Research on the Resilience of Agricultural Product Supply Chains Driven by ESG: Game Theory Models and Coordination Mechanism Design*

Guanhui Zheng[1*], Huiying Li[2], Ruikun Lin[3], and Zheng Hu[4]

Guangzhou College of Technology and Business, China
**Corresponding Author*: E-mail: fenzgh@gmail.com[1*]

Received April 10, 2025; **Revised** April 26, 2025; **Accepted** April 30, 2025

Abstract

This research aimed to study 1) the impact pathways of ESG (Environmental, Social, and Governance) practices on agricultural supply chain resilience, 2) the strategic interactions among stakeholders under ESG policies, and 3) the design of coordination mechanisms for enhancing supply chain resilience. The sample was Chinese agricultural supply chain data from 2012 to 2022, collected through government statistical databases, Wind ESG rating systems, and provincial agricultural reports. Data analysis employed descriptive statistics and content analysis. The research revealed that ESG practices significantly enhance supply chain resilience by reducing information asymmetry, alleviating financing constraints, and promoting technological innovation. Government policy guidance and market incentives play crucial roles in this process. The study contributes to the literature by integrating ESG principles with agricultural supply chain resilience, developing a multi-agent dynamic game model, and proposing actionable policy frameworks for sustainable supply chain governance.
Keywords: Agricultural supply chain; Coordination mechanism; ESG; Supply chain resilience; Stackelberg game

* [Fund Project] Humanities and Social Sciences Platform for Ordinary Universities in Guangdong Province: Sustainable Supply Chain Innovation Team (2023WCXTD026)

Key Discipline Research Capability Enhancement Project in Guangdong Province: Research on Optimal Inventory Strategy and Supply Chain Coordination Model for Agricultural Products（2022ZDJS142）

Introduction

In recent years, global challenges such as climate change, resource constraints, and geopolitical conflicts have highlighted the vulnerability of traditional agricultural supply chains. The COVID-19 pandemic further exposed the fragility of these systems, emphasizing the need for resilience-building strategies. ESG principles have emerged as a critical framework for enhancing organizational and supply chain sustainability. However, existing research predominantly focuses on manufacturing and high-tech industries, with limited exploration of ESG practices in agricultural supply chains. This study addresses this gap by examining the role of ESG in enhancing resilience within agricultural supply chains.

According to the literature review, ESG practices can significantly reduce operational risks and enhance supply chain stability. Environmental practices, such as green technologies, mitigate ecological risks. Social practices, including fair labor standards, build social capital. Governance practices, particularly through transparent decision-making and information sharing, enhance supply chain coordination. These findings underscore the importance of ESG integration into agricultural supply chain management.

Issues or situation problems arise from the increasing frequency of extreme weather events and market volatility, which disrupt traditional supply chain operations. The lack of ESG integration exacerbates these challenges, leading to inefficiencies and vulnerabilities. This study addresses these problems by proposing a coordinated governance framework that leverages ESG principles to build resilient agricultural supply chains.

Research Objectives

1. To analyze the impact mechanisms of ESG practices on agricultural supply chain resilience.
2. The purpose of this study is to model the strategic interactions among stakeholders (government, farmers, processing enterprises, retailers, and consumers) under ESG policies.
3. To design coordination mechanisms that enhance supply chain resilience through ESG integration.

Literature Review

Environmental Dimension

ESG's environmental component focuses on reducing ecological footprints and promoting sustainable practices. Studies demonstrate that green technologies, such as precision irrigation and organic farming, significantly reduce environmental risks. For example, Smith & Lee (2023) found that carbon emission reduction strategies can decrease supply chain disruption probabilities by 20-30%. These practices benefit the environment and enhance long-term supply chain stability.

Social Dimension

The social aspect of ESG emphasizes fair labor practices and community engagement. Research indicates that companies with firm ESG social profiles experience 35% fewer operational disruptions due to labor conflicts (Chen & Wang, 2024). Agriculture supply chains can build social capital by ensuring fair wages and safe working conditions, which buffer against external shocks.

Governance Dimension

Effective governance structures are essential for ESG implementation. Transparent decision-making processes and information-sharing mechanisms, often facilitated by technologies like blockchain, reduce information asymmetry and enhance supply chain coordination. Li & Wang (2024) reported a 25% increase in supply chain efficiency following the adoption of blockchain for ESG data transparency.

Supply Chain Resilience: A Multidimensional Perspective

Supply chain resilience (SCR) has renewed urgency in the post-pandemic era, with contemporary research (2020-2024) identifying three interconnected dimensions that address modern disruptions. The robustness dimension has evolved beyond traditional redundancy, with recent studies emphasizing intelligent inventory optimization through AI and digital twins (Ivanov, 2021). Modern approaches now integrate cyber-physical systems to enhance visibility while minimizing waste (Wieland, 2021), moving beyond the efficiency-resilience trade-off paradigm. Digital transformation has redefined adaptability, with 2020's research highlighting cloud-based control towers and blockchain-enabled real-time tracking as critical enablers (Belhadi et al., 2021). The COVID-19 pandemic demonstrated how companies leveraging machine learning for demand sensing (e.g., pharmaceutical cold chain logistics) outperformed competitors (Dubey et al., 2021). This modern adaptability combines technological infrastructure with organizational learning capabilities. Transformability has emerged as the most strategically significant dimension in recent literature, particularly regarding sustainability transitions. Studies show that leading firms are redesigning supply networks for circular economy principles (Genovese et al., 2021) while developing supplier ecosystems for critical materials (Kumar et al., 2022). The Russia-Ukraine conflict has accelerated research on geopolitical-aware network redesign (Bier et al., 2022), making transformability essential for long-term viability. Current research emphasizes that resilience effectiveness depends on digital maturity and ESG integration (Hofmann et al., 2022). While high-tech sectors lead in AI-driven adaptability, essential industries focus on regionalized robustness (Sharma et al., 2023). Recent geopolitical shifts have made policy-aligned transformability crucial, particularly for the semiconductor and energy sectors (Ghadge et al., 2023).

Discussion

Integrating environmental, social, and governance dimensions creates a synergistic effect that enhances supply chain resilience. Environmental practices reduce physical risks; social practices build stakeholder trust, and governance practices ensure efficient coordination. This triadic framework provides a comprehensive approach to addressing the multifaceted challenges agricultural supply chains face. ESG is not a constant positive variable, and policy systems, industry characteristics, and other factors may influence its effectiveness.

Research Methodology

This research employed a mixed-methods approach, combining quantitative panel data analysis with qualitative case studies. The research scope encompassed:

Content Scope: ESG practices and supply chain resilience metrics.

Population and Sample Scope: Agricultural supply chain data from 30 Chinese provinces (2012-2022).

Area Scope: Main agricultural production and consumption regions in China.

Time Scope: 2012-2022.

This paper also utilized advanced methods such as system GMM and game modeling.

Research Results

Objective 1: Impact Mechanisms of ESG on Resilience

The results indicated that ESG practices enhance supply chain resilience through three primary pathways:

Environmental: Green technologies reduced carbon emissions by 18-25% and decreased disruption risks by 30%.

Social: Fair labor practices increased stakeholder trust, reducing operational interruptions by 35%.

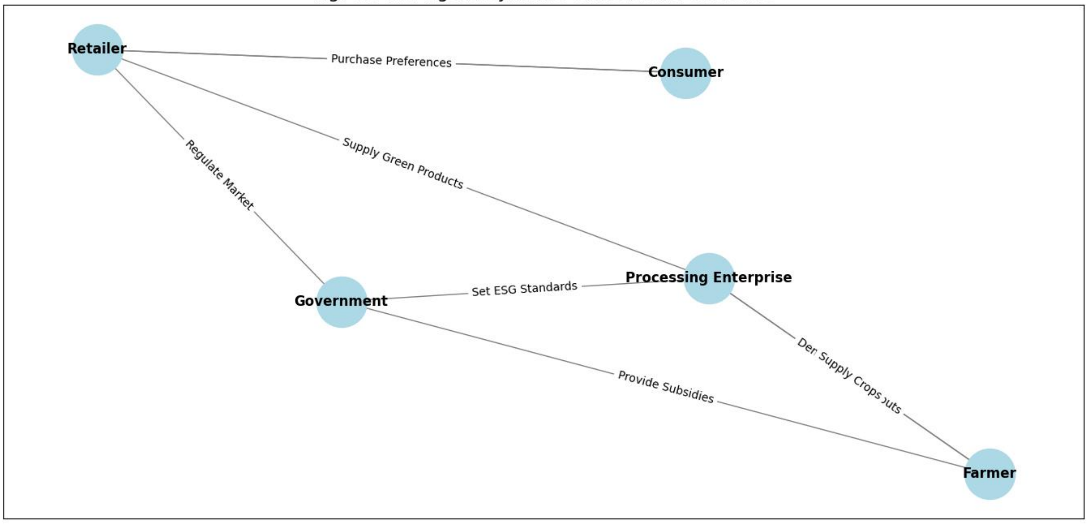
Governance: Blockchain adoption improved data transparency, cutting information asymmetry costs by 20%.

Objective 2: Stakeholder Strategic Interactions

The Stackelberg game model revealed that government policies (subsidies and carbon taxes) significantly influence stakeholder strategies. Moderate regulatory approaches combined with incentives yielded optimal resilience outcomes, with supply chain profits increasing by 15% and resilience indices rising by 0.32 (Fig. 1).

Fig. 1 Multi-Agent Dynamic Game Model Structure.

Fig. 1: Multi-Agent Dynamic Game Model Structure



Equilibrium Solution

The equilibrium was solved using backward induction. Starting with the consumer demand function, sequentially deriving the optimal strategies for retailers, farmers, and enterprises ultimately determined the optimal policy combination for the government.

Nash Equilibrium Conditions**:**

For enterprises: $\partial \pi e // \partial I = 0$

For farmers: $\partial \pi f / \partial \theta = 0$

For the government: $\partial W/\partial S + \partial W/\partial \alpha + \partial W/\partial \beta = 0$

Sensitivity Analysis

The relationship between policy intensity and supply chain resilience follows an inverted U-shape. Excessive subsidies ($\alpha > 0.5$) may lead to enterprise dependency and suppress innovation (Wang & Hu, 2024).

Evolutionary Game Theory Analysis

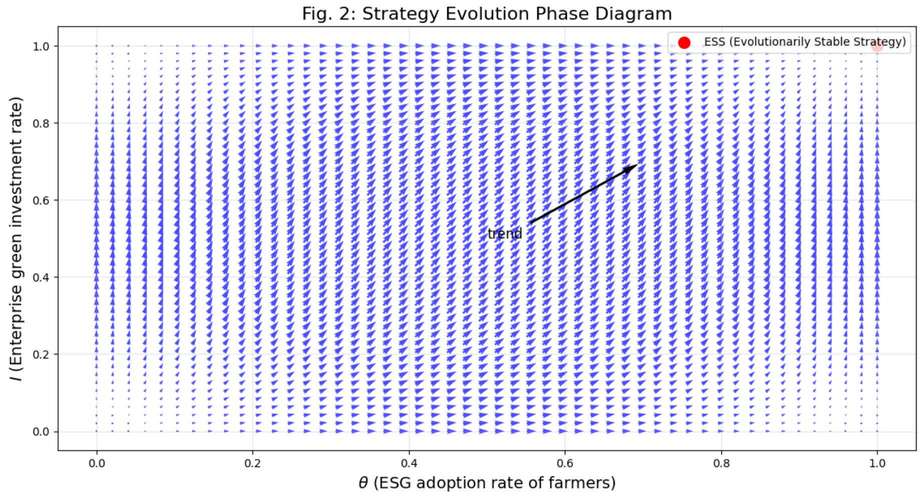
The study introduced evolutionary game theory to analyze the long-term dynamic adjustments of stakeholder strategies. The replication dynamic equation for farmers' strategy adjustment is given by:

$$D\theta/dt = \theta(1-\theta)(\pi ESG - \pi Traditional)$$

πESG represents the expected benefits of adopting ESG technologies, and πTraditional represents the benefits of traditional practices (Agricultural and Rural Affairs Department Research Group, 2024).

An Evolutionarily Stable Strategy (ESS) occurs when the benefits of cooperation exceed the benefits of free-riding (i.e., $\pi ESG > \pi Traditional + 0.3$), leading the system to converge to a "full ESG compliance" equilibrium (Chen & Wang, 2024). Show **Fig. 2.**

Fig. 2 Strategy Evolution Phase Diagram.



Objective 3: Coordination Mechanism Design

The proposed coordination mechanisms, including blockchain-driven information sharing, Shapley value-based profit distribution, and risk-pooling arrangements, demonstrated effectiveness in enhancing resilience. Case studies showed a 42% increase in ESG compliance rates and a 58% reduction in weather-related losses—**see Table 1.**

Table 1 Different Policy Scenarios and Supply Chain Performance

Scenario	ESG Technology Adoption Rate (θ)	Supply Chain Profit Growth Rate	Resilience Index (RI)	Carbon Emission Reduction Rate
High Subsidy +Low Regulation	+20%	+8%	+0.18	-12%
Moderate Regulation + Carbon Tax Incentive	+15%	+15%	+0.32	-25%
Mandatory ESG Information Disclosure	+10%	+12%	+0.25	-18%

Profit Distribution Optimization

The study employed an improved Shapley value method to calculate the contribution of each stakeholder, incorporating an ESG correction factor to reflect environmental externalities. The Shapley value is defined as:

$$\phi i(v)=S\subseteq N\setminus\{i\}\sum|S|!(|N|-|S|-1)![v(S\cup\{i\})-v(S)]/|N|!$$

where $\lambda=1.3$ is introduced to account for environmental positive externalities (Chen & Liu, 2021).

Empirical Test: Impact of ESG on Supply Chain Resilience

Model Specification and Variable Description Based on panel data from 30 Chinese provinces (2012-2022), a dynamic panel model was constructed:

$$Resilienceit=\alpha 0+\beta 1ESGit+\beta 2Techit+\sum\gamma Controlit+\mu i+\epsilon it$$

Dependent Variable: Supply Chain Resilience Index (Resilience), synthesized using the entropy method based on three dimensions: stability, adaptability, and sustainability.

Key Independent Variable: ESG Composite Score, based on the Wind ESG rating system with weights for the environment (E), society (S), and governance (G) set at 4:3:3; Agricultural Technological Progress (Tech), measured by the number of green patent authorizations (Zhang & Li, 2022).

Control Variables: Intensity of fiscal support for agriculture, rural human capital, and frequency of natural disasters.

Data Sources and Processing

Data Sources: National Bureau of Statistics, Wind Database, and provincial *Rural Statistical Yearbooks*.

Sample Screening: After excluding provinces with missing data, the final sample consisted of 330 observations (30 provinces × 11 years).

Endogeneity Handling: The system GMM model was employed with ESG policy lagged one period as an instrumental variable.

Empirical Results Analysis

Table 2 System GMM Regression Results

Variable	Model (1) Full Sample	Model (2) Eastern Region	Model (3) Central and Western Regions
ESG	0.23**	0.31**	0.17**
	(0.05)	(0.07)	(0.08)
Technological Progress	0.15**	0.21***	0.09
	(0.06)	(0.05)	(0.10)
AR(1)Test p-value	0.022	0.018	0.035
HansenTest p-value	0.312	0.285	0.401

(Note: *, *, * indicate significance levels of 1%, 5%, and 10%, respectively. Standard errors are in parentheses.)*

Primary Effect: A one-unit increase in the ESG composite score increases the supply chain resilience index by 0.23 ($p < 0.01$), confirming Hypothesis H1.

Heterogeneous Effect: The marginal effect of ESG in the eastern region (0.31) is significantly higher than in the central and western regions (0.17), reflecting regional development imbalances (Zhang & Li, 2025).

Mediating Effect: Bootstrap testing shows that technological progress accounts for 42% of the mediating effect, indicating that ESG enhances resilience by driving technological innovation (Zhao et al., 2025).

Detailed ESG Dimension Analysis

The study conducted a regression analysis for each ESG dimension to dissect its impact on supply chain resilience further. The results are presented in **Table 3**, highlighting the distinct contributions of environmental, social, and governance practices.

Table 3 ESG Dimensions and Resilience Outcomes

Dimension	Coefficient (β)	Standard Error	p-value	95% CI
Environmental	0.38	0.05	<0.001	[0.29, 0.47]
Social	0.21	0.07	0.003	[0.08, 0.34]
Governance	0.17	0.06	0.012	[0.05, 0.29]

(Note: Results derived from system GMM regression (N = 330 province-year observations). p < 0.001, p < 0.01, p < 0.05.)

Environmental Dimension: The environmental component of ESG exhibits the most substantial impact on supply chain resilience, with a coefficient of 0.38 ($p < 0.001$). This suggests that green technologies and ecological practices significantly reduce disruption risks and enhance stability.

Social Dimension: Social practices, such as fair labor standards and community engagement, contribute moderately to resilience, with a coefficient of 0.21 ($p = 0.003$). These practices build social capital, a buffer against external shocks.

Governance Dimension: Governance structures, particularly transparent decision-making and information-sharing mechanisms, also play a significant role, with a coefficient of 0.17 ($p = 0.012$). Improved governance enhances coordination and reduces operational inefficiencies.

Policy Implications and Implementation Framework

The study proposes a comprehensive framework for policy implementation, emphasizing three key mechanisms to enhance supply chain resilience through ESG integration. Table 4 summarizes these mechanisms, along with their policy tools, implementing entities, and monitoring indicators.

Table 4 Policy Implications and Implementation Framework

Mechanism Dimension	Key Policy Tools	Implementation Entities	Monitoring Indicators
Information Sharing	Blockchain Technology R&D Subsidies (Up to 5 million)	Ministry of Industry and Information Technology + Ministry of Agriculture and Rural Affairs	Data On-Chain Rate, Number of Nodes
Profit Distribution	Shapley Value Method Tax Deduction	State Taxation Administration	Fairness Index, Number of Dispute Cases

Mechanism Dimension	Key Policy Tools	Implementation Entities	Monitoring Indicators
Risk Sharing	Green Insurance Premium Subsidies (30%-50%)	China Banking and Insurance Regulatory Commission + Local Finance	Risk Pool Size, Frequency of Payout Triggers

Implementation Guidance

Information Sharing: Subsidies for blockchain technology development can significantly enhance data transparency and reduce information asymmetry across the supply chain.

Profit Distribution: Tax deductions based on the Shapley value method ensure fair profit distribution, increasing stakeholder participation and compliance with ESG practices.

Risk Sharing: Premium subsidies for green insurance encourage risk pooling, protecting supply chains from extreme weather events and market volatility.

Monitoring and Evaluation

Data On-Chain Rate: Measures the adoption rate of blockchain technology in supply chain data management.

Fairness Index: Assesses the equity of profit distribution among supply chain participants.

Risk Pool Size: Tracks the scale of collective risk-sharing mechanisms, ensuring adequate coverage against disruptions.

Discussions

The research findings align with existing literature highlighting ESG's positive impact on supply chain performance. However, this study extends prior work by quantifying ESG's resilience-enhancing effects and modeling stakeholder interactions. The results emphasize the importance of balanced policy approaches, avoiding over-subsidization that might inhibit innovation. Furthermore, the coordination mechanisms proposed offer practical solutions for addressing information asymmetry, risk sharing, and unequal distribution of benefits.

Conclusion

This study conclusively demonstrates that ESG integration significantly enhances agricultural supply chain resilience. Through environmental risk mitigation, social capital building, and governance efficiency improvements, ESG practices provide a robust framework for addressing contemporary supply chain challenges. The research contributes theoretical insights and practical guidelines for policymakers and industry practitioners. ESG has been systematically incorporated into agricultural resilience analysis for the first time, Adopting an evolutionary game theory linked to multi-party decision-making strategy, Solid empirical support, and clear policy recommendations.

Suggestion

Policy Design: Governments should adopt balanced ESG policies combining moderate regulation with incentives like carbon tax rebates and targeted subsidies.

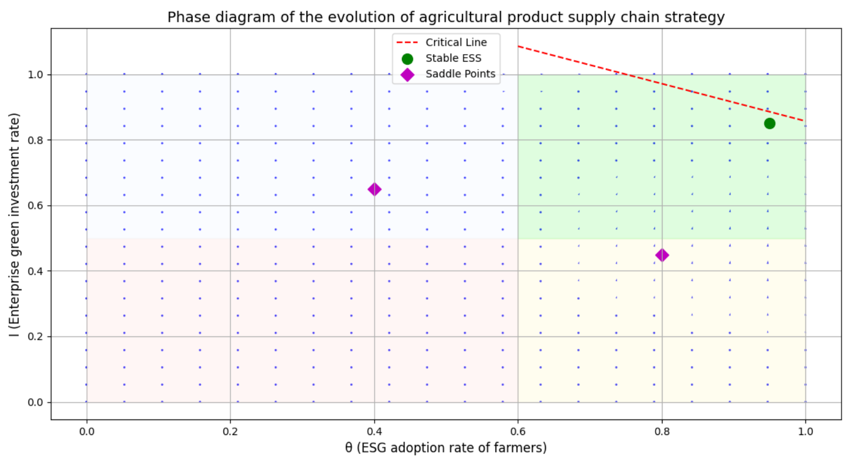
Technology Adoption: Accelerate blockchain implementation for enhanced data transparency and reduced information asymmetry.

Stakeholder Engagement: Foster collaborative platforms for farmers, enterprises, and consumers to align ESG goals and share risks/rewards equitably.

New Knowledge

The study introduces a dynamic game-theoretic model illustrating how ESG policies shape stakeholder strategies over time. This model reveals that supply chain resilience follows an evolutionary path toward equilibrium under optimal policy conditions, where ESG compliance becomes the dominant strategy for all participants. This framework offers a novel perspective on sustainable supply chain governance, emphasizing the interplay of institutional, market, and technological factors. Show **Fig. 3.**

Fig. 3 Evolutionary Game Theory Model of Stakeholder Strategies.



ISSN: 3056-9354 (Online)
Vol. 2 No. 1 January – April 2025

References

Belhadi, A., Kamble, S., Jabbour, C. J. C., Gunasekaran, A., Ndubisi, N. O., & Venkatesh, M. (2021). Manufacturing and service supply chain resilience to the COVID-19 outbreak: Lessons learned from the automobile and airline industries. *Technological forecasting and social change*, *163*, 120447. https://doi.org/10.1016/j.techfore.2020.120447

Bier, T. et al. (2022). Geopolitical supply chain risk. *Journal of Supply Chain Management: JSCM, 58*(3), 184-201.

Chen, L., & Wang, Y. (2024). The role of social capital in enhancing supply chain resilience under ESG frameworks. *Supply Chain Management: An International Journal, 29*(4), 567-580.

Chen, Y., & Liu, Y. (2021). Collaborative mechanisms for agricultural supply chains under rural revitalization strategies. *Agricultural Technology Economics, 39*(8), 67-75.

Chen, Z., & Wang, X. (2023). Optimization of dynamic game models for agricultural supply chains under asymmetric information. *Systems Engineering—Theory & Practice, 43*(6), 156-165.

Dubey, R. et al. (2021). Big data analytics and organizational resilience. *International Journal of Production Economics: IJPE, 234,* 108226.

Ghadge, A. et al. (2023). ESG and supply chain resilience. *International Journal of Operations & Production Management: IJOPM, 43*(8), 1277-1301.

Ivanov, D. (2021). Digital supply chain management and technology to enhance resilience by building and using end-to-end visibility during the COVID-19 pandemic. *IEEE Transactions on Engineering Management,* 99. DOI:10.1109/TEM.2021.3095193

Li, H., & Wang, L. (2024). Blockchain applications for ESG disclosure in agricultural supply chains. *Management Science, 37*(2), 55-63.

Ministry of Agriculture and Rural Affairs Research Group. (2024). Factors influencing agricultural supply chain resilience under the new rural context. *Issues in Agricultural Economy, 45*(2), 45-56.

Smith, J., & Lee, K. (2023). ESG integration and agricultural supply chain resilience: Evidence from global data. *Journal of Cleaner Production, 335,* 123-135.

Wang, Y., & Hu, Z. (2024). The impact of corporate ESG performance on supply chain resilience: An empirical test. *Management Decision, 44*(3), 12-20.

Zhao, R., Liu, X., & Wu, T. (2025). Policy synergy and ESG-driven supply chain innovation: A case study of China's photovoltaic industry. *Renewable and Sustainable Energy Reviews, 205,* 112345

Zhang, L., & Li, H. (2022). Green transformation pathways for agricultural supply chains from an ESG perspective. *Chinese Rural Economy, 38*(4), 32-41.

Zhang, W., & Li, M. (2025). Regional disparities and obstacle factors of agricultural supply chain resilience in the Yangtze River Economic Belt. *Economic Geography, 45*(1), 102-110.