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Towards Sustainable Supply Chains: Evaluating the Role of Supply Chain Diversification in Enhancing Corporate ESG Performance

Xihong Wang [1], Hui Wu [2], Yang Shen [3] and Tao Wang [4,*]

[1] School of Economics and Management, Northwest University, Xi'an 710127, China; wxh@stumail.nwu.edu.cn
[2] School of Economics and Management, Nanjing Forestry University, Nanjing 210037, China; huiwu@njfu.edu.cn
[3] Institute of Quantitative Economics, Huaqiao University, Xiamen 361021, China; yangs@stu.hqu.edu.cn
[4] School of Economics and Management, Chongqing Jiaotong University, Chongqing 400074, China
* Correspondence: 611220121012@mails.cqjtu.edu.cn

Abstract: Supply chain diversification (SCD) is widely acknowledged as a crucial strategy for sustainable supply chain management. However, its influence on environmental, social, and governance (ESG) performance remains unclear. This study will explore the impact of SCD on ESG performance and uncover the underlying mechanisms drawing on the structure–conduct–performance (SCP) paradigm. To achieve this, we employ a multidimensional fixed effects model for empirical analysis utilizing panel data from China's A-share listed companies from 2010 to 2023. The findings reveal that SCD enhances ESG performance. For large-scale enterprises or those engaged in highly competitive or high-pollution industries and labor-intensive or capital-intensive sectors, as well as those that are located in the eastern and central regions, the positive impact of SCD on ESG is relatively more pronounced. The mechanism analysis shows that green innovation and digital transformation act as mediators through which SCD drives ESG improvements. Furthermore, environmental uncertainty (EU) positively moderates the relationship between SCD and ESG performance. These insights provide a guiding framework, rich in theoretical depth and practical significance, for enterprises committed to developing sustainable supply chains and pursuing long-term outstanding performance within complex and dynamic market environments.

Keywords: supply chain diversification; ESG; listed company; sustainable development

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1. Introduction

Given the increasingly severe global climate change and environmental issues, promoting sustainable development has become a global goal [1]. Corporate sustainability requires the coordinated development of economic, environmental, and social dimensions [2,3]. ESG (environmental, social, and governance) encompasses a company's responsibilities to improve their environmental, social, and governance performance [4]. Among these dimensions, the environmental aspect includes carbon footprint management, resource management, and climate change, among other aspects [5]. The social dimension includes employee rights, community engagement, and diversity and inclusion, among other aspects [6]. The governance dimension encompasses internal corporate governance [6], corporate behavior, and employee relations, among other aspects [7]. These dimensions have become key indicators for measuring corporate sustainability capabilities [8–10]. An

increasing number of investors, consumers, and policymakers are also adopting ESG as a critical basis for assessing the long-term value of enterprises [4,11,12]. According to the Global Sustainable Investment Review 2022 report released by GSIA, the value of sustainable investment assets reached USD 30.3 trillion in 2022. Therefore, determining how to enhance corporate ESG performance has become crucial for companies to maintain competitiveness and achieve sustainable development.

However, enterprises often face internal constraints, such as limited technological and financial resources, when improving their ESG performance [4,13,14]. Simultaneously, environmental turbulence [15] also hinders the stability of resource acquisition for enterprises. The supply chain network is a critical channel for companies to access resources [16]. Supply chain diversification (SCD) emphasizes building multi-source supplier networks and diversified customer relationships, helping companies to break free from reliance on single resource pathways and enhancing the resilience and resource acquisition capabilities of supply chains [17,18]. Consequently, it may allow companies to improve their ESG performance. In practice, exemplary cases include Apple, which launched a supplier clean energy program and successfully reduced its carbon dioxide emissions by 18.5 million metric tons in 2023. IKEA, by implementing a customer diversification strategy, not only effectively met the consumption demands of different regional markets but also actively promoted the adoption of sustainable lifestyles. Therefore, exploring the driving mechanisms of ESG performance from the perspective of SCD is of significant importance. However, existing research primarily focuses on the role of internal resource allocation in improving ESG [19,20], while the potential contribution of external-level SCD to ESG performance has not been sufficiently explored.

Based on these considerations, this study addressed the following three research questions: (1) How does SCD affect ESG performance? (2) Do corporate green innovation and digital transformation serve as mediating mechanisms in the relationship between SCD and ESG performance? (3) How does environmental uncertainty influence the relationship between SCD and ESG performance? To answer these questions, we used panel data from Chinese A-share listed companies from 2010 to 2023 as our research sample. Through theoretical and empirical analyses, we aimed to reveal the impact of SCD on ESG performance and the related mechanisms.

Our study makes several contributions to the literature on supply chain management and sustainable performance. First, in response to one study [21] that considered the research on ESG in supply chain management to be insufficient, this study explores the intrinsic relationship between SCD and ESG performance from the perspective of SCD. It addresses whether and how SCD drives ESG performance, providing a new perspective and theoretical foundation for ESG research in supply chain operations management. Second, based on the SCP framework, this study reveals the critical mediating roles of green innovation and digital transformation in the relationship between SCD and ESG performance. This finding not only deepens the understanding of the mechanisms through which SCD impacts ESG performance but also offers theoretical guidance for companies on achieving sustainable development through green innovation and digital transformation in supply chain practices. Finally, this study explores the moderating role of environmental uncertainty in SCD's influence on ESG performance and further investigates the heterogeneous effects of SCD on ESG performance. This finding uncovers the boundary conditions of external environmental factors influencing the effectiveness of SCD, enriches the theoretical discussion on the relationship between environmental dynamics and ESG performance in supply chain management, and provides practical insights for companies on how to optimize supply chain strategies to achieve ESG goals under varying levels of environmental uncertainty.

The following sections are organized as follows: Section 2 is a literature review. Section 3 provides the theoretical basis and research hypotheses. Section 4 details the methodology and the data analysis. The results are presented in Section 5. Section 6 discusses the findings and their implications.

2. Literature Review

2.1. The SCP Paradigm

The SCP paradigm posits that the external structural features of an industry influence the formulation of organizational strategies, leading to rational, planned actions that motivate organizational conduct [22]. These approaches significantly impact an organization's pursuit of good performance [23–25]. The SCP framework originally stemmed from industrial organization theory and was later incorporated into research areas such as strategic management and supply chain management. For example, Ralston et al. [26] employed the SCP framework to argue that supply chain integration, as a critical structural feature, leads to quick-response strategies, thereby positively impacting firm performance. Mackelprang et al. [27] used the SCP framework to confirm that suppliers' innovation strategies enable companies to respond to industry structures, consequently affecting financial performance. Morgan et al. [28] applied the SCP framework to verify the positive influence of resource commitment and sustainable supply chain management on operational performance, while Vu and Ha [29] confirmed the relationship between diversification and corporate performance based on the SCP framework. Grover and Dresner [30], based on the SCP framework and competitive dynamics, investigated the relationships between political actions in supply network resources, supply chain strategies, and firm performance, while Hou et al. [16] employed the SCP framework to investigate the impact of green supply chain knowledge networks on ESG performance.

In this study, the SCP paradigm serves as an appropriate framework to identify the relationship between SCD and ESG. SCD involves the diversified layout of enterprises in terms of suppliers, customers, logistics channels, and other aspects [17]. This diversification may alter the position and structure of enterprises within the supply chain network [31], and it can, thus, be regarded as a form of market structure. The network structure may determine the allocation of organizational resources [22], thereby influencing the selection and direction of corporate behaviors, ultimately affecting performance [16]. Based on this logic, considering that SCD, as a market structure, may influence corporate technological transformation behaviors, and that green innovation and digital transformation are crucial technological pathways for enhancing ESG performance [6,32,33], this study employs the SCP paradigm to explain how SCD affects corporate ESG performance through both green innovation and digital transformation behaviors. Additionally, the SCP framework emphasizes that environmental conditions directly impact market structure and competition [30]. Environmental uncertainty encompasses the volatility and complexity of market demand, technological advancements, supplier relationships, and other environmental factors, which collectively determine the strategic choices and responsive behaviors of enterprises [34]. Therefore, we also incorporate environmental uncertainty into the research framework as an external shock variable to analyze the impact of the SCD structure on corporate ESG performance under conditions of market environmental uncertainty.

2.2. Influence of SCD on Enterprise Performance

SCD is a strategic structure that enables enterprises to avoid over-dependence on a small number of suppliers or customers for purchasing or sales [35,36]. As key stakeholders, suppliers and customers significantly influence corporate economic and environmental outcomes. SCD enhances corporate competitiveness, improves supply chain adaptability,

boosts economic performance, and supports environmental sustainability. For instance, Lin et al. [35] demonstrated that SCD can provide firms with valuable social capital and knowledge resources, enhancing their earning capacity, while Wang et al. [17] highlighted that SCD effectively mitigates the negative impacts of supply chain disruptions on organizational performance. Similarly, Feng and Wang [36] found that SCD enhances a firm's dynamic capabilities, contributing positively to digital transformation efforts. Additionally, Sharma et al. [37] emphasized the role of stakeholder participation in sustainability practices, noting that while supplier involvement improves environmental performance, customer involvement does not significantly impact either environmental or economic outcomes, while Lin and Zhu [38] demonstrated that SCD in the renewable energy sector can enhance the total factor productivity of enterprises. However, SCD also has challenges. A more diversified supply chain can increase complexity, requiring firms to invest additional resources in management, which may negatively affect their overall performance [39].

2.3. Factors Influencing ESG Performance

The existing literature examines the factors influencing ESG from internal and external perspectives. From an internal perspective, corporate strategy plays a pivotal role in shaping ESG. For instance, Rajesh et al. [40] emphasized the importance of corporate social responsibility strategies as key indicators of ESG scores. In addition, firm characteristics are crucial determinants of ESG. These characteristics include non-financial attributes such as corporate structure [14], corporate culture [41], and human and intellectual resources [21], as well as financial attributes such as free cash flow and idle resources [8]. Finally, corporate governance is another vital aspect of ESG. Key factors identified in the literature include board diversity [42], managerial myopia [43], and executive compensation structures [44], all significantly influencing ESG.

With regard to external influencing factors, the formulation and implementation of policies and regulations play a pivotal role in shaping corporate behavior, not only through direct regulatory measures or subsidies but also by providing substantive guidance that influences ESG. Studies have shown that tax incentives [45], green financial reforms [46], and environmental tax laws [47] have positive impacts on ESG outcomes. Recent research has also highlighted the influence of public environmental awareness on ESG, with He et al. [48] demonstrating that media coverage significantly enhances corporate ESG ratings.

Moreover, given the growing body of literature on ESG research, growing scholarly attention has been paid to ESG in supply chain operations management, which is the most relevant to our study. In Table 1, we summarize the relevant literature on supply chain operations management and ESG. Past scholars have primarily focused on the impact of supply chain digitalization [13,49–51], intelligent supply chains [52], supply chain networks [53], green supply chain knowledge networks [16], and supply chain finance [54] on ESG performance.

Overall, investigating the impact of SCD on ESG is particularly urgent in current research. Firstly, the existing literature indicates that while SCD enhances corporate competitiveness and supply chain resilience, it also negatively affects management costs and complexity. This uncertainty makes the relationship between SCD and ESG worthy of in-depth exploration. Secondly, prior studies on the influencing factors of ESG have primarily focused on internal corporate characteristics and external policies and regulations. Although research on ESG in supply chain operations management has gradually gained attention, many scholars emphasize the impact of technologies (such as supply chain digitalization) on ESG. In contrast, SCD focuses on the diversity of supply chain structures and resource allocation; however, how SCD affects ESG still lacks systematic discussion.

Table 1. The literature on ESG-related antecedents in supply chain management.

Reference	Theory	Independent Variable	Key Findings
Tian et al. [13]	Stakeholder theory	Supply chain digitalization	Supply chain digitalization improves ESG by enhancing internal operational efficiency, increasing inter-firm trade credit, and strengthening external oversight
Shen et al. [50]	None	Supply chain digitalization	Supply chain digitalization can alleviate financing constraints and improve corporate governance, thereby enhancing ESG
Zhu and Zhang [51]	None	Supply chain digitalization	Supply chain digitalization can enhance ESG performance by strengthening corporate governance, improving total factor productivity, and alleviating financing constraints
Chen et al. [49]	None	Supply chain digitalization	Supply chain digitalization significantly promotes corporate ESG by reducing information asymmetry and alleviating financing constraints
Qiao et al. [52]	Resource orchestration theory	Smart supply chain	Smart supply chain practices stimulate corporate social responsibility (CSR) disclosure, thereby enhancing ESG
Yang et al. [53]	None	Supply chain network	Peer companies within the supply chain network can significantly enhance the ESG performance of the target company
Hou et al. [16]	Knowledge-based theory, social network theory, and dynamic capabilities theory, Structure–conduct–performance framework	Green supply chain knowledge network	The green supply chain knowledge network fosters corporate green technology innovation and enhances ESG performance, with knowledge integration capability exhibiting a positive moderating effect
Wang et al. [54]	None	Supply chain finance	Supply chain finance can alleviate financial constraints and strengthen oversight to enhance ESG
Our research	Structure–conduct–performance framework	Supply chain diversification	SCD can enhance green innovation and digital transformation, thereby strengthening ESG performance. Environmental uncertainty (EU) positively moderates the relationship between SCD and ESG performance

In response to the aforementioned research gaps, firstly, our study will construct a theoretical framework model based on the SCP framework to examine the impact of SCD on ESG. Secondly, we will empirically test the effect of SCD on ESG performance and further analyze the heterogeneous effects under different scenarios. Thirdly, we will explore the potential pathways through which SCD influences ESG, revealing the intrinsic mechanisms and boundary conditions related to this impact. Lastly, based on the research findings, we will provide practical guidance for enterprises on how to enhance sustainability through SCD strategies.

3. Hypothetical Development

3.1. SCD and ESG Performance

The SCP framework suggests that organizations adopt strategies in response to the market, thereby altering corporate conduct and impacting performance [22]. Diversification is crucial in enhancing an enterprise's competitive advantage [55]. SCD is regarded as a strategic structure in supply chain management [56]. This strategy drives firms to establish supply chain relationships with a larger number of suppliers and customers, which is crucial for complementary resources and capabilities, as well as effective governance within

the company [57]. It facilitates corporate learning and assimilating diverse human, technological, and knowledge resources, along with sustainable development strategies from suppliers and customers [36,58,59], which are then applied to corporate ESG management practices. Moreover, ESG performance is positively correlated with the ESG performance of firms upstream and downstream of the supply chain. Outstanding ESG performance by one party may encourage partners to follow suit, thereby driving the entire supply chain toward a more sustainable direction [53]. Additionally, supplier diversification enables firms to select suppliers with superior social responsibility performance [58] that typically possess advanced environmental technologies and can provide more eco-friendly raw materials [60]. Based on this, we posit the following hypothesis:

H1: *SCD has a positive effect on ESG performance.*

3.2. The Mechanism of Green Innovation

Based on the SCP framework, we believe that SCD influences corporate green innovation, thereby promoting ESG. Specifically, the reasons are as follows: First, SCD increases opportunities for firms to acquire innovation, innovation knowledge, and talent resources [36,61]. These resources help firms to integrate and reconfigure technologies and knowledge from different fields, thereby enhancing their willingness to engage in green innovation. Second, SCD provides a foundation for external suppliers and customers to participate in product development. External resources and knowledge from the supply chain positively impact corporate green product innovation [62], and both customer and supplier involvement positively influence green product innovation [63]. This increases a firm's motivation to pursue green innovation. Finally, SCD offers firms more varied choices for suppliers and partners, forming a closer supply chain network. This network structure positively affects a firm's ability to acquire resources and enhances green innovation outcomes [64]. By utilizing green innovation, firms can reduce energy consumption and carbon emissions [65], thereby mitigating negative environmental impacts in their production processes and positively influencing their ESG [6,32]. Based on this, we propose the following hypothesis:

H2: *SCD improves ESG performance by promoting the GI.*

3.3. The Mechanism of Digital Transformation

Based on the SCP framework, the impact of SCD on corporate digital transformation is complex and multidimensional. First, SCD enables firms to obtain more digital technologies and resources from external suppliers and customers, thereby achieving optimal resource allocation and complementarity. This provides resource support for the digital transformation of corporations [36]. Second, the increased complexity of supply chain relationships due to SCD drives firms to leverage digital technology in supply chain management. The use of digital technologies helps to reduce information asymmetry and transaction costs, enhances information transparency, and improves corporate governance and social responsibility [33]. Additionally, digital technologies can enhance the visibility and traceability of the supply chain [7], enabling firms to monitor and manage carbon emissions more effectively, thereby strengthening corporate sustainability [66]. Finally, by adopting digital operations, firms can reduce information barriers [19,67], enhance operational speed and efficiency, reduce labor costs [68], and enhance customer service to improve ESG performance. Based on this, we posit the following hypothesis:

H3: *SCD enhances ESG performance by promoting DT.*

3.4. Moderating Role of Environmental Uncertainty

The SCP framework is also used to explain how the external environment is a critical factor influencing corporate strategy and performance [22,69]. A high environmental uncertainty implies frequent changes in the external environment, under which the advantages of SCD become more pronounced, as it can enhance a firm's adaptability and reduce risks [35]. Firms often prefer to acquire more social capital and knowledge through SCD in highly uncertain environments [35]. When a firm has high relational capital, its partners are more willing to engage in resource acquisition and knowledge exchange to overcome uncertainties in the external environment [70]. Similarly, Zhang et al. [71] argued that in highly uncertain environments, firms must obtain more external resources and engage more frequently in information and knowledge exchanges with partners to improve their performance. Additionally, in highly uncertain environments, suppliers' and customers' involvement in a firm's green product innovation has a positive impact [63]. Companies can enhance their social and environmental performance by strengthening cooperation with suppliers and customers and meeting market demands in more socially and environmentally friendly ways [72]. Based on this, we posit the following hypothesis:

H4: *EU positively moderates the relationship between SCD and ESG performance.*

Figure 1 presents the theoretical model of this study.

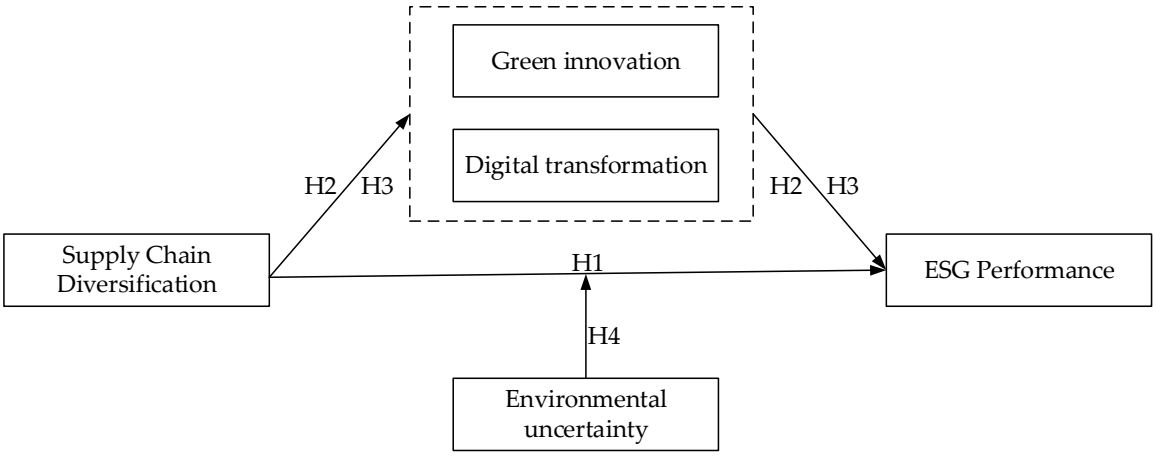


Figure 1. Conceptual framework.

4. Data and Methods

4.1. Data and Sample

China was selected as the sample for this study for the following reasons: First, as a significant participant in the global economy, the extensive and complex nature of China's supply chains provides rich data and cases spanning multiple industries, allowing us to comprehensively analyze the specific impacts of SCD strategies on the ESG of enterprises in different sectors. Second, in recent years, the Chinese government has introduced numerous policies focusing on ESG issues and promoting sustainable development, providing strong support for corporate practices. Finally, China has continuously explored diversification paths in the face of uncertainty in the global trade environment and supply chain risks. This process not only challenges traditional management models but also fosters many innovative cases with notable achievements in ESG, offering valuable lessons for global enterprises.

This study selected China's A-share listed companies data from 2010 to 2023 for the following reasons: Prior to 2010, ESG disclosure by Chinese listed companies was mainly voluntary, resulting in relatively low levels of ESG disclosure and standardization. In

2010, the Ministry of Finance of the People's Republic of China, along with four other ministries and commissions, jointly issued the "Application Guidelines for Enterprise Internal Control No. 4: Social Responsibility", which, for the first time, incorporated social responsibility covering aspects such as environmental protection and employees' rights into the enterprise internal control system. This policy shifted ESG disclosure in China from principled advocacy to operational norms. Therefore, selecting 2010 as the starting point allowed for acquiring richer and more accurate data, providing a solid foundation for the large-scale panel data analysis conducted in this study. Additionally, extending data collection to 2023 could clarify the latest developments in corporate ESG practices, thereby ensuring the timeliness and practical relevance of research results. Therefore, this study obtained SCD, ESG performance, and control variable data for China's A-share listed companies and their top five suppliers and customers from 2010 to 2023 through the CSMAR and Wind databases.

After manual collation, the companies listed in the financial sector were excluded, and samples with abnormal operations, such as ST and *ST companies, were removed. In addition, samples with missing key variables were eliminated, resulting in a final dataset of 35,316 observations from 4598 firms. In this study, all continuous variables were Winsorized at the 1% and 99% quantiles to reduce the errors caused by extreme values.

4.2. Variable Measurement

Regarding the dependent variables, this study used the Huazheng ESG rating index to measure the ESG performance of enterprises [19]. The Huazheng Index, drawing on internationally recognized methodologies and practical experience, as well as integrating China's national conditions and capital market characteristics, encompasses 16 themes with more than 40 minor indicators across the three dimensions of environmental, social, and corporate governance. It is one of the most reliable datasets currently available for assessing the ESG performance of Chinese listed companies [73]. The rating score ranges from 1 to 9, and we use the average of the four quarterly scores to measure ESG performance.

Regarding the independent variable, we used the average sum of supplier and customer diversification to measure SCD based on relevant studies [17,36]. Specifically, supplier diversification was measured via the inverse index of the purchase ratio of the top five suppliers, while customer diversification was quantified via the inverse index of the sales ratio of the top five customers. The rationale for adopting this method was that suppliers and customers are two core components of a firm's supply chain, and the average of supplier and customer diversification can more comprehensively capture the level of diversification in both upstream and downstream aspects of the supply chain [74]. The equation for calculating supplier (customer) diversification is presented in Equation (1):

$$Supplier(customer)diversification = -\sum_{j=1}^{5}\left(\frac{Procurement_{i,j,t}(Sales_{i,j,t})}{Procurement_{i,t}(Sales_{i,t})}\right) \quad (1)$$

For the mechanism variables, we adopted the natural logarithm of the total number of green patent applications plus one as a proxy variable for green innovation [75]. Patent data provided a more accurate and quantifiable measure of innovation output, and patent applications reflected the extent of a company's commitment to green innovation. Second, we used the digitization transformation word frequency from the CSMAR database to build indicators for enterprise digital transformation [75]. The word frequency in the annual report can reflect the strategic characteristics and future prospects of the enterprise and, to a large extent, the business philosophy followed by the enterprise and the development path under the guidance of this concept [33]. We added one to the counted word frequencies

and then applied the natural logarithm to measure the degree of digital transformation within the enterprises.

Regarding the moderating variable, since the coefficient of variation in enterprise market sales is less susceptible to managerial manipulation, it is a more reliable and objective indicator of external environmental constraints [76]. Therefore, we adopted industry-adjusted market environmental uncertainty for assessing environmental uncertainty [34,77]. The specific calculation formula is shown in Equation (2):

$$EU(Z_i) = \sqrt{\sum_{t-1}^{5} (z_i - \bar{z})^2 / 5} / \bar{z} \quad (2)$$

where Z_i is the market environmental uncertainty for firm i in year t, while $\bar{z}$ is the five-year mean.

Regarding the control variables, based on previous studies [10,17,35,36], this study controlled for factors that may influence both the independent and dependent variables. These variables include firm-specific characteristics, corporate governance variables, etc. Additionally, we controlled for individual, year, and industry-level fixed effects in our regression models. Table 2 provides definitions and measurements of all variables.

Table 2. Variable definitions.

Type	Variable Name	Symbol	Variable Measurement
Dependent variables	ESG performance	ESG	Huazheng ESG rating index
Independent variables	Supply chain diversification	SCD	(supplier diversification + customer diversification)/2
Mechanism variable	Green innovation	GI	Ln (total number of green patent applications + 1)
	Digital transformation	DT	Ln (digital transformation word frequency + 1)
Moderating variables	Environmental uncertainty	EU	Measured by the coefficient of variation of industry-adjusted firms' sales revenue over the past 5 years.
Control variables	Company size	Size	Ln (total assets)
	Total leverage ratio	Lev	Total liabilities/Total assets
	Listing age	ListAge	Ln (2023-year of listing + 1)
	Cash holdings	Cash	(Monetary funds + trading financial assets)/ Total assets
	Number of board members	Board	Ln (number of directors)
	Proportion of independent directors	Indep	Number of independent directors/ Total number of board members
	Ownership nature	Soe	1 for state-owned holding enterprises and 0 for others
	Cash equivalents	Liqui	Short-term investments/Total assets
	Management fee ratio	Mfee	Administrative expenses/revenue
	Fixed assets ratio	Fixed	Net fixed assets/total assets

4.3. Modeling

For model selection, the Hausman tests confirmed that the fixed-effect models were appropriate for our analyses [78]. We established a linear model with high-dimensional fixed effects of individual, year, and industry to examine the impact of SCD on ESG performance. The regression model is shown in Equation (3):

$$ESG_{i,t,k} = \alpha_0 + \beta_1 SCD_{i,t,k} + \sum \beta_j X_{i,t,k} + \mu_i + \delta_t + \gamma_k + \varepsilon_{i,t,k} \quad (3)$$

In this model, $ESG_{i,t,k}$ represents ESG performance, SCD represents supply chain diversification, $X_{i,t,k}$ represents a set of control variables, i represents the individual firm, t represents time, k represents industry, α_0 represents the intercept of the model, β represents

the regression coefficients of the relevant variables, and ε represents a random disturbance term. Additionally, μ_i represents individual-specific fixed effects, δ_t represents year fixed effects, and γ_k captures industry-specific fixed effects.

5. Empirical Results

5.1. Summary Statistics

The descriptive statistics are presented in Table 3. The mean ESG performance score for the dependent variable was 4.155, indicating an intermediate level of ESG performance for the entire sample, with a standard deviation of 0.934, indicating a relatively large variation in ESG scores, reflecting differences in ESG practices between companies. The closer the independent variable SCD is to 0, the higher the diversification degree. The minimum value of SCD is −0.897, the maximum value is −0.033, and the average value is −0.340, indicating that the diversification degree of the supply chain is generally low. To address concerns about multicollinearity, we calculated the VIF values for all variables. The highest observed VIF value was 2.683, indicating that multicollinearity was not a significant concern.

Table 3. Descriptive statistics.

Variable	N	Mean	SD	Min	Max	VIF
ESG	35,316	4.155	0.934	1.000	6.750	-
SCD	35,316	−0.340	0.169	−0.897	−0.033	1.076
Size	35,316	22.200	1.288	18.96	26.44	1.740
Lev	35,316	0.407	0.204	0.008	0.999	2.683
ListAge	35,316	2.033	0.931	0.000	3.434	1.575
Cash	35,316	0.216	0.152	0.012	0.841	1.693
Board	35,316	2.269	0.254	1.609	2.996	1.157
Indep	35,316	0.385	0.075	0.231	0.615	1.055
Soe	35,316	0.290	0.454	0.000	1.000	1.360
Liqui	35,316	0.069	0.203	−0.602	0.613	2.343
Mfee	35,316	0.084	0.065	0.007	0.502	1.219
Fixed	35,316	0.202	0.150	0.001	0.708	1.631

Spearman's correlation tests were conducted for all variables, with the results presented in Table 4. The table reveals a positive correlation between SCD and ESG performance, suggesting that SCD has a favorable effect on ESG performance.

Table 4. Results of phase relationship analysis.

Variable	ESG	SCD	Size	Lev	ListAge	Cash	Board
ESG	1						
SCD	0.132 ***	1					
Size	0.202 ***	0.230 ***	1				
Lev	−0.124 ***	0.136 ***	0.485 ***	1			
ListAge	−0.131 ***	0.151 ***	0.451 ***	0.379 ***	1		
Cash	0.156 ***	−0.072 ***	−0.230 ***	−0.451 ***	−0.324 ***	1	
Board	−0.059 ***	0.056 ***	0.238 ***	0.174 ***	0.226 ***	−0.118 ***	1
Indep	0.078 ***	0.019 ***	−0.069 ***	−0.065 ***	−0.078 ***	0.028 ***	−0.195 ***
Soe	0.029 ***	0.040 ***	0.345 ***	0.269 ***	0.426 ***	−0.132 ***	0.279 ***
Liqui	0.147 ***	−0.091 ***	−0.356 ***	−0.619 ***	−0.349 ***	0.211 ***	−0.186 ***
Mfee	−0.142 ***	−0.031 ***	−0.347 ***	−0.233 ***	−0.053 ***	0.072 ***	−0.020 ***
Fixed	−0.081 ***	−0.053 ***	0.119 ***	0.104 ***	0.136 ***	−0.364 ***	0.117 ***
	Indep	Soe	Liqui	Mfee	Fixed		
Indep	1						
Soe	−0.163 ***	1					
Liqui	0.070 ***	−0.253 ***	1				
Mfee	0.027 ***	−0.085 ***	0.058 ***	1			
Fixed	−0.044 ***	0.166 ***	−0.400 ***	−0.082 ***	1		

Note: *** $p < 0.01$.

5.2. Baseline Regression Results

Table 5 presents the results of the main regression analysis. Column (1) contains no control variables, and column (2) lists the regression results with control variables. The results show that the regression coefficient for the relationship between SCD and ESG is 0.203 ($p < 0.01$), supporting H1. Column (3) presents the effect of customer diversification (CD) on ESG. The regression coefficient for CD is positive and significant at the 1% level, indicating a positive effect on ESG. Column (4) shows the effect of supplier diversification (SD) on ESG. The regression coefficient for SD is positive at the 10% significance level, suggesting that SD has a positive influence on ESG.

Table 5. Results of main regression.

Variable	(1) ESG	(2) ESG	(3) ESG	(4) ESG
SCD	0.208 ***	0.203 ***		
	(2.958)	(2.972)		
CD			0.152 ***	
			(2.824)	
SD				0.084 *
				(1.690)
Size		0.243 ***	0.245 ***	0.246 ***
		(13.574)	(13.761)	(13.827)
Lev		−0.654 ***	−0.654 ***	−0.653 ***
		(−9.026)	(−9.030)	(−8.995)
ListAge		−0.242 ***	−0.241 ***	−0.240 ***
		(−12.594)	(−12.560)	(−12.504)
Cash		0.132 **	0.131 **	0.128 **
		(2.038)	(2.020)	(1.982)
Board		−0.186 ***	−0.186 ***	−0.186 ***
		(−7.919)	(−7.900)	(−7.898)
Indep		0.382 ***	0.383 ***	0.381 ***
		(5.298)	(5.309)	(5.287)
Soe		0.057 *	0.056 *	0.056 *
		(1.851)	(1.830)	(1.828)
Liqui		0.157 ***	0.156 **	0.156 **
		(2.585)	(2.566)	(2.557)
Mfee		−1.100 ***	−1.089 ***	−1.098 ***
		(−7.762)	(−7.676)	(−7.736)
FIXED		−0.123	−0.120	−0.117
		(−1.332)	(−1.298)	(−1.260)
_cons	4.226 ***	−0.073	−0.149	−0.195
	(176.433)	(−0.181)	(−0.373)	(−0.488)
Firms/Year/Ind FE	Yes	Yes	Yes	Yes
N	35,316	35,316	35,316	35,316
R^2	0.565	0.587	0.587	0.587

Note: the t-statistics with individual cluster-robust standard errors are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.3. The Mediation Mechanism Model

We use the three-step method to test the mediation mechanism [79] and construct the regression model as shown in Equations (4) and (5):

$$M_{i,t,k} = \alpha_0 + \beta_1 SCD_{i,t,k} + \sum \beta_j X_{i,t,k} + \mu_i + \delta_t + \gamma_k + \varepsilon_{i,t,k} \quad (4)$$

$$ESG_{i,t,k} = \alpha_0 + \beta_1 SCD_{i,t,k} + \beta_2 M_{i,t,k} + \sum \beta_j X_{i,t,k} + \mu_i + \delta_t + \gamma_k + \varepsilon_{i,t,k} \quad (5)$$

where $M_{i,t,k}$ represents green innovation and digital transformation. The other parameters are the same as those in Equation (3).

We combined Equations (3)–(5) to test the mechanisms. The regression results are presented in Table 6. Column (1) and (2) reveal that the estimated coefficient of SCD is positive and significant, indicating that SCD notably enhances ESG performance through green innovation, thereby supporting H2. Column (3) and (4) reveal that the estimated coefficient of SCD is positive and significant at the 1% level, implying that SCD significantly promotes ESG performance through digital transformation, thus supporting H3.

Table 6. Results of the mediation and moderating effects.

Variable	(1) GI	(2) ESG	(3) DT	(4) ESG	(5) ESG
SCD	0.160 **	0.196 ***	0.289 ***	0.196 ***	0.145 *
	(2.344)	(2.870)	(3.626)	(2.861)	(1.960)
GI		0.041 ***			
		(5.561)			
DT				0.025 ***	
				(3.382)	
EU					−0.048 ***
					(−7.504)
SCD×EU					0.057 *
					(1.866)
Size	0.361 ***	0.228 ***	0.210 ***	0.238 ***	0.251 ***
	(17.785)	(12.724)	(10.263)	(13.196)	(13.106)
Lev	0.007	−0.653 ***	−0.198 **	−0.649 ***	−0.576 ***
	(0.108)	(−9.032)	(−2.414)	(−8.944)	(−7.603)
ListAge	−0.061 ***	−0.240 ***	0.175 ***	−0.246 ***	−0.239 ***
	(−3.166)	(−12.503)	(7.902)	(−12.829)	(−11.210)
Cash	−0.140 **	0.138 **	−0.247 ***	0.138 **	0.132 *
	(−2.332)	(2.137)	(−3.435)	(2.136)	(1.928)
Board	0.015	−0.187 ***	0.099 ***	−0.189 ***	−0.163 ***
	(0.645)	(−7.947)	(4.283)	(−8.019)	(−6.488)
Indep	0.078	0.377 ***	−0.166 **	0.386 ***	0.330 ***
	(1.162)	(5.244)	(−2.373)	(5.354)	(4.211)
Soe	0.083 ***	0.053 *	−0.049	0.058 *	0.028
	(2.732)	(1.729)	(−1.513)	(1.894)	(0.627)
Liqui	0.054	0.156 **	−0.027	0.158 ***	0.172 ***
	(0.952)	(2.557)	(−0.411)	(2.596)	(2.642)
Mfee	0.279 **	−1.112 ***	−0.135	−1.096 ***	−1.121 ***
	(2.117)	(−7.865)	(−0.896)	(−7.738)	(−7.412)
Fixed	−0.014	−0.123	−0.544 ***	−0.110	−0.108
	(−0.154)	(−1.333)	(−5.203)	(−1.186)	(−1.107)
_cons	−6.994 ***	0.217	−3.242 ***	0.009	−0.275
	(−15.440)	(0.540)	(−7.046)	(0.023)	(−0.641)
Firms/Year/Ind FE	Yes	Yes	Yes	Yes	Yes
N	35,278	35,278	35,316	35,316	29,697
R^2	0.762	0.588	0.821	0.588	0.613

Note: the t-statistics with individual cluster-robust standard errors are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.4. The Moderating Mechanism Model

To investigate how EU moderates the influence of SCD on ESG performance, we formulated the regression model presented in Equation (6):

$$ESG_{i,t,k} = \alpha_0 + \beta_1 SCD_{i,t,k} + \beta_2 SCD_{i,t,k} \times EU_{i,t,k} + \beta_3 EU_{i,t,k} + \sum \beta_j X_{i,t,k} + \mu_i + \delta_t + \gamma_k + \varepsilon_{i,t,k} \quad (6)$$

Here, $EU_{i,t,k}$ represents environmental uncertainty. The meanings of the other parameters are the same as those in Model (3).

Column (5) of Table 6 presents the regression results for the moderating effect of EU. The coefficient of the interaction term was 0.057, being statistically significant at the 10% level. The moderating effect of EU is depicted in Figure 2. Calculating the slope, the results indicate that when EU is in the high-score group, the relationship between SCD and ESG

is positive and significant (β = 0.212, t = 2.765, $p < 0.01$). In contrast, when EU was in the low-score group, the relationship between SCD and ESG was not statistically significant (β = 0.078, t = 0.892, $p > 0.1$). These findings support H4.

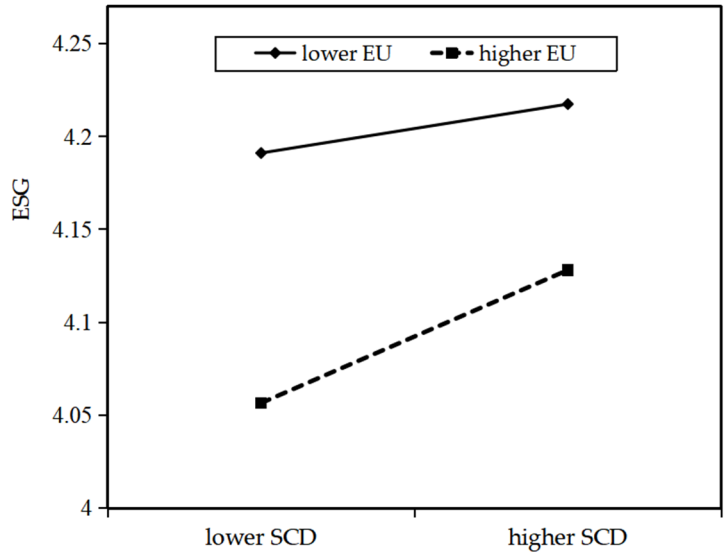


Figure 2. The moderating effect of EU.

5.5. Robustness Test

We employed several robustness-testing methods to ensure the reliability of the results. First, to eliminate the possibility of generating chance findings in this study, we changed the ESG measurement method to use the annual total score of the Huazheng ESG rating, and the results presented that the conclusion was not reliant on a single measurement methodology. The results are shown in column (1) of Table 7.

Second, we employ the inverse sum of the Herfindahl–Hirschman Index for the largest customer and supplier as an alternative SCD metric [35] to enhance robustness. The regression results are shown in column (2) of Table 7.

Third, to eliminate the potential distortion of data caused by the pandemic, the applicability of the research findings under normal economic conditions was ensured. We removed post-2020 data, restricted the sample period to 2010–2019, and then re-ran the regression analysis. The results are presented in column (3) of Table 7.

Fourth, to mitigate the impact of inter-industry variations, the analysis is concentrated on a single sector to validate the robustness of the conclusions within that specific industry. We retained only the data from the manufacturing industry and conducted the regression again; the result is shown in column (4) of Table 7.

Fifth, considering that the impact of SCD on ESG performance may exhibit a time lag, we conducted a regression analysis with SCD lagged by one period, following the method of a previous study [80]. The results presented in column (5) of Table 7 indicate that the one-period-lagged SCD has a positive effect on ESG performance at a 10% significance level, which further validates the robustness of the benchmark test.

Table 7. Robustness test.

Variable	(1) ESG	(2) ESG	(3) ESG	(4) ESG	(5) ESG
SCD	0.165 **	0.205 **	0.264 ***	0.208 **	0.137 *
	(2.575)	(2.020)	(2.860)	(2.277)	(1.761)
Size	0.209 ***	0.243 ***	0.249 ***	0.252 ***	0.190 ***
	(9.964)	(11.409)	(9.336)	(10.643)	(9.296)
Lev	−0.397 ***	−0.745 ***	−0.432 ***	−0.625 ***	−0.834 ***
	(−5.557)	(−8.853)	(−4.222)	(−6.625)	(−10.064)
ListAge	−0.130 ***	−0.230 ***	−0.308 ***	−0.307 ***	−0.105 ***
	(−4.408)	(−9.735)	(−9.829)	(−12.539)	(−4.798)
Cash	−0.185 ***	0.111	0.216 **	0.112	0.239 ***
	(−3.138)	(1.460)	(2.558)	(1.419)	(3.396)
Board	−0.045 **	−0.189 ***	−0.195 ***	−0.181 ***	−0.207 ***
	(−2.142)	(−6.802)	(−5.988)	(−6.480)	(−8.147)
Indep	0.154 **	0.345 ***	0.273 ***	0.384 ***	0.524 ***
	(2.346)	(3.932)	(2.798)	(4.506)	(6.814)
Soe	−0.137 ***	0.010	0.085	0.050	0.078
	(−5.627)	(0.254)	(1.176)	(1.172)	(1.630)
Liqui	−0.016	0.144 **	0.294 ***	0.168 **	0.129 *
	(−0.280)	(2.041)	(3.372)	(2.216)	(1.904)
Mfee	−0.452 ***	−1.281 ***	−0.492 ***	−1.283 ***	−1.637 ***
	(−2.953)	(−7.851)	(−2.795)	(−6.338)	(−10.609)
Fixed	−0.064	−0.125	0.112	−0.069	−0.274 ***
	(−0.697)	(−1.153)	(0.908)	(−0.643)	(−2.761)
_cons	2.020 ***	−0.092	−0.231	−0.177	0.891 *
	(4.392)	(−0.194)	(−0.385)	(−0.335)	(1.938)
Firms/Year/ Ind FE	Yes	Yes	Yes	Yes	Yes
N	35,316	25,093	23,752	22,353	22,353
R^2	0.587	0.589	0.685	0.577	0.610

Note: the t-statistics with individual cluster-robust standard errors are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Sixth, double machine learning was capable of more effectively addressing endogeneity issues, high-dimensional data, and complex nonlinear relationships, thereby validating the reliability and robustness of the regression analysis results. We further utilized double machine learning methods, including Random Forest, Gradient Boosting, Lasso Regression, Support Vector Machine, and Neural Networks, to estimate the impact of SCD on ESG. The results are presented in columns (1) to (6) of Table 8. The findings show that the coefficients for SCD estimated using each of these algorithms are significant at the 1% level, further confirming the robustness of our research findings.

Table 8. Double machine learning test.

Variable	(1) ESG	(2) ESG	(3) ESG	(4) ESG	(5) ESG	(6) ESG
θ_0	0.248 ***	0.361 ***	0.392 ***	0.579 ***	0.198 ***	0.462 ***
	(0.044)	(0.047)	(0.048)	(0.038)	(0.046)	(0.028)
DML model	RF	GBDT	RR	SVM	Lasso	NN
Control	Yes	Yes	Yes	Yes	Yes	Yes
Firms/Year /Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
N	35,316	35,316	35,316	35,316	35,316	35,316

Note: standard error are in parentheses; *** $p < 0.01$.

Finally, we further employed the sensitivity analysis method proposed by [81] to systematically examine the robustness of the baseline results under potential omitted variable interference. This method assumes that the omitted variable has n times the explanatory power of the comparison variable. Considering the firms' listing age had already been controlled for in the baseline model and that it was naturally correlated with potential omitted variables. Therefore, we chose listing age as the comparison variable for the sensitivity analysis. Figures 3 and 4 present the comparison results between the omitted variable and the comparison variable "ListAge". The results show that when the strength of the omitted variable is three times that of "ListAge", the regression coefficient remains positive (t-value = 1.95, $p < 0.1$). This indicates that even in the presence of omitted variables, as long as their impact on firm ESG performance does not exceed three times that of the comparison variable "ListAge", the baseline regression results will not be significantly affected. In fact, firm age is an important factor influencing firm ESG performance, and the likelihood of omitted variables having an impact strength more than three times that of firm age is low. Thus, the reliability of the baseline regression results is validated.

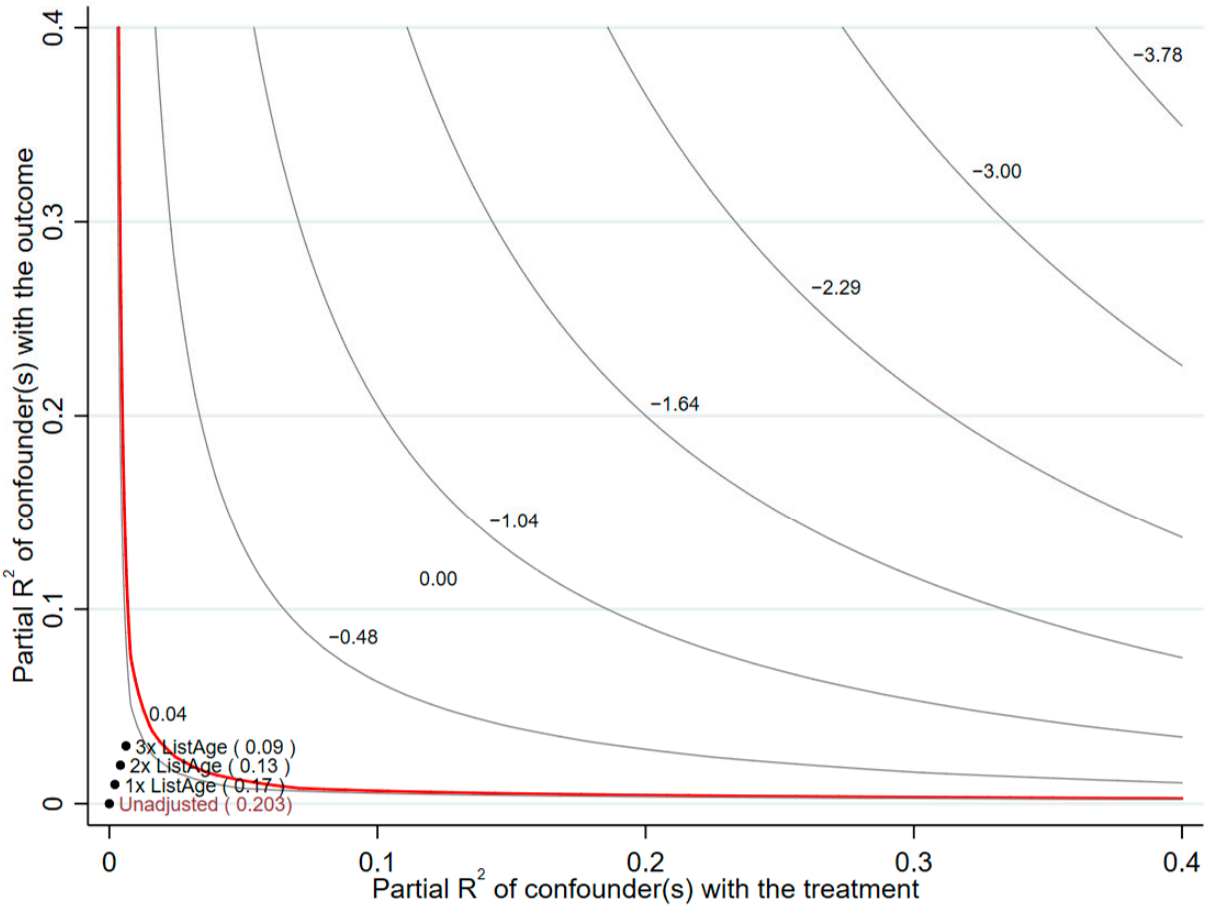


Figure 3. Sensitivity analysis coefficients.

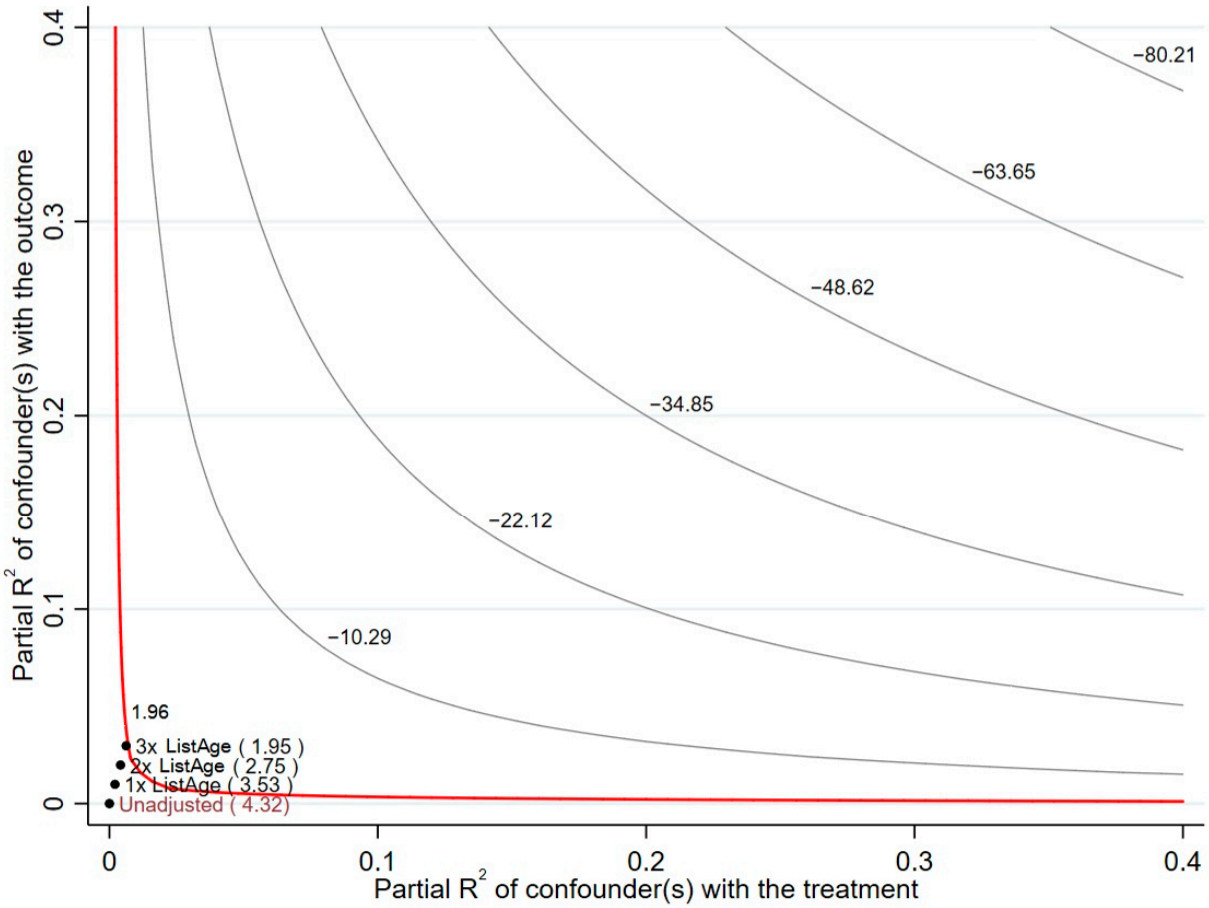


Figure 4. Sensitivity analysis t-value.

5.6. Endogeneity Test

We employed three methods for endogeneity testing. First, this study may face the issue of reverse causality, where firms with better ESG performance tend to have higher levels of SCD. To address this issue, we employed Two-Stage Least Squares (2SLS) method to mitigate potential endogeneity concerns [80]. The SCD of other firms in the same industry and year likely influences the SCD of the focal firm but does not directly affect its ESG performance, which satisfies the conditions for using an instrumental variable. Therefore, we employed the average SCD value of other firms within the same industry and year as an instrumental variable (SCD_IV1) and conducted regression. Columns (1) and (2) of Table 9 report the regression results obtained using the 2SLS method. The first-stage regression results show that the estimated coefficient of the instrumental variable is significantly positive, confirming its relevance. Additionally, the regression results passed the weak instrumental variable test and the underidentification test, indicating that the selection of the instrumental variable is reasonable. The second-stage regression results demonstrate that the coefficients of SCD, after fitting with exogenous variables, are significantly positive at the 5% levels This finding suggests that after addressing endogeneity using the instrumental variable, SCD still significantly enhances ESG performance.

Table 9. Endogeneity test.

Variable	2SLS		Heckman Two-Step Method		PSM
	(1) SCD	(2) ESG	(3) ESG_Dum	(4) ESG	(5) ESG
SCD_IV1	0.896 ***				
	(28.852)				
Mandatory			0.731 ***		
			(15.548)		
IMR			−0.655 ***	−0.655 ***	
			(−8.807)	(−8.807)	
SCD		0.355 **		0.200 ***	0.203 ***
		(2.391)		(2.751)	(2.971)
Size	0.034 ***	0.278 ***	0.277 ***	0.102 ***	0.243 ***
	(16.888)	(26.269)	(17.791)	(4.122)	(13.535)
Lev	−0.001	−0.709 ***	−0.925 ***	−0.165 *	−0.651 ***
	(−0.088)	(−10.354)	(−8.652)	(−1.797)	(−8.987)
ListAge	0.011 ***	−0.210 ***	−0.233 ***	−0.168 ***	−0.241 ***
	(4.423)	(−18.579)	(−13.717)	(−7.508)	(−12.545)
Cash	−0.028 **	0.557 ***	0.531 ***	−0.075	0.133 **
	(−1.982)	(8.539)	(5.207)	(−1.028)	(2.052)
Board	0.005	−0.223 ***	−0.215 ***	−0.082 ***	−0.185 ***
	(0.790)	(−7.696)	(−4.877)	(−3.014)	(−7.877)
Indep	0.051 ***	0.885 ***	1.263 ***	−0.202 **	0.377 ***
	(2.967)	(10.478)	(9.487)	(−2.057)	(5.234)
Soe	−0.019 ***	0.185 ***	0.124 ***	−0.019	0.055 *
	(−3.923)	(7.239)	(3.404)	(−0.435)	(1.794)
Liqui	−0.022 *	0.490 ***	0.405 ***	−0.011	0.160 ***
	(−1.721)	(7.906)	(4.327)	(−0.167)	(2.620)
Mfee	0.069 **	−0.922 ***	−1.346 ***	−0.492 ***	−1.098 ***
	(2.150)	(−6.518)	(−6.257)	(−3.037)	(−7.746)
Fixed	−0.040 **	−0.082	0.356 ***	−0.259 ***	−0.123
	(−2.453)	(−1.043)	(2.912)	(−2.591)	(−1.331)
Constant	−0.830 ***	−1.124 ***	−5.808 ***	3.329 ***	−0.066
	(−18.020)	(−4.246)	(−16.506)	(5.810)	(−0.163)
Kleibergen-Paap rk LM	823.414 ***				
Cragg-Donald Wald F	6177.117 ***				
Stock-Yogo	[16.380]				
Firms/Year/Ind FE	Yes	Yes	Yes	Yes	Yes
N	35,221	35,221	31,000	30,588	35,278
R^2	0.150	0.187		0.612	0.587

Note: the t-statistics with individual cluster-robust standard errors are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Second, this study employed the Heckman two-stage model for bias correction to mitigate the selection bias caused by the endogenous selection behavior of firms' SCD. In the first stage, whether a firm's ESG exceeded the annual industry average (ESG_Dum) was used as the dependent variable, and whether a firm was mandated to disclose a social responsibility report or sustainability report (Mandatory) was introduced as an exogenous explanatory variable. If a firm was required to disclose a report in a specific year, Mandatory was assigned a value of 1; otherwise, it was 0. A probit regression model was used for estimation, yielding the inverse Mills ratio (IMR) as the self-selection parameter. The IMR was then included as an additional control variable in the second-stage model for re-estimation, and the results are shown in columns (3) and (4) of Table 9. In the first stage, Mandatory is significantly positively

correlated with ESG_Dum at the 1% level, indicating that firms voluntarily disclosing social responsibility reports are more likely to have higher ESG performance. The selection of the exogenous variable is reasonable and aligns with theoretical expectations. In the second stage, the coefficient of IMR is significantly negative, and the regression coefficient of SCD on ESG is 0.200 ($p < 0.01$). The results demonstrate that after controlling for sample self-selection bias, the positive impact of SCD on ESG remains.

Third, this study employed the propensity score matching (PSM) method for robustness testing to thoroughly investigate the potential impact of sample selection bias on the research conclusions. First, the sample was divided into two groups based on the annual industry average level of SCD, with samples above the average assigned to the treatment group and the rest assigned to the control group. Second, a series of matching variables were selected to filter the sample. Third, the one-to-one nearest neighbor matching was used to pair each treatment group sample with the most similar control group sample. Finally, regression analysis was conducted on the matched sample firms. Figure 5 shows the distribution differences of the matching variables before and after matching. The matching results indicate that the standardized bias of the covariates is below 5%, meaning that most control variables passed the balance test. Column (5) of Table 9 presents the regression results for the PSM subsample, with a regression coefficient of 0.203 ($p < 0.01$), demonstrating that the findings of the baseline regression are robust.

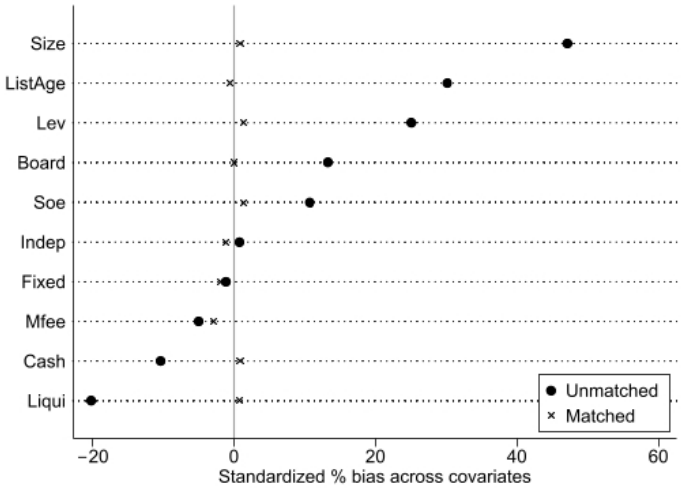


Figure 5. Distribution of standard deviation.

5.7. Heterogeneity Analysis

The empirical tests in the preceding section sufficiently demonstrated that SCD can significantly enhance ESG. However, they have not revealed whether this positive effect is heterogeneous across different types of enterprises. To gain a deeper understanding of the heterogeneous effects of SCD on ESG, we conducted analyses from the perspectives of firm characteristics, industry characteristics, and regional heterogeneity.

First, heterogeneity analysis based on firm size was performed. Large enterprises typically possess more resources, such as capital, technology, and talent, while small and medium-sized enterprises (SMEs) may have limited resources, making it challenging to effectively manage diversified supply chains and potentially increasing operational risks due to SCD. In this study, the sample was divided into large enterprises and SMEs based on the median firm size within each year and industry for group testing. The results, as shown in column (1) of Table 10, indicate that the regression coefficient of SCD on ESG for the SMEs group is 0.155 ($p < 0.1$). Column (2) of Table 10 shows that the regression coefficient of SCD on ESG for the large enterprise group is 0.214 ($p < 0.05$). These results

suggest that the positive impact of SCD on ESG is more pronounced in large enterprises. A possible explanation is that large enterprises generally have stronger market influence and resources, as well as mature supply chain management systems, enabling them to optimize supply chain structures to enhance ESG performance.

Table 10. Heterogeneity analysis of firms and industries.

Variable	(1) ESG	(2) ESG	(3) ESG	(4) ESG	(5) ESG	(6) ESG
SCD	0.155 *	0.214 **	0.115	0.201 **	0.176 **	0.345 **
	(1.703)	(1.969)	(1.228)	(2.069)	(2.245)	(2.497)
Size	0.209 ***	0.355 ***	0.240 ***	0.257 ***	0.260 ***	0.200 ***
	(6.029)	(11.118)	(10.023)	(10.117)	(12.314)	(5.568)
Lev	−0.649 ***	−0.727 ***	−0.676 ***	−0.657 ***	−0.668 ***	−0.605 ***
	(−6.441)	(−5.870)	(−6.782)	(−6.695)	(−7.889)	(−4.211)
ListAge	−0.349 ***	−0.087 **	−0.223 ***	−0.249 ***	−0.232 ***	−0.269 ***
	(−12.942)	(−2.325)	(−8.065)	(−9.396)	(−10.503)	(−6.467)
Cash	0.059	0.150	0.197 **	0.037	0.233 ***	−0.110
	(0.732)	(1.314)	(2.285)	(0.400)	(3.106)	(−0.851)
Board	−0.164 ***	−0.189 ***	−0.160 ***	−0.169 ***	−0.179 ***	−0.196 ***
	(−5.181)	(−5.339)	(−4.818)	(−4.829)	(−6.576)	(−4.403)
Indep	0.343 ***	0.332 ***	0.415 ***	0.344 ***	0.319 ***	0.535 ***
	(3.500)	(3.177)	(4.125)	(3.242)	(3.821)	(3.977)
Soe	0.045	0.079 **	−0.006	0.098 **	0.077 **	0.034
	(0.869)	(2.017)	(−0.135)	(2.358)	(2.210)	(0.550)
Liqui	0.104	0.158	0.209 ***	0.141	0.120 *	0.251 **
	(1.288)	(1.566)	(2.587)	(1.618)	(1.668)	(2.168)
Mfee	−1.026 ***	−0.983 ***	−1.022 ***	−0.895 ***	−1.076 ***	−1.178 ***
	(−5.935)	(−3.327)	(−5.508)	(−4.301)	(−7.074)	(−3.080)
Fixed	−0.093	−0.167	−0.258 **	−0.089	−0.186	−0.091
	(−0.769)	(−1.084)	(−2.102)	(−0.707)	(−1.623)	(−0.654)
_cons	0.776	−2.989 ***	−0.114	−0.430	−0.447	0.915
	(1.056)	(−4.068)	(−0.214)	(−0.742)	(−0.946)	(1.125)
Firms/Year/Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
N	17,457	17,522	17,725	16,642	25,290	9854
R^2	0.630	0.597	0.637	0.629	0.601	0.581

Note: the t-statistics with individual cluster-robust standard errors are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Second, we performed heterogeneity analysis of the degree of industry competition degree. Industry competition may affect companies' willingness and capability to disclose ESG information. In a fiercely competitive market, firms are more inclined to leverage external resources to address such challenges to maintain their competitiveness within the supply chain or defend against attacks from competitors. To explore how the degree of industry competition differentially impacts the effect of SCD on ESG, we used the Herfindahl Index to assess the intensity of competition in the market and divided the sample into low-competition and high-competition groups based on the annual industry median. The results show that, as presented in column (3) of Table 10 for the low-competition group, the coefficient of the impact of SCD on ESG is 0.115 ($p > 0.1$), while in column (4), for the high-competition group, this coefficient is 0.201 ($p < 0.05$). A possible reason for this is that enterprises in highly competitive industries typically face stronger market supervision and reputational risks. To maintain their competitive advantage, these enterprises may be more proactive in enhancing their ESG performance through SCD.

Third, heterogeneity analysis based on high-pollution enterprises was performed. High-pollution enterprises typically face stronger environmental pressures and regulatory requirements, making them more inclined to improve their environmental performance through SCD to comply with regulations and mitigate environmental risks. To test this effect, we categorized enterprises into high-pollution and non-high-pollution groups based on the CSMAR database. As shown in column (5) of Table 10, the regression coefficient of SCD on ESG for the non-high-pollution group is 0.176 ($p < 0.05$). Column (6) of Table 10 indicates that the regression coefficient of SCD on ESG for the high-pollution group is 0.345 ($p < 0.05$). The results suggest that the positive impact of SCD on ESG is more pronounced in high-pollution enterprises. A possible explanation is that high-pollution enterprises are typically subject to stricter environmental regulations and greater pressure to reduce emissions. They may be more inclined to replace high-pollution suppliers, introduce clean energy suppliers, or seek to collaborate with diversified suppliers, thereby reducing their environmental impact and enhancing their ESG performance.

Fourth, industry heterogeneity analysis based on production factor intensity was performed. We categorized the sample into labor-intensive, capital-intensive, and technology-intensive industries for regression analysis. As shown in column (1) of Table 11, the regression coefficient of SCD on ESG for the labor-intensive group is 0.252 ($p < 0.1$). Column (2) of Table 11 shows that the regression coefficient of SCD on ESG for the capital-intensive group is 0.267 ($p < 0.05$). Column (3) of Table 11 shows that the regression coefficient of SCD on ESG for the technology-intensive group is 0.143 ($p > 0.1$). The results suggest that the positive impact of SCD on ESG is more pronounced in labor-intensive and capital-intensive enterprises. A possible explanation is that labor-intensive enterprises often face more labor-related issues, and SCD can help these enterprises to better manage social responsibilities, for instance, by selecting compliant suppliers or promoting labor standards within the supply chain, thereby enhancing ESG performance. Capital-intensive enterprises tend to rely on substantial capital investments, typically exhibit constrained organizational agility due to the inherent rigidity of their operational and financial structures. SCD can mitigate the risk of supply chain disruptions and improve efficiency, thus boosting ESG performance. Technology-intensive enterprises depend on advanced technologies and innovation, and there is limited scope and demand for SCD, thus having an insignificantly impact on ESG performance.

Finally, based on the geographical location of enterprises, we categorized the sample into enterprises in the eastern, central, and western regions for testing. Table 11 presents the empirical results from columns (4) to (6), showing that SCD positively impacts ESG performance for enterprises in the eastern and central regions, while no significant effect is observed for enterprises in the western region. A possible explanation is that the eastern and central regions have higher levels of economic development, more advanced infrastructure [82], and greater resource allocation toward technological innovation and green development. These factors make it easier for enterprises in these regions to adopt advanced technologies and management practices when implementing SCD strategies, thereby promoting higher ESG performance.

Table 11. Analysis of industrial and regional heterogeneity.

Variable	(1) ESG	(2) ESG	(3) ESG	(4) ESG	(5) ESG	(6) ESG
SCD	0.252 *	0.267 **	0.143	0.193 **	0.560 ***	0.003
	(1.670)	(2.124)	(1.464)	(2.383)	(3.098)	(0.018)
Size	0.216 ***	0.236 ***	0.266 ***	0.236 ***	0.273 ***	0.272 ***
	(4.949)	(7.042)	(9.881)	(10.865)	(5.536)	(5.095)
Lev	−0.612 ***	−0.381 ***	−0.817 ***	−0.679 ***	−0.446 **	−0.608 ***
	(−3.855)	(−2.874)	(−7.610)	(−8.033)	(−2.132)	(−2.707)
ListAge	−0.151 ***	−0.293 ***	−0.282 ***	−0.253 ***	−0.231 ***	−0.169 ***
	(−3.139)	(−7.394)	(−10.105)	(−11.233)	(−4.141)	(−2.687)
Cash	−0.044	0.046	0.178 **	0.126 *	0.311 *	−0.173
	(−0.293)	(0.337)	(2.008)	(1.692)	(1.837)	(−0.804)
Board	−0.146 ***	−0.184 ***	−0.192 ***	−0.185 ***	−0.146 **	−0.232 ***
	(−3.166)	(−3.921)	(−5.857)	(−6.504)	(−2.365)	(−3.556)
Indep	0.331 **	0.426 ***	0.347 ***	0.465 ***	0.096	0.315
	(2.109)	(3.185)	(3.466)	(5.508)	(0.509)	(1.453)
Soe	0.030	0.075	0.037	0.063	0.074	−0.032
	(0.549)	(1.300)	(0.759)	(1.623)	(1.174)	(−0.419)
Liqui	0.054	0.350 ***	0.057	0.146 **	0.217	0.192
	(0.406)	(3.072)	(0.648)	(2.037)	(1.421)	(1.050)
Mfee	−0.568	−1.388 ***	−1.074 ***	−1.137 ***	−0.804 *	−1.252 ***
	(−1.532)	(−4.740)	(−5.587)	(−6.920)	(−1.926)	(−3.077)
Fixed	−0.396 **	0.012	−0.221	−0.148	−0.108	−0.219
	(−2.081)	(0.080)	(−1.550)	(−1.352)	(−0.438)	(−0.944)
_cons	0.255	0.072	−0.383	0.110	−0.840	−0.778
	(0.261)	(0.095)	(−0.636)	(0.225)	(−0.764)	(−0.636)
Firms/Year/Ind FE	Yes	Yes	Yes	Yes	Yes	Yes
N	7692	9496	17,293	25,554	5015	3746
R^2	0.636	0.603	0.590	0.580	0.594	0.613

Note: the t-statistics with individual cluster-robust standard errors are in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6. Discussion and Implications

6.1. Discussion

Based on the SCP framework, in this study, a model was designed to examine the impact of SCD on ESG and its potential mechanisms. Based on the empirical results, several important conclusions were drawn. First, the findings indicate a positive correlation between SCD and ESG. These results are consistent with those reported in the literature. As Zheng et al. [83] suggested, customer concentration negatively impacts ESG. Wen et al. [80] posited that customer concentration is negatively correlated with suppliers' CSR performance. Furthermore, Richard et al. [61], working from a resource-based perspective, demonstrated that supplier diversification is a valuable resource for procurement organizations to create competitive advantages. Our findings also support this view, confirming that SCD can enhance ESG.

Second, the mechanism analysis reveals that green innovation and digital transformation play significant roles in the relationship between SCD and ESG, consistent with previous research. Specifically, SCD facilitates technological exchange and cooperation among different suppliers, enhancing enterprises' ability to produce green products [63], and green innovation can significantly improve a company's ESG. Furthermore, Feng and Wang [36] argue that SCD can promote corporate digital transformation. Zhao and Cai [33] and Qi et al. [84] suggest that digital transformation has a positive effect on improving a company's ESG.

Finally, this study indicates that environmental uncertainty plays a positive moderating role between SCD and ESG. This finding aligns with prior research [85], who suggest that under higher environmental uncertainty, companies increase their corporate social responsibility practices to reduce enterprise risks. Similarly, managers may be more willing to increase ESG engagement during periods of high uncertainty, and economic policy uncertainty positively impacts ESG [12].

6.2. Theoretical Implications

This study makes several significant contributions to the theoretical research on corporate supply chain management and ESG performance. First, our research introduces the SCP framework into the study of ESG performance and expands supply chain-level factors as antecedents affecting ESG performance, providing a new perspective for enterprises to enhance their ESG performance through supply chain management. This differs from previous studies that explored various factors influencing ESG performance from the perspectives of resource-based theory [14,86], stakeholder theory [8,87], institutional theory [88], and resource dependence theory [89]. Based on the SCP framework, this study discusses how the structural characteristics and resource effects of SCD can change corporate conduct and, therefore, affect ESG performance. It also conducts comparative analyses across firm characteristics, industry characteristics, and different regions. This responds to the call for research on how sustainable supply chain management at the supply chain level can influence ESG [21]. To the best of our knowledge, this study is one of the first to explore ESG performance from the perspective of the SCP framework, expanding the theoretical horizons of ESG research.

Second, based on the SCP framework, we constructed a theoretical framework of "supply chain diversification (Structure)–green innovation and digital transformation (Conduct)–ESG Performance (Performance)". The findings not only explain how SCD affects ESG performance but also expand research on the antecedents of ESG performance. On the one hand, previous literature suggests that SCD can increase corporate access to external resources [35,36], and our study supports this view, confirming that SCD can enhance the resource effect of enterprises. On the other hand, previous studies have argued that ESG is influenced by internal strategic factors, corporate characteristics, corporate governance, board diversity [4,14,90], and external industry competition environments [91]. In contrast, we considered how SCD at the structural level affects corporate green innovation and digital transformation conduct, in turn influencing ESG. This enriched the research on the mechanism of SCD and the influencing factors of ESG, offering new perspectives on how enterprises can achieve ESG goals through managing sustainable supply chains.

Finally, we explored the boundary relationship of environmental uncertainty. The existing literature primarily considers the direct impact of environmental uncertainty on ESG [11,34]. However, there is less focus on how environmental uncertainty, as a moderating variable, influences the impact of supply chain structure on corporate non-financial performance. This study confirms that environmental uncertainty enhances the effect of SCD on ESG. This finding provides theoretical insights for formulating effective sustainable supply chain management strategies to enhance ESG in uncertain environments.

6.3. Management Implications

These findings have significant implications for guiding enterprises in formulating supply chain strategies and enhancing sustainable performance. Firstly, senior executives and operations managers should fully recognize the strategic value of SCD, reduce dependence on traditional linear supply chains, and rationally build diversified supply chain networks based on business needs and strategic objectives to gain external resources

through collaborative partnerships with diverse stakeholders. Simultaneously, ESG goals should be integrated into the risk assessment and incentive mechanisms for supply chain partners, promoting sustainable procurement and collaborative innovation, enabling long-term improvements in ESG performance.

Secondly, enterprises should prioritize green innovation and digital technologies when implementing SCD strategies. On one hand, to ensure sustainable development, enterprises should actively engage suppliers and partners with green innovation advantages across various fields, establishing cross-industry green innovation collaboration networks. Through joint research and development, sharing green technology resources, and other approaches, they can jointly explore green innovation solutions for energy conservation, emissions reduction, resource recycling, etc., thereby stimulating green innovation vitality across different supply chain sectors. Simultaneously, by leveraging the abundant resources and market channels brought by SCD, enterprises can accelerate the transformation and application of green innovation achievements. On the other hand, enterprises should accelerate the deep integration of digital technologies with supply chain operations and management. By embedding technologies such as RFID, IoT, and blockchain into supply chains, they can ensure the transparency and traceability of ESG data, not only enhancing stakeholder trust but also better meeting regulatory requirements. Additionally, enterprises can further enhance the application of artificial intelligence to support demand forecasting and supplier evaluation. By integrating these digital technologies, enterprises can improve supply chain visibility and sustainability, enhance resource resource allocation efficiency, and strengthen environmental governance capabilities, thereby providing robust technological support for ESG goals.

Lastly, the implementation of SCD strategies could be adapted for different types of enterprises. From a market environment standpoint, in situations of high environmental uncertainty, enterprises can establish dynamic risk assessment mechanisms and implement SCD strategies at appropriate times to mitigate supply chain risks and effectively promote ESG practices. Regionally, enterprises located in China's eastern region can leverage their strong economic foundation and open the market environment to further enhance ESG performance by exploiting the advantages of SCD. From an industry standpoint, enterprises in highly competitive industries should utilize SCD to integrate resources from various stakeholders and strengthen collaboration with upstream and downstream partners to improve ESG performance. Enterprises in high-pollution industries should treat SCD as a critical opportunity for ESG transformation, increasing investments in clean technologies and environmental protection equipment and encouraging upstream and downstream suppliers to jointly reduce pollutant emissions, thereby achieving sustainable production. Enterprises in capital-intensive industries should focus on the in-depth integration of SCD and ESG and increase investments in technology and equipment for green supply chain construction to enhance the stability and sustainability of the supply chain. Enterprises in labor-intensive industries should diversify supply chains to strengthen cooperation with suppliers, promote social responsibility management in the supply chain and improve employee satisfaction and loyalty, laying a solid foundation for their own sustainable development. From the perspective of enterprise characteristics, large scale enterprises and those with high capital intensity should fully leverage their resource and scale advantages to guide supply chain partners in adopting ESG principles, formulate and improve industry standards, and enhance the overall sustainability of the industry.

6.4. Limitations and Future Research

This study has some limitations. First, it primarily focuses on listed companies in China's A-share market, which may limit the universality of the conclusions. Future

studies could include samples from more countries or regions, which would help us to understand the relationship between SCD and ESG performance more comprehensively. Second, although this study considers green innovation and digital transformation as potential mechanisms, there may be other unidentified mediating variables. Finally, the role of environmental uncertainty as a moderating variable has only been preliminarily verified. However, future research could delve deeper into the specific impact of economic policy uncertainty on the relationship between SCD and ESG.

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