

Article

Customer Environmental Performance and Supplier Green Innovation: A Sustainable Supply Chain Perspective

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Abstract: With the growing emphasis on sustainable development, the impact of customer environmental performance on innovation activities has attracted more attention. Using a dataset of Chinese A-share listed companies from 2009 to 2022, this study empirically investigates the relationship between customer environmental performance and supplier green innovation. The results show that customer environmental performance has a significant positive effect on supplier green innovation. Mechanism analysis reveals that customer environmental performance promotes supplier green innovation through four pathways: supply chain transmission, market investment expectations, institutional policies, and financial constraints. The impact of customer environmental performance on supplier green innovation is more pronounced when the customer enterprise is state-owned, the supplier enterprise is state-owned, or the supplier enterprise holds ISO14001 certification. This study contributes to the literature on supply chain sustainability and provides valuable insights for enterprises on enhancing competitiveness and promoting sustainable supply chain transformation through improved environmental performance.

Keywords: supplier green innovation; customer environmental performance; supply chain; sustainable development



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1. Introduction

Environmental pollution has become increasingly severe, highlighting the growing tension between economic growth and environmental protection. Rapid economic development often comes at the cost of ecological degradation. In 2020, Xi Jinping, Chairman of China, announced at the United Nations that China aims to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. Enterprises should take responsibility for environmental pollution. Currently, corporate pollutant emissions account for over 80% of total emissions [1].

As a key component of corporate social responsibility, corporate environmental responsibility reflects a company's voluntary commitment to addressing environmental issues through its operations and stakeholder interactions, thereby contributing to sustainable development [2]. Studies have shown that enhancing corporate environmental responsibility can effectively mitigate negative impacts on the natural environment [3]. Improving corporate environmental performance is thus critical not only for social sustainability but also for achieving China's dual carbon goals. Therefore, the Chinese government has strengthened the regulatory framework for information disclosure, encouraging or mandating the disclosure of environmental and social responsibility information. In 2016,

the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) issued the Guiding Opinions on State-owned Enterprises Better Fulfilling Social Responsibilities, requiring state-owned enterprises to take responsibility for social and environmental issues throughout their operations. These guidelines also called for establishing comprehensive social responsibility reporting systems and regularly publishing reports to enhance transparency and reporting quality.

In sustainable supply chains, the environmental responsibility of individual firms extends to the entire supply chain. Corporate environmental responsibility not only affects a firm's own economic performance but also generates spillover effects on supplier behavior [3]. As key external stakeholders of suppliers, customer firms' focus on supply chain sustainability can effectively influence supplier behavior. Existing studies indicate that customers' Environmental, Social, and Governance (ESG) performance significantly affects suppliers' innovation activities [4]. On the one hand, the environmental performance of customer firms is influenced by the overall environmental performance of the supply chain. Poor environmental performance by suppliers can directly affect customers' overall environmental goals, regulatory compliance, and public image. As a result, customers have sufficient motivation to pressure or incentivize suppliers to undertake innovative activities. On the other hand, customers with strong environmental performance are more inclined to establish long-term partnerships with suppliers capable of providing green solutions. To sustain such relationships, suppliers are motivated to engage in green innovation, enhancing their competitiveness and customer satisfaction.

Hence, the following three research questions are addressed in this paper: (1) Can firms serve as effective external drivers for promoting green innovation among suppliers? (2) Through which mechanisms can firms influence suppliers' green innovation activities? and (3) Is there any heterogeneity in the impact of customer environmental performance on supplier green innovation? To answer these questions, this study selects Chinese A-share listed companies from 2009 to 2022 as the research sample. Using an instrumental variable approach, generalized method of moments (GMM), and three-stage least squares (3SLS) to address endogeneity issues, the study empirically analyzes the determinants of supplier innovation within the context of sustainable supply chains, particularly focusing on the impact of customer firms' environmental performance on supplier green innovation.

The findings of this paper reveal that improved environmental performance by customer firms significantly boosts supplier green innovation, thereby advancing the sustainability of the supply chain. This study contributes to three strands of the literature: First, while prior studies have explored the relationship between corporate ESG performance and supplier green innovation, this study specifically examines the impact of customer firms' environmental performance (E-scores) on supplier green innovation. This approach clarifies the mechanisms by which environmental factors drive green innovation, addressing ambiguities surrounding the roles of social and governance factors and offering new insights into the drivers of supplier green innovation. Second, this study delves into the mechanisms and transmission effects of customer firms' environmental performance, highlighting its contribution to supply chain sustainability through supply chain transmission, market investment expectations, institutional policies, and supplier financial constraints. Third, by employing an instrumental variable approach, GMM, and 3SLS, this study effectively addresses the endogeneity issue of the regression, ensuring the consistency and robustness of model estimations.

The remainder of this paper is organized as follows. Section 2 provides a detailed review of the existing literature and introduces the hypotheses. Section 3 presents the research design, including the sample, data sources, variables, and model specifications. Section 4 illustrates the main empirical results, the mechanisms of innovation-environment

nexus, the heterogeneity analysis, and robustness checks. Finally, Section 5 draws the main conclusion with implications.

2. Literature Review and Research Hypotheses

2.1. Existing Studies

2.1.1. Corporate Environmental Performance

Current research on corporate environmental performance spans various topics, including environmental information disclosure, performance measurement, environmental quality, green innovation, and environmental policies. Among these, the effects and outcomes of corporate environmental performance are key areas of interest.

The effects of corporate environmental performance can be categorized into internal governance factors and external environmental factors. Internal governance factors include firm characteristics, shareholder and board characteristics, and managerial operations. External environmental factors encompass mandatory government regulations and voluntary regulations from external stakeholders. For the internal governance, extensive research has explored the influence of firm characteristics on environmental performance, reaching similar results: corporate environmental responsibility is closely related to firm size and financial performance, with heavy-polluting industries and state-owned enterprises demonstrating stronger environmental responsibility and better environmental performance [5].

Studies have also analyzed how shareholder and board characteristics promote environmental performance. Ren et al. (2021) noted that larger board size, greater equity balance, and a higher proportion of independent directors promote better corporate environmental behavior [6]. From the managerial perspective, executive characteristics such as age, education, tenure, and professional background positively influence environmental performance [7]. On the external level, government policies and regulations impose mandatory requirements, compelling firms to enhance their environmental performance for compliance. Liu and Guo (2023) found that mandatory environmental regulations positively affect both monetary and non-monetary environmental information disclosure in heavy-polluting industries [8].

From the perspective of its impact, existing literature has extensively demonstrated the theoretical foundations and mechanisms by which corporate environmental performance influences economic outcomes, innovation, corporate reputation, and international markets. First, strong corporate environmental performance can mitigate stock price volatility risk [9], thereby alleviating financing constraints [10] and enhancing financial performance and corporate value. Second, corporate environmental performance significantly promotes innovation. Fang and Hu (2023) suggested that the employee care reflected in ESG performance helps alleviate agency problems, improve employee welfare, and increase employee enthusiasm for innovation, thereby enhancing innovation efficiency [11]. Third, improvements in corporate environmental performance can enhance corporate reputation.

2.1.2. Corporate Environmental Performance in Sustainable Supply Chains

Sustainable supply chains, a critical domain within supply chain management research, aim to integrate sustainability principles across the entire supply chain, encompassing all stages from supplier selection to the end of a product's lifecycle. Broadly, sustainable supply chains emphasize the integration of economic, social, and environmental responsibilities. Narrowly, the focus is on social and environmental dimensions [12], with the environmental dimension addressing issues such as carbon emissions, resource efficiency, and waste management. These specific environmental requirements directly influence suppliers' environmental practices and technological innovation, whereas the direct connection between

economic and social factors and green innovation is comparatively weaker. Accordingly, this study focuses on the environmental dimension in supply chain management.

From the perspective of the customer–supplier nexus, research on the effects of customer environmental performance has been limited, with most studies concentrating on broader ESG performance. Existing research generally falls into two categories: (1) spillover effects of customer ESG performance in the supply chain and (2) effects of customer ESG performance on supplier innovation. For instance, Tang et al. (2023) demonstrated significant spillover effects of customer ESG performance on suppliers' ESG performance, indicating that customers can influence suppliers to adhere to similar ESG standards [13]. Another group of studies examines the influence of customer ESG performance on supplier innovation [4,14]. Customer ESG ratings significantly promote suppliers' green innovation by reducing financial constraints, encouraging increased innovation investment, and enhancing supplier managers' green awareness.

While existing research has largely clarified the determinants of corporate environmental performance, its effects, particularly through supply chains, remain underexplored. Prior studies have predominantly addressed the overall relationship of ESG performance, often overlooking the impact of the environmental dimension, especially regarding its effects on supplier innovation. This study addresses this gap by focusing specifically on customer environmental performance, investigating how it impacts supplier innovation through the supply chain.

2.2. Research Hypotheses

2.2.1. Customer Environmental Performance and Supplier Green Innovation

With increasing legislative and social focus on environmental issues, firms seeking to maintain competitive advantages cannot overlook environmental concerns. In recent years, environmental performance has become a main point for investors and the public, prompting companies to adopt various environmental management practices to meet stakeholder expectations and enhance and protect their environmental image [15]. Research indicates that disclosing environmental information to strengthen environmental practices improves corporate environmental reputation [16]. Tang et al. (2012) further demonstrated a positive correlation between environmental reputation and overall corporate reputation [17]. Firms now recognize that strong environmental performance not only aids reputation management but also builds sustainable competitive advantages.

Green innovation aims to reduce energy consumption and environmental pollution through innovative products, processes, and organizational structures. For firms, green innovation involves not only the typical spillover effects of innovation but also external environmental cost issues. This “dual externality” often diminishes firms' incentives to engage in green innovation. Institutional theory posits that corporate behavior is shaped by institutional pressures from external environments, including laws, industry standards, social norms, and customer demands. From the customer's perspective, stakeholder theory suggests that when upstream suppliers exhibit poor environmental performance, customer firms, as key stakeholders, are adversely affected, as suppliers' irresponsible behaviors can harm customers' reputations. Existing studies show that failing to meet environmental standards may lead to negative publicity or reputational damage for purchasing companies [18].

Firms thus face both the hard constraints of legal regulations and the soft pressures from customers. In global supply chains, customer firms, as key stakeholders of suppliers, increasingly emphasize their own environmental performance and exert influence on upstream suppliers through the supply chain. The significant benefits that customers provide grant them substantial bargaining power to influence suppliers [19]. For example,

customer firms can directly impact suppliers' strategies and operations by demanding compliance with environmental sustainability and green product standards. When customer firms require suppliers to provide products or services that meet environmental standards, suppliers face pressure to comply. Suppliers are compelled to engage in green innovation to secure ongoing business opportunities. Under such pressure, suppliers must enhance their green product offerings and continually innovate to remain competitive. This mechanism not only promotes the diffusion and application of green innovation but also facilitates the green transformation of the entire supply chain, contributing to broader environmental sustainability goals. Based on the above analysis, this study proposes the following hypothesis:

H1. *Customer environmental performance can effectively promote supplier green innovation.*

2.2.2. Transmission Mechanisms

(1) Supply Chain Transmission

Customer concentration refers to the proportion of a firm's revenue derived from its major customers. According to regulations issued by the China Securities Regulatory Commission (CSRC) in 2007, listed companies must disclose the sales revenue and its proportion from their top five customers, which represents the company's customer concentration. Customer concentration reflects not only the sales strategy but also the bargaining power of its customers, thereby influencing suppliers' strategic decisions, risk management, and innovation patterns.

When customers set high environmental performance standards, they often exert pressure on suppliers to adopt green practices. However, green innovation typically requires substantial investments, and firms face limited resources. If a firm's customer base is overly dispersed, resources must be distributed across many customers, reducing the focus on each customer and increasing the risk of customer attrition. In contrast, a high level of customer concentration indicates significant dependence on key customers and limited bargaining power. In organizational relationships, the core determinant of management decisions is the expectation of improving transaction efficiency and reducing transaction costs [20]. Building stable partnerships with major customers enables firms to maximize resource utilization and minimize the costs associated with investments required for new customer collaborations [21]. As a result, when managers decide to pursue green innovation, they are more inclined to make larger investments, as stable supply chain relationships enhance efficiency and mitigate the risks of customer turnover. Based on this, the following hypothesis is proposed:

H2. *Customers' environmental performance influences suppliers' green innovation through customer concentration.*

(2) Market Investment Expectations

Tobin's Q is the ratio of a firm's market value to the replacement cost of its assets and is commonly regarded as an indicator of market investors' expectations of the firm's future profitability and growth potential. A higher Tobin's Q reflects optimistic market expectations of a firm's ability to generate above-average returns on investment.

Yang and Liu (2009) found that firms with a Tobin's Q greater than 1 experience stock price increases when adopting external innovation, while those with a Tobin's Q less than 1 benefit from internal innovation [22]. Strong environmental performance—such as reducing pollution, enhancing resource efficiency, and adopting green technologies—improves a firm's social image, mitigates regulatory and legal risks, and attracts environmentally conscious investors. These actions enhance market expectations of the firm's future prof-

itability and competitiveness. According to signaling theory, a firm's green initiatives send positive signals to external stakeholders, leading investors to anticipate higher financial returns, thus driving up its Tobin's Q.

Furthermore, when customers exhibit strong environmental performance, suppliers may anticipate increasingly stringent requirements and standards in green development. This drives suppliers to prioritize green innovation to meet customer expectations and market demands. This expectation-driven behavior reflects suppliers' efforts to maintain or enhance their partnerships with key customers by strengthening competitiveness through green innovation. Such innovation enables suppliers to retain their position under growing regulatory and market pressure. Based on this, the following hypothesis is proposed:

H3. *Customers' environmental performance influences suppliers' green innovation through expectations (Tobin's Q).*

(3) Policy Mechanism

Governmental policies and regulations could potentially affect a firm's environmental innovation directly or indirectly [23]. Governmental policies or policy uncertainties play a critical role in shaping the interaction between customer environmental performance and supplier green innovation. Policies such as environmental subsidies, tax incentives, and stricter environmental regulations create external pressures and incentives for firms to prioritize environmental performance. When firms adopt higher environmental standards to align with these policies, their demand for eco-friendly inputs and sustainable practices increases. This demand motivates suppliers to engage in green innovation to meet their customers elevated environmental requirements. However, the implementation of these policies, on the other hand, may reduce the environment-innovation elasticity since the environmental performance of customers becomes better. Therefore, it will mitigate the effect of customer environmental performance on supplier green innovation. Based on this, the following hypothesis is proposed:

H4. *Customers' environmental performance influences suppliers' green innovation through institutional policies.*

(4) Financial Constraints Mechanism

Green innovation typically requires substantial investment in research and development, technology upgrades, and production adjustments [24,25]. Suppliers with limited access to financial resources may struggle to meet these demands, thereby weakening the impact of customer environmental performance on supplier green innovation efforts. In such cases, even environmentally conscious firms may find it challenging to influence suppliers' innovation activities, as financial barriers prevent suppliers from responding effectively to environmental requirements. Based on this, the following hypothesis is proposed:

H5. *Customers' environmental performance influences suppliers' green innovation through suppliers' financial constraints.*

3. Data and Methodology

3.1. Sample Selection and Data Sources

Although the China Securities Regulatory Commission (CSRC) mandated the disclosure of major customers (top five) and their sales revenue by listed companies as early as 2001, most companies only began providing detailed customer information from 2009. Additionally, non-listed companies' Environmental (E) scores are not covered by any institutional databases. Thus, this study uses Chinese A-share listed companies from 2009 to

2022 as the research sample. Data on A-share listed companies and their top five customers were obtained from the China Research Data Services Platform (CNRDS) and processed as follows: We first excluded abnormal trading samples, such as those marked as ST or ST*. Then, samples with missing values were dropped. In China, listed companies are required to disclose key customer information (mainly the top customers) in their annual reports. After matching each supplier with its main customers, the final dataset includes 2775 “customer–supplier–year” observations.

Our key explanatory variable customer environmental performance (E-score) comes from the Huazheng ESG database. Supplier green innovation data are from the CNRDS database, and other financial data are from the China Stock Market and Accounting Research (CSMAR) database. To mitigate the influence of outliers, all continuous variables are winsorized at the top and bottom 1%.

3.2. Variable Definitions

3.2.1. Dependent Variables

Supplier Green Innovation: Measured as the natural logarithm of the total number of green patent applications plus one. Compared to the number of granted green patents, green patent applications better reflect the current state of corporate green innovation.

3.2.2. Independent Variable

Customer Environmental Performance: Measured using E-scores from the Huazheng ESG database. The Huazheng ESG evaluation system draws extensively from the core principles of international ESG frameworks while integrating the unique characteristics of Chinese information disclosure practices and corporate attributes. The system is constructed with environmental theme indicators encompassing five secondary indicators—climate change, resource utilization, environmental pollution, environmental friendliness, and environmental management—alongside 17 tertiary indicators and multiple layers of base-level indicators.

The E-score ranges from 0 (poorest environmental performance) to 100 (perfect environmental performance). The calculation process begins with establishing theoretical benchmark levels for each indicator based on literature review, practical experience, and national standards. Indicators are then standardized to eliminate dimensional differences. Structured and unstructured data are categorized, with values assigned to unstructured data. Missing values are imputed using statistical methods. Weightings for tertiary indicators are set according to industry attributes, and individual indicator scores are multiplied by their respective weights to calculate the weighted E score. Finally, the weighted scores undergo industry-specific adjustments to ensure that company rankings remain consistent within their respective industries.

3.2.3. Control Variables

Referring to Fang and Hu (2023), this study includes the following control variables: firm size (size), firm age (lnage), return on assets (roa), and liquidity (cash) [11]. In the robustness check, more control variables, such as R&D spending as the percentage of gross revenue, the number of directors, and the shareholding ratio of the top five shareholders, etc., are added to avoid the potential omitted variable bias. All control variables are on the suppliers’ side when the dependent variable is supplier green innovation. Additionally, industry and year-fixed effects are controlled. To better capture the elasticity in the relationship between customers’ environmental performance and suppliers’ green innovation, and to enhance the comparability of variables, this study applies the natural logarithm to all positive level variables. Table 1 provides the definitions of the key variables used in the analysis.

Table 1. Variable definitions.

Types	Name	Variable	Definition
Dependent Variable	Supplier green innovation	lnpat_green	The natural logarithm of the total number of green patent applications plus one
		lnpat1_green	The natural logarithm of the number of green invention patent applications plus one
		lnpat2_green	The natural logarithm of the number of green utility model patent applications plus one
		lngrant_green	The natural logarithm of the total number of green patent grants plus one
	Supplier innovation	lnpat	The natural logarithm of the total number of patent applications plus one
		lnRD	The natural logarithm of the R&D spending
Independent Variable	Customer environmental performance	lnE	The natural logarithm of E-scores from Huazheng ESG
		lnE_Bloomberg	The natural logarithm of E-scores from Bloomberg ESG
Mechanism Variable	Customer concentration	lnCC	The natural logarithm of customer concentration
	Tobin's Q	TobinQ	The value of Tobin's Q
Control Variable	Firm size	size	The natural logarithm of the total assets
	Firm age	lnage	The natural logarithm of firm age
	Return on assets	roa	Return on assets
	Liquidity	cash	The ratio of cash and cash equivalents to current liabilities
	R&D spending	lnRDratio	The natural logarithm of the R&D spending over gross revenue
	Director	lnDirector	The natural logarithm of the number of directors
	Shareholders	top5	Shareholding ratio of the top five shareholders
Instrumental Variable	Average of E-score	lnE_avg	The natural logarithm of the average E-score of firms in the same industry.
	Negative ESG news	neg	The proportion of negative ESG news

The descriptive statistics for the main variables are presented in Table 2. The natural logarithm of E-scores (*lnE*) has a mean value of 4.153 and a minimum value of 3.823, indicating that customer firms generally exhibit moderate ESG performance, with most firms placing considerable emphasis on fulfilling environmental responsibilities. For supplier green innovation, the natural logarithm of green patent applications (*lnpat_green*) has a mean value of 0.215 and a standard deviation of 0.468, suggesting that suppliers' overall level of green innovation is relatively low, with noticeable variation among firms. Among the control variables, firm size (*size*) has a mean of 21.749, firm age (*lnage*) averages at 1.727, return on assets (*roa*) has a mean of 0.04, and liquidity (*cash*) averages at 0.214. These results are consistent with existing literature and indicate that China's listed companies are still in a growth phase.

Table 2. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
lnpat green	2775	0.215	0.468	0	1.609
lnpat1 green	2775	0.162	0.471	0	4.898
lnpat2 green	2775	0.149	0.456	0	4.635
lngrant green	2775	0.203	0.522	0	5.075
lnpat	2775	1.532	1.436	0	8.019
lnE	2775	4.153	0.122	3.823	4.341
lnE_Bloomberg	1403	2.479	0.637	0.734	4.022
size	2775	21.749	1.188	19.692	24.129
lnage	2775	1.727	0.992	0	3.091
roa	2775	0.040	0.061	−0.313	0.128
cash	2764	0.214	0.365	−0.659	1.164
lnRDratio	1793	1.201	1.283	−6.320	3.997
lnDirector	2754	2.291	0.233	1.609	3.219
top5	2754	0.518	0.203	0.207	0.994
lnAVGE	2657	4.161	0.088	3.693	4.462
neg	2514	0.107	0.299	0	1

3.3. Model Specification

Based on the analysis above, the following regression models are constructed to test the hypotheses:

$$\ln pat_green_{it} = \beta \ln E_{kt} + X'\gamma + \alpha_j + \theta_t + \varepsilon_{it} \quad (1)$$

where $\ln pat_green_{it}$ denotes the natural logarithm of the number of green patents applied by supplier i in year t , representing the level of supplier green innovation. The green invention patents ($\ln pat1_green_{it}$) and green utility model patents ($\ln pat2_green_{it}$) are also used as dependent variables. $\ln E_{kt}$, our key explanatory variable, is the E-score of the customer firm k associated with supplier i in year t , representing customer environmental performance. X' represents a set of control variables on the supplier side, including firm size, firm age, return on assets, and liquidity [11]. α_j is the industry fixed effects, θ_t is the year fixed effects, ε_{it} is the error term.

For robustness checks, supplier green innovation is also measured using the total number of patent applications, R&D spending, and the number of granted patents. Customer environmental performance is primarily measured using the E-score from the Huazheng ESG database, and the general ESG score from Huazheng and the E-score from the Bloomberg ESG database are used as alternatives.

To address potential endogeneity issues, this study employs both pooled ordinary least squares (POLS) and fixed-effects models as baseline regressions. Furthermore, it introduces the mean environmental score of other firms in the same industry and the proportion of negative ESG news instrumental variables and applies two-stage least squares (2SLS) to obtain consistent estimators.

The first-stage regression is as follows:

$$\ln E_{it} = \beta \ln \bar{E}_{kt} + X'\gamma + \alpha_j + \theta_t + e_{it} \quad (2)$$

Using the predicted values $\ln \hat{E}_{jt}$ from the first stage, the second stage estimates are given by:

$$\ln pat_green_{it} = \beta \ln \hat{E}_{kt} + X'\gamma + \alpha_j + \theta_t + \varepsilon_{it} \quad (3)$$

However, the environmental performance of other firms in the same industry may not be strictly exogenous, as it could influence supplier innovation through supply chain linkages. To address this, we use the lagged value of customer environmental performance

as an instrumental variable and apply the generalized method of moments (GMM) to resolve endogeneity issues.

Additionally, to account for potential reverse causality, this study constructs simultaneous equations and employs three-stage least squares (3SLS) for further robustness, effectively addressing endogeneity concerns.

4. Empirical Analysis

4.1. Baseline Regression

Table 3 presents the baseline regression results for the relationship between customers' environmental performance (*lnE*) and suppliers' green innovation, measured by the number of green patents total (*lnpat_g*), green invention patents (*lnpat1_g*), and green utility model patents (*lnpat2_g*).

Table 3. Baseline regression.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dep.Var	POLS lnpat_g	POLS lnpat1_g	POLS lnpat2_g	FE lnpat_g	FE lnpat1_g	FE lnpat2_g	FE lnpat_g	FE lnpat1_g	FE lnpat2_g
lnE	0.255 *** (0.069)	0.241 *** (0.068)	0.132 ** (0.064)	0.262 *** (0.069)	0.216 *** (0.067)	0.147 ** (0.064)	0.231 *** (0.074)	0.173 ** (0.070)	0.162 ** (0.066)
size	0.082 *** (0.009)	0.076 *** (0.011)	0.081 *** (0.011)	0.084 *** (0.009)	0.078 *** (0.011)	0.083 *** (0.011)	0.101 *** (0.010)	0.097 *** (0.012)	0.091 *** (0.012)
lnage	−0.085 *** (0.011)	−0.067 *** (0.011)	−0.079 *** (0.011)	−0.074 *** (0.011)	−0.056 *** (0.011)	−0.069 *** (0.011)	−0.050 *** (0.011)	−0.038 *** (0.011)	−0.048 *** (0.011)
roa	−0.127 (0.156)	−0.198 (0.155)	−0.100 (0.111)	−0.171 (0.155)	−0.196 (0.154)	−0.132 (0.113)	−0.092 (0.169)	−0.131 (0.167)	−0.050 (0.126)
cash	−0.044 * (0.024)	−0.020 (0.023)	−0.055 ** (0.023)	−0.039 (0.024)	−0.016 (0.023)	−0.050 ** (0.023)	0.007 (0.028)	0.027 (0.026)	−0.005 (0.025)
Constant	−2.467 *** (0.342)	−2.371 *** (0.376)	−2.012 *** (0.360)	−2.548 *** (0.347)	−2.318 *** (0.369)	−2.120 *** (0.364)	−2.854 *** (0.367)	−2.602 *** (0.402)	−2.427 *** (0.387)
Industry FE							✓	✓	✓
Year FE				✓	✓	✓	✓	✓	✓
Obs	2764	2764	2764	2764	2764	2764	2755	2755	2755

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The results are reported across multiple model specifications, with columns (1) to (3) showing the results from a pooled ordinary least squares (POLS) estimation and columns (4) to (9) presenting fixed effects (FE) estimation that account for industry and year fixed effects. In all regressions, the coefficient for *lnE* is positive and statistically significant, with values ranging from 0.132 to 0.262. This suggests that customers' environmental performance has a positive impact on suppliers' green innovation, thus confirming hypothesis H1. The fixed effects estimations further control for unobserved heterogeneity across industries and years, ensuring that the results are not driven by time or industry-specific factors. Overall, the findings suggest that customers' environmental performance plays a significant role in promoting suppliers' green innovation, with consistent effects across different patent measures.

For control variables, firm size (*size*) is significantly positive in all models, indicating that larger firms tend to have higher levels of green innovation. However, firm age (*lnage*) is significantly negative in all models, suggesting that firm age reduces green innovation. Moreover, the coefficient of return on assets (*roa*) and cash (*cash*) vary in sign across different models, representing that the impact of net profit margins and liquidity on green innovation may be complex.

Overall, the regression results reveal that customer environmental performance positively promotes supplier green innovation, indicating that focusing on environmental performance can help stimulate green innovation in the supply chain, contributing to the overall shift in the supply chain toward sustainable development. These findings provide important empirical evidence for firms to enhance their environmental performance to achieve sustainable development.

4.2. Addressing Endogeneity Issues

This study may have potential endogeneity issues, such as reverse causality—where suppliers with stronger green innovation capabilities may improve the environmental performance of their customers through the supply chain. To address this concern, we first construct a lagged independent variable model and further employs two-stage least squares (2SLS) and generalized method of moments (GMM) regressions. The regression results are presented in Table 4.

Table 4. Addressing endogeneity concern.

	(1)	(2)	(3)
Dep.Var	LAG lnpat_gr	IV lnpat_g	GMM lnpat_g
L.lnE	0.553 *** (0.190)		
L.size	0.139 *** (0.028)		
L.lnage	−0.058 * (0.029)		
L.roa	0.071 (0.320)		
L.cash	−0.069 (0.062)		
L.lnpat_g			0.080 (0.265)
lnE		0.664 *** (0.184)	3.056 * (1.626)
size		0.103 *** (0.011)	0.061 * (0.035)
lnage		−0.056 *** (0.012)	−0.047 (0.045)
roa		−0.098 (0.184)	−0.757 * (0.454)
cash		−0.014 (0.030)	−0.005 (0.069)
First-stage <i>p</i> -value		0.000	
AR (1)			0.057
AR (2)			0.426
Industry FE	✓	✓	✓
Year FE	✓	✓	✓
Obs	501	2388	508
Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$			

In column (1), the use of lagged independent variables in the regressions helps to mitigate endogeneity problems arising from reverse causality. The results show that the coefficient for environmental performance (*lnE*) in the lagged independent variable model is 0.553, significant at the 1% level. This further supports the positive impact of customer environmental performance on supplier green innovation. In column (2), following the approach of Sun et al. (2024) [14], the average environmental performance of other listed

companies in the same industry (lnE_{avg}) is selected as an instrumental variable. In addition, we use the proportion of negative ESG news (neg) as another instrument, and two-stage least squares (2SLS) estimation is employed. The first-stage p-values of those two variables are both 0.000, indicating that the instrumental variables are effective in solving the endogeneity issue. Both instrumental variables are valid because they are highly related to the endogenous variable but not correlated with the error term. Regression results show that the coefficient of lnE on $lnpat_green$ in column (2) is significantly positive, confirming that the instrumental variable approach yields results consistent with the baseline regressions. It further verifies the positive impact of customer environmental performance.

Nevertheless, environmental performance may also have spillover effects in industry. If different customers of a supplier belong to the same industry, the average industry environmental performance could directly affect the supplier's green innovation. Therefore, the average environmental performance of the same industry may still exhibit endogeneity. To address this, we adopt the generalized method of moments (GMM) approach, using lagged values of endogenous variables as their own instruments. This resolves the issue of selecting instruments, and the results are shown in column (5). The coefficient of lnE on $lnpat_green$ is 3.056, significant at the 10% level. The AR(1) test is significant, while the AR(2) test is not, indicating that the model is valid and confirming the robustness of our findings.

In conclusion, after addressing the endogeneity issues using various instrumental variable methods, the positive impact of customer environmental performance on supplier green innovation remains significant. This provides more robust evidence for policymakers and business managers, supporting the notion that improving customer environmental performance can promote green innovation among suppliers.

To further address the endogeneity issue, this study adopts the simultaneous equation and employs three-stage least squares (3SLS) to resolve the endogeneity problem arising from reverse causality. The results, shown in Table 5, provide validation of the impact of customer environmental performance (lnE) on supplier green innovation ($lnpat_green$). Specifically, we treated both customers' environmental performance and suppliers' green innovation as endogenous variables to address potential endogeneity caused by reverse causality. The relationship between customers' environmental performance and suppliers' environmental performance is significantly positive and the effect of customer environmental performance on supplier green innovation remains consistent.

Table 5. Further endogeneity concern: 3SLS.

Dep.Var	(1)	(2)
	3SLS lnE	3SLS $lnpat_g$
$lnE_{supplier}$	0.062 *** (0.022)	
$size_consumer$	0.014 *** (0.001)	
$lnage_consumer$	−0.001 (0.003)	
$roa_consumer$	0.355 *** (0.065)	
$cash_consumer$	−0.075 *** (0.014)	
lnE		1.245 *** (0.353)
$size$		0.105 *** (0.011)

Table 5. Cont.

Dep.Var	(1)	(2)
	3SLS lnE	3SLS lnpat_g
lnage		−0.050 *** (0.013)
roa		−0.038 (0.182)
cash		0.027 (0.033)
Constant	3.495 *** (0.097)	−6.647 *** (1.455)
Industry FE	✓	✓
Year FE	✓	✓
Obs	2248	2248
Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$		

4.3. Transmission Mechanisms

Based on the theoretical analysis presented earlier, supply chain transmission, market investment expectations, institutional policies, and financial constraints are potential mechanisms through which customer environmental performance influences supplier green innovation. This study introduces customer concentration (*lnCC*), Tobin's Q (*TobinQ*), green financial reform and innovation pilot zones (*treat*), and financial constraints (*SA*) as moderating variables to further explore the combined effects of customer environmental performance (*lnE*), customer concentration (*lnCC*), Tobin's Q (*TobinQ*), pilot zones (*treat*), and financial constraints (*SA*) on supplier green innovation (*lnpat_green*). The regression models are constructed as follows:

$$\ln pat_green_{it} = \beta_1 \ln E_{kt} + \beta_2 \ln E_{kt} \times Z_{kt} + X'_j \gamma + \alpha_j + \theta_t + \varepsilon_{it} \quad (4)$$

where Z_{kt} represents the moderating variables (*lnCC*, *TobinQ*, *treat*, or *SA*). The regression results are presented in Tables 6 and 7.

First, in columns (1) and (4) of Table 6, the regression coefficients for *lnE* on supplier green innovation are 0.212 and 0.228, respectively, and both are significant at the 1% level. This confirms the previous finding that customer environmental performance has a significant positive effect on supplier green innovation. Additionally, the interaction term *lnE#lnCC* in columns (1)–(3) of Table 6 is positive, indicating that in more concentrated market environments, the positive effect of customer environmental performance on supplier green innovation is even higher. This validates hypothesis H2. Furthermore, the interaction term *lnE#TobinQ* in columns (4)–(6) of Table 6 has a positive and significant impact on supplier green innovation, suggesting that a high Tobin's Q may enhance the positive effect of customer environmental performance on green innovation.

The analysis in Table 6 reveals the mechanisms of customer environmental performance, customer concentration, and Tobin's Q on supplier green innovation. The results highlight the importance of market structure and future expectations in driving green innovation, offering valuable insights for firms in formulating green strategies and enhancing market competitiveness.

Table 6. Transmission mechanisms: supply chain and market expectation.

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Var	Concentrate lnpat_g	Concentrate lnpat1_g	Concentrate lnpat2_g	Expectation lnpat_g	Expectation lnpat1_g	Expectation lnpat2_g
lnE	0.212 *** (0.073)	0.146 ** (0.069)	0.154 ** (0.065)	0.228 *** (0.075)	0.173 ** (0.071)	0.158 ** (0.067)
lnE#lnCC	0.006 ** (0.003)	0.009 *** (0.003)	0.003 (0.002)			
lnE#TobinQ				0.003 *** (0.001)	0.003 ** (0.001)	0.002 ** (0.001)
size	0.106 *** (0.010)	0.104 *** (0.012)	0.093 *** (0.013)	0.109 *** (0.011)	0.106 *** (0.013)	0.098 *** (0.013)
lnage	−0.048 *** (0.011)	−0.035 *** (0.011)	−0.047 *** (0.011)	−0.054 *** (0.012)	−0.044 *** (0.012)	−0.050 *** (0.012)
roa	−0.078 (0.169)	−0.112 (0.168)	−0.044 (0.125)	−0.098 (0.177)	−0.142 (0.177)	−0.036 (0.131)
cash	0.011 (0.028)	0.032 (0.026)	−0.004 (0.025)	0.006 (0.028)	0.026 (0.027)	−0.004 (0.025)
Constant	−2.925 *** (0.371)	−2.702 *** (0.406)	−2.456 *** (0.394)	−3.035 *** (0.381)	−2.800 *** (0.426)	−2.560 *** (0.408)
Industry FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Obs	2754	2754	2754	2709	2709	2709

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 7. Transmission mechanisms: policy and financial constraints.

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Var	Policy lnpat_g	Policy lnpat1_g	Policy lnpat2_g	Fin Cons lnpat_g	Fin Cons lnpat1_g	Fin Cons lnpat2_g
lnE	0.236 *** (0.074)	0.178 ** (0.069)	0.164 ** (0.066)	0.247 *** (0.089)	0.269 *** (0.089)	0.123 (0.093)
lnE#treat	−0.021 ** (0.008)	−0.020 ** (0.009)	−0.009 (0.008)			
lnE#SA				−0.004 (0.012)	−0.025** (0.012)	0.010 (0.015)
size	0.100 *** (0.010)	0.096 *** (0.012)	0.091 *** (0.012)	0.102 *** (0.010)	0.100 *** (0.012)	0.090 *** (0.012)
lnage	−0.049 *** (0.011)	−0.037 *** (0.011)	−0.047 *** (0.011)	−0.048 *** (0.013)	−0.026 ** (0.012)	−0.052 *** (0.013)
roa	−0.082 (0.168)	−0.122 (0.167)	−0.046 (0.126)	−0.088 (0.170)	−0.112 (0.169)	−0.058 (0.128)
cash	0.006 (0.028)	0.026 (0.026)	−0.006 (0.025)	0.007 (0.028)	0.028 (0.026)	−0.006 (0.024)
Constant	−2.845 *** (0.366)	−2.594 *** (0.402)	−2.423 *** (0.387)	−2.868 *** (0.373)	−2.689 *** (0.417)	−2.391 *** (0.402)
Industry FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Obs	2755	2755	2755	2755	2755	2755

Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Abnormal environmental performance is often subject to regulation, suggesting that environmental governance could influence the relationship between corporate social responsibility and innovation. Since 2017, the green financial reform and innovation pilot zones established by the State Council in 10 regions across 7 provinces aim to explore

local green financial development pathways. By building a green financial service system, the policy seeks to incentivize more resources toward green and low-carbon sectors. Such policies can be viewed as a form of industry or economic adjustment. Comparing the relationship between environmental performance and green innovation before and after the implementation of these policies could help us better capture this relationship. Table 7 presents the results under two mechanisms: the policy mechanism (Columns 1–3) and the financial constraints mechanism (Columns 4–6). Columns (1)–(3) in Table 7 demonstrate the policy-related mechanism. The coefficient of the interaction term $\ln E \# treat$ is negative, indicating that being in a green pilot zone significantly reduces the positive relationship between customers' environmental performance and suppliers' green innovation, though the impact remains positive overall. This suggests that institutional policies and customers' environmental performance act as substitutes in driving suppliers' green innovation. Specifically, when customer firms are located in green pilot zones, their suppliers' green innovation is significantly influenced by policy requirements. The environment-innovation elasticity decreases in green pilot zones, diminishing the positive effect of customers' environmental performance.

Regarding the financing constraints mechanism, the key independent variable, $\ln E$, becomes significant only in Column (5), where the number of green invention patents is used as the dependent variable. This indicates that as customer firms face higher financial constraints, the positive effect of customers' environmental performance on green invention patents is significantly mitigated. However, financial constraints, as captured by the SA index, do not appear to significantly influence the relationship between the $\ln E$ and green patents total, and $\ln E$ and green utility model patents.

4.4. Heterogeneity Analysis and Robustness Check

The heterogeneity analysis in Table 8 examines the role of different types of firms in the relationship between customer environmental performance and supplier green innovation. Specifically, we focus on three dummy variables: whether the supplier is a state-owned enterprise (gov), whether the customer enterprise is a state-owned enterprise ($gov_consumer$), and whether the supplier has ISO14001 certification (ISO).

In columns (1) and (2), the regression coefficients for $\ln E$ on supplier green innovation ($\ln pat_green$) are 0.201 and 0.204, respectively, while the interaction terms $\ln E \# gov$ and $\ln E \# gov_consumer$ have coefficients of 0.021 and 0.009, both significantly positive. This suggests that when both the supplier and the customer are state-owned enterprises, the impact of customer environmental performance on supplier green innovation is stronger. This may be due to state-owned enterprises (SOEs) having advantages in policy guidance and resource acquisition, allowing them to better respond to customer environmental requirements and actively engage in green innovation. Moreover, as customers, SOEs have higher bargaining power and influence in the supply chain, which enables them to effectively push suppliers towards green innovation. Furthermore, SOEs typically face stricter environmental policies and compliance requirements, which could further motivate their suppliers to intensify their green innovation efforts.

In column (3), the coefficient for the interaction term $\ln E \# ISO$ is 0.033, and it is significant at the 1% level. This suggests that suppliers with ISO14001 certification can enhance the positive effect of customer environmental performance on their green innovation. ISO14001 certification represents that a firm has reached certain international standards in environmental management and possesses a more complete environmental management system. Such firms are more likely to respond to customer environmental requirements and actively invest in green innovation activities. This result highlights the key role of external environmental and market pressures in driving corporate green innovation. Encouraging

firms to obtain ISO certification and leveraging the influence of state-owned enterprises in the supply chain can more effectively promote supplier green innovation and contribute to sustainable development.

Table 8. Heterogeneity analysis.

	(1)	(2)	(3)
Dep.Var	Hetero1 lnpat_g	Hetero2 lnpat_g	Hetero3 lnpat_g
<i>lnE</i>	0.201 *** (0.075)	0.204 *** (0.075)	0.236 *** (0.074)
<i>lnE#gov</i>	0.021 *** (0.006)		
<i>lnE#gov_consumer</i>		0.009 * (0.005)	
<i>lnE#ISO</i>			0.033 *** (0.006)
<i>size</i>	0.088 *** (0.010)	0.099 *** (0.010)	0.094 *** (0.010)
<i>lnage</i>	−0.063 *** (0.012)	−0.047 *** (0.012)	−0.046 *** (0.011)
<i>roa</i>	−0.078 (0.178)	−0.049 (0.172)	−0.144 (0.170)
<i>cash</i>	0.004 (0.028)	−0.004 (0.029)	0.012 (0.028)
<i>Constant</i>	−2.455 *** (0.375)	−2.734 *** (0.376)	−2.750 *** (0.365)
Industry FE	✓	✓	✓
Year FE	✓	✓	✓
Obs	2625	2509	2734
Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$			

This study further replaces the dependent variables with the total number of supplier patents, R&D spending, and the number of granted green patents, respectively, to test the sensitivity of our analysis. The results, presented in columns (1), (2), and (3) of Table 9, show that the regression coefficients for customer environmental performance (*lnE*) on supplier innovation are 0.455, 0.514, and 0.182, respectively, all significant at the 5% level. It indicates that the positive effect of customer environmental performance on supplier innovation remains robust under different measurements of the dependent variable.

In columns (4) and (5), the independent variable, customer environmental performance, is replaced with an E score from the Bloomberg database and the general ESG score from the Huazheng database. The results remain consistent.

In column (6), more control variables, such as R&D spending as the percentage of gross revenue, the number of directors, and the shareholding ratio of the top five shareholders, etc., are added to avoid the potential omitted variable bias and further test the robustness of our results. Due to the significant number of missing values in R&D spending, our baseline regression continues to use the original control variables to ensure the regression results cover a broader range of customer–supplier–year data. However, we conducted robustness tests by adding other control variables, and the results remain consistent.

Table 9. Robustness check.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dep.Var	robust1 lnpat	robust2 lnRD	robust3 lngrant_g	robust4 lnpat_g	robust5 lnpat_g	robust6 lnpat_g	robust7 lnpat_g
lnE	0.455 ** (0.210)	0.514 ** (0.201)	0.182 ** (0.076)			0.273 *** (0.096)	0.252 *** (0.087)
lnE_Bloomberg				0.033 * (0.020)			
lnESG					0.286 ** (0.137)		
size	0.349 *** (0.030)	0.901 *** (0.031)	0.119 *** (0.013)	0.097 *** (0.013)	0.101 *** (0.010)	0.096 *** (0.013)	0.130 *** (0.014)
lnage	−0.211 *** (0.033)	−0.096 *** (0.031)	−0.051 *** (0.012)	−0.058 *** (0.017)	−0.050 *** (0.011)	−0.059 *** (0.016)	−0.061 *** (0.013)
roa	1.614 *** (0.429)	4.383 *** (0.586)	−0.328 ** (0.164)	−0.068 (0.218)	−0.110 (0.170)	−0.068 (0.250)	−0.053 *** (0.015)
cash	−0.067 (0.081)	0.124 * (0.072)	0.049 * (0.028)	−0.008 (0.039)	0.006 (0.028)	0.005 (0.035)	−0.005 (0.014)
lnRDratio						0.022 * (0.013)	
lnDirector						0.231 *** (0.046)	
top5						0.236 *** (0.071)	
Constant	−7.620 *** (1.070)	−4.217 *** (1.150)	−3.056 *** (0.413)	−1.886 *** (0.277)	−3.135 *** (0.639)	−3.547 *** (0.500)	−3.520 *** (0.481)
Industry FE	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓
Obs	2755	2005	2755	1391	2755	1762	2880
Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$							

Finally, the regression sample is adjusted by including ST firms and removing the win-sorization treatment (Column 7). The coefficient for customer environmental performance (*lnE*) is still significantly positive at the 1% level, consistent with the baseline regression results. These findings further confirm the robustness of the baseline results.

5. Conclusions and Implications

The green transformation and innovation of supply chains are essential to promoting high-quality economic development and achieving the coordinated development of resource efficiency and environmental protection. The emphasis on environmental protection offers unprecedented opportunities for building sustainable supply chains. The active efforts of customer firms in environmental performance provide strong support and motivation for suppliers' green innovation, creating a mutually beneficial ecosystem. This shift not only strengthens the resilience and stability of the supply chain but also lays the foundation for achieving sustainable development.

For example, Walmart, through the introduction of its "Sustainability Index" scoring system, required suppliers to reduce packaging and carbon emissions, incorporating environmental metrics into procurement contracts. This directly impacted suppliers' order shares, with non-compliant suppliers facing downgrades or elimination. In response, suppliers adopted green innovation measures. Unilever launched OMO concentrated laundry detergent in Brazil, with a formula six times more concentrated than the original, allowing consumers to dilute it at home. This innovation reduced packaging volume and cut plastic use by 75%. Similarly, in 2021, P&G introduced 100% reusable aluminum can packaging, complemented by recyclable refill pouches, reducing plastic usage by 60%. These efforts

enabled Walmart to achieve its goal of reducing one billion tons of greenhouse gas emissions across its value chain six years ahead of the 2030 target. Additionally, this initiative pressured the fast-moving consumer goods (FMCG) industry to improve packaging design, accelerating the sector's transition toward sustainability.

To better understand the effect of environmental performance on green innovation from a “customer–supplier” perspective, this study, based on data from A-share listed companies in China from 2009 to 2022, constructs a “customer–supplier–year” matched sample to explore the impact of customer environmental performance on supplier green innovation. Using methods such as pooled ordinary least squares (POLS), fixed effects models (FE), instrumental variables (IV), generalized method of moments (GMM), and three-stage least squares (3SLS), this study comprehensively investigates the impact of customer environmental performance on supplier innovation behavior. Additionally, heterogeneity analysis and robustness checks were conducted to ensure the reliability of the results. The multi-perspective, multi-method research design effectively addresses endogeneity issues and reveals the potential mechanisms affecting supplier green innovation.

The research results show that customer environmental performance has a significantly positive impact on supplier green innovation. Firms with excellent environmental performance can motivate suppliers to increase their investment in green innovation through several mechanisms. The heterogeneity analysis further reveals that external factors, such as the nature of the enterprise and ISO certification, strengthen the effect of customer environmental performance on supplier green innovation. The robustness checks confirm that the positive impact of customer environmental performance on supplier green innovation holds under different model specifications and variable measurements.

The findings of this study provide solid evidence for the linkage between customer environmental performance and supplier green innovation, emphasizing the importance of promoting green innovation. Based on these findings, policymakers should encourage improving environmental performance and incorporate it into supply chain management evaluation indicators. By implementing stricter environmental regulations and offering tax incentives or subsidies, governments can motivate firms to improve their environmental management standards while promoting supplier green innovation. Furthermore, governments should encourage firms to obtain ISO certification to enhance environmental management standards, which will strengthen the positive influence of customer environmental performance on supplier green innovation. Additionally, consumers should consider the environmental performance of firms when selecting products, creating a green consumer market that drives companies to continuously improve their environmental performance.

Although this study has made significant contributions in both theoretical and empirical analysis, there are some limitations. First, this study primarily uses data from Chinese listed companies, and the generalization of the results may be constrained by regional and industry factors. Future research could consider using data from different countries or regions for comparative analysis. Second, this study mainly relies on existing firm data and does not deeply explore the specific environmental management practices and green innovation activities within firms. Future research could integrate firm interviews or case studies to gain deeper insights.

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