformation consulting for small and medium-sized enterprises to help them apply for subsidies and certifications.The China Communications and Transportation Association has taken the lead in formulating a catalogue for the promotion of green technologies in the logistics industry, which will be updated semi-annually to clarify the effects, costs and applicable scenarios of technology emission reduction, and reduce the risk of technology selection by enterprises.Industry associations should also jointly build an industry-level green innovation platform with leading enterprises to focus on overcoming common technical problems, such as battery sharing standards, carbon data exchange interface specifications, etc., and set up an open pool of green technologies for small and medium-sized enterprises to provide affordable technology licenses through a membership system.In addition, regular green skills talent training programs are carried out, and emerging courses are developed in cooperation with vocational colleges to reserve talents for the transformation of the industry.

These measures combine the coercive and regulatory power of government policies with the technical guidance and standard coordination power of industry associations to not only prevent market distortions caused by the “one size fits all” policy, but also accurately enable enterprises to solve the problems of the green transformation of small and medium-sized enterprises, and provide institutional and technical guarantees for the construction of a sustainable logistics ecosystem.

7.2 Research Conclusions

This research examined green innovation drivers in Chinese logistics enterprises through a supply chain collaboration lens, yielding three key findings that advance understanding of collaborative innovation in logistics services. First, supply chain collaboration serves as the primary driver of green innovation performance, suggesting that information sharing and coordinated environmental initiatives across logistics networks create synergistic benefits exceeding individual firm efforts. Second, policy effectiveness is contingent on ownership structure, with state-owned enterprises demonstrating superior responsiveness to environmental regulations compared to private firms, highlighting the importance of institutional context in innovation policy design. Third, internal organizational capabilities amplify the benefits of external collaboration, indicating that green innovation requires simultaneous investment in internal resources and external partnership development.These findings contribute to logistics informatics and service science literature by demonstrating how inter- organizational information systems and collaborative mechanisms facilitate innovation diffusion within service networks. The study reveals that green innovation in logistics transcends individual firm boundaries, requiring coordinated responses across supply chain partners supported by robust information sharing platforms and aligned environmental objectives.

For logistics service providers, the research suggests prioritizing development of collaborative partnerships with suppliers and customers while simultaneously building internal green capabilities through R&D investment and environmental management systems. The differential policy effects across ownership types indicate that private logistics firms may require alternative incentive mechanisms, such as market-based rewards or technology subsidies, rather than regulatory pressure alone.Policymakers should design differentiated approaches recognizing that state-owned and private enterprises respond differently to environmental initiatives due to varying resource access, institutional obligations, and strategic priorities. Effective policy implementation requires understanding these structural differences and tailoring interventions accordingly.

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Reference

Abd Elghany, M. "Advanced Technologies and International Business: A Comprehensive Review of Digital Transformation in Global Operations." Journal of Logistics, Informatics and Service Science 12.1 (2025): 231-262.DOI:10.33168/JLISS.2025.0113.

Agyabeng-Mensah, Yaw, Ebenezer Afum, and Charles Baah. "Green corporate reputation and innovation: the role of non-supply chain learning and green supply chain knowledge." International Journal of Emerging Markets 18.11 (2023): 4884-4906.https://doi.org/10.1108/IJOEM-08-2021-1277.

Al Kabbani, Marwa, and Serene Dalati. "Analysis Of Conflict Management Styles And Organisational Performance." Journal Of Management Changes In The Digital Era 4.01 (2025): 44-68.

Alexandrou, Stelios E., Panayides, P. M., Tsouknidis, D. A., & Alexandrou, A. E."Green supply chain management strategy and financial performance in the shipping industry." Maritime Policy & Management 49.3 (2022): 376-395.DOI：10.1080/03088839.2022.1883141.

Al-Khatib, Ayman Wael. "The impact of big data analytics capabilities on green supply chain performance: is green supply chain innovation the missing link?." Business Process Management Journal 29.1 (2023): 22-42.https://doi.org/10.1108/BPMJ-08-2022-0416.

An, Zhiyuan,He, E., Wang, X., Liu, Y., Zhao, Y., & Bai, J. "Influencing Factors and Path Analysis of Regional Green Logistics Implementation: An Empirical Analysis Based on TOE Theoretical Framework." Polish Journal of Environmental Studies 34.4 (2025): 4587-4603.https://doi.org/10.1108/JES-10-2024-0714.

Bai, Xuesong, Arnaldo Coelho, and Beatriz Lopes Cancela. "The relationship between green supply chain and green innovation based on the push of green strategic alliances." Corporate Social Responsibility and Environmental Management 31.2 (2024): 1026-1041.https://doi.org/10.1002/csr.2619.

Balint, Martin, Joao M. Vilas-Boas da Silva, and Monika Maria Mohring. "Green innovations in third-party logistics: managerial reasons, external stakeholder influences and contingencies in the natural-business environment." Cogent Business & Management 12.1 (2025): 2460613.https://doi.org/10.1080/23311975.2025.2460613.

Cheng, Cheng, Yanan Han, and Xiaohang Ren. "Analysis of technological innovation on provincial green development levels of logistics industry in China." Environmental Science and Pollution Research 30.18 (2023): 53020-53036.https://doi.org/10.1007/s11356-023-26054-w.

Hassan, Muneeb Ul, Ikram, M., Ismail, J., & Ahmed, W."The effect of worker's impression of executing green supply chain management network on hotels performance: perspective of developing country." International Journal of Services and Operations Management 51.1 (2025): 20-38.https://doi.org/10.1504/IJSOM.2025.146177.

Jazairy, Amer, and Robin von Haartman. "Analysing the institutional pressures on shippers and logistics service providers to implement green supply chain management practices." International Journal of Logistics Research and Applications 23.1 (2020): 44-84.https://doi.org/10.1080/13675567.2019.1584163.

Jazairy, Amer, Pohjosenpera, T., Prataviera, L. B., & Juntunen, J. "Innovators and transformers: Revisiting the gap between academia and practice: Insights from the green logistics phenomenon." International Journal of Physical Distribution & Logistics Management 55.4 (2025): 341-360.https://doi.org/10.1108/IJPDLM-12-2023-0497.

Kong, Ting, Feng, T., Huang, Y., & Cai, J. "How to convert green supply chain integration efforts into green innovation: A perspective of knowledge-based view." Sustainable Development 28.5 (2020): 1106-1121.https://doi.org/10.1002/sd.2062.

Letunovska, Nataliia, Offei, F. A., Junior, P. A., Lyulyov, O., Pimonenko, T., & Kwilinski, A. "Green supply chain management: The effect of procurement sustainability on reverse logistics." Logistics 7.3 (2023): 47.https://doi.org/10.3390/logistics7030047.

Li, Guo, Li, L., Choi, T. M., & Sethi, S. P. "Green supply chain management in Chinese firms: Innovative measures and the moderating role of quick response technology." Journal of Operations Management 66.7-8 (2020): 958-988.https://doi.org/10.1002/joom.1061.

Lisi, Wei, Rui Zhu, and Chunlin Yuan. "Embracing green innovation via green supply chain learning: The moderating role of green technology turbulence." Sustainable Development 28.1 (2020): 155-168.https://doi.org/10.1002/sd.1979.

Liu Ximei, and Xu Yuanyuan. "Constructing an Evaluation Index System for Smart, Green, and Low-Carbonization of Third-Party Logistics Enterprises Based on Complex Science Thinking." Journal of North China Electric Power University (Social Sciences) 1.1 (2020): 35-41. https://dx.doi.org/10.14092/j.cnki.cn11-3956/c.2020.01.005.

Liu Zhongyan, Xiong Xingyu, and Hu Shouchen. "Paths to Improve Green Performance of Listed Logistics Enterprises under the TOE Framework." Journal of Chongqing Jiaotong University (Social Sciences Edition) 25.3 (2025): 62. http://xbskb.cqjtu.edu.cn/CN/.

Liu, Aijun, Maurice Osewe, and Yangyan Shi. "Green logistics in China: a systematic literature review." International Journal of Logistics Systems and Management 45.1 (2023): 88-107.https://doi.org/10.1504/IJLSM.2023.130972.

Liu, Dongyan, Ni Sun, and Xiugang Zhu. "ESG ratings empower high-quality development of logistics enterprises through digital transformation and green innovation." Scientific Reports 15.1 (2025): 22861.https://doi.org/10.1038/s41598-025-06029-2

Liu, Shu, Ramayah Thurasamy, and Sri Rahayu Hijrah Hati. "Determinants and Outcomes of Green Technology Innovation Adoption among Third-Party Logistics Firms in China: A SEM-ANN Analysis." Systems 12.9 (2024): 331.https://doi.org/10.3390/systems12090331.

Liu, Yulong, Henry FL Chung, and Lili Mi. "Fostering sustainable logistics businesses: the role of innovation ecosystems and institutional contexts for logistics firms in China." Asia Pacific Journal of Marketing and Logistics 35.1 (2023): 35-53.https://doi.org/10.1108/APJML-06-2021-0412.

Makhlouf, Hamdi, Nejmeddine Chatti, and Lassaad Lakhal. "The impact of TQM and green innovation on corporate sustainability: the mediating role of green supply chain management." International Journal of Quality & Reliability Management 40.10 (2023): 2592-2611.https://doi.org/10.1108/IJQRM-10-2022-0291.

Matos, Stelvia V., Schleper, M. C., Hall, J. K., Baum, C. M., Low, S., & Sovacool, B. K. "Beyond the new normal for sustainability: transformative operations and supply chain management for negative emissions." International Journal of Operations & Production Management 44.13 (2024): 263-295.https://doi.org/10.1080/23302674.2023.2208277.

Mayar Soulieman Abdulwili, Danial Jameel Kamal Aldeen, Serene Dalati. “Reimagining Supply Chain Resilience: Developing RENIAS and EPI for Humanitarian Logistics in Crisis-affected Regions - Conceptual Framework with an Illustrative Case in Aleppo.” Journal of Service, Innovation and Sustainable Development 6.1 (2025):137. DOI: 10.33168/SISD.2025.0109

Nicoletti, Bernardo, and Andrea Appolloni. "Green Logistics 5.0: a review of sustainability-oriented innovation with foundation models in logistics." European Journal of Innovation Management 27.9 (2024): 542-561.https://doi.org/10.1108/EJIM-07-2024-0787.

Nikseresht, Ali, Davood Golmohammadi, and Mostafa Zandieh. "Sustainable green logistics and remanufacturing: a bibliometric analysis and future research directions." The International Journal of Logistics Management 35.3 (2024): 755-803.https://doi.org/10.1108/IJLM-03-2023-0085.

Prataviera, Lorenzo Bruno, Alessandro Creazza, and Sara Perotti. "A call to action: a stakeholder analysis of green logistics practices." The international journal of logistics management 35.3 (2024): 979-1008.https://doi.org/10.1108/IJLM-09-2022-0381.

Puja Sharma, Dipendra Karki. “Blockchain Technology in the Digital Era: Global Research Trends and Financial Innovation.” Journal of Management Changes in the Digital Era 2 (2025): 93. DOI: 10.33168/JMCDE. 2025.0107

Sadiq, Muhammad, Chien, F., Staniewski, M. W., & Tufail, B. "The convergence of environmental innovation, stakeholder pressure, open innovation in logistics firms: pathway to renewable energy in the presence of managerial cognition & competitive advantage." Technological and Economic Development of Economy 31.3 (2025): 892-915.https://doi.org/10.3846/tede.2025.23858.

Shou, Yongyi, Shan, X., Dai, J., Xu, D., & Che, W. "Actions speak louder than words? The impact of subjective norms in the supply chain on green innovation." International Journal of Operations & Production Management 43.6 (2023): 879-898.https://doi.org/10.1108/IJOPM-04-2022-0265.

Zhang, Hao, Sun, X., Dong, K., Sui, L., Wang, M., & Hong, Q."Green innovation in regional logistics: Level evaluation and spatial analysis." International Journal of Environmental Research and Public Health 20.1 (2022): 735.https://doi.org/10.3390/ijerph20010735.