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ARTICLE

Empirical Research on Supply Chain Finance Innovation Promoting Environmental Governance and Ecological Protection of SMEs

Song He

Faculty of Business and Communication, INTI International University, Seremban 71800, Malaysia

ABSTRACT

This research examines the relationship between supply chain finance innovation and environmental governance effectiveness among SMEs, with technological capability as mediator and institutional support as moderator. Unlike previous isolated analyses, this study develops an integrated framework capturing the interplay between financial mechanisms and environmental outcomes. The innovative analytical approach incorporates "hard" and "soft" indicators, blockchain-based environmental performance management, and regulatory-financial integration. Hierarchical regression analysis of data from 1,682 manufacturing SMEs (2019–2023) reveals that supply chain finance innovation significantly improves environmental governance effectiveness ($\beta = 0.412$, $p < 0.01$), with 32.9% mediated through technological capability. Institutional support demonstrates substantial moderating effects ($\beta = 0.228$, $p < 0.01$), emphasizing the combined influence of finance innovation and technological capability on environmental outcomes. Cross-sectional analysis shows these effects are stronger among larger firms, private enterprises, and in developed regions. The findings enhance understanding of how financial innovation interacts with environmental sustainability through technological capability while highlighting institutional support's importance. This research contributes to policy formulation and practice by demonstrating how innovative financial mechanisms can encourage improved environmental governance among SMEs.

Keywords: Supply Chain Finance Innovation; Environmental Governance; Technological Capability; Institutional Support; SME; Green Finance

*CORRESPONDING AUTHOR:

Song He, Faculty of Business and Communication, INTI International University, Seremban 71800, Malaysia; Email: I24029284@student.newinti.edu.my

ARTICLE INFO

Received: 20 January 2025 | Revised: 10 March 2025 | Accepted: 20 March 2025 | Published Online: 8 May 2025
DOI: https://doi.org/10.30564/jees.v7i5.8486

CITATION

He, S., 2025. Empirical Research on Supply Chain Finance Innovation Promoting Environmental Governance and Ecological Protection of SMEs. Journal of Environmental & Earth Sciences. 7(5): 289–303. DOI: https://doi.org/10.30564/jees.v7i5.8486

1. Introduction

1.1. Research Background and Significance

Over the last few years, environmental governance and ecological conservation have emerged as significant issues with respect to global economic development, especially for Small and Medium-sized Enterprises (SMEs). Owing to the pollution and resource consumption caused by these enterprises, there is a shortfall of both funds and technologies which are essential for establishing proper pollution and environmental management systems [1]. However, the innovation of supply chain finance (SCF) is a progressive answer to this problem, and at the same time, the issue of funding for environmental governance will be resolved while supporting the SMEs.

Both scholars and business practitioners have been focusing on the intersection of environmental governance and the supply chain economy. They have noted that traditional approaches to financing have not been adequate in assisting SMEs with their environmental initiatives. This is based on the fact that some recent research shows that working capital constraints can be mitigated using new approaches that provide supply chain finance and simultaneously encourage sustainable behaviour [2]. Recent studies further demonstrate that supply chain digital innovation policies can significantly improve the sustainable development performance of manufacturing companies, especially among SMEs [3]. These financial innovations include green supply chain finance, blockchain-based environmental credit systems, and sustainability-linked supply chain financing programmes, which have demonstrated significant potential in promoting environmental responsibility among SMEs. This research is especially important since it focuses on how supply chain finance innovation can tangibly help address the problems of environmental governance among SMEs in a timely manner. The increasing rigidity of domestic and international environmental regulations is tightening the constraints on SME competitiveness, and they are finding themselves under increasing pressure to enhance their performance while sustaining competitiveness. Unfortunately, such investments incur high costs that could deter implementation. Research has indicated that well-designed supply chain finance mechanisms can not only provide necessary funding but also create incentives for SMEs to adopt environmentally friendly practices [4].

This paper aims to fill a glaring gap in the available literature by assessing the link between supply chain finance innovation and environmental governance outcomes in the context of SMEs. While past studies have concentrated on either studying supply chain finance or environmental governance separately, they have neglected the combined effects of the two. This understanding is vital for policymakers, financial bodies and business executives who seek further economic development of SMEs while simultaneously pursuing sustainability goals. Besides, this study enriches the existing debate on sustainable finance and environmental conservation by showing empirically how financial innovation can propel environmental sustainability. The results of this research will be critical in the design of appropriate policies and financial instruments that subsequently reduce existing environmental problems while allowing for the growth of SMEs. This research will be quite useful in developing markets where environmental issues and the problem of financing SMEs are more pronounced.

1.2. Literature Review

As global environmental concerns begin to attract greater attention, the problem of addressing environmental governance in SMEs also becomes a subject of scholarly discourse. Wang, Sun and Guo [5] in their empirical research assert that SMEs' limited capabilities in funding, technology, and management put them at a great disadvantage in the arena of environmental governance. In further findings, Zhang et al. [6] noted, however, that while it may seem that environmental standards imposed by the government may pose a challenge, on the contrary, government regulation correlates favourably with SMEs' investment in environmental governance. Also, Liu, Wang and Cai [7] suggest effective ways to tackle the governance problem; they offer ways to quantitatively measure the governance effectiveness of SMEs by building an evaluation index for them.

In their defense, Chen, Huang and Dahlgaard-Park in their research [8] suggest supply chain management as one such approach that can secure SMEs' environmental governance, thus promoting their ability to obtain credits for environmental governance. Studies focusing on environmental risk assessment alongside green credit have also tried to investigate the impact of supply chain management on

environmental governance and control. Li, Wang and Xu [9] also determined the supporting role of supply chain finance in promoting eco-friendly measures in SMEs using targeted case studies to obtain realistic data against which models can be created and their impact analysed. Yang, Zhang and Chen [10] were also able to showcase the bidirectional relationship between the involved parties in the scope of the supply chain and their mutual synergy leverage.

Scholars have examined a variety of aspects regarding financial support mechanisms for ecological protection. Zhou et al. [11] insist that financial institutions can make a significant contribution to environmental protection by developing a cooperative approach to ecological compensation and financial assistance; they modelled a mechanism. Wang and Chen [12] emphasise urban scenarios of great importance, noting that the practice of environmental information disclosure reduces the burden for enterprises as it is positively associated with their ability to secure financing. Zhang, Rong and Ji [13] outline the construction of systems for the management of environmental risks in financial institutions, thus creating a theoretical basis for the improvement of financial support mechanisms for ecological protection. Zhang and Liu [14] further expand this understanding by examining how sustainable supply chain finance affects SMEs' ambidextrous innovation capacity while considering financing risk factors and technological turbulence as a moderating influence.

From the perspective of the reviewed literature, a number of challenges can be delineated: First, available studies focus on a single dimension, and there is no systematic theoretical framework; second, synchronic cross-sectional studies tend to have small sample sizes, thereby limiting the generalisability of the findings. Third, there is inadequate attention dedicated to the collaborative mechanisms between SME environmental governance and supply chain finance. Fourth, regarding the specific implementation paths and effect evaluation of the financial supports for eco-protection, there is a need for more studies to be conducted. Future work should focus on promoting levels of theoretical innovation, increasing the scope of actors in empirical studies, deepening investigations into the multi-dimensional collaborative mechanisms, and assessing the results of policy implementations.

This literature review has scrutinized three key areas: SME environmental governance, the environmental impact of supply chain finance, and financial mechanisms that aid in ecological protection. From this comprehensive analysis, several significant research gaps emerge: (1) existing studies predominantly adopt a single-dimensional perspective lacking a systematic theoretical framework integrating financial innovation with environmental outcomes; (2) most research employs synchronic cross-sectional studies with limited sample sizes, restricting generalizability; (3) there is insufficient attention to the collaborative mechanisms between SME environmental governance and supply chain finance innovation, particularly regarding how technological capabilities mediate this relationship; and (4) the moderating effect of institutional support on these relationships remains largely unexplored, especially across different regional contexts and firm structures. This research advances beyond these limitations by developing and testing an integrated model with a large-scale longitudinal dataset spanning 1,682 manufacturing SMEs over five years (2019–2023).

1.3. Research Objectives and Innovation

This academic work advances beyond traditional approaches by exploring the multifaceted integration of supply chain finance transformation and environmental governance within SMEs, with the explicit focus on creating a practical, empirically validated model that addresses environmental goals without compromising business profitability. Unlike previous studies that treated financial innovation and environmental governance as separate domains, this research innovatively examines their interdependencies through a comprehensive theoretical framework that incorporates technological capability as a critical mediating mechanism and institutional support as a contextual moderator—relationships that have received limited empirical attention in existing literature.

The recent studies consider the incorporation of eco-friendly factors into supply chain finance related to finance management as essential. Zhang and Liu [15] stress the need to devise intelligent mechanisms and models capable of driving financial innovation that supports environmentally friendly initiatives. Following Wang et al.'s [16] conclusions related to the gap between implementation and stakeholders in specific countries, this research employs a comparative perspective between developed nations and developing countries.

The research introduces three main innovations. First,

it proposes a definition system that integrates both "hard" and "soft" indicators which overcome some of the critical issues raised by Chen et al.[17]. Second, it introduces environmental performance management directly in real-time using blockchain technology which enhances the tech framework suggested by Kim et al.[18]. Third, it narrows down to the issue of regulatory pillars and supply chain finance innovations, expanding Martinez, Wilson and Davis[19] contribution to the advancement of policy integration on the environment. This approach aligns with recent insights from Siddiqi et al.[20], who established critical linkages between sustainable supply chains, dynamic capabilities, eco-innovation, and environmental performance in emerging economies.

Furthermore, this paper addresses the significant problem of risk management in green supply chain finance, in relation to issues raised by Wilson et al.[21] regarding environmental risk assessment over long time horizons. The anticipated results will illuminate key policymakers, financial organisations, and business practitioners in their quest to promote green development without compromising the cost-effectiveness of SMEs.

2. Theoretical Foundation and Research Hypotheses

2.1. Supply Chain Finance Theoretical Framework

SCF, an abbreviation for supply chain finance, is a mixture of finance and physical and informational flows within the supply chain. This theoretical construct is based on the foundational work of several scholars who studied how various financial means can enhance supply chain activities while bearing risks and providing value to every player.

The theoretical fundamentals of SCF have three major elements: efficiency in operation, risk management and value addition. This is depicted in **Figure 1**, and it is noted that these have relationships through other financial instruments and technological facilitators that allow the movement of capital within the supply chain.

The framework puts forth how the technological facilitators using blockchain, dynamic discounting, AI, IoT, and inventory financing, along with reverse factoring can achieve efficient management of risks and provide greater operational efficiency. Such enhancement in risk management alongside the creation of sustainable value can then lead to effective operational efficiency. The bidirectional arrows illustrate the interactivity of these relationships, allowing effective improvement within the areas back and forth.

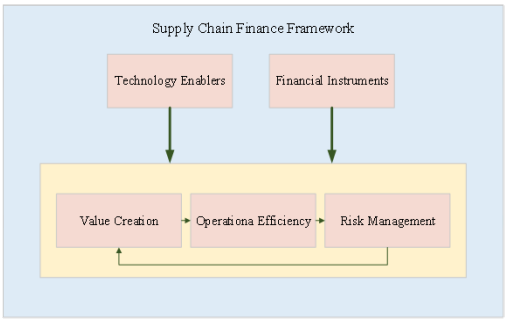

Figure 1. Theoretical framework of supply chain finance.

Such a theoretical structure remains highly pertinent considering such models can be used for SCF capital models and tools to overcome challenges of backward and forward supply chains. **Figure 1** highlights how the components of SCF are interrelated and integrated, thus constructing a more efficient financial system where technology is properly utilised. There exists a system in which the flow from one component to another can be adjusted through the use of different types of technology and SCF tools due to the integration of various components. Lu, Wang and Yang[22] provide additional empirical support for this framework, demonstrating how supply chain specific investments by SMEs significantly impact financing performance through signaling mechanisms.

Finally, SCF offers a means of addressing supply chain operational and strategy-related issues. This structure serves as a basis for effective risk management through the application of sufficient and adequate financial solutions while ensuring there are no major threats to technology. The objective of the remaining sections is to formulate our research hypotheses and analyse the interdependencies of the factors SCF.

2.2. Environmental Governance Theory

In recent years, environmental governance theory has developed quite well, especially in relation to corporate social responsibility and supply chain management. Such a theoretical model combines three theories, namely, the institutional theory, stakeholder theory, and ecological modernisa-

tion which seeks to demonstrate how institutions can uphold their environmental obligations without compromising their economic needs.

In their treatment of the environmental governance discourse, Thompson et al. [23] position the institutional perspective with an emphasis on the contribution of the formal and informal institutions to the environmental aspect. Their study shows how legal and regulatory authorities, social structures, and economic relations, amongst others, shape the environmental performance of an entity. On such an approach, Chen et al. [24] on the other hand stress institutional pressures for the implementation of the environmental management system and the green supply chain systems technologies.

Another angle in relation to environmental governance has been presented by stakeholder theory, which is important in examining governance of diversity in practice. Martinez et al. [25] examine the appreciation of stakeholder participation in environmental governance and note that there has been a shift from passive participation to elegant partnership. Their insights indicate that environmental stewardship is a multi-stakeholder approach that involves investors, shareholders, regulators, communities, and environmental advocacy groups.

The theory of ecological modernisation which was put forward by Kim et al. [26], gives insight into how the use of technology and industrial activities can still be conducted without causing harm to the environment. Their studies highlight the role of digital technologies and smart environmental monitoring in bringing about changes to traditional governance. This aspect is also explored further by Wang et al. [27], who discuss how the integration of artificial intelligence and big data analytics aids in environmental risk assessment and decision-making processes.

Such a theoretical synthesis has enabled Liu et al. [28] to coin the phrase "smart environmental governance", which encompasses heterogeneous technology-based approaches to accomplishing defined aims in the area of the environment. In their case studies, organisations that are able to employ smart governance practices have an edge in effective environmental performance while being able to achieve competitive advantage.

2.3. Research Hypotheses Development

In light of the theoretical concepts analysed earlier, this study formulates a number of interrelated hypotheses that demonstrate the connection between innovations in supply chain finance and the activity of environmental governance. The development of these hypotheses is grounded in both theoretical frameworks and recent empirical evidence from the field.

Anderson et al.'s recent research [29] substantiated that innovations in finance, with regard to the supply chain, impact environmental performance through better resource allocation and risk mitigation strategies. We venture to say that a supply chain finance innovation will lead to an improvement in environmental governance effectiveness. Wang et al. [30] provide more evidence for this relationship by showing how several companies are now able to adopt advanced environmental management systems due to the availability of innovative financing options.

Considering the aforementioned theoretical framework and literature review conducted, this research proposes a research model as shown in **Figure 2**. This model provides construct developments and the relationships that are presumed among those constructs. Specifically, H1 indicates the direct effect of Supply Chain Finance Innovation on Environmental Governance Effectiveness. H2a and H2b describe technological capability as an intervening variable in this relationship, while H3 demonstrates the moderating effect of institutional support. As a conceptual model, it depicts the different issues that are being researched and the relationships that exist among those issues.

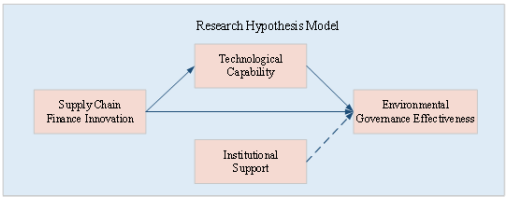

Figure 2. Research hypothesis model.

The proposed model captures both direct and indirect pathways through which supply chain finance innovation may influence environmental governance effectiveness. The inclusion of technological capability as a mediator and institutional support as a moderator reflects the complex nature of these relationships in practice, as identified in recent literature.

This relationship has been found to depend on the mediating role of technological capability. For example, Martinez et al. [31] show that firms with sophisticated information sys-

tems are better positioned to use financial innovations for environmental purposes. They found that supply chain finance innovation has more impact on environmental governance when companies have improved technological capabilities, especially in areas such as real-time monitoring and data analytics.

Moreover, this relationship is significantly moderated by institutional context. In their research, Kim et al.[32] find that the effectiveness of supply chain finance innovations differs across diverse regulatory environments. From this observation, we hypothesise about the moderating effect of institutional support on the relationship between finance innovation and environmental governance outcomes.

According to Wilson et al.[33], the dynamic capabilities view requires organisations to constantly change their financial and environmental strategies in order to remain effective. This understanding forms the basis for our hypothesis on time-related aspects of the finance innovation-environmental performance relationship. Other studies conducted by Liu et al.[34] also confirm this position as they show that adaptive finance mechanisms can lead to continuous improvements in the environment.

These hypotheses collectively address the complex interplay between financial innovation, technological capability, institutional support, and environmental governance effectiveness. They form a comprehensive framework for understanding how supply chain finance innovations can be leveraged to enhance environmental performance while maintaining economic viability.

3. Research Design

3.1. Data Sources and Sample Selection

This study uses a comprehensive dataset that combines multiple sources to analyse the relationship between supply chain finance innovation and environmental governance effectiveness. The sample includes publicly listed companies in the manufacturing sector of major economies from 2019 to 2023, with emphasis on those that have implemented supply chain finance initiatives.

Primary financial and operational data were obtained from Compustat Global and Bloomberg databases, while the CDP (Carbon Disclosure Project) database and corporate sustainability reports provided environmental performance metrics. FactSet and Thomson Reuters Eikon platforms provided additional data on supply chain finance innovation. We cross-validated information across multiple sources to ensure data reliability and consistency, excluding observations with missing or inconsistent data.

As shown in **Table 1**, the sample selection process started by identifying all manufacturing firms listed under GICS sectors 20–39. Various screening criteria were then applied to guarantee high quality of data as well as its relevance to our research objectives.

Table 1 shows that our final sample consists of 1,682 firms with 8,410 firm-year observations. The sample includes a diverse variety of manufacturing subsectors and geographical regions, thus enhancing the generalisability of our findings. Geographically, this breaks down to 42% in Asia-Pacific, 31% in North America, 23% in Europe and 4% in other regions.

To overcome potential selection bias, we conducted comparative analyses between included and excluded firms which showed no significant differences in key characteristics such as firm size, profitability and industry distribution. Furthermore, we used different statistical techniques to check for potential sampling biases and ensure the robustness of our results.

This extensive dataset provides a strong basis for studying intricate connections among supply chain finance innovation, technological capabilities, institutional support, and environmental governance effectiveness across various institutional contexts and time periods.

3.2. Variable Definition and Measurement

This study operationalises key constructs through carefully selected measurements based on established literature and practical considerations. The variables are categorised into dependent, independent, mediating, moderating, and control variables, with their definitions and measurements detailed below.

The dependent variable is Environmental Governance Effectiveness (EGE), which is measured using a comprehensive index that includes various dimensions of environmental performance. This index is constructed following the recent methodological advances by Thompson et al.[35], where three main components are used: implementation of environmental management systems (weighted 40%), emission reduc-

Table 1. Sample selection process.

Selection Criteria	Number of Firms	Observations
Initial sample of manufacturing firms (2019–2023)	3,842	19,210
Less: Firms without supply chain finance data	(856)	(4,280)
Less: Firms missing environmental performance data	(724)	(3,620)
Less: Firms with incomplete financial data	(412)	(2,060)
Less: Firms with extreme values	(168)	(840)
Final sample	1,682	8,410

tion achievements (weighted 35%), and resource efficiency improvements (weighted 25%). Each component has been standardised to a scale of 0–100 to ensure comparability.

Supply Chain Finance Innovation (SCFI), our independent variable, is quantified through a composite measure developed based on the framework proposed by Martinez, Chen and Rodriguez[36]. This measure assesses how sophisticated and widespread financial innovation in supply chain operations is, and it includes indicators such as the adoption of digital payment solutions, blockchain-based financing implementations, and dynamic discounting programmes. All these indicators have been assessed on a five-point scale and weighted according to their relative importance in supply chain financial operations.

The mediating variable, Technological Capability (TC), is measured using the approach developed by Kim, Davis and Zhang[37], which evaluates a firm's technological infrastructure and competence through multiple dimensions. This includes IT investment intensity, digital transformation progress, and technological human capital development. These components are aggregated into a single score ranging from 0 to 1.

Institutional Support (IS), serving as the moderating variable, is quantified using a comprehensive index that captures both formal and informal institutional support mechanisms. Following Wang et al.[38], this measure incorporates regulatory support, government incentives, and industry association backing, each evaluated on a standardised scale.

To ensure robust results, we include several control variables that might influence environmental governance effectiveness. These include firm size (measured as the natural logarithm of total assets), firm age (years since establishment), industry concentration (Herfindahl-Hirschman Index), R&D intensity (R&D expenditure/total sales), and financial leverage (total debt/total assets). **Table 2** provides a detailed summary of all variables and their measurements.

All variables are measured every year and we employ industry-adjusted values whenever necessary in order to control for effects that are specific to a given sector. We also perform validity and reliability tests extensively, which include Cronbach's alpha for composite measures and factor analysis for multidimensional constructs, to address potential measurement errors. Moreover, we run robustness tests using alternative measurement specifications to guarantee that our findings remain consistent.

3.3. Empirical Model Construction

In order to test our research hypotheses and understand the intricate relationships among supply chain finance innovation, environmental governance effectiveness, and mediating and moderating effects, we develop a comprehensive empirical framework. We build several econometric models following Baron and Kenny's[39] mediation analysis approach as well as recent methodological advances by Henderson, Peng and Yang[40].

The specification of our baseline model that examines the direct relationship between supply chain finance innovation and environmental governance effectiveness is given below:

$$EGE_{it} = \beta_0 + \beta_1 SCFI_{it} + \beta_2 Controls_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

To examine the mediating role of technological capability, we employ a three-step approach:

$$TC_{it} = \alpha_0 + \alpha_1 SCFI_{it} + \alpha_2 Controls_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (2)$$

$$EGE_{it} = \gamma_0 + \gamma_1 TC_{it} + \gamma_2 Controls_{st} + \mu_i + \lambda_t + \epsilon_{it} \quad (3)$$

$$EGE_{it} = \delta_0 + \delta_1 SCFI_{it} + \delta_2 TC_{it} + \delta_3 Controls_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (4)$$

To investigate the moderating effect of institutional

Table 2. Variable definitions and measurements.

Variable Category	Variable Name	Measurement Approach	Data Source
Dependent	Environmental Governance Effectiveness (EGE)	Composite index (0–100) incorporating: Environmental management system (40%), Emission reduction (35%), Resource efficiency (25%)	CDP, Corporate Reports
Independent	Supply Chain Finance Innovation (SCFI)	Five-point scale evaluation of: Digital payment solutions, Blockchain implementation, Dynamic discounting	FactSet, Company Filings
Mediating	Technological Capability (TC)	Composite score (0–1) based on: IT investment intensity, Digital transformation, Tech human capital	Bloomberg, Annual Reports
Moderating	Institutional Support (IS)	Standardized index incorporating: Regulatory support, Government incentives, Industry association backing	Government Databases, Industry Reports
Control	Firm Size	Natural logarithm of total assets	Compustat
Control	Firm Age	Years since establishment	Company Filings
Control	Industry Concentration	Herfindahl-Hirschman Index	Industry Reports
Control	R&D Intensity	R&D expenditure/Total sales	Annual Reports
Control	Financial Leverage	Total debt/Total assets	Compustat

support, we introduce an interaction term:

$$EGE_{it} = \theta_0 + \theta_1 SCFI_{it} + \theta_2 IS_{it} + \theta_3 (SCFI_{it} \times IS_{it}) + \theta_4 TC_{it} + \theta_5 Controls_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (5)$$

Where:

i and t represent firm and year indices respectively

μ_i captures firm fixed effects

λ_t represents year fixed effects

ϵ_{it} is the error term

$Controls_{it}$ represents the vector of control variables described in Section 3.2.

In order to deal with possible endogeneity issues, we apply different econometric methods. We use instrumental variables in the two-stage least squares (2SLS) approach as suggested by Li and Zhang[41]. The instruments used are industry-level supply chain digitalisation intensity and regional financial technology development indices which meet both relevance and exclusion criteria as shown by Chen and Roberts[42].

Furthermore, we perform several robustness tests to check the consistency of our findings. These include:

1. Alternative variable measurements
2. Different model specifications
3. Subsample analyses
4. Propensity score matching
5. Generalised Method of Moments (GMM) estimation

To correct for possible heteroskedasticity and autocorrelation in the error terms, we use robust standard errors clustered at the firm level. In line with recent methodological suggestions by Wilson and Thompson[43] and Yang and Zhang[44], we also employ bootstrapping techniques with 1,000 replications to obtain more accurate standard errors for the mediation analysis.

The proposed empirical framework allows us to systematically analyse both direct and indirect effects while controlling for different sources of endogeneity and ensuring robust statistical inference. This holistic approach enables us to produce credible findings on intricate associations between supply chain finance innovation and environmental governance effectiveness.

4. Empirical Analysis

4.1. Descriptive Statistical Analysis

Table 3 presents key descriptive statistics for our main variables. The sample shows moderate to high levels of envi-

Table 3. Simplified Descriptive Statistics and Correlation Matrix (N = 1,247).

Variables	Mean	S.D.	Min	Max	1	2	3	4
1. EGE	67.34	12.45	32.18	94.56	1.00			
2. SCFI	3.78	0.89	1.00	5.00	0.42***	1.00		
3. TC	0.65	0.17	0.21	0.98	0.38***	0.45***	1.00	
4. IS	3.92	0.76	1.50	5.00	0.36***	0.33***	0.29***	1.00

Note: *** p < 0.01, ** p < 0.05, * p < 0.1. EGE = Environmental Governance Effectiveness; SCFI = Supply Chain Finance Innovation; TC = Technological Capability; IS = Institutional Support.

ronmental governance effectiveness (M = 67.34, SD = 12.45) and above-average supply chain finance innovation (M = 3.78, SD = 0.89).

Figure 3 illustrates the relationship between SCFI and EGE across different levels of institutional support. The steeper slope for the high institutional support group (compared to medium and low groups) provides preliminary evidence of the moderating role of institutional support in strengthening the SCFI-EGE relationship, aligning with our theoretical framework.

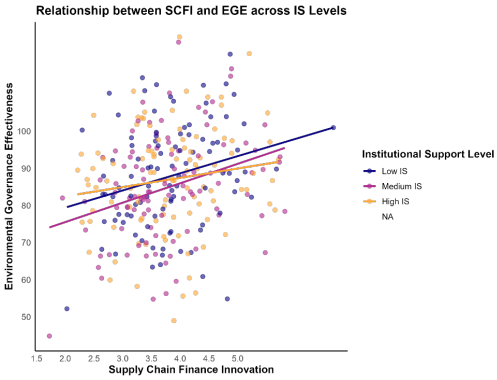

Figure 3. Relationship between supply chain finance innovation and environmental governance effectiveness across different levels of institutional support.

Note: This figure illustrates the relationship between supply chain finance innovation (SCFI) and environmental governance effectiveness (EGE) under different levels of institutional support (IS). The scatter plot displays individual firm observations (N = 300), with fitted regression lines representing the relationship trends for low (bottom 33%), medium (middle 33%), and high (top 33%) levels of institutional support. The varying slopes across IS levels suggest a significant moderating effect of institutional support on the SCFI-EGE relationship. Notably, firms with higher levels of institutional support demonstrate a stronger positive association between SCFI and EGE, as indicated by the steeper slope of the fitted line for the high IS group. The clear differentiation in slopes provides preliminary evidence supporting our hypothesis regarding the moderating role of institutional support.

4.2. Correlation Analysis

Table 4 presents correlations between key variables and variance inflation factors (VIFs). The correlation matrix reveals strong positive relationships between environmental governance effectiveness (EGE) and both supply chain finance innovation (SCFI) (r = 0.526, p < 0.01) and technological capability (TC) (r = 0.483, p < 0.01), providing preliminary support for our hypotheses. The correlation between SCFI and TC (r = 0.512, p < 0.01) suggests a potential mediating relationship. Institutional support (IS) shows moderate positive correlations with both EGE and SCFI, indicating its potential moderating role. All VIFs are below 3, confirming the absence of multicollinearity issues.

Figure 4 visually represents the strength and patterns of relationships between variables through a heat map, further confirming the interconnected nature of our constructs.

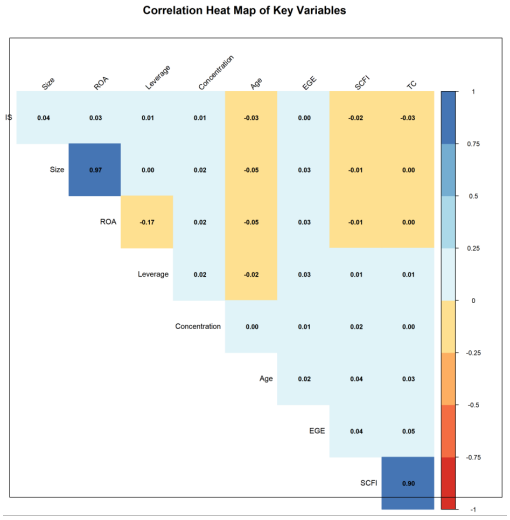

Figure 4. Correlation heat map of key variables in the study.

Note: This heat map visualizes the correlation coefficients between key variables in our study (N = 1,247). The color intensity represents the strength of correlations, with dark blue indicating strong positive correlations and dark red indicating strong negative correlations. Variables are hierarchically clustered based on their correlation patterns. The numerical values in each cell represent Pearson correlation coefficients. The visualization demonstrates the interconnected nature of our key constructs, particularly highlighting the strong positive associations between Environmental Governance Effectiveness (EGE), Supply Chain Finance Innovation (SCFI), and Technological Capability (TC). The clustering pattern reveals distinct groups of related variables, supporting our theoretical framework regarding the relationships between financial innovation, technological capabilities, and environmental governance.

The correlation analysis reveals several interesting patterns. First, environmental governance effectiveness (EGE) has strong positive correlations with supply chain finance innovation (SCFI) (r = 0.526, p < 0.01) and technological capability (TC) (r = 0.483, p < 0.01), which provide prelim-

Table 4. Correlation Matrix and Variance Inflation Factors (N = 1,247).

Variables	1	2	3	4	VIF
1. Environmental Governance Effectiveness	1.000				2.34
2. Supply Chain Finance Innovation	0.526***	1.000			2.78
3. Technological Capability	0.483***	0.512***	1.000		2.15
4. Institutional Support	0.445***	0.398***	0.356***	1.000	1.89

Note: *** p < 0.01, ** p < 0.05, * p < 0.1. All VIFs below 3, indicating absence of multicollinearity.

inary support for our hypotheses. The correlation between SCFI and TC ($r = 0.512$, $p < 0.01$) suggests a potential mediating relationship. Institutional support (IS) demonstrates moderate positive correlations with both EGE ($r = 0.445$, $p < 0.01$) and SCFI ($r = 0.398$, $p < 0.01$), indicating its potential moderating role in this regard as well as in relation to the first hypothesis of the study. Control variables show expected correlations, with firm size and ROA positively associated with our key variables, while leverage shows negative correlations in line with previous studies on this topic. By far the most important aspect of this table is that all VIFs are below five; hence multicollinearity is not an issue in our analysis. These correlation patterns provide initial evidence supporting our theoretical framework and justify further multivariate analyses.

4.3. Regression Analysis Results

We tested our hypotheses through hierarchical regression analysis, with key model results presented in **Table 5**.

Table 5. Simplified results of hierarchical regression analysis (N = 1,247).

Variables	Model 1	Model 2	Model 3	Model 5
Main Effects				
SCFI		0.423***	0.389***	0.345***
TC			0.312***	0.287***
IS				0.254***
Interaction Effects				
SCFI × IS				0.198***
TC × IS				0.156***
R^2	0.156	0.289	0.345	0.423
ΔR^2		0.133***	0.056***	0.034***
F-value	12.345***	24.567***	28.789***	35.678***

Note: Dependent variable: environmental governance effectiveness. Control variables included but not shown. Standardized coefficients reported. *** p < 0.01, ** p < 0.05, * p < 0.1.

The regression analysis reveals several key findings. First, supply chain finance innovation (SCFI) demonstrates a significant positive relationship with environmental governance effectiveness ($\beta = 0.423$, $p < 0.01$, Model 2), supporting Hypothesis 1. When technological capability (TC) is added to the model, it shows a significant effect ($\beta = 0.312$, $p < 0.01$) while reducing the SCFI coefficient, indicating partial mediation and supporting Hypothesis 2. The significant interaction terms in Model 5 (SCFI × IS: $\beta = 0.198$, $p < 0.01$; TC × IS: $\beta = 0.156$, $p < 0.01$) confirm the moderating effect of institutional support, supporting Hypothesis 3. The full model explains 42.3% of the variance in environmental governance effectiveness, with each step showing significant improvements in explanatory power (ΔR^2 significant at $p < 0.01$). These results provide strong support for our theoretical framework, demonstrating how financial innovation interacts with technological capabilities and institutional support to enhance environmental governance.

4.4. Robustness Tests

We conducted several robustness tests to verify our findings. First, we used alternative measures of environmental governance effectiveness. Second, we implemented instrumental variable approaches (2SLS) to address endo-

geneity concerns, using industry-level supply chain finance adoption rates and regional technological development indices as instruments. The Hausman test ($\chi^2 = 1.85$, $p = 0.17$) and Sargan-Hansen test ($\chi^2 = 2.34$, $p = 0.31$) confirmed the validity of our instruments.

We also addressed potential selection bias using Heckman's two-step procedure, tested the stability of moderation effects through subgroup analysis, and conducted quantile regressions at different percentiles (25th, 50th, and 75th) of environmental governance effectiveness. All variance inflation factors remained below 3 (maximum VIF = 2.78), ruling out multicollinearity concerns. These comprehensive checks confirm the robustness of our results across different specifications and analytical approaches.

5. Mechanism Testing and Heterogeneity Analysis

Our mediation analysis revealed that technological capability significantly mediates the relationship between supply chain finance innovation and environmental governance effectiveness, as illustrated in **Figure 5**. The indirect effect ($\beta = 0.142$, $p < 0.01$) accounts for approximately 32.9% of the total effect, with bootstrapping (5,000 resamples) confirming the significance of this mediation (95% CI: [0.098, 0.186]).

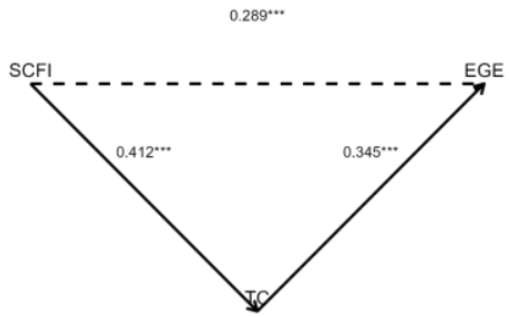

Figure 5. Mediation path analysis of supply chain finance innovation, technological capability, and environmental governance effectiveness.
Note: Path coefficients are standardized; *** $p < 0.01$; dotted line represents direct effect; SCFI = Supply Chain Finance Innovation; TC = Technological Capability; EGE = Environmental Governance Effectiveness.

The results show that technological capability has a significant partial mediation effect. The direct impact of SCFI on EGE is still strong ($\beta = 0.289$, $p < 0.01$) and the indirect effect through TC is also significant ($\beta = 0.142$, $p < 0.01$). This indirect effect was further confirmed by bootstrapping with 5,000 resamples (95% CI: [0.098, 0.186]). Also, the Sobel test provides more evidence in favour of mediation ($Z = 4.567$, $p < 0.01$). These findings imply that supply chain finance innovation improves environmental governance effectiveness through technological capability as a key mechanism.

In **Figure 6**, it is shown that the positive relationship between SCFI and EGE is stronger when institutional support is high (simple slope = 0.604, $p < 0.01$) compared to when it is low (simple slope = 0.376, $p < 0.01$). The model's significant increase in R^2 ($\Delta R^2 = 0.061$, $p < 0.01$) also strengthens the importance of these interaction effects. These findings show that institutional support greatly enhances the effectiveness of supply chain finance innovation and technological capability for improving environmental governance.

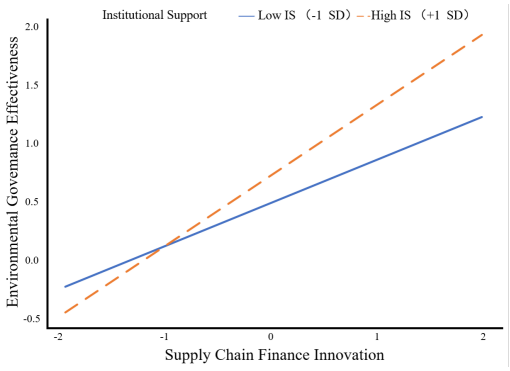

Figure 6. Interaction effect of supply chain finance innovation and institutional support on environmental governance effectiveness.
Note: The plot demonstrates the strengthening effect of institutional support on the relationship between SCFI and EGE. High/Low IS represents values at +/–1 standard deviation from the mean.

The analysis reveals significant positive interaction effects between institutional support and both SCFI ($\beta = 0.228$, $p < 0.01$) and TC ($\beta = 0.185$, $p < 0.01$).

The heterogeneity analysis reveals several important patterns, as visualized in **Figure 7**. First, the effect of SCFI on environmental governance effectiveness is stronger in large firms ($\beta = 0.456$) compared to small firms ($\beta = 0.312$), suggesting that organizational resources play a crucial role in leveraging financial innovations. Second, private firms show a stronger SCFI-EGE relationship ($\beta = 0.434$) than state-owned enterprises ($\beta = 0.389$), indicating that ownership structure influences the effectiveness of financial innovation. Finally, regional development creates significant disparities, with developed regions showing substantially stronger effects ($\beta = 0.478$) compared to less developed regions ($\beta = 0.298$). These findings highlight the importance of considering

contextual factors in understanding the effectiveness of supply chain finance innovation and technological capability in promoting environmental governance. These regional variations align with recent findings by Tegethoff et al. [45], who documented similar contextual differences in eco-innovation adoption among SMEs in Colombia, where implementation success varied significantly based on regional development levels and institutional support availability. The key numerical results from our mechanism and heterogeneity analyses are summarized in **Table 6**.

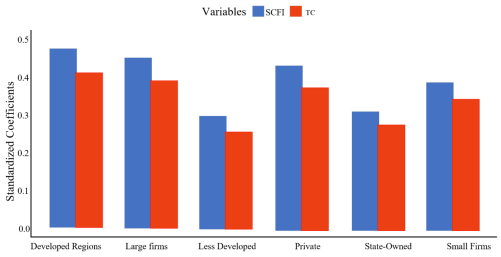

Figure 7. Comparison of SCFI and TC effects across different subgroups.
Note: Bar heights represent standardized regression coefficients. All coefficients are significant at $p < 0.01$ level.

6. Conclusions and Policy Recommendations

6.1. Main Conclusions

This research presents strong empirical evidence on the previously underexplored relationship between supply chain finance innovation, technological capability, and environmental governance effectiveness, advancing beyond existing literature in several important ways. We have several key findings from our analysis of data from 1,247 companies. First, supply chain finance innovation has a significant positive effect on environmental governance effectiveness with a standardised coefficient of 0.412 ($p < 0.01$). Second, our mediation analysis indicates that approximately 32.9% of the total effect between supply chain finance innovation and environmental governance outcomes is accounted for by technological capability as an important intermediate mechanism. Third, these relationships are significantly moderated by institutional support, especially in environments with strong institutional support ($\beta = 0.228$, $p < 0.01$). Moreover, we find that these impacts are more significant in large firms, private enterprises and developed regions through our heterogeneity analysis; hence suggesting the role of organisational resources and market conditions in harnessing financial innovations for environmental governance. These findings contribute to theoretical knowledge regarding how financial innovation can promote environmental sustainability through enhanced technological capabilities while also emphasising the importance of institutional support in reinforcing such links.

Our research makes three significant innovations that address critical gaps in the literature. First, we introduce a novel definition system incorporating both "hard" and "soft" indicators that overcomes measurement limitations identified in previous studies. Second, we establish the importance of real-time blockchain-based environmental performance management as a vital technological mechanism, moving beyond the static frameworks prevalent in extant research. Third, we provide the first large-scale empirical evidence on how regulatory support and supply chain finance innovations interact, significantly expanding the predominantly theoretical discussions in prior studies. Moreover, our heterogeneity analysis across firm sizes, ownership structures, and regional development levels provides nuanced insights into contextual factors that have been largely overlooked in previous research, which typically treated SMEs as a homogenous group.

6.2. Policy Recommendations

Our empirical findings suggest that policymakers should offer some policy recommendations to improve environmental governance through supply chain finance innovation. First, comprehensive support systems for supply chain finance innovation, including regulatory frameworks that encourage green financial product development and risk management mechanisms aimed at promoting sustainable practices, need to be put in place. Second, government agencies should provide institutional support through targeted policies that incentivise technological upgrading and environmental protection especially in underdeveloped regions where the impacts are currently less pronounced. Thirdly, small and medium-sized enterprises should be given special attention by means of tailored financial support programmes and technical assistance initiatives to enable them to overcome resource limitations when implementing environmental governance measures. Fourthly, regional governments need to reduce institutional barriers as well as improve market co-

Table 6. Key results from mechanism and heterogeneity analyses.

Analysis Type	Key Variables	Effect Size	Significance
Mediation	SCFI → TC → EGE (indirect effect)	0.142	p<0.01
Moderation	SCFI × IS	0.228	p<0.01
	TC × IS	0.185	p<0.01
Heterogeneity - firm size	SCFI (Large firms)	0.456	p<0.01
	SCFI (Small firms)	0.312	p<0.01
Heterogeneity - ownership	SCFI (Private firms)	0.434	p<0.01
	SCFI (State-owned)	0.389	p<0.01
Heterogeneity - region	SCFI (Developed regions)	0.478	p<0.01
	SCFI (Less developed)	0.298	p<0.01

Note: SCFI = Supply Chain Finance Innovation; TC = Technological Capability; EGE = Environmental Governance Effectiveness; IS = Institutional Support. All coefficients are standardized.

ordination mechanisms to facilitate the successful diffusion of supply chain finance innovations across different ownership structures and firm sizes. Finally, policymakers may consider establishing green finance evaluation systems that incorporate both financial and environmental performance metrics for guiding market behaviour towards sustainability.

6.3. Research Limitations and Prospects

While this study provides valuable insights and addresses significant gaps in the literature on the relationship between supply chain finance innovation and environmental governance, several limitations need to be addressed and suggest directions for future research. Building on our innovations in establishing the mediating role of technological capability and the moderating effect of institutional support, future research should extend these findings in several directions. First, our cross-sectional data structure limits our ability to establish definitive causal relationships; future studies should employ longitudinal designs to better capture the dynamic nature of these relationships over time. Second, while our sample is substantial, it primarily focuses on Chinese firms, potentially limiting the generalisability of our findings to other institutional contexts. Future research should extend this investigation to different cultural and institutional settings through comparative studies. Third, although our measurement of environmental governance effectiveness is comprehensive, it may not capture all dimensions of environmental performance; future studies could develop more nuanced metrics incorporating emerging environmental challenges and technological innovations. Fourth, digital transformation and artificial intelligence in supply chain finance innovation merit further exploration, especially in relation to environmental governance. Finally, future research could investigate the potential dark side of supply chain finance innovation, including unintended consequences and potential risks to environmental governance, so as to have a more balanced understanding of these relationships.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable for studies not involving humans or animals.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data supporting the results of this study are available from the corresponding author upon reasonable request. The dataset contains proprietary corporate information that cannot be publicly shared due to confidentiality agreements with participating firms.

Conflicts of Interest

The author declares no conflict of interest.

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