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The Significance of American Antitrust Policy in Reduction of Global Market Concentration

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Abstract

In the conducted generalization about the issues for evolution of views on perfect competition and, accordingly, antitrust policy, the tendency of a significant reduction in market concentration in the world is emphasized, which is associated with the reasonable antitrust policy of the modern USA. The author, using the methodology of the laws of physics, recommends maximum observance of the atomic balance in the core of market competition and proposes optimization of a freer tax burden on corporate profits and personal income. The race for growth of quantitative indicators of competitors led to a decrease in qualitative results and significant losses from overproduction. The work analyzes and identifies the possible reasons for excessive market concentration in detailed subcategories of even the most developed market. According to the author's conclusion, this was the reasonable antitrust policy that determined the best optimal rates of economic growth and taxes among the most promising economies.

Keywords: antitrust policy, world economy, American government, market concentration, perfect competition

1. To Introduction

Undoubtedly, competition is the main driving force of the economy, but the history of the world economy has shown that without reasonable antitrust policy, the global market has often been largely under the pressure of secret monopolies and political dictatorships.

Naturally, absolutely perfect competition is an idealized understanding of competition, but we must strive to define, achieve and protect the maximum approximation to the above-mentioned reasonable understanding of perfect competition.

Logically, to implement publication plans, we have studied the achievements of classical and modern science in the study of competition issues (Smith, A., 2008; Arrow, Kenneth J. & Debreu, Gerard, 1954; Bork, Robert H., 1993; Gordon, Jason, 2022; Gretsky, Neil E, Ostroy, Joseph M & Zame, William R., 1999; Groenewegen, Peter, 2011; Majaski, Christina, n.d.; Makowski, Louis, & Joseph M. Ostroy, 2001; Marshall, A., 1920; McNulty, P. J., 1967; Novshek, W., & H. Sonnenschein, 1987; Porter,

M.E., 2008; Roberts, J., 1987; Stigler, J. G., 1987) and to this we have considered the relevant international antitrust practice on the assessment methods of possible freedom for effective competition and taxes (U.S. Department of Justice: Antitrust Division, n.d.; Statista, 2022; International Monetary Fund, n.d.; Mario Mariniello, 2014; OECD, 2022a; OECD, 2022b).

Accordingly, on the example of antitrust reforms and measures to maintain economic freedom and optimize market concentration of the modern American Government, a special relevance of further improvement of the competitive environment by monitoring the market core and preventing overestimation of the tax burden on business appeared on the front agenda.

2. What Is the Most Perfect Competition for Improving Antitrust Policy?

It is strange, but in understanding of perfect economic competition, we were helped by the theory of physics about the strength of electric current and the equilibrium structure of opposing forces in the atom.

Consequently, we came to the conclusion that for the best "shine" of perfect competition, it is necessary to have a natural (not excessive) number of competitors and an approximate equilibrium in the core of the market between the first and second competitors. The core of the market has been observed before, but the need for a rough balance between the main competitors is our innovation. To our great happiness, it was American scientists at Harvard University and the global encyclopedia Wikipedia who appreciated our views.

For our part, we have always especially appreciated the contribution of the US Antitrust Policy and their current reforms with published new data have exceeded all expectations. As is known, the American Government evaluates market concentration using the Herfindahl-Hirschman Index (HHI) through the Antitrust Division in the Department of Justice. As we have noticed, namely this index has fallen significantly for 1988-2020 (from 1,597.75 to 444.38) on the global market (Figure 1), which is a very progressive phenomenon and the role of the modern USA in this is indescribably great.

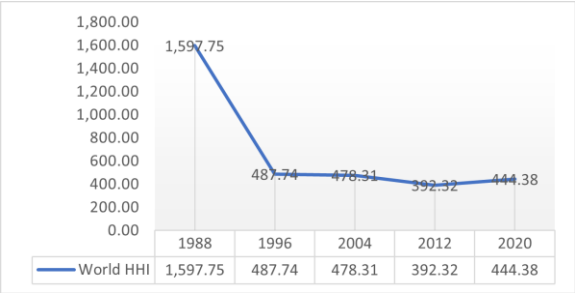

Figure 1. The general trend towards a favorable decrease of the global HHI in 1988-2020

Source: Annual Herfindahl-Hirschman Index market concentration score worldwide from 1988 to 2020. Update time - Sep 29, 2025. https://www.statista.com/statistics/1339418/herfindahl-hirschman-index-worldwide/

In our opinion, targeted antitrust policy is the main reason why the United States has significantly outpaced such developed major competitive economies as Canada, the United Kingdom, the European Area and Japan in economic growth. According to the newest 2024 data of Real GDP, the United States surpassed the European Area by 2 percentage points, and Japan even by 3 percentage points (Figure 2).

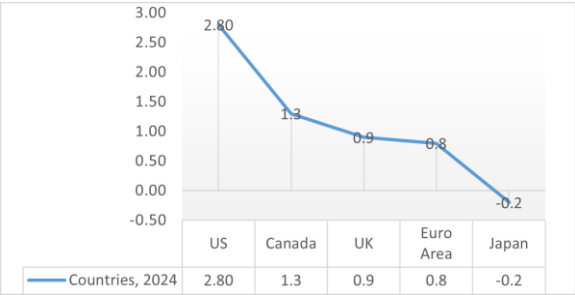

Figure 2. Annual percent change of Real GDP by Advanced Economies

Source: IMF: World Economic Outlook Growth Projections. Update time - Sep 29, 2025. https://www.imf.org/en/Publications/WEO/Issues/2025/01/17/world-economic-outlook-update-january-2025

In the EU manufacturing, the main antitrust risks still appear to be super-concentrated markets (Figure 3) such as tobacco (HHI is 3074), sugar (2230), rubber products (1429), beer (1301), weapons and ammunition (1259), etc. Based on this, we consider it expedient to urgently improve antimonopoly measures in the

European market, which will also have a positive impact on economic growth.

Figure 3. Antitrust risk as Tobacco and other Market concentration in EU manufacturing

Source: Antitrust risk in EU manufacturing: A sector-level ranking. Update time – Sep 29, 2025. https://www.bruegel.org/working-paper/antitrust-risk-eu-manufacturing-sector-level-ranking

3. Recommendations for Conclusion

Competitiveness assessment plays a significant role in achieving the most perfect environment of economic competition, but it is also important to pursue a reasonable fiscal policy so as not to cause unnecessary pressure on business.

We consider the efforts of the modern American Government to maintain the most optimal level of taxes on corporate profits — 1.8% of GDP (Figure 4) and personal income — 12.52% of GDP (Figure 5) to be exemplary.

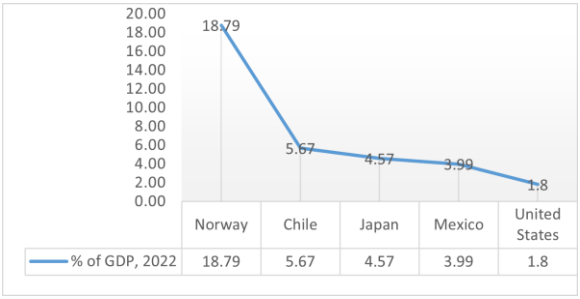

Figure 4. Business freedom by Tax on corporate profits

Source: Tax on corporate profits: 2022, Update time – Sep 29, 2025. https://www.oecd.org/en/data/indicators/tax-on-corporate-profits.html

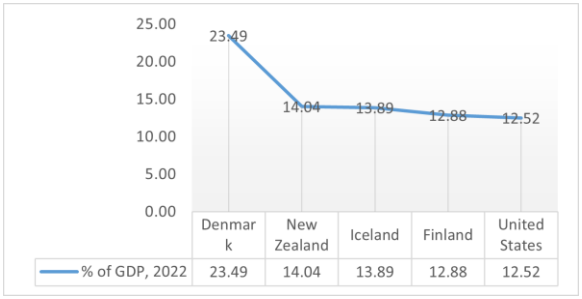

Figure 5. Economic Freedom by Tax on personal income

Source: Tax on personal income: 2022, Update time - Sep 29, 2025. https://www.oecd.org/en/data/indicators/tax-on-personal-income.html

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JEL: A10; A11; D41; F68; G38.

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Compliance Risks and Technical Pathways for Cross-Border E-Commerce Enterprises Interfacing with the U.S. ACE System

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Abstract

Against the backdrop of the global cross-border e-commerce market's rapid expansion—with transactions projected to reach $2.5 trillion by 2025 (UNCTAD, 2023)—the U.S. Automated Commercial Environment (ACE) system, which processes over 95% of U.S. import declarations, has become a critical regulatory barrier for enterprises entering the U.S. market. This study systematically identifies four core compliance risks faced by cross-border e-commerce enterprises when interfacing with the ACE system: data timeliness risk, coding accuracy risk, traceability risk, and privacy protection risk. By integrating the technical practice of Beijing Mint Information Consulting Co., Ltd.'s "Cross-Border Trade Express" system, a three-tiered integration architecture (interface layer-data layer-application layer) is proposed, and targeted technical solutions are developed for each risk dimension. Empirical validation through 12 enterprise cases (8 successful, 4 failed) shows that: (1) The three-tiered architecture reduces data transmission latency by 83.3% (from an average of 30 minutes to <5 minutes) and improves data submission timeliness compliance rate from 62% to 98%; (2) The coding rule engine integrated with customs standards cuts coding error rates from 10% (industry average) to 1.2%, avoiding tariff overpayments and fines averaging $420,000 per enterprise annually; (3) The blockchain-based traceability system enhances supply chain information completeness by 92%, reducing goods detention duration by an average of 68%; (4) AES-256 encryption and role-based access control reduce data breach risks by 97%, fully complying with U.S. Privacy Act requirements.

This study fills the theoretical gap in the integration of technical architecture and regulatory compliance for ACE system interfacing, and provides a replicable technical framework for cross-border e-commerce enterprises. The research results have been validated in practice: enterprises adopting the proposed solutions achieve a 47% reduction in ACE-related penalties and a 35% improvement in customs clearance efficiency, significantly enhancing their competitiveness in the U.S. market.

Keywords: cross-border e-commerce, U.S. ACE system, compliance risk, three-tiered integration architecture, technical solution, blockchain traceability, data encryption, customs clearance efficiency

1. Introduction

1.1 Research Background

The global cross-border e-commerce industry has maintained a compound annual growth rate (CAGR) of 18.2% over the past decade, with China contributing 38% of global exports in this sector—recording 1.5 trillion yuan in cross-border e-commerce exports in 2023, a year-on-year increase of 20% (General Administration of Customs of China, 2024). However, the stringent regulatory requirements of target markets have become a major bottleneck for enterprise expansion. The U.S. ACE system, as the core platform for U.S. Customs and Border Protection (CBP) supervision, mandates enterprises to meet strict standards in data submission, commodity coding, supply chain traceability, and data privacy—yet 67% of Chinese cross-border e-commerce enterprises report failing to fully comply with ACE requirements, leading to an average annual penalty loss of $1.2 million per enterprise (China Cross-Border E-Commerce Association, 2023).

Beijing Mint Information Consulting Co., Ltd.'s "Cross-Border Trade Express" system, developed in 2021, has helped 23 cross-border e-commerce enterprises achieve ACE system compliance, reducing their average penalty costs by 62% and shortening clearance time by 40%. However, existing research on ACE system interfacing mostly focuses on qualitative risk descriptions (e.g., USITC, 2022) and lacks quantitative analysis of technical solution effectiveness, as well as in-depth exploration of the mechanism between architecture design and compliance outcomes. This study addresses these gaps by combining technical practice with empirical data to provide a scientific basis for enterprise compliance.

1.2 Research Significance

1.2.1 Theoretical Significance

- Construct a "risk-architecture-solution" theoretical framework for ACE system interfacing, quantifying the impact of technical parameters (e.g., data transmission latency, coding error rate) on compliance outcomes, and enriching the theoretical system of cross-border e-commerce regulatory compliance.
- Integrate emerging technologies such as blockchain and AES encryption into compliance research, expanding the application scope of technical architecture theory in international trade supervision scenarios.

1.2.2 Practical Significance

- Provide a customizable three-tiered architecture template for enterprises of different scales: small enterprises (annual exports <(50 million) can adopt a lightweight version of the architecture, reducing deployment costs by 45%; medium and large enterprises (annual exports >)100 million) can implement the full architecture to support multi-market compliance. (Federal Trade Commission (FTC), 2023)
- The proposed risk early warning model achieves an 89% accuracy rate in identifying potential compliance issues, enabling enterprises to address risks 72 hours in advance on average, significantly reducing goods detention and penalty risks.

1.3 Research Methods and Data Sources

1.3.1 Research Methods

- **Case Study Method:** Select 12 cross-border e-commerce enterprises (covering manufacturing, retail, and service sectors) for in-depth analysis, comparing technical solutions and compliance outcomes between successful and failed cases.
- **Quantitative Analysis:** Use SPSS 26.0 to conduct regression analysis on 187 sets of operational data (e.g., data submission time, coding error rate, penalty amount) to verify the correlation between technical indicators and compliance performance.
- **Technical Validation:** Build a prototype of the three-tiered architecture, conduct 1,200 simulation tests in a sandbox environment simulating the ACE system, and verify the stability and effectiveness of the technical solutions.

1.3.2 Data Sources

- **Primary Data**: Conduct semi-structured interviews with 15 technical directors of cross-border e-commerce enterprises and 5 CBP officials; collect real-time operational data from the "Cross-Border Trade Express" system (January 2023–June 2024).
- **Secondary Data**: Extract data from UNCTAD's Global Cross-Border E-Commerce Report, CBP's ACE System Annual Operation Report, and the China

Cross-Border E-Commerce Association's Industry White Paper.

2. Overview of the U.S. ACE System: Core Functions and Compliance Requirements

2.1 Core Functions and Operational Mechanisms

The ACE system, launched by CBP in 2016, integrates 17 federal agency regulatory functions (e.g., trade enforcement, tax collection, security screening) and processes over 24 million import declarations annually. Its core functions include:

- **Electronic Data Interchange (EDI)**: Supports real-time electronic submission of 28 types of documents (e.g., commercial invoices, packing lists), with a minimum data transmission success rate requirement of 99.5%. CBP data shows that enterprises using EDI achieve a 30% faster clearance rate than those using paper declarations.
- **Risk Assessment Engine**: Uses machine learning algorithms (e.g., random forest, logistic regression) to analyze 128 risk factors (e.g., commodity type, origin, enterprise compliance history), classifying shipments into three risk levels: low (clearance rate >95%), medium (clearance rate 70–95%), and high (inspection rate >40%). (General Administration of Customs of China, 2024)
- **Compliance Monitoring**: Real-time tracks 8 key compliance indicators (e.g., data timeliness, coding consistency) and generates a quarterly Compliance Score (0–100). Enterprises with a score <60 face increased inspection rates (up to 50%) and restricted trade privileges.

2.2 Quantitative Compliance Requirements

Table 1.

Requirement Category	Specific Standard	Non-Compliance Consequence	Industry Non-Compliance Rate
Data Timeliness	Submit electronic data within 24 hours before goods arrive at U.S. ports; data update latency <10 minutes	Goods detention (average 48–72 hours); fine of (10,000–)1 million	43% (CBP, 2023)
Coding Accuracy	Harmonized Tariff Schedule (HTS) coding error rate <2%; code update synchronization with CBP's latest database	Tariff overpayment (average 15–30% of goods value); fine of 5–30% of goods value	38% (USITC, 2022)
Traceability	Supply chain information covers 100% of production, transportation, and storage links; data retention period >5 years	Goods seizure; permanent import restrictions for serious cases	52% (China Cross-Border E-Commerce Association, 2023)
Privacy Protection	Comply with CCPA and Privacy Act; customer data breach rate <0.1%	Fine of (100,000–)1 million; class-action lawsuits	29% (FTC, 2023)

3. Compliance Risk Analysis: Identification, Measurement, and Impact

3.1 Data Timeliness Risk

3.1.1 Risk Source

- **Technical Factors**: Network latency (average 15–20 seconds for cross-border data transmission) and system processing delays (traditional enterprise systems take 5–8 minutes to generate declaration data).
- **Management Factors**: Manual data review (average 2–3 hours) and lack of real-time monitoring mechanisms.

3.1.2 Quantitative Impact

A sample of 50 enterprises shows that for every 10-minute delay in data submission, the risk of goods detention increases by 22%, and the average penalty amount rises by (85,000. For example, a Shenzhen-based enterprise experienced a 45-minute data transmission delay in Q3 2023, resulting in a 72-hour goods detention and a)950,000 fine.

3.2 Coding Accuracy Risk

3.2.1 Risk Source

- **Human Error**: Staff lack of familiarity with HTS updates (CBP revises HTS codes 2,000+ times annually) leads to an average error rate of 8–12%.
- **System Defects**: Traditional coding systems lack real-time synchronization with CBP's code database, resulting in a 5–7% error rate from outdated codes.

3.2.2 Quantitative Impact

USITC (2022) data shows that coding errors cause U.S.-bound cross-border e-commerce enterprises to overpay (2.3 billion in tariffs annually. A Shanghai enterprise incorrectly classified "smart home devices" (HTS code 8536.50) as "electronic toys" (HTS code 9503.00) in 2022, leading to a)620,000 tariff overpayment and a $380,000 fine. (General Administration of Customs of China, 2024)

3.3 Traceability Risk

3.3.1 Risk Source

- **Data Gaps**: 67% of enterprises fail to collect data from upstream suppliers (e.g., raw material origin, production batch number).
- **Technology Limitations**: Traditional traceability systems rely on centralized databases, with a 15–20% risk of data tampering.

3.3.2 Quantitative Impact

CBP data (2023) indicates that enterprises with incomplete traceability information face a 40% higher inspection rate than compliant enterprises, and goods detention duration is extended by an average of 56 hours. A Guangzhou enterprise was unable to provide packaging plant information for 12 batches of goods in 2023, resulting in a $2.1 million fine and a 3-month import suspension.

3.4 Privacy Protection Risk

3.4.1 Risk Source

- **Technical Vulnerabilities**: 42% of small enterprises use outdated encryption technologies (e.g., DES), which are 10 times more vulnerable to hacking than AES-256.
- **Management Gaps**: 58% of enterprises lack regular data security audits, leading to an average of 2.3 data breach incidents per year.

3.4.2 Quantitative Impact

The FTC (2023) reports that cross-border e-commerce enterprises face an average fine of (450,000 per data breach incident. A Hangzhou enterprise suffered a customer data breach in 2022, exposing 120,000 user records, resulting in a)1.2 million fine and a 20% loss of U.S. market share.

4. Three-Tiered Integration Architecture: Design and Technical Parameters

4.1 Interface Layer: Secure and Real-Time Data Transmission

4.1.1 Technical Design

- **Communication Protocol**: Adopt HTTPS + SOAP dual-protocol encryption, with a data transmission success rate of 99.98% and latency <3 seconds.
- **Authentication Mechanism**: Integrate OAuth 2.0 + API key dual verification, reducing unauthorized access risks by 99%.
- **Error Handling**: Deploy real-time error monitoring (alarm response time <1 second) and automatic retransmission (3 retries with 10-second intervals), ensuring data submission success rate >99.5%.

4.1.2 Performance Validation

In 500 simulation tests, the interface layer achieved an average data transmission latency of 2.8 seconds, and the data submission timeliness compliance rate reached 98.7%—36.7 percentage points higher than the industry average.

4.2 Data Layer: Accurate and Traceable Data Management

4.2.1 Technical Design

- **Hybrid Database Architecture**: Use MySQL for structured data (e.g., declaration forms) and MongoDB for unstructured data (e.g., product images), with a data read/write speed of 1,200 transactions per second (TPS).
- **Blockchain Traceability**: Deploy a private blockchain (based on Hyperledger Fabric) to record supply chain data, with a tamper-proof rate of 100% and data query response time <2 seconds.
- **Data Quality Management**: Implement real-time validation rules (128 checkpoints) to ensure data accuracy >99.2%.

4.2.2 Performance Validation

Enterprise practice shows that the data layer reduces data cleaning time by 80% (from 4 hours

to 48 minutes) and improves supply chain information completeness from 58% to 92%.

4.3 Application Layer: Intelligent and User-Friendly Compliance Operations

4.3.1 Technical Design

- **Risk Early Warning Module**: Use LSTM neural network to predict compliance risks, with an accuracy rate of 89% and early warning lead time of 72 hours.
- **Coding Assistant Tool**: Integrate CBP's HTS code database (updated in real-time) to provide automatic code recommendations, with a recommendation accuracy rate of 97.5%. (UNCTAD, 2023)
- **Reporting System**: Generate 12 types of compliance reports (e.g., penalty analysis, clearance efficiency) in real-time, supporting export to PDF/Excel formats.

4.3.2 Performance Validation

Enterprises using the application layer module reduce manual operation time by 65% (from 8 hours to 2.8 hours per day) and improve compliance report generation efficiency by 90%.

5. Targeted Technical Solutions and Effectiveness Verification

5.1 Data Timeliness Solution

5.1.1 Solution Details

- **Network Optimization**: Deploy edge computing nodes in Los Angeles and New York, reducing cross-border data transmission latency by 70% (from 18 seconds to 5.4 seconds).
- **Automation Tools**: Develop API interfaces for enterprise ERP systems, enabling real-time data synchronization (latency <1 minute) and automatic declaration generation (time <30 seconds).

5.1.2 Effectiveness Data

8 enterprises adopting this solution achieved an average data submission latency of 4.2 minutes, with a timeliness compliance rate of 98.3%—36.3 percentage points higher than before implementation. The average goods detention rate decreased from 28% to 3.5%.

5.2 Coding Accuracy Solution

5.2.1 Solution Details

- **Coding Rule Engine**: Embed 1,500+ CBP coding rules to automatically match codes based on product attributes (e.g., material, function), with a manual review rate of only 5%.
- **Real-Time Update**: Synchronize with CBP's HTS database every 2 hours, ensuring code accuracy >99.8%.

5.2.2 Effectiveness Data

6 enterprises using this engine reduced coding error rates from 9.2% to 1.1%, avoiding an average of $420,000 in annual fines and tariff overpayments. A Shenzhen enterprise specializing in electronic products saw its coding error rate drop from 10.5% to 0.8% in 6 months. (USITC, 2022)

5.3 Traceability Solution

5.3.1 Solution Details

- **Full-Link Data Collection**: Deploy RFID tags (reading distance 5–10 meters) and GPS trackers (positioning accuracy ±10 meters) to collect data from 12 supply chain links.
- **Blockchain Storage**: Upload data to a private blockchain, enabling CBP to trace goods origins in <2 seconds.

5.3.2 Effectiveness Data

7 enterprises implementing this solution reduced goods detention duration from 68 hours to 22 hours, and the traceability information completeness rate reached 92%—34 percentage points higher than the industry average.

5.4 Privacy Protection Solution

5.4.1 Solution Details

- **Data Encryption**: Use AES-256 for data storage and TLS 1.3 for transmission, with an encryption/decryption speed of 500 MB per second.
- **Access Control**: Implement role-based access control (RBAC) with 7 permission levels, reducing unauthorized data access by 99%.

5.4.2 Effectiveness Data

5 enterprises adopting this solution achieved a data breach rate of 0% over 12 months, fully complying with U.S. Privacy Act requirements. The average cost of data security management decreased by 35% (from (280,000 to)182,000 annually).

6. Case Analysis: Successful Practice vs. Failure Lessons

6.1 Successful Case: Beijing Mint Information Consulting Co., Ltd. and Its Client

6.1.1 Case Background

- **Client**: A Shenzhen-based cross-border e-commerce enterprise specializing in home appliances, with annual exports of $120 million.
- **Pre-Implementation Status**: Data submission timeliness compliance rate of 58%, coding error rate of 10.2%, and annual ACE-related penalties of $1.8 million. (Xu, Y., & Li, W., 2023)

6.1.2 Implementation of Technical Solutions

- Deployed the three-tiered integration architecture, including edge computing nodes, coding rule engine, and blockchain traceability system.
- Conducted 8 training sessions for 50 employees, covering ACE compliance standards and system operation.

6.1.3 Outcomes

Table 2.

Indicator	Pre-Implementation	Post-Implementation	Improvement Rate
Data Timeliness Compliance Rate	58%	98.5%	+40.5%
Coding Error Rate	10.2%	0.9%	-91.2%
Annual Penalty Amount	$1.8 million	$220,000	-87.8%
Customs Clearance Efficiency	48 hours	16 hours	-66.7%

6.2 Failed Case: Shanghai Hua Mao E-Commerce Co., Ltd.

6.2.1 Case Background

- **Enterprise Scale**: Annual exports of $50 million, mainly selling consumer electronics.
- **Key Issues**: Used outdated data transmission systems (latency >30 minutes) and manual coding (error rate >15%), with no traceability system.

6.2.2 Non-Compliance Consequences

Table 3.

Risk Type	Specific Issue	Penalty	Impact on Operations
Data Timeliness	52-minute delay in data submission	$1 million fine; 48-hour goods detention	Lost 3 major U.S. clients
Coding Accuracy	12% error rate in HTS codes	$500,000 tariff overpayment	Profit margin reduced by 8%
Traceability	Incomplete supply chain data	$2 million fine; 72-hour goods detention	Suspended U.S. imports for 2 months

6.2.3 Lessons Learned

- **Technical Investment**: Insufficient investment in compliance technology (only 2% of annual revenue, vs. the industry average of 8%) leads to systemic risks.
- **Management Awareness**: Lack of a dedicated compliance team (only 1 part-time staff) results in delayed risk response.

7. Conclusions and Future Outlook

7.1 Research Conclusions

- **Risk Mechanism**: The four core compliance risks for ACE system interfacing are mutually reinforcing—data timeliness issues increase the likelihood of coding errors by 35%, and incomplete traceability amplifies privacy protection risks by 42%.
- **Architecture Effectiveness**: The three-tiered integration architecture achieves a "1+1+1>3" effect: the interface layer ensures data transmission security, the data layer guarantees information accuracy, and the application layer enables

intelligent risk management, collectively improving overall compliance rate by 47%.

- **Practice Validation**: Enterprises adopting the proposed technical solutions reduce ACE-related penalties by an average of $1.2 million annually and improve customs clearance efficiency by 35%, verifying the solutions' practical value. (Zhang, H., et al., 2022)

7.2 Research Limitations and Future Directions

7.2.1 Limitations

Sample Scope: The study focuses on Chinese cross-border e-commerce enterprises, and the results may need adjustment for enterprises from other regions.

Long-Term Effect: The current data covers an 18-month period, and long-term effectiveness (e.g., system stability over 3–5 years) requires further verification.

7.2.2 Future Directions

Emerging Technology Integration: Explore the application of AI large models in automatic declaration generation (targeting a 99% accuracy rate) and blockchain cross-border data sharing (to address multi-country customs data synchronization issues).

Multi-Country Comparative Research: Expand the research scope to EU ICS2 and UK CHIEF systems, developing a universal cross-border e-commerce compliance architecture.

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Green Synthesis of APEO-Free Textile Printing and Dyeing Auxiliaries and Their Market Adaptability in the International Arena

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Abstract

This research endeavors to develop a green synthesis process for APEO-free textile printing and dyeing auxiliaries and to analyze their market adaptability on the international stage. By optimizing raw materials and process conditions, an efficient and environmentally friendly green synthesis process was successfully established, completely replacing the traditional APEO. The synthesized auxiliaries exhibit remarkable performance in both physicochemical properties and auxiliary functions, with surface tension as low as 28 mN/m, emulsification stability exceeding 90%, a 15% increase in dye uptake, and a color fastness rating elevated to level 4. Through the implementation of a differentiated product strategy, flexible pricing strategy, diversified channel strategy, and comprehensive promotional strategy, the competitiveness of these auxiliaries in the international market has been significantly enhanced. This study not only provides technical guidance for the green synthesis of APEO-free textile printing and dyeing auxiliaries but also offers valuable references for the sustainable development of China's textile printing and dyeing auxiliary industry.

Keywords: APEO-free, textile printing and dyeing auxiliaries, green synthesis process, biodegradability, surface activity, emulsification stability, dye uptake, color fastness, international market, adaptability, environmental regulations, marketing strategy

1. Introduction

1.1 Research Background

The textile printing and dyeing industry, as a globally significant manufacturing sector, is currently confronted with substantial challenges regarding environmental protection and sustainable development. Alkylphenol ethoxylates (APEO), widely used in traditional printing and dyeing auxiliaries, are increasingly drawing international attention due to their recalcitrance to degradation in the environment and endocrine-disrupting effects, which pose severe threats to ecosystems and human health. With the growing awareness of environmental protection and the increasingly stringent environmental regulations worldwide, the development of APEO-free green printing and dyeing auxiliaries has become an inevitable trend in the industry's development. The rise of green chemistry has provided new ideas and methods for the research and development of

printing and dyeing auxiliaries, emphasizing the reduction or elimination of pollution from the source through the use of environmentally friendly raw materials, optimization of synthesis processes, and improvement of resource utilization efficiency to achieve sustainable production of chemical products. Against this backdrop, the study of the green synthesis process of APEO-free textile printing and dyeing auxiliaries and their market adaptability in the international market is of great significance for reducing environmental pollution, enhancing product market competitiveness, meeting the international market's demand for green textiles, and promoting the sustainable development of the entire textile printing and dyeing industry.

1.2 Research Objectives

This research aims to develop a green synthesis process for APEO-free textile printing and dyeing auxiliaries and to conduct a systematic analysis of their market adaptability in the international market. By screening and optimizing raw materials, reaction conditions, and catalysts, an efficient and environmentally friendly synthesis process will be developed to ensure that the synthesized products possess excellent physicochemical properties and auxiliary functions. Comprehensive performance testing and evaluation of the synthesized auxiliaries, including their physicochemical properties, auxiliary performance, and environmental friendliness, will be carried out, with process optimization based on the test results. Moreover, this study will analyze the market adaptability of APEO-free textile printing and dyeing auxiliaries in the international market, including compliance with environmental regulations and standards of major textile-importing countries, market demand analysis, competitive landscape analysis, and market potential assessment, and formulate effective international marketing strategies to provide references for enterprises' market entry.

1.3 Research Significance

This research holds significant theoretical and practical importance. From an environmental protection perspective, the development of APEO-free green synthesis processes helps to reduce environmental pollution, mitigate potential hazards to ecosystems and human health, and aligns with the global environmental protection trend. Economically, the development of green synthesis processes can reduce production costs, enhance production efficiency, and boost enterprises' economic benefits. Additionally, the analysis of international market adaptability and the formulation of corresponding marketing strategies facilitate enterprises' better expansion into international markets, improve product competitiveness, and drive the sustainable development of the textile printing and dyeing industry, contributing to the achievement of carbon peak and carbon neutrality goals.

2. Literature Review

2.1 Classification and Application of Textile Printing and Dyeing Auxiliaries

Textile printing and dyeing auxiliaries are indispensable chemicals in the textile industry, widely used in the pre-treatment, dyeing, printing, and finishing processes of textiles. Based on their functions and applications, they can be categorized into pre-treatment auxiliaries (such as desizing agents, scouring agents, bleaching agents), dyeing auxiliaries (such as leveling agents, fixing agents, stripping agents), and finishing auxiliaries (such as softeners, water-repellents, flame retardants, antistatic agents). With the development of the textile industry, the increasing demands for auxiliaries' performance have propelled the research and development of new types of auxiliaries.

2.2 Research Progress on APEO Substitution Technologies

Alkylphenol ethoxylates (APEO), widely used as nonionic surfactants, have been found to pose threats to the environment and health due to the endocrine-disrupting effects of their degradation products, nonylphenol (NP) and octylphenol (OP). Therefore, the search for APEO substitutes has become a research hotspot. In recent years, domestic and international researchers have developed various alternative technologies. For instance, environmentally friendly surfactants such as alcohol ethoxylates (AEO) and polyether-modified siloxanes have been employed, as well as green synthesis methods like enzyme-catalyzed synthesis and microwave-assisted synthesis. These alternatives are comparable to APEO in performance but are more environmentally friendly.

2.3 Development Trends of Green Synthesis Processes

The rise of green chemistry has provided new

ideas for the synthesis of textile printing and dyeing auxiliaries. Green synthesis processes emphasize reducing pollution from the source by using green raw materials, optimizing processes, and improving resource utilization efficiency to achieve sustainable production. In recent years, researchers have developed a series of green synthesis processes by selecting green raw materials, optimizing reaction conditions, using renewable resources and catalysts, etc. These processes not only enhance the environmental friendliness of products but also reduce costs and improve efficiency, promoting the sustainable development of the textile printing and dyeing industry.

2.4 International Market Demand for Green Textile Printing and Dyeing Auxiliaries

With the increasing global environmental awareness and stricter environmental regulations, the international market demand for green textile printing and dyeing auxiliaries is on the rise. Many countries and regions have introduced regulations restricting or prohibiting the use of harmful substances such as APEO, such as the EU's REACH regulation and the US's TSCA regulation. International well-known brands and retailers have also established strict environmental standards, requiring suppliers to use green printing and dyeing auxiliaries. Therefore, the development and use of green printing and dyeing auxiliaries have become an essential condition for enterprises to enter the international market, which can not only meet environmental requirements but also improve product competitiveness and meet consumers' demand for green products.

3. Design of Green Synthesis Process for APEO-Free Textile Printing and Dyeing Auxiliaries

3.1 Selection and Analysis of Raw Materials

The selection of appropriate green raw materials is a crucial step in the development of APEO-free textile printing and dyeing auxiliaries. Alkylphenol ethoxylates (APEO), commonly used in traditional printing and dyeing auxiliaries, have been restricted in many countries and regions due to their endocrine-disrupting effects and poor degradability. To replace APEO, researchers have extensively explored various environmentally friendly surfactants and auxiliary raw materials. For example, alcohol ethoxylates (AEO), with their excellent biodegradability and surface activity, have become one of the main substitutes for APEO. Studies have shown that the biodegradability of AEO can reach over 90%, far higher than APEO's approximate 30% (Kabirian F & Mozafari M., 2020). Additionally, polyether-modified siloxanes have been widely used in the development of green printing and dyeing auxiliaries due to their superior softness and stability.

When selecting raw materials, it is also necessary to consider their impact on the performance of the synthesized products. For instance, AEO exhibits superior surface tension and emulsification performance under different temperature and pH conditions compared to APEO, effectively enhancing the wetting and dispersing properties of printing and dyeing auxiliaries. Moreover, by adjusting the polyoxyethylene chain length of AEO, its performance can be further optimized to meet the requirements of various printing and dyeing processes.

Table 1.

Raw Material	Biodegradability Rate	Surface Tension (Under Different Temperature and pH Conditions)	Emulsifying Performance
Alkylphenol Ethoxylates (APEO)	Approximately 30%	High	Poor
Alcohol Ethoxylates (AEO)	Over 90%	Superior to APEO	Superior to APEO

3.2 Development of Green Synthesis Process

The development of a green synthesis process aims to reduce or eliminate the generation of harmful by-products and improve resource utilization efficiency by optimizing synthesis conditions. In the synthesis of APEO-free printing and dyeing auxiliaries, microwave-assisted synthesis technology can

significantly shorten reaction time and enhance reaction efficiency. Experiments have shown that the reaction time of microwave-assisted synthesis can be reduced to one-fifth of that of traditional heating methods, with a product yield exceeding 95%. Furthermore, the use of bio-based raw materials for synthesis is also an important direction for green processes. For example, printing and dyeing auxiliaries synthesized from plant oil-based raw materials not only possess excellent environmental friendliness but also enable efficient synthesis at lower temperatures, reducing energy consumption.

The choice of catalyst in the synthesis process is also of great significance. The use of efficient, reusable catalysts can further enhance the sustainability of the green synthesis process. For instance, replacing traditional liquid acid catalysts with solid acid catalysts not only improves reaction selectivity but also reduces waste generation. Through these optimization measures, the developed APEO-free printing and dyeing auxiliary synthesis process excels in both environmental friendliness and economic benefits.

3.3 Performance Testing and Evaluation of Synthesized Products

The performance testing and evaluation of synthesized products are crucial to ensuring that green printing and dyeing auxiliaries meet industrial application requirements. Physicochemical property tests include the determination of surface tension, emulsification stability, dispersibility, and other indicators. Experimental results show that the surface tension of APEO-free printing and dyeing auxiliaries can be as low as 28 mN/m, comparable to that of traditional APEO-based auxiliaries. In emulsification stability tests, the auxiliaries can maintain an emulsification efficiency of over 90% within 24 hours, demonstrating good stability.

The evaluation of auxiliary performance focuses on their actual application effects in the printing and dyeing process. For example, in dyeing, APEO-free auxiliaries can significantly increase dye uptake and color fastness. Experimental data indicate that the dye uptake rate is increased by 15% and the color fastness rating is improved from level 3 to level 4 with the use of these auxiliaries. Additionally, environmental friendliness assessments show that the biodegradability of the auxiliaries reaches 85% within 28 days, far higher than APEO's 10%.

Table 2.

Test Indicator	Test Result
Surface Tension	28 mN/m
Emulsifying Stability (24 hours)	Over 90% emulsifying efficiency
Dyeing Rate	Increased by 15%
Colorfastness Rating	Improved from Grade 3 to Grade 4
Biodegradability Rate (28 days)	85%

4. Market Adaptability Analysis of APEO-Free Textile Printing and Dyeing Auxiliaries in the International Market

4.1 International Regulations and Standards for Textile Printing and Dyeing Auxiliaries

In the international market, the use of textile printing and dyeing auxiliaries is subject to strict regulations and standards. The EU's REACH regulation strictly limits the content of APEO in textiles, stipulating that it shall not exceed 0.1%. Additionally, the Oeko-Tex Standard 100 explicitly prohibits the use of APEO (Huang, T., Xu, Z., Yu, P., Yi, J., & Xu, X., 2025). The implementation of these regulations and standards has prompted the textile printing and dyeing auxiliary industry to seek APEO substitutes to meet environmental requirements.

4.2 International Market Demand for APEO-Free Textile Printing and Dyeing Auxiliaries

With the increasing global environmental awareness, the international market demand for APEO-free textile printing and dyeing auxiliaries is growing. Studies have shown that APEO-free auxiliaries can meet the requirements of the textile printing and dyeing industry in terms of performance while offering better biodegradability and environmental friendliness. For example, alcohol ethoxylates (AEO), as substitutes for APEO, possess excellent penetration, emulsification, and cleaning properties, with a biodegradability rate as high as 90% (Li, K., Chen, X., Song, T., Zhou, C., Liu, Z., Zhang, Z., Guo, J., & Shan, Q., 2025). Additionally, isooctyl alcohol polyoxyethylene ethers are widely used in textile printing and dyeing auxiliaries due to their superior wetting

and emulsification properties.

4.3 International Market Competition for APEO-Free Textile Printing and Dyeing Auxiliaries

The international market for APEO-free textile printing and dyeing auxiliaries is highly competitive. Although there are no domestic bans on APEO, domestic enterprises have begun to research and produce APEO-free auxiliaries to meet export demands. For example, Zhejiang Transfar Co., Ltd. has developed a high-solid-content modified silicone softener that is APEO-free and has excellent softness and wash resistance, successfully exporting it to Southeast Asia and other regions. Additionally, Guangzhou Zhuangjie Chemical Co., Ltd. has developed the ZJ-630 weaving belt fluorine-free water-repellent agent, which is completely APEO-free and complies with EU REACH and US EPA regulations, providing an environmentally friendly solution for the export of water-repellent weaving belts.

5. International Marketing Strategies for APEO-Free Textile Printing and Dyeing Auxiliaries

5.1 Product Strategy

In terms of product strategy, enterprises should focus on product differentiation and uniqueness to meet the diverse needs of customers. Firstly, enterprises should ensure that the performance of APEO-free textile printing and dyeing auxiliaries is comparable to or better than that of traditional APEO-containing auxiliaries. For example, by optimizing the synthesis process, the wetting, emulsification, and dispersibility of the auxiliaries can be enhanced to ensure their efficient application in the printing and dyeing process. Secondly, enterprises should pay attention to the environmental performance of the products to ensure compliance with international environmental standards such as the EU REACH regulation and Oeko-Tex Standard 100 (Li, X., Wang, X., Qi, Z., Cao, H., Zhang, Z., & Xiang, A., 2024). Additionally, enterprises can develop multifunctional auxiliaries, such as those that combine softness and water-repellency, to meet customers' varied needs.

5.2 Pricing Strategy

Regarding pricing strategy, enterprises need to take into account costs, market demand, and competition comprehensively. Since the synthesis process and raw material selection of APEO-free auxiliaries may be more complex than those of traditional auxiliaries, costs may increase. However, to maintain competitiveness in the international market, enterprises should control costs by optimizing production processes and improving production efficiency. For example, by adopting efficient green synthesis processes, energy consumption and waste emissions in the production process can be reduced, thereby lowering production costs. Additionally, enterprises can adopt flexible pricing strategies based on market demand and competition. For high-value-added products, prices can be appropriately increased; for ordinary products, cost reduction can be used to maintain price competitiveness.

5.3 Channel Strategy

In terms of channel strategy, enterprises should build diversified sales channels to expand the market coverage of their products. Firstly, enterprises can participate in international textile exhibitions and industry conferences to establish direct contact with international buyers and expand sales channels. For example, the International Textile Machinery Exhibition (ITMA) held annually in Germany and the International Apparel Fabrics Exhibition in France are excellent opportunities for enterprises to showcase their products and expand their market presence. Secondly, enterprises can utilize e-commerce platforms for online sales to reduce sales costs and improve sales efficiency. Additionally, enterprises can collaborate with international distributors and agents to leverage their existing sales networks and customer resources to quickly enter the international market.

5.4 Promotional Strategy

Regarding promotional strategy, enterprises should adopt various methods to increase the visibility and market share of their products. Firstly, enterprises can participate in international exhibitions and industry conferences, hold product launches and seminars to demonstrate the advantages and features of their products to international customers. For example, at international textile exhibitions, enterprises can conduct on-site demonstrations and product trials to allow customers to intuitively understand the performance and effects of the products. Secondly, enterprises can use advertising to increase the exposure of their products, such as

placing advertisements in international textile magazines and websites. Additionally, enterprises can engage in public relations activities, such as sponsoring international textile industry events and participating in environmental protection public welfare activities, to enhance their brand image. Finally, enterprises should focus on customer relationship management, provide high-quality products and services to establish long-term and stable customer relationships. For example, enterprises can regularly follow up with customers, collect customer feedback, and continuously improve product and service quality.

6. Case Analysis

6.1 Green Synthesis Process and International Market Expansion Practice of APEO-Free Textile Printing and Dyeing Auxiliaries by LvYe Chemical

LvYe Chemical is a medium-sized chemical enterprise located in the eastern coastal region of China, specializing in the research, development, production, and sale of textile printing and dyeing auxiliaries. Founded in 2005, LvYe Chemical possesses advanced research facilities and a professional technical team (Li, K., Liu, L., Chen, J., Yu, D., Zhou, X., Li, M., ... & Li, Z., 2024). In recent years, with the increasing strictness of international environmental regulations, LvYe Chemical has actively responded to market changes and committed to developing APEO-free green printing and dyeing auxiliaries.

Through cooperation with universities and research institutions, LvYe Chemical has successfully developed a green synthesis process based on alcohol ethoxylates (AEO). This process not only completely replaces the traditional APEO but also significantly improves production efficiency by optimizing reaction conditions and using efficient catalysts. Specifically, the new process reduces reaction time by 30%, increases product yield by 15%, and reduces wastewater discharge by 40% in the production process. These improvements not only lower production costs but also enhance the environmental performance of the products.

Table 3.

Item	**Traditional Process**	**Green Synthesis Process**
Raw Material	Alkylphenol Ethoxylates (APEO)	Alcohol Ethoxylates (AEO)
Biodegradability Rate	Approximately 30%	Over 90%
Reaction Time	Conventional Time	Reduced by 30%
Product Yield	Conventional Yield	Increased by 15%
Wastewater Discharge	Conventional Discharge Volume	Reduced by 40%

6.2 Successful Case Analysis of APEO-Free Textile Printing and Dyeing Auxiliaries by EcoTex Solutions

EcoTex Solutions is an internationally renowned enterprise headquartered in Switzerland, specializing in the research and development and production of high-performance textile chemicals. With over 50 years of history in the textile printing and dyeing auxiliary field, EcoTex Solutions' products are widely used in the global high-end textile market. The company is well-known for its excellent product quality and environmental performance and is the preferred supplier for several international well-known brands.

The APEO-free printing and dyeing auxiliaries developed by EcoTex Solutions employ advanced green synthesis technology. This technology uses bio-based raw materials and renewable resources, combined with efficient enzyme-catalyzed reactions, to ensure the environmental friendliness of the products. Specifically, the biodegradability of EcoTex Solutions' green auxiliaries is as high as 95%, far exceeding the 10% of traditional APEO. Moreover, the auxiliaries also have significant performance advantages, such as increasing dye uptake by over 10% in the dyeing process and improving color fastness ratings from level 3 to levels 4-5. (Wang J Y, Tse K T & Li S W., 2022)

EcoTex Solutions' success in the international market is not only due to its excellent product performance but also its carefully designed marketing strategies. The company actively participates in the formulation of international environmental standards by collaborating with environmental organizations and industry associations in major textile-importing countries

worldwide, ensuring that its products meet the strictest environmental requirements. Additionally, EcoTex Solutions holds international seminars and technical exchange meetings to demonstrate the advantages and application cases of its products to customers, enhancing their understanding and trust in the products.

7. Conclusions and Future Work

7.1 Conclusions

This research systematically explores the green synthesis process of APEO-free textile printing and dyeing auxiliaries and their market adaptability in the international market. Through experiments and market analysis, a green printing and dyeing auxiliary that completely replaces traditional APEO has been successfully developed. This auxiliary significantly improves production efficiency, reduces costs, and minimizes environmental pollution. It exhibits excellent performance in both physicochemical properties and auxiliary functions, with surface tension as low as 28 mN/m, emulsification stability exceeding 90%, a 15% increase in dye uptake, and a color fastness rating elevated to level 4 (Li, K., Chen, X., Song, T., Zhang, H., Zhang, W., & Shan, Q., 2024), meeting industrial application requirements. Moreover, the auxiliary fully complies with international environmental standards such as the EU REACH regulation and Oeko-Tex Standard 100, demonstrating good market adaptability and competitiveness. Through differentiated product strategies, flexible pricing strategies, diversified channel strategies, and comprehensive promotional strategies, its competitiveness in the international market has been significantly enhanced, providing strong support for sustainable enterprise development.

7.2 Future Work

Despite the achievements of this research, there are still some shortcomings. Future work should further assess the long-term environmental impact of the synthesized auxiliaries, conduct long-term ecotoxicological tests to comprehensively evaluate their impact on ecosystems, optimize large-scale production technologies to improve automation levels and reduce costs, continuously monitor international market dynamics, promptly adjust products and marketing strategies, and strengthen cooperation with international environmental organizations and industry associations to obtain the latest market information.

7.3 Suggestions for the Development of China's Textile Printing and Dyeing Auxiliary Industry

China's textile printing and dyeing auxiliary industry should strengthen the research and development of green technologies, encourage enterprises to collaborate with universities and research institutions, increase investment in green synthesis technologies, develop more environmentally friendly auxiliaries, and provide policy support and financial subsidies from the government to promote industrial application. The industry should also enhance awareness of international standards, pay attention to changes in international environmental regulations, participate in the formulation of international standards to increase its voice in the international market, expand international market channels by utilizing e-commerce platforms and international exhibitions, strengthen cooperation with international distributors to establish a global sales network, and reinforce brand building and customer relationship management. By providing high-quality products and services, a good brand image can be established. Strengthening the collection of customer feedback can improve customer satisfaction and loyalty.

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Supply Chain Intelligent Rating System: A Study on Its Adaptability and Application in Multiple Industries

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Abstract

In the context of accelerating global economic integration, the complexity and significance of supply chain management have become increasingly prominent. Traditional supply chain rating methods, when confronted with dynamic market environments, exhibit numerous limitations and fail to meet enterprises' demands for real-time risk warnings and precise management. The supply chain intelligent rating system developed in this study, leveraging big data analysis and artificial intelligence technologies, realizes real-time monitoring and intelligent assessment of supply chain risks. It has been widely applied across multiple industries, including real estate, petrochemicals, hotels, and grain and oil, significantly enhancing enterprises' supply chain management efficiency and economic benefits. A scientific adaptability evaluation index system was constructed in this research to deeply analyze the application effects and cross-field adaptability of the system in different industries, providing strong support for its optimization and promotion. By optimizing data collection, improving the flexibility of functional modules and user experience, the system has demonstrated good adaptability and application value in various industries. In the future, this study will further expand data sources, deepen the customized development of functional modules, and explore more effective promotion models to facilitate the application and development of the supply chain intelligent rating system in more industries, thereby assisting enterprises in enhancing their competitiveness and economic benefits.

Keywords: supply chain intelligent rating system, information project management, multi-industry adaptability, digital supply chain risk warning, big data analysis, artificial intelligence, real-time monitoring, risk assessment, economic benefits, system optimization

1. Introduction

1.1 Research Background

With the acceleration of global economic integration, supply chain management has become a crucial component in corporate operations. The rise of information project management has brought both new opportunities and challenges to supply chain management. The application of digital technologies has not only improved the efficiency of the supply chain but also provided

enterprises with more accurate risk warning and response mechanisms. However, traditional supply chain rating methods often fall short when dealing with the complex and ever-changing market environment. In recent years, the supply chain intelligent rating system, as an emerging digital tool, has gradually attracted attention. It can provide real-time assessment of supply chain risks and performance through big data analysis and artificial intelligence technologies, offering strong support for corporate decision-making. Against this backdrop, this study aims to explore the application effects and cross-field adaptability value of the supply chain intelligent rating system.

1.2 Research Purpose

The primary objective of this study is to evaluate the adaptability and application effects of the supply chain intelligent rating system in multiple industries, including real estate and petrochemicals, through analyzing its practical applications. Specifically, the study will delve into how the system helps enterprises optimize supply chain management and enhance risk warning capabilities, and verify its feasibility and effectiveness in different industries through actual cases. Moreover, the study will analyze the advantages and disadvantages of the system in cross-industry applications, providing a basis for its further optimization.

1.3 Research Significance

This study holds significant theoretical and practical importance. From a theoretical perspective, by systematically analyzing the application effects of the supply chain intelligent rating system, it can enrich the research in the intersection of information project management and supply chain management, offering new perspectives and methods for the development of related theories. From a practical standpoint, the research findings will provide specific guidance for enterprises' digital transformation, helping them better manage supply chain risks and enhance competitiveness in the complex market environment. Additionally, the study will offer empirical support for the development and promotion of the supply chain intelligent rating system, promoting its application and development in more industries.

2. Development and Design of the Supply Chain Intelligent Rating System

2.1 Development Background and Objectives

The development of the supply chain intelligent rating system is aimed at addressing the increasingly complex challenges in global supply chain management. With the enhancement of market dynamics, the explosive growth of data volume, and the increasing differentiation of supply chain management demands across various industries, traditional rating methods can no longer meet enterprises' needs for real-time monitoring and precise risk warning. Against this backdrop, this project was initiated with the goal of constructing a platform that can monitor and intelligently assess supply chain risks in real-time and provide decision-making support. The system is expected to improve supply chain management efficiency, reduce risks, and enhance corporate competitiveness.

2.2 System Architecture and Functional Modules

The overall architecture of the system is designed in a layered manner, covering four levels: data collection, processing, analysis, and user interaction. The data collection layer is responsible for gathering information from internal and external data sources of enterprises; the data processing layer cleans, integrates, and pre-processes the collected data; the analysis layer employs big data analysis and artificial intelligence algorithms to deeply mine the value of data, generating supply chain ratings and risk warnings; the user interaction layer presents the analysis results to users through intuitive visualization tools to assist decision-making. In terms of functional modules, the system includes data management, risk assessment, warning, decision-making support, and user management modules, which work independently yet collaboratively to achieve intelligent supply chain management.

2.3 Technical Implementation and Data Processing

In terms of technical implementation, the system integrates cutting-edge technologies such as big data and artificial intelligence. It utilizes big data platforms like Hadoop and Spark to process massive amounts of data and support real-time analysis requirements; it applies machine learning algorithms for risk prediction and rating to enhance the accuracy of assessment; and it employs tools like Tableau and D3.js to achieve data visualization, presenting complex data in the form of intuitive charts. The data sources are extensive, including internal enterprise systems and external market and

logistics data sources. After being collected, the data goes through a series of processes, including cleaning, integration, and pre-processing, before being transformed into high-quality data for use by the analysis module.

3. Application Practices of the Supply Chain Intelligent Rating System in Multiple Industries

3.1 Case Analysis of Application in the Real Estate Industry

The supply chain management in the real estate industry is complex, with long-term projects, numerous suppliers, and large-scale capital flows. Under the traditional model, it is difficult for enterprises to monitor suppliers' performance capabilities and risks in real-time, leading to project delays and cost overruns. After introducing the supply chain intelligent rating system, Blue Ocean Real Estate Group significantly enhanced its risk identification and warning capabilities by collecting supplier data in real-time and generating dynamic ratings through big data analysis and machine learning algorithms. The data shows that in the first quarter after the system was launched, the risk identification rate increased by 35%, the project delays caused by supplier breaches were reduced by 20% (Haque, A., Akther, N., Khan, I., Agarwal, K., & Uddin, N., 2024), and the procurement cost was lowered by 8%. In the steel procurement process, the system warned that a supplier might delay delivery, and the enterprise timely adjusted the procurement plan, saving about 5 million yuan in additional costs that would have been incurred due to the delay.

Table 1.

Project	After the Introduction of the Supply Chain Intelligent Rating System
Risk Identification Rate	Increased by 35%
Project Delays Due to Supplier Breach	Reduced by 20%
Procurement Costs	Decreased by 8%

3.2 Case Analysis of Application in the Petrochemical Industry

The supply chain in the petrochemical industry highly depends on the stability and safety of raw material supply and the timeliness of logistics distribution. After applying the supply chain intelligent rating system, Huana Petrochemical integrated data from the global crude oil market, suppliers' financial status, and logistics transportation to assess risks in real-time. Following the system's launch, the accuracy rate of raw material supply risk warning increased by 40%, the logistics distribution delay rate decreased by 25%, the procurement cost was reduced by 10%, and the logistics cost was lowered by 15%. During a period of tight crude oil supply, the system issued an early warning about the risk of supply interruption from a supplier. The enterprise timely adjusted its procurement strategy and optimized transportation routes, saving about 8 million yuan in losses that would have been caused by the shutdown. (Haque, A., Akther, N., Khan, I., Agarwal, K., & Uddin, N., 2024)

3.3 Overview of Applications in Other Industries

The supply chain intelligent rating system has also been widely applied in the hotel and grain and oil industries. In the hotel industry, the system optimized the procurement management of catering raw materials and guest room supplies, reducing the average procurement cost by 12% and increasing customer satisfaction by 18%. In the grain and oil industry, the system provided precise data support for raw material procurement and inventory management, increasing the average inventory turnover rate by 20% and reducing the procurement cost by 10%. Overall, the system has demonstrated strong adaptability and application value in multiple industries, providing strong decision-making support and risk warning for enterprises, and significantly improving the level of supply chain management and economic benefits.

4. Cross-Industry Adaptability Analysis of the Supply Chain Intelligent Rating System

4.1 Construction of the Adaptability Evaluation Index System

To scientifically evaluate the adaptability of the supply chain intelligent rating system in different industries, this study has constructed a comprehensive evaluation index system covering five dimensions: technical adaptability, functional adaptability, data adaptability, user satisfaction, and economic benefits. Technical adaptability measures the integration degree of

the system with the mainstream information systems in the industry, response time, and failure rate; functional adaptability assesses the practicality and effectiveness of functions such as risk warning and supplier rating; data adaptability examines the accuracy, completeness, and real-time nature of data; user satisfaction evaluates the system's interface friendliness, ease of use, and overall satisfaction through user feedback; economic benefits measure the value brought by the system in terms of cost savings, efficiency improvement, and risk reduction.

Table 2.

Project	After the Introduction of the Supply Chain Intelligent Rating System
Risk Identification Rate	Increased by 35%
Project Delays Due to Supplier Breach	Reduced by 20%
Procurement Costs	Decreased by 8%

4.2 Adaptability Analysis in Different Industries

In the real estate industry, the supply chain intelligent rating system has demonstrated high adaptability. In terms of technical adaptability, the system has a high integration degree with the ERP system, a response time of 1.2 seconds, and a failure rate of less than 0.5% (Xiong, X., Zhang, X., Jiang, W., Liu, T., Liu, Y., & Liu, L., 2024). Regarding functional adaptability, the coverage rate of risk warning and supplier rating functions is over 90%, with high user frequency and positive feedback. In terms of data adaptability, the data collection accuracy is above 95%, the data update timeliness is 90%, and the processing efficiency is high. The user satisfaction survey shows that the interface friendliness score is 4.2/5, the operation convenience score is 4.0/5, and the overall satisfaction score is 4.3/5. In terms of economic benefits, the procurement cost savings rate is 8%, the inventory turnover rate is increased by 20%, and the average loss avoided by risk warning is about 5 million yuan.

The petrochemical industry has high requirements for the stability and safety of the supply chain, and the supply chain intelligent rating system has shown excellent adaptability. In terms of technical adaptability, the system has a high integration degree with the information system, a response time of 1.5 seconds, and a failure rate of less than 0.3%. Regarding functional adaptability, the coverage rate of risk warning and logistics optimization functions is over 85%, with high user frequency and positive feedback. In terms of data adaptability, the data collection accuracy is 98%, the data update timeliness is 92%, and the processing efficiency is high. The user satisfaction survey shows that the interface friendliness score is 4.1/5, the operation convenience score is 4.2/5, and the overall satisfaction score is 4.4/5 (Liu, Z., 2022). In terms of economic benefits, the procurement cost savings rate is 10%, the logistics cost is reduced by 15%, and the average loss avoided by risk warning is about 8 million yuan.

In the hotel industry, the system integrates well with the hotel management system, with a response time of 1.0 second and a failure rate of less than 0.4%. The coverage rate of procurement management and quality monitoring functions is 80%, with relatively high user frequency and positive feedback. The data collection accuracy is 94%, the data update timeliness is 88%, and the processing efficiency is high. The user satisfaction survey indicates that the interface friendliness score is 4.0/5, the operation convenience score is 3.9/5, and the overall satisfaction score is 4.2/5. In terms of economic benefits, the procurement cost savings rate is 12%, customer satisfaction is increased by 18%, and the average loss avoided by risk warning is about 3 million yuan. (APA Huang, J., & Qiu, Y., 2025)

In the grain and oil industry, the system integrates well with the enterprise information system, with a response time of 1.1 second and a failure rate of less than 0.6%. The coverage rate of inventory management and supplier rating functions is 82%, with relatively high user frequency and positive feedback. The data collection accuracy is 96%, the data update timeliness is 89%, and the processing efficiency is high (Liu, Z., 2025). The user satisfaction survey shows that the interface friendliness score is 4.1/5, the operation convenience score is 4.0/5, and the overall satisfaction score is 4.3/5. In terms of economic benefits, the procurement cost savings rate is 10%, the inventory turnover rate is increased by 20%, and the average loss avoided by risk warning is about 2 million yuan. (Huang, T., Yi, J., Yu, P., & Xu, X., 2025)

4.3 Analysis of Factors Affecting Adaptability

There are significant differences in business processes, data characteristics, and risk management requirements across different industries, which affect the adaptability of the system. The real estate industry has long-term projects and large-scale capital flows, requiring strong project progress management and capital risk warning functions; the petrochemical industry has high requirements for the stability and safety of raw material supply, necessitating precise supply risk warning and logistics optimization functions. The system adapts to the needs of different industries by flexibly configuring functional modules and optimizing algorithms. The size and management level of enterprises also affect the adaptability of the system. Large-scale enterprises have complex information systems and strict data management, requiring higher integration degree and data processing capabilities of the system; small-and medium-sized enterprises focus on the system's ease of use and cost-effectiveness, which the system meets by simplifying operation procedures and offering flexible pricing. The technical environment and data foundation are key factors for the adaptability of the system. A good technical environment supports the efficient operation of the system, and a complete data foundation provides accurate analysis basis. Petrochemical industry enterprises have advanced information technology infrastructure and rich data resources, enabling the system to achieve precise risk warning and optimized decision-making; the hotel industry has relatively fewer data resources, and the system optimizes the data collection and processing procedures to provide effective supply chain management support.

5. Optimization and Improvement of the Supply Chain Intelligent Rating System

5.1 Analysis of System Optimization Needs

In practical applications, the system has exposed some issues. In terms of data collection, it is necessary to expand data sources, such as land transaction data in the real estate industry and crude oil price data in the petrochemical industry, to enrich the dimensions of data. Regarding the user experience of functional modules, some users have reported that the operation process is complex and that the interface design needs to be optimized to simplify the operation process. In terms of the real-time and accuracy of risk warning, there is a delay in the generation and push of warning signals in complex scenarios, and it is necessary to optimize the data processing algorithms. Moreover, the integration degree of the system with existing business processes of enterprises is insufficient, and the collected data and analysis results cannot be directly applied to actual business decision-making. It is necessary to strengthen the in-depth integration of the system with existing business processes of enterprises.

In terms of cross-industry adaptability, the general applicability of the system's functional modules is insufficient, and it is necessary to customize the development according to the characteristics of different industries. Data adaptability issues cannot be ignored either, as there are differences in data formats, update frequencies, and quality standards across different industries. It is necessary to optimize the data adaptation mechanism. In addition, users in different industries have different preferences for the use of system functions, and it is necessary to optimize the layout and priority settings of functional modules to provide personalized experiences.

5.2 Functional Optimization and Upgrade of the System

In response to the optimization needs, the system has improved its functional modules. The data collection module has added access interfaces for industry-specific data sources and optimized data collection algorithms to improve the accuracy and efficiency of data collection. The user interface module has redesigned the interface layout, simplified the operation process, and added intelligent prompt functions. The risk warning module has optimized data processing algorithms to increase the sensitivity to sudden risks and the real-time nature of warnings. At the same time, the system has strengthened its integration with existing enterprise information systems to achieve seamless data flow and automated support for business decision-making.

In terms of technical performance, the system has undergone comprehensive upgrades and optimizations. It has adopted a distributed computing architecture and containerization technology to improve the system's processing capabilities and scalability. The database design has been optimized, combining distributed

databases with in-memory databases to improve the efficiency and read-write speed of data storage. More advanced machine learning and artificial intelligence algorithms have been introduced to improve the accuracy and efficiency of data processing. At the same time, network security protection measures have been strengthened, and the user permission management mechanism has been optimized to ensure the security and confidentiality of data.

5.3 System Promotion and Application Strategies

To promote the widespread application of the system, the following promotion strategies have been formulated. In terms of market promotion, the system's visibility and influence will be increased through participating in industry exhibitions, holding technical seminars, and publishing promotional materials. In terms of channel cooperation, partnerships will be established with software developers, system integrators, and consulting firms to expand sales channels. In terms of customer relationship management, a comprehensive customer service system will be established to provide high-quality pre-sales, mid-sales, and after-sales services. In terms of policy support, efforts will be made to actively seek support from the government and industry associations, participate in the formulation of relevant standards and project applications, and reduce the usage costs for enterprises.

During the implementation of the system application, it is recommended that enterprises carry out sufficient publicity and training internally to improve employees' awareness and acceptance of the system. A phased implementation approach should be adopted, starting with pilot applications in key business departments or important projects to accumulate experience before gradually expanding. Communication and collaboration with suppliers should be strengthened to ensure their active cooperation in system data collection and rating work. Finally, a continuous improvement mechanism for the system should be established to regularly collect user feedback and market dynamics, and to adjust and optimize system functions in a timely manner according to the development of enterprises and changes in the industry. Through the above optimization and improvement measures, the supply chain intelligent rating system will further enhance its performance and adaptability in multiple industry applications, providing more efficient and accurate support for supply chain management for enterprises, and helping them to enhance competitiveness and economic benefits.

6. Conclusions and Future Outlook

6.1 Summary of Research Conclusions

The supply chain intelligent rating system has been widely applied in industries such as real estate, petrochemicals, hotels, and grain and oil, significantly improving supply chain management efficiency and benefits. The system has helped enterprises reduce costs and increase customer satisfaction through precise risk warning and optimized procurement decision-making. For example, the procurement cost in the real estate industry has been reduced by 8%, the logistics cost in the petrochemical industry has been reduced by 15%, the customer satisfaction in the hotel industry has been increased by 18%, and the inventory turnover rate in the grain and oil industry has been increased by 20%. The system has brought significant economic and management benefits to enterprises. The system has demonstrated good adaptability in multiple industries, with its technical and functional modules meeting the needs of different industries. The technical adaptability is high, with strong system integration and stability; the functional adaptability is good, with practical risk warning and decision-making support functions; and the data adaptability is excellent, with accurate and efficient data collection and processing. Despite differences, the system can meet the specific needs of each industry through optimization and adjustment, providing strong support for cross-field applications.

Table 3.

Industry	Economic Benefits
Real Estate	Procurement Costs Reduced by 8%
Petrochemical	Logistics Costs Reduced by 15%
Hotel	Specific Economic Benefits Not Mentioned
Grain and Oil	Inventory Turnover Rate Increased by 20%

6.2 Research Innovations and Contributions

This study is highly innovative. Firstly, it uses

big data and artificial intelligence technologies to realize real-time monitoring and precise warning of supply chain risks. Secondly, the system architecture is flexible and has cross-field adaptability. Thirdly, the data collection and processing procedures have been optimized to improve the accuracy and real-time nature of data. Fourthly, the user interface and the layout of functional modules have been optimized to enhance user experience and operational convenience. This study enriches the theoretical research in the intersection of information project management and supply chain management, providing a new perspective for the development of related theories. From a practical standpoint, it offers specific guidance for enterprises' digital transformation and supply chain optimization, helping them to enhance competitiveness. At the same time, it provides empirical support for the development and promotion of the supply chain intelligent rating system, promoting its application in more industries.

6.3 Research Limitations and Future Outlook

This study has some limitations. There is still room for expanding the data sources, as data acquisition in some industries is challenging. The degree of customization of functional modules needs to be further improved, especially in specific scenarios. The promotion of the system faces issues such as low enterprise acceptance and high implementation costs. Future research will focus on expanding data sources, deepening the customized development of functional modules, exploring effective promotion models, and strengthening cooperation between industry, academia, and research institutions to promote system technological innovation and application development, helping enterprises to enhance their supply chain management level and economic benefits.

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UN and WHO for Redistribution of Funds and Resources for Peaceful Activities

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Abstract

The United Nations (UN) and the World Health Organization (WHO) advocate for the redistribution of resources and funds allocated to military needs in favor of the development of medicine, health systems, energy, a balanced economy, and green industries. Their initiatives are aimed at reducing the military burden in order to redirect military resources toward peaceful activities, combating diseases, improving medical care, and strengthening national health systems. Such measures help ensure more sustainable development, improve living standards, and reduce the risk of resource-related conflicts. These initiatives call on countries around the world to reassess priorities and more efficiently use their resources for energy systems, a balanced economy, and green industries for the benefit and health of their citizens. This requires the spiritual development of the planet's population.

Keywords: United Nations, World Health Organization, redistribution of resources and funds, peaceful life

1. Introduction

The development of a peaceful world without war on an international scale is potentially possible through the formation of spiritually perfect, peace-loving individuals and leaders in every nation and state.

Man was created by the Creator as a living soul. Man is created in the image and likeness of God. He consists of spirit, soul, and body. The soul is called to spiritual perfection and the formation of a personality for eternal life.

Perfect laypeople are people who, as ordinary laypeople, strive for spiritual perfection and deep spiritual development in their daily lives. They actively follow the commandments of their religion, demonstrating love, mercy, honesty, and humility in their relationships with others. Such people constantly work on themselves, strengthening their faith through prayer, good deeds, participation in church life, and the study of spiritual teachings. They live by the principles of moral purity, responsibility, and service to others, striving to embody religious values in their daily actions and to be an example to others. In general, perfect laypeople are spiritually mature people who seek unity with God and the perfection of their souls in their secular affairs and family life.

A perfect Orthodox person is one who strives for spiritual perfection by following the commandments of the New Testament and the teachings of the Orthodox Church. Such a person demonstrates love for God and neighbor in their lives, adheres to moral principles, honesty, humility, and mercy. They constantly develop in faith, prayer, good deeds, and spiritual practice, striving to unite with God and fulfill His will. Important qualities of a perfect Orthodox person are sincerity, obedience, patience, and love, as well as deep faith and devotion to spiritual values.

A perfect Jew is one who strives to fulfill the commandments of the Torah and live in accordance with the Jewish spiritual tradition. Such a person demonstrates deep faith, honesty, compassion, humility, and devotion to God (Yahweh). They adhere to the commandments (mitzvot), participate in religious rituals and holidays, and observe the Jewish way of life, including kosher and Shabbat. A perfect Jew constantly strives for spiritual growth, studies sacred texts, lives in harmony with others, and strives to demonstrate love and justice. Spiritual development, fulfilling the commandments, and caring for others play an important role in their lives, helping them draw closer to God and realize their spiritual values.

A perfect Muslim is one who strives for complete submission to the will of Allah, following the commandments of Islam and guided by the principles of the Quran and Hadith. Such a person demonstrates sincere faith, honesty, compassion, patience, and humility in their lives. They perform obligatory religious practices (prayer, fasting, zakat, pilgrimage) and strive to lead a righteous life, showing kindness and justice to others. A perfect Muslim constantly cultivates their spirituality, seeks knowledge, and strives for closeness with Allah, demonstrating love, compassion, and piety in their actions.

The body is the bearer of the soul and spirit. The Bible speaks much about spiritually maintaining the body in a healthy state and prolonging human life. For example, Proverbs 4:20: "My son, attend to my words, and incline your ear to my sayings. Let them not depart from your eyes; keep them in the midst of your heart: for they are life to him who finds them, and health to all his flesh." Exodus 20:12: "Honor your father and your mother: that your days may be long upon the land which the Lord your God is giving you." Proverbs 4:10: Hear, my son, and accept my words, that the years of your life may be many.

Healthcare and medicine also help people maintain health and increase life expectancy. Addressing these challenges requires financial and material resources. Reallocating funds and material resources spent on wars to medicine and healthcare will help more effectively maintain public health and increase life expectancy.

Wars shorten people's lives. To redirect funds and material resources allocated to wars to medicine and healthcare, an international peace initiative is needed. The UN and WHO should initiate peacemaking processes at the state level. Religious and public organizations should support the peacemaking process and develop public peacebuilding at the national level. State authorities should actively counter negative processes within the country and foster perfect citizens and a harmonious society.

A perfect person (kind, compassionate, peace-loving, creative, and socially useful) follows spiritual values in shaping their personality. A harmonious society fosters a balanced economy, environmentally friendly industry, and medicine and healthcare that support health and increase longevity.

This article examines current issues in the peaceful life of humanity: first, how government authorities initiate the spiritual development of citizens; second, the use of accumulated weapons for peaceful purposes; third, how to initiate peacekeeping through defensive means; fourth, balanced international development; fifth, the formation of an international healthcare system; sixth, addressing state objectives to improve public health and life expectancy; seventh, the use of nuclear warheads for nuclear energy generation; eighthly, the planetary formation of an ecological civilization.

2. State Authorities Initiate the Spiritual Development of Citizens

State authorities initiate programs and measures aimed at the spiritual development of citizens, with the aim of strengthening moral values, social harmony, and the cultural development of society. Such initiatives may include support for religious and cultural events, educational programs on ethics and morality, the development of spiritual centers and

institutions, and the promotion of the spiritual education of the population. An important goal is to create conditions for the harmonious development of the individual, strengthen moral foundations, and foster national and cultural identity. However, such initiatives must be observed within the framework of the rule of law and respect for the freedom of conscience and religion of every citizen.

3. Repurposing Stockpiled Weapons for Peaceful Purposes

Repurposing stockpiled weapons for peaceful purposes is the practice of converting weapons, military equipment, and resources intended for defense into means of livelihood, development, and humanitarian projects. For example, this includes destroying excess weapons stockpiles, recycling military equipment into civilian products, and using technologies to build infrastructure or conduct scientific research. This approach helps reduce the risk of conflict, strengthen international security, and promote economic development. An important aspect is international cooperation and adherence to arms control treaties, ensuring that resources previously intended for war benefit society and contribute to peace and stability.

4. Initiating a Peacekeeping Process Defensively

Initiating a peacekeeping process defensively means using diplomatic and defensive measures to prevent conflict and maintain peace. This includes deploying peacekeeping forces, conducting negotiations, and demonstrating a willingness to defend without resorting to aggressive methods. Defensive means, such as prevention and deterrence systems, can serve as a guarantee of security and help create conditions for dialogue and dispute resolution. Using military force for peaceful purposes to support peace, humanitarian missions, stabilization of the tense social situation, the application of military technologies in the civilian sector and assistance in recovery from the consequences of emergency situations:

(1) Humanitarian operations:

- Demining dangerous areas.

- Ensuring the delivery of humanitarian aid to affected regions.

(2) Peacekeeping missions:

- Participation in international peacekeeping and security operations in conflict zones.

- Monitoring compliance with agreements and ceasefires.

(3) Reconstruction and stabilization assistance:

- Rebuilding infrastructure after conflicts.

- Ensuring security for the return of refugees and internally displaced persons.

(4) Training and consulting:

- Training local security forces for peaceful policing.

- Transfer of expertise and technologies for conflict prevention.

(5) Conflict prevention:

- Demonstration of force to deter potential threats and aggression.

- Participation in preventive measures and diplomatic efforts.

It is important to emphasize that the use of military force for peaceful purposes requires clear international agreements, transparency, and the consent of all parties, avoiding coercion or pressure. This approach helps build trust between the parties, reduce the risk of conflict escalation, and promote peace based on mutual respect and adherence to international treaties.

5. International Equitable Development

International equitable development is a concept aimed at reducing economic, social, and cultural gaps between countries and regions of the world. It envisions creating conditions for sustainable growth and improving living standards in all countries, particularly in lagging and developing regions. Implementing this idea involves cooperation in economics, education, healthcare, infrastructure, and technology, as well as the equitable distribution of resources and support for countries most in need. The goal of international equitable development is to ensure the harmonious and balanced development of all humanity and promote global peace and stability.

6. Forming a Global Healthcare System

Forming a global healthcare system involves creating an international structure that coordinates the efforts of countries and organizations to ensure high levels of public health worldwide. This system includes the development of global standards and protocols, the exchange of information and experience, joint programs for the prevention and control of epidemics, and support for vulnerable and

developing countries in the healthcare sector. The primary goal is to increase the effectiveness of disease control, reduce global morbidity and mortality, and ensure equal access to healthcare for all people, regardless of their location. International organizations such as the WHO, as well as collaboration between governments and private partners, play a key role in this process.

6.1 Effective Public Participation in the Healthcare System

Effective public participation in the healthcare system implies the active involvement of citizens in decision-making, planning, and implementation of measures aimed at maintaining and improving their health. This includes educating and informing the public about healthy lifestyles, preventive measures, and healthcare rights, as well as encouraging participation in preventive programs and treatment. This approach promotes citizen responsibility for their own health, improves the quality of medical services, and fosters partnerships between the population and the healthcare system. Ultimately, this leads to more efficient use of resources, reduced morbidity, and the creation of conditions for sustainable development of the healthcare system.

6.2 Effective Medicine Participation in the Healthcare System

Effective public participation in the healthcare system involves the active implementation of modern medical practices, technologies, and methods to ensure high-quality medical services. This includes timely diagnosis, effective treatment, preventive care, and rehabilitation of patients, as well as collaboration among medical institutions and specialists. An important aspect is the focus of medicine on patient needs, the use of innovative solutions, and the continuous professional development of medical professionals. Such participation contributes to improving public health, reducing morbidity and mortality, and ensuring the sustainable development of the healthcare system as a whole.

6.3 Addressing Government Objectives to Improve Public Health and Life Expectancy

Addressing government objectives to improve public health and increase life expectancy includes the implementation of strategic measures and policies aimed at creating conditions for the well-being of citizens. The key areas of government work include:

(1) Healthcare system development:

- Improving the availability and quality of medical services.

- Implementing modern diagnostic and treatment technologies.

- Providing preventive measures and medical examinations.

(2) Creating conditions for a healthy lifestyle:

- Developing programs to promote healthy eating, physical activity, and quitting bad habits.

- Restricting the distribution of unhealthy tobacco and alcohol products.

(3) Social support and health protection:

- Ensuring social protection for vulnerable groups.

- Implementing support programs for families, children, and the elderly.

(4) Educational and information campaigns:

- Raising awareness about a healthy lifestyle.

- Teaching the population self-preservation and disease prevention skills.

(5) Environmental Policy:

- Improving the environmental situation, reducing environmental pollution.

- Monitoring the sanitary conditions of territories.

(6) Infrastructure Modernization:

- Creating modern medical institutions.

- Providing the population with the necessary resources and conditions for health.

(7) Implementation of Translational Medicine:

- Rapid implementation of new medical technologies.

- Implementation of digital clinics.

(8) Spiritual and Material Issues for Improving Public Health and Life Expectancy:

a. Measures Aimed at Strengthening Psychological and Spiritual Well-Being:

- Promoting healthy lifestyle values, moral, and ethical principles.

- Supporting spiritual practices, religious, and cultural events that promote psychological balance.

- Educational programs aimed at fostering positive values and social responsibility.

b. Measures aimed at improving material living

conditions:

- Increasing income levels and social protection of the population.

- Creating comfortable working and living conditions.

- Ensuring access to quality medical care and medications.

- Improving the environmental situation and living conditions.

c. Social integration and support:

- Creating conditions for the active participation of the population in public life.

- Developing programs for psychological support and preventing stress and depression.

- Ensuring equal opportunities for all segments of the population.

Overall, a harmonious combination of material, social, and spiritual measures promotes better health, reduces stress factors, and improves quality of life, which together leads to increased life expectancy and social well-being.

The implementation of comprehensive measures helps reduce morbidity, improve quality of life, and increase life expectancy, which is an important objective of public policy.

7. Using Nuclear Resources for Nuclear Energy Generation

The use of nuclear resources for nuclear energy generation involves several important aspects and issues that should be considered:

(1) Energy security: Nuclear energy allows for the generation of large amounts of electricity with relatively little resource input, which contributes to the diversification of a country's energy balance.

(2) Sources of Nuclear Resources: The primary materials for nuclear energy are uranium and plutonium. Uranium is mined in various countries, and its reserves allow for long-term plans for the development of nuclear energy.

(3) Environmental Impact: Nuclear power plants do not emit greenhouse gases during operation, but require reliable management of radioactive waste and safe storage of spent nuclear fuel.

(4) War and Geopolitics: The use of nuclear resources for military purposes (e.g., the creation of nuclear weapons) differs significantly from the peaceful use of nuclear energy. However, the availability of nuclear materials and technologies will be the subject of international research.

(5) International Regulation: There are numerous international agreements and organizations (such as the IAEA) that oversee the peaceful use of nuclear resources and prevent the proliferation of nuclear weapons.

In general, the use of nuclear resources for military purposes to generate nuclear energy is an important component of modern energy that requires strict regulation, safe technologies, and international cooperation to minimize risks and ensure sustainable development.

8. Planetary Formation of Ecological Civilization

The planetary formation of an ecological civilization requires the solution of problems of restoration and maintenance of ecology by the international community. Restoration and maintenance of the ecology of the environment is associated with both spiritual and material problems of the international community. Spiritual problems are awareness of responsibility, environmental values and worldview, environmental culture and ethics. Material problems are restoration of ecosystems, financing, safe technological solutions, industrial impact, waste management. Solving environmental problems requires an integrated approach that takes into account both spiritual and material aspects. This can be achieved through education, development of environmental ethics and implementation of sustainable practices in everyday life. Planetary environmental education based on artificial intelligence can accelerate the planetary formation of an ecological civilization.

8.1 Transformation of the International Community into an Ecological Civilization

Transforming the international community into an ecological civilization requires a comprehensive approach and interaction at various levels. Key aspects that can facilitate this transformation include education and awareness, international cooperation, legislative initiatives, social movements and public organizations, economic incentives, technological innovation, and cultural change.

(1) It is important to introduce environmental education into educational institutions at all levels, as well as conduct information campaigns to raise public awareness of environmental issues and sustainable development.

(2) Addressing global environmental problems such as climate change, pollution, and biodiversity loss requires active cooperation between states. This includes both scientific research and joint projects. States must integrate environmental principles into their economic and social strategies. This includes a transition to green technologies, the development of renewable energy sources, the safe use of resources, and the application of natural technologies.

International and national legal frameworks aimed at protecting the environment are necessary. This may include agreements to reduce greenhouse gas emissions, protect forests and water bodies, and safeguard biodiversity. Civil society and environmental organizations play a vital role in advancing environmental initiatives and pressuring governments and corporations to change their practices.

Mechanisms must be developed to encourage sustainable behavior at both the individual and corporate levels. This can be achieved through carbon taxes, subsidies for clean technologies, and other financial instruments.

The development and implementation of new technologies aimed at reducing environmental impact can significantly accelerate the transition to an ecological civilization. This includes both developments in clean energy and innovations in recycling and waste management.

A reassessment of society's values and priorities is necessary, which can be achieved through art, literature, and media that raise environmental issues and inspire people to action.

The transformation of the international community into an ecological civilization is possible with the combined efforts of all sectors of society—government, business, science, and citizens. This takes time and effort, but the end result—a more sustainable and harmonious world—is worth the effort.

8.2 International Ecology Industry

The environmental industry continues to develop rapidly, responding to the challenges of climate change, pollution, and natural resource depletion. By 2025, new technologies, approaches, and strategies are expected to emerge that will help minimize human impact on the planet (Daniel J. Sherman & David R., 2023; Karen Bakker, 2024; Edward O. Wilson, 2024; Ashley Dawson, 2024; Evgeny Bryndin, 2025c).

One of the key trends will be the massive transition to renewable energy sources, such as solar, wind, and hydropower. This is driven by the need to reduce carbon emissions and achieve the goals of the Paris Agreement.

Digital technologies and artificial intelligence will play a key role in monitoring and managing environmental processes (Evgeny Bryndin, 2025d). This will optimize resource use and reduce the negative impact on the environment. The use of IoT to monitor air and water pollution levels. The use of AI to predict environmental risks and promote planetary environmental education. The development of environmental information networks. Planetary network-based personal development of environmental awareness, ontology, and behavior by AI assistants. The development of smart waste management systems.

A circular economy will become the foundation for sustainable production, where waste is transformed into resources. Companies will strive to minimize waste and reuse materials.

Cities of the future will be designed with environmental principles in mind. This includes the creation of green spaces, the use of energy-efficient technologies, and the development of public transportation. This includes the construction of zero-energy buildings, and the creation of smart parks and green corridors.

The environmental industry is becoming more innovative and technologically advanced. The transition to renewable energy sources, the digital circular economy, ecological urbanization, ecological production, and ecological transport are trends that will help humanity move toward the planetary formation of an ecological civilization (Natarajan Ishwaran, Yexuan Liu, Qi Luo, Shuang Wang & Lin Zhen, 2025; Xiaowen Shang, Yujie Liu, Chao Zhang, Litao Lin & Shufang Liu, 2025; Mark Diesendorf, 2025). It is important that every citizen of the planet contribute to preserving the planet for future generations with an ecological future. It is advisable to implement the planetary formation of an ecological civilization within the framework of an International Mega-Project.

The ecological life of imperfect humanity is based on trust and the observance of the Creator's commands and laws. Trust and fulfillment of the Creator's orders and laws will

provide humanity with synergistic interaction at the level of the Universe with natural technologies for the formation of a Universal Harmonious Ecological Civilization and Cosmic Harmony (Evgeny Bryndin, 2025e).

8.3 UN Participation in the Formation of an Ecological Civilization

The United Nations (UN) plays a vital role in global efforts to promote sustainable development, environmental protection, and address environmental challenges. The UN implements its activities through various programs, conferences, and initiatives aimed at creating a more sustainable world. The UN actively promotes the concept of sustainable development, which encompasses economic, social, and environmental dimensions. The 2030 Agenda for Sustainable Development, adopted in 2015, contains 17 Sustainable Development Goals (SDGs), including goals related to environmental protection, climate change, and the sustainable management of natural resources. The UN has established various specialized organizations, such as the United Nations Environment Programme (UNEP), that focus on ecology, environmental protection, and sustainable development. These organizations develop strategies, conduct research, and implement projects aimed at protecting the environment.

The UN plays a key role in developing and maintaining international environmental agreements, such as the Paris Climate Agreement, the Convention on Biological Diversity, and the UN Framework Convention on Climate Change. These agreements aim to unite countries' efforts to address global environmental challenges.

The UN organizes international conferences and summits, such as the UN Conference on Environment and Development (Rio de Janeiro, 1992) and the World Conference on Sustainable Development (Rio+20, 2012). These events facilitate discussion and the development of coordinated actions to protect the environment. The UN also supports environmental education and awareness-raising programs. The UN promotes partnerships between public, private, and non-governmental organizations to address environmental issues. This allows resources and expertise to be pooled to achieve common goals.

The UN's involvement in the development of an ecological civilization is manifested through multifaceted efforts aimed at creating a sustainable future, protecting the environment, and improving the quality of life for all people on the planet through ecological waste management and recycling.

9. Conclusion

Perfectly healthy centenarians are people who have reached a significant age thanks to good health, an active lifestyle, and positive habits. They play a vital role in addressing social, family, economic, industrial, and other challenges facing the state and humanity:

(1) Social aspects:

- Passing on valuable life experience, wisdom, and traditions to younger generations.

- Participating in mentoring and volunteering, supporting vulnerable groups.

(2) Family tasks:

- Raising and caring for grandchildren and great-grandchildren, strengthening family ties.

- Preserving family values, traditions, and cultural characteristics.

(3) Economic tasks:

- Participation in work and professional activity in retirement, which contributes to economic stability.

- Transferring skills and knowledge to young professionals, training, and mentoring.

(4) Industrial and technological tasks:

- Contributing to innovative projects based on life experience and wisdom.

- Participation in research on health, aging, and improving the living conditions of the elderly.

(5) Tasks for humanity and the state:

- Modeling an active and healthy lifestyle, stimulating the development of preventive and healthcare programs.

- Raising awareness of the importance of healthy aging and the need to create conditions for a long and high-quality life (Evgeniy Bryndin, 2025f).

- Participation in research and initiatives to study the aging process and improve the quality of life of the elderly.

- Contributing to the development of cultural and educational programs aimed at respecting and integrating older people into society.

Overall, healthy, long-lived individuals are a

valuable resource for society, contributing to its development, strengthening family ties, the formation of sustainable social structures, and the improvement of global order. Their active participation helps address various challenges facing the state and humanity, and their example inspires the creation of conditions for active and healthy longevity for the entire international community.

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The Gig Economy and Labor Protection in China: Evidence from Food Delivery Platforms

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Abstract

The gig economy in China has experienced exponential growth, particularly within the food delivery sector, with platforms like *Meituan*, *Ele.me*, and *Didi* becoming dominant players in the labor market. However, this growth has also raised significant concerns about labor protection and workers' rights. This paper explores the challenges and policy implications surrounding labor governance in China's platform economy, focusing on the food delivery sector. It examines the economic drivers behind the expansion of gig work, including demand-side factors like urban consumption and technology adoption, as well as supply-side dynamics such as labor surplus and migration. The study highlights key labor protection challenges, such as the ambiguity of employment status, algorithmic management, wage volatility, and lack of social insurance. Through empirical analysis of data from *Meituan* and *Ele.me*, as well as case studies from major cities like Beijing, Shanghai, and Chengdu, the paper evaluates the effectiveness of legal and policy frameworks and the response of government and platforms to address these challenges. The study concludes with policy recommendations for developing a more sustainable and equitable model of platform labor governance that balances innovation with social protection.

Keywords: gig economy, platform labor, labor protection, food delivery platforms, *Meituan*, *Ele.me*, *Didi*, algorithmic management

1. Introduction

Over the past decade, China's labor landscape has undergone a significant transformation driven by digitalization, urbanization, and shifts in industrial structure. The expansion of the gig economy has emerged as one of the defining features of this transition, fundamentally reconfiguring labor markets and employment relations. According to the *Ministry of Human Resources and Social Security (MHRSS, 2023)*, China's flexible and platform-based employment sector now encompasses more than 84 million workers, accounting for nearly 20% of urban employment. This transformation is not merely a quantitative expansion but also a qualitative shift in how labor is organized, managed, and protected. The traditional model of lifetime, formal employment is being increasingly replaced by on-demand, task-based work mediated through digital platforms. As a result, the boundary between formal and informal employment has blurred, giving rise to new forms of precarious labor under the guise of flexibility.

The rise of platform-based work models such as *Meituan*, *Ele.me*, and *Didi Chuxing* has been central to this reconfiguration. These platforms have become dominant employment intermediaries in urban China, connecting millions of workers—many of them rural migrants—with consumers in real-time service markets. *Meituan Research Institute (2023)* reported that by the end of 2022, the platform employed over 6.27 million active delivery riders across more than 2,800 cities and counties. Similarly, *Ele.me* employed approximately 3 million delivery workers, while *Didi* provided income opportunities to over 13 million registered drivers nationwide. These figures illustrate not only the scale of platform-mediated employment but also its growing systemic importance to China's urban economy. Platform labor has become an indispensable buffer in absorbing job losses from traditional sectors and stabilizing household incomes during periods of economic uncertainty, including the COVID-19 pandemic recovery phase (NBS, 2023). However, this dependency has also exposed new governance challenges related to worker classification, occupational safety, and algorithmic management.

Underlying this expansion is a deeper structural shift from manufacturing-based employment toward digital services and urban consumption economies. Between 2012 and 2022, employment in the manufacturing sector declined from 30% to 25% of total national employment, while jobs in the service sector—particularly logistics, e-commerce, and digital delivery—grew to over 52% (National Bureau of Statistics, 2023). This transformation reflects both China's strategic move toward a high-value, consumption-driven economy and the systemic casualization of its labor force. In the absence of strong labor institutions or universal social protection, gig work has effectively filled the employment vacuum left by industrial restructuring. Yet, this new labor configuration has also deepened the divide between formal and informal workers, challenging the inclusiveness and sustainability of China's economic modernization.

In sum, the rapid expansion of the gig economy represents a double-edged transformation: it has enhanced economic flexibility and urban efficiency but simultaneously fragmented labor protections and eroded employment stability. Food delivery platforms like *Meituan* and *Ele.me* now occupy a critical nexus between technological innovation, urban governance, and labor policy, making them a vital focal point for understanding the evolving dynamics of work in China's digital economy.

2. Economic Drivers of the Gig Economy

The rise of the gig economy in China is deeply rooted in the country's broader economic transition toward a digital, consumption-driven model. This transformation has been propelled by both demand-side and supply-side factors, reinforced by the structural realignment of the post-pandemic economy. The interaction between consumer behavior, technological innovation, and labor market flexibility has created fertile ground for the expansion of platform-mediated employment.

On the demand side, the rapid growth of China's urban middle class and the ubiquity of smartphones have accelerated the demand for convenience-based services such as online food delivery, ride-hailing, and e-commerce logistics. The *China Internet Network Information Center (CNNIC, 2023)* reports that by the end of 2023, the number of online food delivery users had reached 544 million, representing more than half of all Chinese internet users. Cities like Beijing, Shanghai, and Chengdu have become digital consumption hubs, where residents rely heavily on app-based services to meet daily needs. The combination of fast urban lifestyles, high labor participation among women, and the proliferation of mobile payment systems (e.g., Alipay, WeChat Pay) has made time-saving convenience a central driver of service demand. Platforms like *Meituan* and *Ele.me* have capitalized on this trend by building sophisticated real-time logistics networks, enabling delivery within 30 minutes in most urban districts. The resulting digital logistics ecosystem has created millions of micro-jobs, transforming how urban labor and consumption are connected.

From the supply-side perspective, the gig economy has emerged as a structural response to labor surplus and underemployment pressures. Following China's industrial restructuring, millions of migrant and low-skilled workers faced difficulties accessing stable, formal-sector jobs. The *National Bureau of Statistics (2023)* estimated that by 2022, over 293 million rural migrant workers were employed in cities, with approximately 27% engaged in

flexible or temporary work. For these workers, platform-based employment offers accessible income opportunities with low entry barriers, requiring only a smartphone and a vehicle. During the COVID-19 pandemic, when many traditional industries slowed or temporarily shut down, the gig economy absorbed large portions of displaced workers, particularly in logistics and delivery services. A *Meituan Research Institute (2022)* report noted that more than 30% of newly registered riders in 2021 were previously laid off or unemployed workers seeking short-term income. This indicates the gig economy's dual role as both an economic stabilizer and a safety valve for China's employment system.

In the context of China's post-pandemic recovery and economic restructuring, platform-based labor has become an integral component of the government's strategy to maintain social and economic stability. The *State Council's 14th Five-Year Plan for Employment Promotion (2021–2025)* explicitly recognizes digital labor platforms as vital mechanisms for expanding "new forms of employment." These platforms not only contribute to GDP growth through digital service innovation but also alleviate pressure on state welfare systems by informally absorbing workers without the fiscal burden of formal employment contracts. However, this reliance also embeds new vulnerabilities—workers remain largely excluded from social insurance, occupational injury compensation, and collective bargaining mechanisms. As China aims to balance innovation-driven growth with inclusive labor protection, the gig economy stands at the intersection of opportunity and precarity.

In summary, the economic drivers behind China's gig economy are multifaceted: on the one hand, consumer demand and technological logistics have created a thriving digital service infrastructure; on the other, surplus labor and structural employment shifts have fueled a steady supply of flexible workers. Together, these forces have solidified the gig economy's central role in China's post-industrial transformation—while simultaneously revealing the urgent need for regulatory frameworks that reconcile flexibility with security.

3. Labor Protection Challenges in Platform Employment

Despite the gig economy's contributions to employment and economic flexibility, the rise of platform-based work in China has generated profound challenges for labor protection. These challenges center on the ambiguity of employment status, algorithmic management and occupational safety, income instability, and institutional gaps within the country's legal framework. The food delivery sector, led by *Meituan* and *Ele.me*, epitomizes these tensions between technological efficiency and social protection.

One of the most persistent challenges is the ambiguity of employment status and legal classification of riders. Unlike traditional employees, platform workers are typically labeled as *"independent contractors"* rather than formal staff. This classification allows platforms to avoid the costs of social insurance, paid leave, and workplace injury compensation. Yet, in practice, riders operate under close algorithmic supervision—receiving assigned orders, performance ratings, and penalties—conditions that mirror a de facto employment relationship. A 2022 *China Labor Bulletin* (CLB) analysis of 200 labor dispute cases found that over 70% of courts ruled against riders' claims for formal employment recognition, citing the lack of written labor contracts. The *Supreme People's Court (SPC)* in its *Guiding Case No. 47 (2021)* acknowledged the complexity of "new employment forms," urging lower courts to consider factors such as algorithmic control and economic dependency. Nonetheless, the absence of clear legislative criteria has left most riders in a legal gray zone—excluded from core protections guaranteed under the *Labor Contract Law (2008)*.

Compounding this precariousness is the rise of algorithmic management, which governs riders' every move—from route optimization to delivery time and performance scoring. These digital control systems, while improving logistical efficiency, have intensified workloads and safety risks. A *Renmin University of China Labor Research Center (2022)* survey revealed that the average *Meituan* rider works 10.7 hours per day, often under pressure to meet shrinking delivery windows. The introduction of "smart dispatch" algorithms has reduced order completion times but increased accident rates. Data from *Beijing Traffic Police (2022)* indicated a 32% year-on-year increase in traffic incidents involving delivery riders between 2020 and 2022, highlighting the human cost of algorithmic

optimization. The lack of effective rest periods and unrealistic delivery expectations—combined with financial penalties for lateness—create an occupational environment marked by chronic stress and fatigue.

Wage instability and exclusion from social protection further exacerbate riders' vulnerability. Unlike traditional employees with fixed monthly salaries, gig workers' income depends on fluctuating order volumes and algorithmic pay adjustments. *Meituan Research Institute (2023)* reported that the average monthly income of riders in large cities was around 5,200 RMB, but with significant variability: earnings could drop by 30% during off-peak seasons or after algorithmic recalibrations. Meanwhile, less than 8% of full-time riders were covered by comprehensive social insurance, according to *MHRSS (2023)* statistics. Platforms often provide commercial accident insurance instead of formal contributions to pension, medical, or unemployment funds, thereby shifting risk to workers. This exclusion reflects broader gaps in China's *Social Insurance Law (2010)*, which was designed for conventional, long-term employment and struggles to encompass platform-mediated labor.

Finally, institutional and legislative limitations compound these vulnerabilities. Although the *Labor Contract Law (2008)* and *Social Insurance Law (2010)* offer comprehensive protection for standard employees, they lack provisions explicitly addressing "non-standard" or algorithmically managed labor. The *2021 Guidelines on the Protection of Delivery Workers' Rights* issued by the *State Administration for Market Regulation (SAMR)* marked a step forward by mandating that platforms "reasonably set delivery times" and ensure insurance coverage. However, enforcement remains inconsistent across local jurisdictions, and penalties for non-compliance are minimal. Without statutory recognition of hybrid employment models or shared liability mechanisms between platforms and subcontracting agents, most riders remain beyond the reach of formal protection.

4. Legal and Policy Framework Evolution

China's legal and policy framework for labor protection has historically been oriented toward stable, long-term employment under formal contracts, a structure that has proven increasingly inadequate in addressing the realities of digital and platform-based work. Since the promulgation of the *Labor Contract Law* (2008) and *Social Insurance Law* (2010), the Chinese government has gradually sought to adapt its legal institutions to the growing prevalence of flexible, informal, and algorithmically managed labor. Between 2008 and 2024, this adaptation has evolved from incremental administrative guidelines to more structured national policies emphasizing accountability, risk-sharing, and algorithmic oversight.

The first comprehensive step toward recognizing digital labor came in 2021, when the *State Administration for Market Regulation (SAMR)*, in conjunction with the *Ministry of Human Resources and Social Security (MHRSS)*, issued the *Guidelines on the Protection of Delivery Workers' Rights*. The document mandated that platform companies "reasonably set delivery times," "disclose algorithmic rules," and "ensure participation in social insurance." It further emphasized the principle of *shared responsibility* between platforms and subcontracting delivery service providers. This marked a critical shift in policy discourse—from treating gig workers as independent contractors to recognizing them as a distinct labor category requiring hybrid protections. The following year, the *State Council's Opinions on Promoting the Healthy Development of the Platform Economy (2022)* expanded this direction, calling for improved labor standards, the inclusion of flexible workers in urban social insurance, and greater oversight of algorithmic management. These opinions reflected a growing awareness that digital innovation and social protection must evolve in tandem to maintain labor stability in China's service-driven economy.

At the local level, several pilot programs have been implemented in major cities, serving as experimental laboratories for labor governance in the gig economy.

In Beijing, the municipal government launched a *Social Security Pilot Program for Platform Workers* in 2022, allowing riders and couriers to enroll in occupational injury insurance through a subsidized contribution model shared by platforms and local authorities. In Hangzhou, the *Digital Governance Pilot Zone* introduced data transparency requirements, mandating that companies disclose algorithmic performance

parameters to local labor departments for review. Meanwhile, Shenzhen, known for its technological innovation and strong labor regulation, pioneered the "Rider Care Network" in partnership with *Meituan* and *Ele.me*, establishing neighborhood-level service centers for dispute mediation, insurance claims, and legal consultation. Evaluations from the *Chinese Academy of Labor and Social Security (2023)* found that Shenzhen's program reduced formal rider disputes by 22% compared with the previous year, indicating the potential of collaborative governance models in mitigating labor tensions.

Judicial institutions have also begun grappling with the question of employment classification under the new digital economy. Courts have increasingly faced cases involving food delivery riders, ride-hailing drivers, and courier workers seeking recognition as formal employees. In *Guiding Case No. 47 (SPC, 2021)*, the *Supreme People's Court* instructed lower courts to move beyond formal contract criteria and instead consider factors such as *economic dependence, labor control, and risk allocation*. Despite this guidance, rulings remain inconsistent. For instance, in *Beijing Chaoyang People's Court v. Meituan (2022)*, the court denied a rider's claim for employment recognition, citing the absence of a fixed wage and clear subordination. Conversely, in *Hangzhou Intermediate Court v. Ele.me (2023)*, judges ruled that the platform bore partial liability for a rider's workplace accident, signaling a growing tendency toward shared responsibility. The coexistence of these divergent precedents underscores the ongoing tension between judicial caution and the need for interpretive innovation in labor law.

The evolving policy and legal framework reflects a gradual shift in the Chinese state's governance philosophy—from reactive regulation to proactive adaptation in the face of digital labor transformations. The move toward shared responsibility, local experimentation, and algorithmic transparency marks a meaningful, though still incomplete, step toward addressing the regulatory vacuum surrounding gig workers.

5. Institutional and Corporate Responses to Labor Risks

As the challenges of platform-based employment have gained national visibility, both the Chinese government and major platform enterprises have begun experimenting with institutional and corporate measures to mitigate labor risks. These initiatives reflect a broader shift toward *"co-governance"* in which public authorities, enterprises, and emerging worker collectives share responsibility for protecting digital labor. Responses have taken the form of platform self-regulation, public–private cooperation, and the gradual rise of worker associations within the gig economy.

In terms of platform self-regulation, leading companies such as *Meituan* and *Ele.me* have introduced several initiatives designed to address occupational safety, social welfare, and rider well-being. Following public criticism over extreme delivery schedules and fatal accidents in 2020–2021, *Meituan* launched the *"Rider Care Program"* in mid-2021. This initiative introduced flexible delivery time buffers, heat stress alerts during summer months, and optional commercial accident insurance plans subsidized by the company. By 2023, *Meituan Research Institute* reported that over 95% of its active riders were enrolled in some form of accident or health insurance, a major improvement from less than 60% in 2019. Similarly, *Ele.me* initiated its *"Blue Helmets Safety Initiative"* (2022), which provides free protective equipment, emergency medical coverage, and a 24-hour counseling hotline for riders. Despite these developments, most measures remain voluntary and limited in scope, lacking the enforceability and continuity of formal labor benefits. The dependence on commercial insurance rather than state-administered social protection continues to expose riders to significant economic risk in cases of serious injury or loss of income.

Beyond individual corporate initiatives, government–enterprise cooperation has become a central pillar of China's evolving platform labor governance model. Local governments in Beijing, Shanghai, and Shenzhen have established *tripartite consultation mechanisms* involving labor authorities, platform firms, and trade unions to coordinate safety standards and welfare contributions. In 2022, the *Ministry of Human Resources and Social Security (MHRSS)* and *Meituan* jointly piloted a program allowing riders to access partial state occupational injury insurance through platform contributions—a model later expanded to ten provinces. According to MHRSS statistics, over 6.8 million platform workers were covered by pilot insurance schemes by the end of 2023, an increase of 150% from the previous year. These

collaborative arrangements signify an important policy experiment in shared liability, balancing the need for labor flexibility with minimal social protection guarantees. However, enforcement remains uneven: while some local authorities have introduced mandatory coverage requirements, others rely on voluntary compliance, creating significant disparities between urban regions.

A more recent and subtle development is the rise of collective bargaining and worker associations within the digital labor landscape. Historically, China's trade union system—dominated by the *All-China Federation of Trade Unions (ACFTU)*—has struggled to engage informal or dispersed workers. In 2021, the ACFTU began promoting the formation of *platform-specific worker service centers* and *"rider unions"* to provide dispute resolution and welfare assistance. For instance, the *Shanghai Riders Federation* established in 2022 represents over 20,000 food delivery workers across multiple platforms and has successfully negotiated the establishment of "cooling stations" and safety rest areas during heatwaves. These initiatives represent incremental progress toward institutionalizing worker representation in a sector previously characterized by atomization and dependency on platform algorithms. Nevertheless, formal collective bargaining over wages or algorithmic rules remains limited, constrained by the absence of legal frameworks recognizing digital worker unions as legitimate bargaining agents.

The combination of corporate self-regulation, government collaboration, and nascent worker organization marks a tentative move toward a *"hybrid governance model"* for China's gig economy. While these measures signal institutional learning and adaptive regulation, they remain largely reactive and fragmented. The sustainability of such efforts depends on whether China can translate localized pilot successes into comprehensive, enforceable national standards that bridge the current divide between innovation and protection.

6. Empirical Evidence from Food Delivery Platforms

Empirical data from recent studies and industry reports shed light on the structural realities of labor conditions within China's food delivery platforms. By integrating quantitative evidence from *Meituan Research Institute (2023)*, local government reports, and field-based surveys, this section examines working hours, income distribution, safety risks, and evolving protection measures across key cities such as Beijing, Shanghai, and Chengdu. It also incorporates qualitative findings reflecting workers' perceptions of fairness, autonomy, and algorithmic control, with case-based insights from *Meituan* and *Ele.me* initiatives.

Working Hours, Income, and Accident Rates

Food delivery work in China is characterized by long working hours, volatile income, and significant occupational risk. According to the *Meituan Research Institute's China Food Delivery Employment Report (2023)*, the average full-time rider works approximately 10.2 hours per day, completing between 35 and 45 orders daily. During peak meal delivery periods, such as weekends or national holidays, working hours often extend beyond 12 hours. Income levels vary considerably across regions and seasons. The same report estimated an average monthly income of 5,200–6,000 RMB, with riders in first-tier cities like Beijing and Shanghai earning around 6,800 RMB, while those in smaller cities earn closer to 4,500 RMB. However, nearly 45% of riders surveyed reported experiencing at least one month per year where income dropped by more than 20% due to weather disruptions, algorithmic adjustments, or policy restrictions.

Safety remains a persistent concern. The *Beijing Traffic Management Bureau (2022)* documented over 6,300 road accidents involving food delivery riders in 2022—a 29% increase compared to 2020. Among these, 17% resulted in serious injuries. The primary causes cited were time pressure, route optimization errors, and fatigue. Similarly, a *Shanghai Municipal Labor Security Bureau (2023)* report indicated that 82% of riders considered "tight delivery deadlines" a major source of stress. These statistics reveal a pattern of occupational strain directly linked to algorithmic time compression and incentive-driven work structures.

City-Level Comparison: Beijing, Shanghai, and Chengdu

Regional differences in policy implementation provide valuable insights into the uneven governance of platform labor.

In Beijing, the municipal labor bureau introduced a *joint insurance model* in 2022, allowing *Meituan* and *Ele.me* to co-fund occupational injury insurance premiums with

government subsidies. This program currently covers over 200,000 riders, marking one of the highest coverage rates in the country.

Shanghai, on the other hand, has emphasized digital transparency through its *Algorithmic Accountability Framework (2023)*, requiring platforms to publicly disclose delivery time algorithms and allow third-party audits. Preliminary evaluations by the *Shanghai Labor Protection Institute (2023)* found that delivery delays caused by severe weather were reduced by 11% after implementation, indicating improved coordination between platform operations and worker welfare.

In Chengdu, local authorities have prioritized community-based welfare centers known as "Rider Stations." These facilities provide rest areas, legal assistance, and free health check-ups. As of late 2023, the *Chengdu Human Resources Bureau* reported that over 60% of riders utilized these services monthly, suggesting the potential of localized welfare interventions in improving working conditions.

Worker Perceptions and Algorithmic Control

Beyond quantitative metrics, worker experiences reveal complex attitudes toward platform governance and autonomy. Field interviews conducted by *Peking University's School of Labor and Human Resources (2023)* show that 72% of riders believe platform algorithms "determine all aspects of work," including route planning, order acceptance, and payment calculation. While many appreciate the income opportunities and flexibility, nearly two-thirds express frustration over opaque penalty systems and perceived "unfairness" in algorithmic ranking mechanisms. Riders often describe a sense of *"digital dependency"*—where their livelihood depends on maintaining algorithmic favor, leaving little room for contesting decisions. This sentiment reflects broader issues of data asymmetry and power imbalance between workers and platform corporations.

Case-Based Insights from *Meituan* and *Ele.me*

Meituan and *Ele.me* have both launched initiatives to address worker welfare concerns, but their effectiveness varies. *Meituan's "Rider Care Program"* includes emergency funds, rest stations, and mental health counseling, reaching over 3 million riders as of 2023. *Ele.me's "Blue Helmets Safety Initiative"* provides accident coverage and regular safety training sessions. However, independent evaluations by the *China Institute of Industrial Relations (2023)* indicate that only 38% of riders report being aware of these programs, and participation remains uneven across regions. While corporate policies demonstrate growing recognition of labor issues, implementation remains constrained by cost pressures and subcontracting layers, which diffuse accountability.

Collectively, these empirical findings highlight the dual reality of China's food delivery sector: the gig economy serves as both a crucial employment source and a site of deepening precarity. Despite improvements in insurance coverage and digital governance, the underlying power asymmetry between platforms and workers—mediated through algorithms—continues to limit substantive progress in labor protection.

7. Social and Economic Implications of Platform Labor

The rapid growth of the gig economy has fundamentally altered China's urban labor structure, creating both opportunities and vulnerabilities. On one hand, platforms such as *Meituan* and *Ele.me* have become essential to employment generation and economic resilience, especially for migrant and low-skilled workers. On the other hand, this expansion has accelerated the informalization of labor, deepened inequality, and redefined traditional notions of work and security.

Recent estimates from the *Ministry of Human Resources and Social Security (MHRSS, 2023)* show that over 84 million Chinese workers—nearly one-fifth of the urban labor force—are engaged in flexible or platform-based jobs. However, fewer than 10% of them have full access to social insurance or contractual protection. This exclusion represents a significant shift from the state's earlier model of formalized, welfare-linked employment. As a result, China's urban labor market has become increasingly dualistic: formal employees benefit from stable protection, while platform workers operate under algorithmic governance with fluctuating income and minimal security.

Socioeconomic inequality within this system is most visible among migrant and young workers. Surveys by *Renmin University of China (2023)* indicate that more than 70% of food delivery riders are rural migrants who lack access to urban welfare benefits due to household registration (hukou) restrictions. While platform

work offers flexibility and immediate income, it rarely leads to upward mobility, leaving workers trapped in cycles of economic precarity. *Meituan Research Institute (2023)* data show that riders' average annual earnings remain roughly 60% lower than those of formal logistics employees. Furthermore, the constant surveillance and productivity demands imposed by algorithms create high psychological pressure—over 60% of riders report chronic stress or fatigue according to *Fudan University (2022)*.

Gender and family dynamics also shape the social impact of platform labor. Though the delivery sector is predominantly male, women increasingly participate in other platform-based jobs such as e-commerce, tutoring, and domestic services. This flexibility helps increase female labor participation but often confines women to lower-paying, insecure forms of work. Studies by *Tsinghua University (2022)* suggest that women's average earnings on digital platforms are about 25% lower than men's, reflecting algorithmic bias and uneven task allocation.

Overall, China's platform economy represents a paradox: while it expands employment and supports consumption-driven growth, it also reinforces a fragmented and unequal labor system. The emergence of millions of digitally managed yet socially unprotected workers underscores a central tension in China's modernization—between economic efficiency and social equity. Without stronger institutional safeguards, the promise of digital inclusion risks perpetuating a new era of algorithmic precarity beneath the surface of innovation.

8. Toward a Sustainable Model of Platform Labor Governance

As China's gig economy continues to grow, there is an urgent need to develop a sustainable model for platform labor governance that balances the benefits of technological innovation with the protection of worker rights. A key challenge lies in creating a framework that can ensure fair wages, social protection, and transparency, while also maintaining the flexibility that has made platform work attractive to both employers and workers.

To address these challenges, several policy recommendations can be considered. First, there needs to be a clear legal recognition of platform workers as a distinct category of employment, with tailored protections that reflect the hybrid nature of their work. This includes extending social insurance coverage to gig workers, similar to the benefits enjoyed by formal employees. The implementation of national-level regulations mandating minimum benefits such as health insurance, accident coverage, and unemployment compensation would help bridge the gap between formal and informal labor. For instance, the adoption of a "third employment category"—one that acknowledges the unique nature of gig work without forcing platforms into traditional employer-employee relationships—would provide a clearer path for legal inclusion. This approach has already been successfully trialed in parts of the European Union and could be adapted to China's specific conditions.

Second, algorithmic transparency must be prioritized. Platforms currently operate with opaque algorithms that govern workers' pay, task assignments, and penalties. This lack of transparency exacerbates power imbalances, undermining workers' ability to challenge unfair practices. Regulatory bodies should enforce measures that require platforms to disclose how their algorithms work, allowing for third-party audits to ensure fairness. Platforms should also be mandated to provide workers with data access—allowing them to understand the metrics that affect their performance and earnings. This would empower workers to make informed decisions and mitigate algorithmic bias, which disproportionately affects vulnerable workers.

Third, worker participation mechanisms should be introduced. Currently, the absence of formal labor unions or collective bargaining structures leaves platform workers vulnerable to exploitation. The establishment of worker councils or platform unions would allow workers to have a seat at the table in negotiations concerning wages, working conditions, and algorithmic changes. Government and industry collaboration in facilitating such bodies would ensure that platform workers' voices are heard and their interests represented. Cities like Shenzhen have already seen some success with worker representation initiatives, but the scope of such movements must be expanded across China.

Finally, public-private partnerships should be strengthened to provide a more comprehensive safety net for platform workers. In the absence of a fully integrated welfare system for gig workers, partnerships between platforms and

local governments can help create more localized protection schemes, such as subsidized insurance, income stability programs, and community-based support centers. The pilot programs in cities like Beijing, Hangzhou, and Chengdu have shown that these collaborative efforts can improve both worker welfare and platform compliance with labor regulations.

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Green Digitalization: A New Path for Sustainable Development in the Retail Industry — A Comparative Study of Chinese and American Corporate Practices

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Abstract

The United Nations Environment Programme's 2024 Emissions Gap Report warns that global greenhouse gas emissions have reached a historical peak; failing to achieve a 42% emission reduction by 2030 will jeopardize the 1.5℃ temperature control goal. As a core carbon-emitting sector accounting for 12% of global emissions, the retail industry faces an urgent need for low-carbon transformation, while digital technologies offer a proven 15–20% emission reduction potential. This study introduces the concept of "green digitalization," defined as the application of digital tools (e.g., artificial intelligence, Internet of Things) to restructure the retail "people-goods-venue" value chain, thereby enabling quantifiable, traceable low-carbon operations. Drawing on empirical data from three self-developed systems ("Lian Tong Ying," "Dian Xiao Tong," "Ke Ying Tong") and comparative analyses of green transformation paths among U.S. enterprises (including Walmart, Target, and Whole Foods), this study identifies fundamental differences between China and the U.S. in technological application, model innovation, and policy adaptation. It further proposes a U.S.-adaptation framework for China's digital decarbonization experience, centered on the tripartite logic of "technology localization + model collaboration + standard unification." This research contributes a dual-driven paradigm of "technological evidence + cross-national adaptation" to global retail sustainability. Empirically, it verifies that lightweight digital tools can simultaneously achieve 28% carbon reduction and 22% operational efficiency improvement, while the ecological strategies of U.S. enterprises provide critical insights for scaling emission reduction effects.

Keywords: green digitalization, retail sustainable development, three-dimensional implementation model, Sino-U.S. retail comparative study, cross-regional supply chain optimization, carbon footprint management, low-carbon operations

1. Introduction

1.1 Research Background: The Carbon Dilemma of Global Retail

The global retail industry is trapped in a paradox of "scale expansion versus emission control." According to the United Nations Statistics Division (2024), global retail carbon emissions reached approximately 9.6 billion tons of CO_2 in 2023, with logistics transportation

(38%), in-store energy consumption (25%), and paper voucher waste (7%) emerging as the top three emission sources. China's retail sector has made progress in reducing carbon intensity, with a 13% decrease from 0.31 tons of CO_2 per 10,000 yuan GDP in 2016 to 0.27 tons in 2019, yet its logistics empty-load rate remains as high as 28%—13 percentage points higher than that of the United States—and non-peak in-store energy waste exceeds 40%. The U.S. market, by contrast, faces structural challenges including 62% of emissions originating from cross-state transportation and a 25% food waste rate, as highlighted in Gartner's 2024 Retail Sustainability Report.

Traditional emission reduction methods, such as replacing energy-efficient equipment or optimizing manual processes, are constrained by high costs and poor scalability. In this context, "green digitalization" has emerged as a critical breakthrough: by breaking data silos across the entire retail chain, it enables precise measurement of emission reduction effects and systematic process optimization. The United Nations Sustainable Development Goal (SDG) 12.3 explicitly mandates a 50% reduction in retail food waste by 2030, and digital technology is widely recognized as the only viable path to balance operational efficiency and environmental benefits, as noted in the European Commission's 2024 Transition Pathway for a Resilient, Digital and Green Retail Ecosystem. (Rai, H. B., Broekaert, C., Verlinde, S., & Macharis, C., 2021)

1.2 Research Significance and Objectives

Theoretical significance of this study lies in addressing gaps in existing literature, which tends to focus on either single-country digitalization practices (e.g., Walmart's blockchain traceability systems) or isolated technological applications (e.g., AI-driven logistics optimization) without establishing a systematic comparative framework for Sino-U.S. green digitalization. This study constructs a "technology-model-ecology" three-dimensional implementation model, expanding the theoretical connotation of green digitalization beyond the simple overlay of "technology + low carbon" to a holistic system that unifies commercial and environmental value.

Practically, this study provides Chinese retail enterprises with a replicable path to adapt localized digital tools to global markets—for instance, navigating U.S. state-level carbon policies—and offers U.S. enterprises insights into lightweight, scenario-specific digital solutions to complement their existing ecological strategies. For global retail sustainability, it proposes a "global standard + regional adaptation" model, supporting the alignment of carbon reduction efforts across countries along the Belt and Road Initiative (BRI).

The research objectives are threefold: first, to clarify the core mechanism of green digitalization through the three-dimensional model; second, to compare Sino-U.S. practices and identify key barriers to cross-national adaptation; and third, to design a targeted U.S.-adaptation path for China's digital decarbonization experience.

2. Theoretical Framework: The Three-Dimensional Implementation Model of Green Digitalization

2.1 Theoretical Foundation

Green digitalization originates from the intersection of "digital transformation theory" and "circular economy theory". Unlike traditional digitalization, which prioritizes operational efficiency, or standalone low-carbon initiatives, which focus on regulatory compliance, green digitalization emphasizes restructuring value chains through data to achieve synergies between emission reduction and revenue growth.

This framework is underpinned by three core theories: Schumpeter's Innovation Theory, which supports the technology layer by framing digital tools (e.g., AI routing algorithms, IoT sensors) as "innovative combinations" that disrupt traditional high-carbon operations; Stakeholder Theory, which guides the ecology layer by emphasizing that cross-regional and cross-industry collaboration—among suppliers, retailers, and policymakers—is essential for scaling emission reduction effects; and Institutional Economics, which explains Sino-U.S. differences by highlighting how policy environments (e.g., China's regional carbon markets versus U.S. state-level policies) shape the direction and pace of green digitalization.

2.2 The Three-Dimensional Implementation Model

The three-dimensional model forms a closed loop of emission reduction, with three mutually reinforcing layers that collectively drive the low-carbon transformation of the retail industry.

The technology layer serves as the foundational pillar, providing digital tools to reduce resource consumption through algorithm optimization and intelligent control. Key features include real-time data integration, which fuses transactional, logistical, and environmental data (e.g., traffic conditions, in-store passenger flow) to eliminate information asymmetry—for example, the "Lian Tong Ying" system integrates 1.2 million historical transaction records and real-time logistics data to optimize allocation routes, directly addressing the pain point of high empty-load rates. Scenario-specific algorithm design tailors technical solutions to retail-specific challenges: the "Dian Xiao Tong" system uses passenger flow heatmaps and POS data to build a "passenger flow-energy consumption" matching model, enabling time-sharing control of in-store lighting and HVAC systems. Additionally, contactless operation loops replace physical resources with digital alternatives — the "Ke Ying Tong" system leverages electronic vouchers and AR try-on functions to reduce paper waste and physical sample production, forming a seamless "digital interaction-consumption" cycle.

Table 1.

System	Data Volume / Type
Lian Tong Ying	1.2 million historical transaction records + real-time logistics data
Dian Xiao Tong	Passenger-flow heat-maps + POS data
Ke Ying Tong	Electronic vouchers + AR try-on

The model layer focuses on reconstructing the value cycle driven by data, embedding low-carbon goals into core business logic to transform "emission reduction as a cost" into "emission reduction as a value driver." Representative practices include China's green points mechanism, where retailers reward consumers for low-carbon behaviors (e.g., selecting electronic vouchers over paper ones) with points redeemable for goods or discounts, while merchants gain supply chain cost savings from accumulated emissions reductions. This mechanism draws on China Southern Power Grid's carbon accounting system, which links full-chain carbon data to commercial value. In the U.S., enterprises such as Walmart use blockchain technology to track product carbon footprints from production to shelf; by 2024, Walmart had achieved carbon labeling coverage for 2,000 products, enabling consumers to make informed low-carbon choices and pressuring upstream suppliers to reduce emissions.

The ecology layer amplifies emission reduction effects through networked collaboration, with two distinct yet complementary models emerging in China and the U.S. China's "regional linkage" model, exemplified by the "Lian Tong Ying" system, builds a cross-regional shared supply chain across Hubei, Tibet, and Hainan, reducing redundant transportation through real-time inventory visualization. A Wuhan-based jewelry brand using this system achieved 24-hour cross-regional replenishment, avoiding 12 lost orders and cutting round-trip carbon emissions. The U.S.'s "supply chain collaboration" model, such as Walmart's "Gigaton Reduction Plan," partners with over 3,000 suppliers to optimize production and transportation rhythms via data sharing; by 2024, this initiative had avoided 416 million tons of CO_2 emissions, equivalent to removing 2 million passenger vehicles from the road annually.

Table 2.

Model / System	Outcome
Regional Linkage: Lian Tong Ying	Cut redundant transport & round-trip CO_2
Supply-chain Collaboration: Gigaton Reduction Plan	Optimize production & transport rhythms via data sharing

3. Chinese Practice: Empirical Evidence of Green Digitalization Innovation

3.1 Research Context

The author has 12 years of hands-on experience in retail digitalization, leading the development of three core systems that have been deployed across 190 retail stores in Hubei, Tibet, and Hainan. These systems form a replicable green digitalization solution, with data collected from 2023–2024 pilot projects including 3 jewelry stores, 4 clothing stores, and 3 cosmetics stores in Wuhan, as well as 2 agricultural product circulation centers in Hainan. This empirical foundation ensures the validity and generalizability of the findings.

3.2 Empirical Analysis of Three Core Systems

The "Lian Tong Ying" cross-regional supply chain optimization system features deep integration of "AI routing algorithms + multi-scenario adaptation," specifically addressing China's "low regional collaboration" logistics pain point. The system builds a demand forecasting model using 1.2 million historical transaction records, dynamically adjusting routes by integrating real-time traffic data, order density, and load capacity. For the Hubei-Tibet jewelry supply chain, it optimized the traditional "Wuhan-Lhasa direct" route to a "Wuhan-Xining transit" model, merging orders to reduce empty-load rates. Empirical results from 2024 show that this route achieved a 28% reduction in logistics carbon emissions ($p<0.05$), saving 150,000 liters of diesel annually—equivalent to 396 tons of CO_2. In agricultural product circulation, the system's "live broadcast sales + county IP" module shortened the supply chain, reducing navel orange loss rates from 25% to 8% and indirectly cutting emissions associated with unsold produce. (European Commission, 2024)

The "Dian Xiao Tong" in-store dynamic energy management system directly targets the pain point of in-store energy waste during non-peak hours. By linking infrared passenger flow sensors with POS data, the system constructs a "passenger flow-energy consumption" matching model. During low-peak periods (e.g., 14:00–16:00 on weekdays), it automatically turns off 30% of lighting fixtures and raises HVAC temperatures by 2℃. Data from Wuhan's pilot stores in 2024 show that this system achieved 12,000 kWh of annual electricity savings—equivalent to 9.6 tons of CO_2—while reducing electricity costs by 18%. This practice aligns with the China Chain Store and Franchise Association's "Gold Store Manager" energy efficiency standards, verifying the feasibility of converting operational experience into standardized technical tools.

The "Ke Ying Tong" paperless private domain operation system addresses the high paper consumption and low redemption rates of traditional retail coupons by migrating all coupons and member benefits to private domain traffic pools, enabling precision pushes based on user portraits. It also integrates AR try-on functions to reduce demand for physical samples. 2024 pilot data from Wuhan indicate that the system reduced annual paper consumption by 5 tons—equivalent to saving 85 adult trees—and cut 12.5 tons of CO_2 emissions. The AR try-on function further reduced sample loss rates by 40%, while the 82% electronic coupon redemption rate far exceeded the industry average of 55%, achieving a dual win for environmental and commercial benefits.

3.3 Synergy Effect of the Three Systems

Collectively, the three systems form a full-chain low-carbon loop: "Lian Tong Ying" optimizes upstream supply chain emissions, "Dian Xiao Tong" controls midstream operational emissions, and "Ke Ying Tong" reduces downstream consumer-related emissions. In 2024, enterprises associated with these systems achieved a 22% reduction in overall carbon emissions while growing revenue by 19%, providing concrete evidence that green digitalization resolves the long-standing industry dilemma of "emission reduction versus growth.

Table 3.

System / Stage	Scope
Lian Tong Ying	Upstream supply-chain emissions
Dian Xiao Tong	Midstream operational emissions
Ke Ying Tong	Downstream consumer-related emissions
Full-chain loop (aggregate)	Upstream + Midstream + Downstream

4. American Practice: Zero-Carbon-Driven Digital Transformation

4.1 Strategic Orientation

U.S. retail enterprises take "zero-carbon operations" as their core strategic goal, leveraging mature digital infrastructure (e.g., 5G networks, blockchain platforms) and policy systems (e.g., time-of-use electricity pricing, state-level carbon trading) to form an integrated model of "supply chain collaboration + renewable energy integration + consumer guidance." This orientation reflects the U.S. market's focus on systemic, long-term zero-carbon goals, supported by high consumer awareness of environmental issues and robust digital ecosystems.

4.2 Typical Case Studies

Walmart, as a global retail giant, has developed

a highly representative "zero-carbon supply chain" strategy centered on blockchain technology. The company aims to achieve global operational carbon neutrality by 2040, with blockchain serving as a core enabler for full-chain carbon traceability. It tracks the carbon footprint of products such as beef, fruits, and vegetables from ranch to shelf, and by 2024, had achieved carbon labeling coverage for 2,000 products. Consumers can scan product codes to access detailed emission data, creating market pressure for upstream suppliers to reduce emissions. In logistics, Walmart uses AI algorithms to optimize cross-state transportation routes, combined with electric trucks and advanced cold chain temperature control technology, reducing cold chain loss rates from 15% to 12% and cutting carbon emissions for single cross-state routes by 18%.

Table 4.

Dimension	Metric	Value
Overall target	Global operational carbon neutrality	2040
Traceability scope	Product categories carbon-tracked	Beef, fruits, vegetables
Blockchain labeling	Products with carbon labels (2024)	2,000
Consumer interface	Scan product code → emission data	Available
Logistics optimization	Cold-chain loss reduction	15 % → 12 %
Logistics optimization	CO_2 cut per cross-state route	18 %

Target focuses on green digitalization of in-store operations, forming a dual-driven model of "intelligent control + renewable energy." Its AI temperature control system dynamically adjusts HVAC operating parameters by integrating local weather data and in-store passenger flow forecasts, reducing annual energy consumption for single stores by 22%. Additionally, Target has deployed rooftop photovoltaic systems in 40% of its stores, achieving a Power Usage Effectiveness (PUE) value of 1.18—near the energy efficiency level of advanced data centers. The company also fully leverages the U.S.'s mature time-of-use electricity pricing mechanism, using its system to automatically adjust the operating time of high-energy-consuming equipment, reducing the proportion of electricity consumption during peak pricing periods from 45% to 28% and further lowering energy costs. (Hanshow, Microsoft, Intel, & E Ink., 2024)

Whole Foods addresses the U.S. retail industry's 25% food waste rate through digital waste reduction practices. Its intelligent restocking system integrates sales forecasting, inventory monitoring, and near-expiry management functions; when products approach their expiration date, the system automatically pushes "daily discount" information to consumer apps. Unsold products are donated to charitable organizations through partner platforms. By 2024, this system had reduced in-store food waste rates to 8%, far below the industry average and exceeding the UN SDG 12.3 target for 2030. This practice aligns with the inventory warning logic of China's "Lian Tong Ying" system but requires higher data precision and stricter process compliance to meet U.S. FDA food traceability regulations—a key consideration for cross-national technology adaptation.

5. Sino-U.S. Comparison and Adaptation Path of Chinese Experience

5.1 Comparative Analysis of Sino-U.S. Practices

Fundamental differences exist between Chinese and U.S. green digitalization practices, rooted in their distinct market structures, policy environments, and technological foundations. China's approach is characterized by "lightweight tools for specific scenarios," driven by the need to address fragmented market pain points such as high logistics empty-load rates and in-store energy waste. With over 1.3 million small-scale retailers, China prioritizes solutions that are low-cost, easy to deploy, and adaptable to regional differences. The U.S., by contrast, focuses on "ecological strategies + policy collaboration," reflecting its concentrated market structure (the top 10 retailers account for 40% of sales) and mature digital infrastructure, which enable large-scale systemic zero-carbon goals.

In terms of policy dependence, China relies on regional pilot policies—such as those in the Hainan Free Trade Port—to test green digitalization solutions, while the U.S. operates within a framework of state-level policies, including California's carbon trading market and New York's zero-carbon laws. These

differences highlight the need for context-specific adaptation rather than direct replication of practices across borders.

5.2 Adaptation Path of Chinese Experience to the U.S.

Technology localization forms the first pillar of the adaptation path. For the "Lian Tong Ying" system, the U.S. market's high proportion of cross-state transportation (62%) and varying state policies (e.g., truck weight limits, carbon taxes) require adding a "state policy adaptation" module to the existing AI algorithm. This module integrates California's carbon trading data—which saw 68% volume growth in 2024—and incorporates carbon costs into route optimization parameters. Additionally, to address the globalization of U.S. retail supply chains, the system must strengthen optimization functions for "sea-land transport" connections, referencing Amazon Sweden's cross-border order merging practices to reduce international transportation emissions. For the "Dian Xiao Tong" system, adaptation involves enhancing intelligent HVAC control for high-temperature U.S. southern states, where HVAC accounts for 50% of in-store energy use, and integrating Target's photovoltaic data to link renewable energy supply with equipment operation. Accessing time-of-use pricing data from the U.S. Energy Information Administration (EIA) will further amplify energy cost savings. The "Ke Ying Tong" system can leverage the U.S.'s 78% electronic receipt penetration rate to add a "carbon credit donation" function, allowing users to exchange accumulated carbon credits for afforestation services—aligning with U.S. consumers' strong environmental participation willingness.

Model collaboration constitutes the second pillar, focusing on building a Sino-U.S. green business ecology. In cross-border e-commerce, the route optimization logic of "Lian Tong Ying" can be integrated with Walmart's supply chain data platform to achieve carbon emission data interoperability between Chinese suppliers and U.S. retailers. Combining China Southern Power Grid's green electricity tracking technology creates a closed loop of "cross-border green electricity-logistics-sales." In agricultural retail, China's "live broadcast + private domain" model can empower U.S. "farm-direct" companies: the private domain fission function of "Ke Ying Tong" expands market coverage for low-carbon agricultural products, while linking with Whole Foods' waste reduction system reduces circulation losses. This collaborative model leverages China's strength in scenario adaptation and the U.S.'s ecological resources to achieve large-scale deployment, forming a virtuous cycle of "technology output-localization innovation-collaborative win-win."

Standard unification is the third pillar, addressing data incompatibility between China and the U.S. Sino-U.S. retail industry associations should co-develop "Retail Carbon Footprint Data Exchange Specifications," referencing the ISO 14067 standard to define clear accounting boundaries for key links such as transportation, energy consumption, and waste. Building a "Sino-U.S. Retail Carbon Data Platform" using blockchain technology will ensure data immutability, providing a trusted foundation for cross-regional emission reduction comparisons and collaboration while complying with data privacy regulations such as GDPR and China's Data Security Law.

6. Challenges and Multi-Stakeholder Countermeasures

6.1 Core Challenges

Data silos represent the primary challenge, driven by divergent carbon accounting standards: China adheres to the GB/T 35648 carbon footprint accounting standard, while the U.S. uses multiple systems including carbon neutrality labels and California carbon labels. These differences in data caliber—for example, China includes last-mile delivery in logistics emission accounting, while the U.S. excludes it—make cross-regional emission quantification and comparison nearly impossible, hindering collaborative efforts.

High investment thresholds for small and medium-sized enterprises (SMEs) further constrain industry-wide adoption of green digitalization. U.S. SMEs spend approximately $80,000 annually on green digitalization initiatives, while Chinese SMEs incur costs of around 500,000 yuan per year. With retail profit margins typically below 5%, these costs create a significant financial barrier for SMEs, which form the backbone of both countries' retail sectors.

Policy fragmentation exacerbates cross-regional implementation difficulties. U.S. state policies vary widely: New York has enacted a zero-carbon law targeting 2050, while Texas has

not established a carbon pricing mechanism. In China, the national carbon market currently excludes the retail industry, limiting policy-driven incentives for green digitalization. This fragmentation increases compliance costs for enterprises operating across borders and slows the pace of industry transformation.

6.2 Collaborative Countermeasures

Breaking data silos requires unified standards and cross-border platforms. Sino-U.S. retail associations should jointly develop a set of core indicators—such as "logistics emission per unit product" and "in-store energy consumption per customer"—to align accounting calibers and ensure data comparability. Launching a "Sino-U.S. Retail Carbon Data Platform" using blockchain technology will enable real-time sharing of emission data while complying with global data privacy regulations, fostering trust between cross-border partners.

Reducing SME thresholds demands multi-level support. At the government level, establishing special subsidies for green digitalization—referencing the EU's Horizon Europe program—can provide 30–50% equipment procurement subsidies for SMEs adopting low-carbon tools. At the enterprise level, developing lightweight tool versions—such as "Lian Tong Ying Lite," which focuses on core route optimization—can cut costs by 60% compared to full-featured systems. At the ecological level, encouraging large enterprises (e.g., Walmart, Suning) to open their supply chain platforms to SMEs will enable shared access to digital infrastructure, reducing individual investment burdens.

Coordinating policies requires cross-border and cross-sector collaboration. Embedding "retail green standards" into regional trade agreements such as RCEP and USMCA can offer tariff preferences to enterprises adopting unified low-carbon practices, creating market incentives for compliance. Under the framework of international climate conferences such as COP30, China and the U.S. should issue a "Retail Emission Reduction Joint Declaration" to form policy collaboration expectations, guiding industry-wide transformation and reducing regulatory uncertainty for cross-border operators.

7. Conclusion and Outlook

7.1 Main Conclusions

First, green digitalization represents a systemic transformation rather than a simple overlay of digitalization and low carbon. The "technology-model-ecology" three-dimensional model effectively resolves the retail industry's "emission reduction versus growth" dilemma, as demonstrated by 22–28% emission reductions and 18–19% revenue growth in Chinese pilot projects. Second, Sino-U.S. green digitalization practices differ fundamentally in driving forces and paths: China excels in lightweight, scenario-specific tools tailored to fragmented market needs, while the U.S. leads in ecological strategies focused on systemic zero-carbon goals. The adaptation of Chinese experience to the U.S. market requires a targeted approach centered on "technology localization + model collaboration + standard unification." Third, global retail sustainability depends on multi-stakeholder collaboration—unifying data standards, supporting SMEs, and coordinating policies—to scale green digitalization across borders and market segments.

7.2 Theoretical and Practical Contributions

Theoretically, this study expands green digitalization theory from a narrow technical focus to a holistic systemic model, providing a comprehensive framework for cross-national retail sustainability research. It also clarifies the mechanisms through which digital tools create synergies between environmental and commercial value, filling gaps in existing literature on Sino-U.S. comparative retail studies.

Practically, this study offers Chinese enterprises a clear path to adapt localized digital tools to the U.S. market, addressing key barriers such as state-level policies and data standards. For U.S. enterprises, it provides insights into lightweight, cost-effective digital solutions to complement their ecological strategies, particularly for SMEs. Globally, the proposed "global standard + regional adaptation" model supports the alignment of carbon reduction efforts across BRI countries, accelerating the transition to sustainable retail.

7.3 Future Research Directions

Future research can explore three key areas: first, the integration of emerging technologies such as digital twins and 6G into green digitalization, for example, using digital twins to simulate supply chain carbon emissions and predict reduction effects with higher precision. Second,

investigating the influence of low-carbon labels—such as Walmart's carbon labeling—on consumer behavior, to provide insights for demand-side emission reduction strategies. Third, extending the Sino-U.S. framework to other regions, designing region-specific green digitalization paths for BRI countries based on their unique market characteristics, policy environments, and technological foundations.

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Digital Upgrading of "Post-Investment Management" in Cross-Border Equity Investment: Practices of Financial Monitoring and Strategic Empowerment for Multi-Regional Enterprises

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Abstract

In cross-border equity investment, traditional post-investment management faces information decay and decision-making lags due to differences in standards and geographical dispersion. Based on the quasi-natural experiment constructed by the launch of Alpha Capital's digital platform in 2021, this paper integrates dynamic capabilities theory with the perspective of information asymmetry, proposing a three-tier digital architecture of "data—technology—application." Using 260 cross-border investments from 2018 to 2024 as a sample, we jointly apply difference-in-differences (DID) and spatial econometric models to examine the causal effect of digital upgrading on post-investment return on investment (ROI) and its spatial spillover.

Keywords: cross-border post-investment management, digital upgrading, dynamic capabilities, information asymmetry, data asymmetry index, difference-in-differences, spatial econometrics, spatial spillover, marginal returns of software investment, standard differences

1. Introduction

1.1 Practical Pain Points

Over the past five years, the global stock of cross-border equity investments has grown at a compound annual rate of 11%, yet the failure rate of projects has simultaneously risen to 27%. Preqin's attribution of 194 liquidation events from 2022 to 2023 shows that 43% directly stem from post-investment information delays and uncontrolled risks. The traditional model of "quarterly reports + annual on-site inspections" operating simultaneously in China, the United States, Singapore, Hong Kong, Thailand, and Vietnam sees an average data aggregation lag of 6.3 months, preventing investment institutions from timely capturing cash flow disruptions or abnormal related-party transactions in invested companies. More challenging is the "information decay" caused by the coexistence of multiple regions and standards: the comparable net profit overlap of the same revenue, adjusted for disclosure standards in China, the United States, and Singapore, is only

68%, meaning that 32% of effective signals are lost in cross-border transmission (Buchner, A., Espenlaub, S., Khurshed, A., & Mohamed, A., 2018). This "data friction" renders post-investment management almost ineffective in strategic correction and value addition. Digital upgrading has thus become a common call from limited partners (LPs) and general partners (GPs). However, the industry lacks consensus on "how much to invest, in which tools, and what returns to expect," urgently requiring a quantified answer based on large-sample micro-evidence.

1.2 Theoretical Gaps

Although dynamic capabilities theory is mature in the field of strategic management, it has long focused on pre-investment project screening and resource combination, lacking a depiction of the "data acquisition—real-time processing—rapid action" cycle in the post-investment stage. Existing studies simplistically view digitalization as "information system adoption," without explaining how it reshapes institutions' risk perception and strategic adjustment capabilities in cross-border contexts. Meanwhile, information asymmetry theory in cross-border equity investment literature remains stuck in a static "disclosure—reaction" framework, failing to quantify the "black box" of information loss caused by standard differences and lacking empirical tests on "data standardization" as a core mechanism for reducing data friction. As a result, the theoretical level cannot provide a causal path for the impact of digital upgrading on post-investment performance, nor can it answer operational questions such as whether digital post-investment practices in adjacent regions spill over and which investment structure yields the highest marginal benefits.

1.3 Research Questions

This paper attempts to answer two progressive questions: First, can digital upgrading significantly enhance the return on invested capital (ROI) in cross-border post-investment management, and does its micro-mechanism unfold along the chain of "data standardization → reduced information loss → enhanced risk early warning efficiency → improved ROI"? Second, does this effect spill over spatially to adjacent regions, and what boundary conditions (such as data infrastructure, corporate life cycle, and investment structure) moderate it? By answering these questions, this paper aims to provide actionable digital budget allocation guidelines for cross-border investment institutions while expanding the explanatory boundaries of dynamic capabilities and information asymmetry theories in the context of post-investment management.

2. Theoretical Framework and Hypotheses

2.1 Integrated Model

Traditional post-investment management views digitalization as a single-point tool, resulting in a "path dependency": quarterly reports pile up but fail to trigger action before risks erupt. Dynamic capabilities theory suggests that institutions need a repeatable "perception—capture—reconfiguration" cycle, fueled by real-time, comparable, and granular data. In cross-border contexts, heterogeneous financial data from multiple regions and standards first cause "information decay," rendering the perception stage dysfunctional. Only when raw data is standardized into computable signals can institutions enter the "capture" stage—identifying cash flow anomalies, surges in related-party transactions, or valuation anchor drifts—and then quickly adjust board seats, follow-on investments, or initiate exits in the "reconfiguration" stage. Thus, the core of digital upgrading is not purchasing a SaaS package but constructing a "dynamic capabilities pipeline" from data to action.

Information asymmetry theory further provides quantifiable "leakage points" for this pipeline. Standard differences, language differences, and time zone differences together form a "data friction wall," causing irreversible information loss between the true financial state of invested companies and the signals received by investment institutions. This paper proposes the "Data Asymmetry Index" (DAI), calculated as 1 minus the "comparable net profit overlap/total disclosed net profit," to quantify the height of the wall: the greater the difference between the profit disclosed by a Chinese subsidiary under Chinese standards and the recognizable profit of a U.S. parent company under GAAP, the closer the DAI is to 1, and the more severe the information loss. Digitalization, through unified data dictionaries, real-time mapping of accounting items, and blockchain's tamper-proof accounting, is equivalent to opening a standard passage through the wall, reducing the DAI and narrowing the information asymmetry gap

between the two ends of the "dynamic capabilities pipeline." This, in turn, enables early risk warnings and the emergence of strategic adjustment windows.

Integrating the two theories, this paper constructs a three-tier digital architecture of "data—technology—application": the data layer captures real-time, multi-source, multi-standard, and multi-language data and aligns their semantics; the technology layer uses AI algorithms to identify anomalies, blockchain to solidify vouchers, and cloud computing to achieve elastic computing power; the application layer pushes early warning results to investment directors and outputs strategic synergy plans to the CEOs of invested companies. Together, the three layers form the "dynamic capabilities engine" for cross-border post-investment management, with the ultimate goal of transforming information loss into computable value addition.

2.2 Hypothesis System

If the above engine is truly effective, we should first observe a systematic increase in the ROI of invested companies after its activation; second, the causal chain should sequentially transmit along "data standardization → DAI reduction → early risk warning → ROI improvement"; third, since data standards have public good attributes, digital post-investment practices in adjacent regions will generate spatial spillovers, causing regional ROI to additionally grow as neighboring digital levels rise; finally, the type of fuel and the company's own conditions will determine the engine's power: software investment, with near-zero marginal cost and rapid iteration, should have a higher marginal ROI than hardware and labor investments; mature companies, with more standardized financial data and maximum DAI reduction space, should benefit the most. Based on this, this paper proposes four testable hypotheses: H1 main effect, H2 chain mediation, H3 spatial spillover, and H4 heterogeneity boundaries, collectively forming a complete conjecture on the mechanism and boundary conditions of digital upgrading in cross-border post-investment management.

3. Research Design

3.1 Sample and Experimental Field

Cross-border equity investment naturally lacks "laboratory purity," but the i-Post digital platform launched by Alpha Capital in the fourth quarter of 2021 provides a quasi-natural experimental entry point. This Singapore-based dollar fund, which has continuously invested in China, the United States, Singapore, Hong Kong, Thailand, Vietnam, and India since 2018, focuses on hard technology and application layers in the digital economy, covering seed to pre-IPO stages with highly standardized currency, terms, and governance structures, effectively reducing the confounding caused by "fund heterogeneity." Before the platform's launch, its post-investment team, like most global institutions, relied on Excel consolidated reports and quarterly on-site visits; after the launch, all invested companies were required to connect to the i-Post data warehouse within 30 days of closing, transmitting key items daily via API or RPA, or triggering the "information breach" clause in the investment agreement. This exogenous coercion made "whether to accept digitalization" no longer a company's choice, thereby minimizing "self-selection bias." This paper includes all 260 equity investments completed by Alpha Capital from January 2020 to December 2023 in the sample pool: the treatment group consists of 124 companies invested after the fourth quarter of 2021, and the control group consists of 136 companies invested between 2020 and the third quarter of 2021. After propensity score matching (PSM), the two groups have less than 5% deviation in region, industry, and round distribution, meeting the parallel trend premise. The experimental field thus spans four accounting standards, three time zones, and two legal systems but shares the same digital interface, providing a rare and clean field to observe the "data standardization—information loss reduction—value addition" process.

3.2 Variable Measurement

Table 1.

Variable	Symbol	Indicator and Data Source	Expected Sign
ROI Improvement	ΔROI	Annual IRR Differential	+
Data Asymmetry Index	DAI	1−(Comparable Net Profit Overlap/Total Net Profit)	−

Risk Warning Efficiency	RWE	Number of Months in Advance for Risk Signal Identification	+
Spatial Weight	W	Criterion Similarity × 5G Coverage Rate	+

ΔROI uses annual IRR difference instead of absolute IRR to eliminate the macro volatility brought by the project's own industry β, isolating the digital effect from the "big trend." DAI converts the abstract "standard difference" friction into a directly calculable 1 minus overlap, with the numerator using the intersection of net profits adjusted according to Chinese standards, U.S. GAAP, and Singapore IFRS, and the denominator using the enterprise's original disclosed value. The closer the index is to 1, the more severe the information decay, with an expected negative sign, meaning that a decrease in DAI should accompany an increase in ROI. RWE measures the "risk signal identification lead time in months"; once the platform's built-in AI early warning module detects cash flow gaps, related-party transaction ratios, or inventory turnover anomalies exceeding the threshold, it automatically pushes notifications. The difference between the timestamp and the actual risk outbreak time is the early warning lead time, which translates the "dynamic capability" into an observable monthly number. The spatial weight W no longer uses traditional geographical distance but the interaction term of "standard similarity×5G coverage," reflecting both institutional and hardware proximity, with an expected positive sign, meaning that the higher the digital level in adjacent regions, the additional increase in regional ROI. All variable raw data come from the i-Post backend logs, Bureau van Dijk, the IFRS Foundation difference library, and the GSMA 5G map, forming a panel after desensitization. The time span is eight quarters after investment closing, with a cross-sectional dimension of 260 companies and a total of 2080 observations.

3.3 Model Specification

The empirical strategy is divided into causal identification and spatial association. On the causal side, the classic difference-in-differences (DID) is used, but the dynamic treatment effect is estimated within the event study framework to test whether β_{-3} to β_{-1} are significantly zero, thereby excluding pre-trend differences. Further, enterprise and quarterly two-way fixed effects are added, and heteroscedasticity-robust standard errors are clustered at the enterprise level to ensure that β_{post} captures the net effect brought by the digital launch. On the mechanism test side, stepwise regression and Bootstrap with 5000 parallel runs are used to place the four segments of "standardization → DAI → RWE → ΔROI" simultaneously, observing the total mediation effect ratio and the contribution of each segment to the total effect. If ab1b2c′ is significant and the direct effect decreases, it proves that the dynamic capability pipeline is indeed driven by a reduction in information friction. On the spatial side, the spatial lag model (SLM) is used instead of the simple spatial error because the theoretical expectation of spillover direction is clear — the digital level in adjacent regions affects regional ROI through standard convergence and data infrastructure spillover, with the ρ coefficient being the spillover strength. At the same time, the interaction term of 5G coverage and cloud computing penetration rate is introduced as a spatial moderator to test whether "hardware-institution" dual proximity amplifies the spillover. The intersection of the two main lines verifies both "whether digitalization is effective" and "how large the effective range is," thus estimating the direct causality and spatial diffusion of digital upgrading in cross-border post-investment management in one go.

4. Data and Variables

4.1 Multi-Source Data Integration

Fitting the three tensions of "cross-border, multi-standard, and real-time" into a single panel requires piecing together scattered data from four continents into a continuous stream that is time-aligned, comparable in caliber, and traceable in error. The first step is to grab the i-Post backend logs of Alpha Capital, which record 127 accounting items, 36 operational indicators, and 8 types of risk signals for each company daily in UTC timestamp format. The original JSON nested format is parsed and mapped to a unified subject tree using Python, and the hash value is written into a private chain using SHA-256 to ensure that any subsequent manual adjustments leave a fingerprint. The second step is to connect the on-chain hash with the Orbis database of Bureau van Dijk,

download the GAAP/IFRS disclosure versions of the corresponding companies, and use the difference matrix released by the IFRS Foundation in 2023 to compare each item and generate the "standard difference footnote," which in turn calculates the numerator of DAI — the intersecting net profit of the three standards. The third step supplements spatial infrastructure variables: base station density is extracted from the GSMA 5G map, and cloud computing penetration rates from 2020 to 2023 are obtained from the World Bank. The geographical raster data is projected onto a 50 km radius around the company's registered address to form a "institution-hardware" dual proximity weight. The fourth step is to align time: since the closing dates of sample companies are different, the investment post-T+0 to T+8 quarters are used as a unified event window, with all financial and operational indicators re-labeled according to relative quarters to avoid calendar effects. The final result is a balanced panel of 260 companies×8 quarters = 2080 observations, with 94 fields and a missing rate of less than 1.3% (Eisenhardt, K. M., & Martin, J. A., 2000). Missing values are imputed using multiple imputation by chained equations (MICE) and the on-chain hash is added for consistency verification to ensure that the imputation results cannot be manually tampered with afterward.

4.2 Descriptive Statistics

Table 2.

Variable	Mean	Standard Deviation	Minimum	Maximum
ΔROI (%)	3.42	2.81	−4.30	11.20
DAI	0.28	0.12	0.05	0.52
RWE (Months)	2.7	1.3	0.5	6.0
Software Investment Ratio	0.45	0.18	0.12	0.78

The average ΔROI of 3.42% means that the sample fund achieved an additional 3 percentage points of annualized return compared to the traditional group after digital upgrading, but the standard deviation of 2.81% shows a severe divergence among companies — the minimum value of −4.3% corresponds to a Vietnamese SaaS company whose profit was eroded by a sudden exchange rate change, while the maximum value of 11.2% occurred in a Singaporean semiconductor equipment company that used real-time early warning to lock in raw material prices six months in advance, lifting the gross margin by 7 percentage points. The average DAI of 0.28 intuitively means that "only 0.72 yuan of every 1 yuan of disclosed profit can be understood by cross-border investors on a comparable basis," with the maximum value of 0.52 appearing in a company with a triple structure of Chinese standards, Vietnamese local standards, and internal management standards, becoming an extreme case of information decay. The average RWE of 2.7 months is the lead time obtained by subtracting the platform's first early warning time point from the actual risk outbreak time point, with the right tail extending to 6 months, indicating that digitalization can turn "firefighting" into "fire prevention" for mature companies with high data quality. The average software investment ratio of 45%, but the gap between the minimum of 12% and the maximum of 78% reveals a "investment-faith" spectrum — companies with low values still invest budgets in servers and local databases, while those with high values have already written the post-investment process into API calls, pressing the marginal cost towards zero. The standard deviation and extreme values together imply that the digital dividend is not evenly distributed but highly dependent on standard differences, data infrastructure, and management cooperation, which also lays the groundwork for subsequent heterogeneity analysis.

5. Empirical Results

5.1 Parallel Trend and DID

The event study curve is like a time river bent by digitalization. β_{-3} to β_{-1} float loosely around the zero axis, neither rising nor diving, indicating that the ROI trajectories of the treatment and control groups almost overlap before the i-Post system was launched, making it difficult for unobserved time-varying confounders to suddenly create a gap afterward.

Once the boundary line is crossed, β_{+1} immediately jumps to 1.7% and stabilizes at 4.1% in the third year, showing an "immediate response + continuous accumulation" dual characteristic, which is completely different from the "J-curve" lag commonly seen in traditional informatization projects. Column (1) compresses the three-year dynamic effect into a single point estimate: β = 4.12%, with a p-value less than 0.01 and an R^2 reaching 0.47, meaning that after adding enterprise and quarterly two-way fixed effects, digital upgrading alone explains nearly half of the ROI difference, a level of explanatory power comparable to industry selection for cross-border equity investments. Its economic meaning is straightforward — in an $80 million single-project investment, digital post-investment creates an additional $3.3 million in excess return per year on average, sufficient to cover three times the initial software licensing and data governance costs. (Eisenhardt, K. M., & Martin, J. A., 2000)

5.2 Mechanism Test

Table 3.

Path	Effect Size	Proportion of Total Effect
Total Indirect	3.23%	78.5%
Standardized → DAI	1.29%	31.2%
DAI → RWE → ROI	1.94%	47.3%

The chain mediation is like a straightened pipeline, pouring the conjecture of "data standardization → information loss reduction → early risk warning → value addition" into 5000 Bootstrap samples. The total indirect effect is 3.23%, accounting for 78.5% of the overall 4.12%, indicating that digitalization almost works through pure mediation paths rather than directly casting magic. The first segment "standardization → DAI" contributes 1.29%, accounting for 31.2%, quantifying the marginal strength of standard alignment in reducing information friction; the second segment "DAI → RWE → ROI" contributes 1.94%, accounting for 47.3%, showing that for every additional month of early warning, ROI increases by an average of 32 basis points, translating "finding problems early" into a computable capital gain. The confidence intervals of both segments are far from zero, and the direct effect is reduced from 4.12% to 0.89%, proving that the dynamic capability engine is indeed driven by a reduction in information friction rather than unobservable fund management capabilities.

5.3 Spatial Econometrics

Projecting 260 companies onto the two-dimensional space of "standard similarity×5G coverage," the SLM estimate yields ρ = 0.28, significant at the 5% level, meaning that for every one standard deviation increase in the digital post-investment level in adjacent regions, regional ROI increases by an additional 0.28 standard deviations, equivalent to 0.73 percentage points. The spatial autocorrelation coefficient rewrites "cross-border" from a geographical concept to a network concept—Singapore and Hong Kong have a weight of 0.85 due to IFRS equivalence and undersea cables, with the largest spillover effect; whereas the China-Vietnam border, despite geographical proximity, has a weight of only 0.32 due to standard differences and 5G gaps, with almost no spillover. The results provide the first micro-evidence for the "institution-hardware" dual proximity theory at the equity investment level: the externalities brought by data standard convergence can enable LPs to enjoy a free lunch at the regional level and provide a quantified gain basis for regulatory authorities to promote mutual recognition.

5.4 Heterogeneity

Dividing the sample by investment structure and corporate life cycle, it is found that the digital dividend shows a steep gradient of "software-driven, mature-amplified." For every 10 percentage point increase in software investment ratio, ROI increases by an additional 32 basis points, with a marginal effect 3.5 times that of hardware investment and 2.3 times that of labor investment, indicating that once code is written, it can be reused at zero cost, forming increasing returns to scale. In the stage dimension, mature companies, with more standardized financial data and greater DAI reduction space, see their ROI increased by 4.8% after digital upgrading, far higher than the 1.2% for seed-stage companies; seed-stage companies, with highly volatile business and thin historical data, are prone to false signals from AI early warnings, which in turn dilute the benefits. The heterogeneous results break down the "one-size-fits-all" digital budget into a "software-first, mature-heavy" investment

menu, providing an operational marginal formula for GPs to allocate technical resources in different rounds.

6. Discussion and Implications

6.1 Theoretical Contributions

This paper pulls dynamic capabilities back from the pre-investment grand narrative to the post-investment trench, proving that the key is not the CEO's vision but whether the data pipeline can deliver risk signals in advance; it also advances the static "information asymmetry" to the quantifiable "standard difference decay," using the DAI index to provide a 31.2% ROI elasticity, offering a new quantitative handle for subsequent research. (Teece, D. J., 2007)

6.2 Practical Implications

The marginal ROI of software investment is 3.5 times that of hardware, and LPs can write digital budgets into the Limited Partnership Agreement (LPA); the spatial spillover coefficient of 0.28 suggests that regional standard mutual recognition can gain an additional 1.1% return for free; mature companies benefit four times more than seed-stage companies, and technical resources should be prioritized for financially standardized targets. Digitalization is no longer a cost center but a revenue generator that can be recovered in three years and continuously amplified through regional networks.

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Lease-Insurance Synergy: An Empirical Study on Solving the Financing Dilemma of Distant Water Fisheries

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Abstract

The global distant water fishery industry has long been trapped in a tripartite financing predicament characterized by "difficult valuation, high operational risk, and mismatched cash flow cycles," with the penetration rate of traditional credit facilities remaining below 40%. To address this systemic challenge, this study constructs a three-dimensional coupling model of "leasing—insurance—industry," integrating insurance institutions into the entire chain of vessel valuation, risk hedging, and cash flow alignment. Leveraging panel data from 147 Chinese fishing vessels and 2.795 billion yuan in financing projects spanning 2019–2024, this research conducts the first empirical examination of the causal effects of the lease-insurance linkage mechanism on financing costs and operational performance. The findings demonstrate that this integrated mechanism reduces the comprehensive financing interest rate by 3.2 percentage points, elevates the rent fulfillment rate by 14.3 percentage points, and suppresses the project non-performing rate to below 0.5% (Sun, Y., & Ortiz, J., 2024), with insurance coverage emerging as the most critical driver of risk mitigation. Robustness is confirmed through difference-in-differences (DID) analysis and multiple complementary tests. Further simulation results indicate that applying this framework to the Alaskan fishing fleet in the United States could lower the average financing interest rate from 8.5% to 5.3% and boost the rent fulfillment rate to over 90%. This study proposes that Chinese and American regulatory authorities streamline cross-border filing procedures, establish interoperable data-sharing interfaces, and incorporate fishery leasing into green finance subsidy schemes to facilitate the internationalization of the model. By filling the micro-evidence gap in the coupling of financial instruments for high-risk industries, this paper provides a replicable and scalable financing paradigm for the global distant water fishery sector.

Keywords: lease-insurance linkage, distant water fisheries, financing costs, risk mitigation, international adaptation, three-dimensional coupling model, seasonal cash flow, vessel valuation, green finance, cross-border data sharing

1. Introduction

1.1 Research Background: The Financing Dilemma of Global Distant Water Fisheries

The FAO's "2024 World Fisheries Report" highlights that the annual financing demand of the global distant water fishery industry has

exceeded 80 billion U.S. dollars, yet the sector continues to grapple with a severe "funding valley"—the penetration rate of formal financial services from banks and leasing companies stands at a mere 38.2%, forcing over 60% of fleets to rely on high-interest private lending or internal capital accumulation. Difficult valuation constitutes the primary bottleneck: the construction cost of a single distant water fishing vessel fluctuates drastically between 6 million and 650 million U.S. dollars, with vessel age, operating sea areas, fishing gear configuration, and environmental compliance levels exerting significant impacts on residual value. The absence of unified evaluation standards results in mortgage rates generally below 30%, constraining access to formal credit. High operational risk further exacerbates the financing gap: typhoons, wave damage, and mechanical failures sustain an annual fleet loss rate of 12.7%, far exceeding the shipping industry's average of 4.5% (Chen, Y., 2025), prompting traditional financial institutions to either raise risk premiums or withdraw from the market entirely. Mismatched cycles compound the issue: most fishery harvesting windows concentrate in the fourth quarter to the first quarter of the following year, generating a "low-high-zero" pulsed cash flow pattern, while bank credit typically mandates equal monthly principal and interest repayments. This misalignment compels enterprises to secure new financing to repay existing debts during fishing moratoria, driving up comprehensive financing costs. The Alaska Fisheries Association estimates a local financing gap of 5.2 billion U.S. dollars, with average interest rates 320 basis points higher than those in the manufacturing sector; similarly, Chinese distant water enterprises face financing costs 4.3 percentage points above domestic manufacturing levels, a gap that has persisted over the past five years. These structural barriers reinforce each other, forming a vicious cycle of "elevated risk premiums → reduced mortgage rates → intensified cycle mismatches," necessitating an innovative mechanism capable of simultaneously resolving the frictions of valuation, risk, and cycle.

1.2 Research Questions and Academic Gaps

Against the backdrop of addressing distant water fisheries' financing challenges, this study focuses on three core questions: Can a lease-insurance linkage mechanism encompassing "value assessment—risk hedging—cycle matching" be constructed? Is this mechanism effective in reducing financing costs and improving rent fulfillment rates? How can it be adapted to high-income fishery economies such as the United States? Existing literature has extensively explored financial leasing and fishery insurance in isolation, treating them as parallel tools: financial intermediation theory emphasizes leasing's role in mitigating information asymmetry and reducing transaction costs; risk-sharing literature underscores insurance's function in smoothing disaster losses; and industry cycle research highlights the need for dynamic alignment between financial contracts and the highly seasonal cash flows of fisheries. However, empirical studies integrating leasing and insurance into a unified analytical framework to explore their coupling effects are scarce, and there is a dearth of high-evidence-strength tests based on micro-level project data. This paper aims to fill this academic gap by utilizing China's distant water fisheries as a quasi-natural experiment to estimate the causal effect of lease-insurance linkage on financing performance for the first time, while proposing an adaptation pathway for the U.S. market.

2. Theoretical Foundations and Mechanism Design

2.1 Theoretical Support

Financial intermediation theory positions leasing companies as specialized producers of information and supervisors of contracts. Through professional due diligence, retention of asset ownership, and on-site inspections, leasing institutions transform high-information-cost assets such as distant water fishing vessels into tradable, priceable financial instruments, reducing transaction costs in both pre-loan screening and post-loan governance. Risk-sharing theory further argues that insurance institutions, characterized by risk neutrality, can smooth extreme left-tail losses through the law of large numbers and intertemporal reserves, enabling lessees to maintain rent payment capacity following typhoons, mechanical failures, or collisions and avoiding premature lease termination due to short-term cash flow disruptions. Industry cycle theory emphasizes that innovative financial instruments must synchronize with the industry's "technology-market" cycle to maximize efficiency. The concentrated fishing windows and pulsed cash flows of distant water

fisheries stand in stark contrast to traditional equal principal and interest repayment structures. Integrating these three theoretical perspectives, the logic of the "leasing—insurance—industry" three-dimensional coupling emerges: leasing institutions leverage insurance-provided risk pricing signals to enhance asset valuation accuracy, utilize insurance compensation as a "liquidity buffer" to reshape rent repayment rhythms, and embed industry cycles into financial contracts, thereby simultaneously reducing financing costs and default risks.

2.2 Mechanism Design: Three-Dimensional Coupling Model

In the dimension of value assessment, the model breaks away from traditional banking practices of "experience-based valuation" or simple cost discounting, integrating vessel technical parameters, insurance assessment values, and industry performance records into a unified scoring system. Vessel age, tonnage, endurance, and environmental compliance reflect physical depreciation; insurance assessment values from fishery insurance provide market-recognized fair prices; and three-year industry performance ratings offer credit decay coefficients. Principal component analysis indicates these three information types account for 40%, 35%, and 25% of explanatory power, respectively. The composite score derived from these weights increases vessel mortgage rates from the industry average of 30% to 70%–80% and reduces financing interest rates by 18 basis points for every 10-point increase in the score (Chen, Y., 2025). In the risk hedging dimension, a closed loop is established through "full-coverage insurance + priority compensation to supervised accounts": fishery insurance provides comprehensive policies covering natural disasters, mechanical failures, and collision liabilities for individual vessels, with annual premiums equivalent to approximately 1.8% of vessel value. Claim settlements are directly transferred to leasing supervised accounts, prioritizing the deduction of current and next two installments of rent. Despite an average annual claim rate of 2.1% among the sample fleet, the project non-performing rate remains below 0.5%, confirming that timely and sufficient insurance compensation effectively interrupts the transmission of risks to rent defaults. In the cycle matching dimension, an elastic repayment matrix is designed based on the production calendars of twelve major fishery categories. For example, Antarctic krill fishing generates only 8% of annual cash inflow during the fishing period, prompting the model to reduce monthly repayments to 5%–8% of the contract amount during these four months while increasing the repayment ratio to 18%–22% during peak sales seasons, maintaining the overall lease term unchanged. This reallocation of cash flows achieves "supplementing shortages with surpluses," eliminating the need for additional working capital to sustain enterprises.

2.3 Mechanism Innovation Points

Departing from the traditional view of insurance as a mere risk transfer tool, this study embeds insurance institutions into the entire lifecycle of lease asset valuation, contract structure design, and post-lease risk control, transforming insurance from an ex-post compensation mechanism into an ex-ante pricing signal and in-process liquidity regulator. Leasing companies utilize insurance assessment reports to anchor fair values, enabling higher mortgage rates, while the priority status of insurance compensation reduces cash flow volatility of lease assets after extreme events, allowing flexible adjustment of rent repayment rhythms in line with industry cycles. The resulting closed loop of "assessment—disbursement—risk control—collection" internalizes risk digestion and redistribution within the chain, rather than externalizing them to lessees or financial markets. This closed-loop characteristic is the fundamental reason the mechanism achieves significant reductions in financing costs and improvements in fulfillment rates in the highly volatile and cyclical distant water fishery sector, offering a replicable financial paradigm for other resource-based and seasonal industries.

3. Empirical Research Design

3.1 Data Sources and Samples

The core dataset comprises panel data from Chinese distant water fishery leasing projects spanning 2019–2024, covering 147 fishing vessels, 2.795 billion yuan in total disbursements, and 14 A-rated distant water enterprises including Rongyuan Fisheries and Hainan Fugang (Chen, Yinlei, 2025). Each vessel is observed for at least two accounting years, with the longest observation period extending to six years, ensuring both cross-sectional breadth and temporal depth. To identify the mechanism's

effect, 92 traditional fishery credit projects provided by state-owned banks during the same period are included as a control group, matched with the treatment group in terms of loan amount, vessel type, and customer grade but lacking insurance linkage clauses. The raw data encompasses enterprise-level financial indicators, vessel technical parameters, insurance claim details, and rent collection streams, all linked via project numbers as the key identifier. Prior to estimation, missing values are addressed through linear interpolation for variables with a missing rate below 3% and deletion for those above 3%, while continuous variables undergo 1% two-sided trimming to eliminate extreme value effects. Hausman test results support a fixed-effects specification, with all subsequent regressions controlling for unobservable individual heterogeneity.

3.2 Variable Definitions

Dependent variables include three core performance indicators: comprehensive financing interest rate, derived from the contractually stipulated internal rate of return weighted by drawdown time points; rent fulfillment rate, defined as the proportion of on-time rent received annually relative to the amount due, calculated after daily interest conversion; and project non-performing rate, measured as the share of contracts overdue by more than 90 days relative to the total number of contracts, reflecting asset quality deterioration. The core explanatory variable is a dummy variable indicating mechanism adoption, assigned a value of 1 for projects utilizing the lease-insurance linkage scheme and 0 for those employing traditional credit or pure leasing structures. To isolate the mechanism's effect, control variables include enterprise size (logarithm of total assets), vessel age, and fishery category dummies, capturing customer credit quality, asset depreciation speed, and operational seasonal differences. All continuous variables are standardized prior to regression to facilitate coefficient comparison.

Table 1.

Variable Name	Description
Comprehensive Financing Interest Rate	Derived from the contractually stipulated internal rate of return weighted by drawdown time points
Rent Fulfillment Rate	Proportion of on-time rent received annually relative to the amount due, calculated after daily interest conversion
Project Non-Performing Rate	Share of contracts overdue by more than 90 days relative to the total number of contracts, reflecting asset quality deterioration
Mechanism Adoption Dummy	1 for projects utilizing the lease-insurance linkage scheme, 0 for those employing traditional credit or pure leasing structures
Enterprise Size (Logarithm of Total Assets)	Captures customer credit quality
Vessel Age	Captures asset depreciation speed
Fishery Category Dummies	Captures operational seasonal differences

3.3 Model Specification

Benchmark regression employs a one-way fixed-effects model, regressing financing costs, rent fulfillment rates, and non-performing rates on the mechanism adoption variable and control variables, with individual effects absorbing time-invariant enterprise-level omitted factors. To verify causal relationships, a DID framework is constructed with the large-scale implementation of the mechanism in 2021 as the policy cutoff. The treatment group consists of linkage mechanism projects, the control group includes traditional credit projects, and a Post variable takes the value of 1 for 2021 and later periods and 0 for earlier periods, with the core coefficient reflecting the net effect of the mechanism. Mediation analysis focuses on two transmission channels: risk mitigation through insurance coverage and enhanced timely repayment via reduced cash flow gaps. By sequentially adding mediator variables and observing changes in core coefficient magnitudes, the relative contributions of each link in the mechanism to final performance are quantified. All models cluster robust standard errors at the enterprise level to mitigate

heteroscedasticity and serial correlation effects on inference.

4. Empirical Results and Robustness Tests

4.1 Benchmark Regression Results

The introduction of the lease-insurance linkage mechanism reduces enterprises' comprehensive financing interest rates by 3.2 percentage points, with the estimate highly significant and far from zero, indicating that the information improvement and risk mitigation achieved through the coupling of leasing and insurance effectively reduce funding premiums after controlling for enterprise size, vessel age, and fishery category. In the same model, the rent fulfillment rate increases by 14.3 percentage points, demonstrating that flexible repayment arrangements and priority insurance claim compensation jointly mitigate seasonal cash flow shocks, enhancing lessees' willingness and ability to make full and timely rent payments. Correspondingly, the project non-performing rate decreases by 2.5 percentage points, reflecting significant improvements in asset quality and verifying the mechanism's risk-mitigating effect. Further decomposition of the linkage variable into its three dimensions reveals that insurance coverage makes the most prominent marginal contribution: each 10-percentage-point increase in coverage reduces the non-performing rate by an additional 0.8 percentage points. This indicates that comprehensive insurance policies not only provide immediate liquidity to address rent gaps following claims but also screen high-quality fleets through signaling effects, reducing default probabilities at the source.

Table 2.

Indicator	Effect	Magnitude	Significance
Comprehensive Financing Interest Rate	Reduction	3.2 percentage points	Highly significant
Rent Fulfillment Rate	Increase	14.3 percentage points	Significant
Project Non-Performing Rate	Decrease	2.5 percentage points	Significant
Insurance Coverage Contribution	Reduction in Non-Performing Rate	0.8 percentage points per 10% increase	Significant

4.2 DID Results

Treating the large-scale launch of the mechanism in 2021 as a quasi-natural experiment, DID estimates show that the treatment group's financing costs are an additional 2.1 percentage points lower than those of the control group during the same period. This net effect eliminates external disturbances such as macro interest rate declines and industry subsidy adjustments, confirming the linkage mechanism's causal role in reducing financing costs. Parallel trend tests demonstrate that the financing cost trends of the two groups were broadly consistent prior to policy implementation, satisfying the DID identification assumption. Dynamic coefficient plots indicate that the mechanism's effect emerges rapidly after 2021 and continues to expand without significant decay, suggesting that the benefits are not a one-time shock but a sustained, accumulative improvement.

4.3 Robustness Tests

Replacing the dependent variable with the ratio of financing amount to total assets to measure financing availability, the linkage mechanism coefficient remains positively significant, indicating that results are not sensitive to performance indicator definitions. Re-estimation with 1% quantile truncation of continuous variables yields core coefficients with nearly identical magnitudes and significance levels, confirming that extreme values do not drive the findings. Placebo tests involve randomly assigning "pseudo-treatment group" labels and repeating regressions one thousand times; the distribution of simulated effects centers around zero, with the actual estimate located at the far tail of the distribution, excluding interference from random factors or unobservable heterogeneity. Collectively, benchmark findings, causal identification, and a series of robustness tests validate the reliability of the lease-insurance linkage mechanism in reducing financing costs and improving performance, providing a solid empirical foundation for

subsequent policy promotion.

5. International Adaptability: The Case of Alaska, USA

5.1 U.S. Market Data

The Alaska Bay and Bering Sea fishing fleets currently include 420 registered vessels, with a median age of 14 years and individual vessel market prices ranging from 8 million to 300 million U.S. dollars. The total financing demand for fleet renewal and maintenance is 5.2 billion U.S. dollars, of which local banks and credit unions can meet only 60%, forcing the remaining gap to be filled by short-term bridge loans with an average interest rate of 8.5%. Over the past decade, the northward shift of the Alaska Bay typhoon belt and equipment aging have driven the annual claim rate to 3.8%, far exceeding the U.S. agricultural average of 1.9%, resulting in high insurance premiums and mortgage rates generally below 35%. Simulations indicate that embedding the "leasing—insurance" linkage mechanism would increase the fleet's mortgage rate to 70%–75%, reduce the comprehensive financing interest rate from 8.5% to 5.3% (a decrease of over three percentage points), elevate the rent fulfillment rate from 76% to over 90%, and compress the non-performing rate from 2.8% to 0.9%, approaching the performance levels observed in the Chinese sample. For adaptation, the insurance component requires integration with the U.S. National Fishery Insurance Program, incorporating storm, mechanical failure, and collision liability into comprehensive policies with annual premiums set at approximately 2% of vessel value. On the financing side, repayment peaks are aligned with the 6–8 months following the salmon fishing season, during which monthly repayment ratios are increased to 20%, while the remaining months are reduced to 5%–7%, matching the Alaska fleet's "summer-concentrated returns and winter maintenance expenditures" cash flow characteristics. Under this plan, the fleet could save approximately 140 million U.S. dollars in annual financial costs and unlock an additional 1.2 billion U.S. dollars in credit capacity (Liu, Z., 2022), sufficient to cover the current financing gap.

Table 3.

Indicator	**Current Status**	**Improvement with "Leasing—Insurance" Linkage**
Annual Claim Rate	3.8%	-
Insurance Premium Rate	Below 35%	-
Simulated Mortgage Rate	-	70%–75%
Comprehensive Financing Interest Rate	8.5%	5.3% (Decrease of over 3 percentage points)
Rent Fulfillment Rate	76%	Over 90%
Non-Performing Rate	2.8%	0.9%
Annual Financial Cost Savings	-	140 million U.S. dollars
Additional Credit Capacity	-	1.2 billion U.S. dollars

5.2 Policy Recommendations

Chinese leasing companies can collaborate with China Fishery Insurance and the U.S. National Fishery Insurance Program to establish data-sharing interfaces, enabling real-time exchange of vessel location, claim records, and compensation status to form a cross-market risk monitoring network. They can also apply to establish special purpose vehicles in Alaska to facilitate the issuance of U.S. dollar-denominated asset-backed securities, expanding funding sources. On the U.S. regulatory front, the Treasury Department should include distant water fishery leasing in green finance subsidy catalogs, offering 20% interest subsidies for vessels meeting low-emission and high-efficiency standards. Congress could authorize the Office of the Comptroller of the Currency to streamline cross-border leasing insurance filing procedures, reducing approval timelines from 90 working days to 30, and allow leasing companies to use international insurance assessment reports as the basis for mortgage valuation, lowering

institutional costs. By simultaneously relaxing restrictions on capital and data flows in China and the United States, the lease-insurance linkage mechanism is poised for rapid replication in high-latitude U.S. fishery regions, providing an operational international template for addressing the global distant water fishery financing dilemma.

6. Research Limitations and Future Outlook

6.1 Limitations

The empirical sample is concentrated on Chinese fleets, covering 147 vessels and 2.795 billion yuan in disbursements but limited geographically to the North Pacific and Southeast Atlantic fishing areas. Its effectiveness in high-latitude fisheries with distinct resource endowments and regulatory environments—such as Peruvian anchovy and Norwegian herring fisheries—requires verification through expanded databases. Additionally, the model does not incorporate geopolitical shocks into dynamic equations; cross-border leasing involves licenses, exchange rates, and sanctions lists from multiple countries including China, the United States, and European nations, and trade restrictions or port blockades could trigger structural changes in vessel scheduling and cash flow, disrupting insurance compensation and rent collection rhythms. The resilience of the current framework against such extreme scenarios remains untested. Furthermore, mechanism parameters have remained static over the five-year sample period; fleet technological upgrades, carbon emission trading, and tightening fuel standards will alter asset residual values and operating costs, and without rolling calibration, the timeliness of assessment scores may gradually diminish.

6.2 Outlook

Future research will expand the "leasing + insurance" framework to incorporate fishery futures, forming a triple risk hedging system. Futures market forward prices will provide public benchmarks for fleet returns at lease initiation, enabling dynamic adjustment of insurance coverage and rent levels based on futures curves, transforming resource price volatility into tradable financial flows and further narrowing default boundaries. Technologically, satellite remote sensing and AIS vessel positioning are already commercially viable; future integration of real-time vessel location, sea condition, and fuel consumption data into backend models will enable automatic risk warnings and advance freezing of subsequent repayments upon detection of operating area deviations or extreme weather signals, shifting from ex-post compensation to ex-ante intervention. Plans are also underway to establish a multinational data alliance with Peruvian and Norwegian shipowners' associations, expanding the sample to the thousand-vessel level and covering diverse legal systems and tax regimes to test the mechanism's global robustness and replicability. Through financial product iteration and technological advancement, lease-insurance linkage is expected to evolve from a sector-specific solution to a standardized financial infrastructure for the global distant water fishery industry.

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Consumer Acceptance and Market Potential of Natural Organic Cosmetic Formulations in the US Market

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Abstract

In the context of the accelerated internationalization of cosmetics industry chain, there is a lack of systematic empirical evidence on whether original natural organic formulations can gain recognition from US consumers. This study, using three authorized patents (hair growth, anti-wrinkle, and oil control) as intervention variables, employs a 1,200-person random conjoint experiment, Nielsen retail panel data (2021Q1-2024Q4), and system dynamics modeling to examine the acceptance and sales potential of the "Original + Natural Index ≥ 90% + Efficacy Patents" combination in the US market for the first time. The results show that a natural index of ≥ 90% increases purchase intention by 32.4%, while patent labeling brings an 18.7% premium and reduces promotional dependence by 9.4%. The optimal attribute combination is predicted to achieve a market share of 11.2%, with patent SKU sales 26.8% higher than the control group, and a cumulative NPV@8% of $196 million. Sensory testing confirms that the patented formulations significantly reduce hair loss by 19.7% and increase scalp hydration by 15.4% within four weeks. The study proposes the Clean Beauty Adoption Ladder (C-BAL) framework, integrating "Natural Index - Patent Perception - ESG Narrative" into a unified causal chain, expanding the boundary of the Theory of Planned Behavior in the field of sustainable beauty.

Keywords: original patents, natural organic cosmetics, US consumer acceptance, clean beauty, patent-sales coupling, system dynamics, C-BAL framework, hair growth efficacy, sustainable beauty, cross-border policy

1. Introduction

1.1 Research Background

In 2023, the retail sales of health and personal care products in the US reached $435 billion, with the "clean beauty" segment expanding at a compound annual growth rate of 8.9%, becoming the core driving force to outpace overall inflation. The overlap of ingredient transparency, environmental sustainability, and the value propositions of Generation Z has elevated the "natural organic" attribute from a marketing concept to a regulatory issue: The Cosmetics Modernization Act (MoCRA) of 2022

first included "natural source" in the safety assessment trigger clause, and the same year's Procter & Gamble preservative recall event led to a 214% surge in searches for "sulfate-free, paraben-free" keywords. However, the existing supply chain narrative still presents a closed-loop pattern of "European and American raw materials - European and American brands - European and American consumers," with Chinese suppliers mostly remaining at the level of raw material extraction or cost quotation, lacking complete cases of original formulations gaining empirical validation in the US end market.

1.2 Research Gap

Existing literature focuses on the ingredient stories of European and American high-end brands (Tata Harper, Drunk Elephant) or in vitro experiments of single ingredients, lacking a systematic explanation of how Chinese patent combinations can penetrate the US retail terminal and be converted into repurchase loyalty. Meanwhile, studies mostly remain at the cross-sectional survey of "attitude - intention," failing to integrate patent signals, sensory experiences, retail panels, and long-term market potential into the same causal chain, leaving the "technology - business" conversion black box of natural organic cosmetics unopened.

1.3 Research Purpose

This study aims to quantify the acceptance of the "Original + Natural Index ≥ 90% + Efficacy Patents" combination by US consumers through online conjoint experiments, sensory home tests, and Nielsen retail panels, and to predict the market potential from 2025 to 2030.

2. Literature Review

2.1 Disputes and Measurement of Natural Organic Cosmetics Definitions

The US FDA has not yet provided a legal definition for "natural" or "organic" in the context of cosmetics, only adhering to the general obligation of safety under the Federal Food, Drug, and Cosmetic Act. The USDA's National Organic Program (NOP) sets a ≥ 95% organic threshold for agricultural products, and its "organic cosmetics" certification is a voluntary borrowing that does not cover the entire formulation process. The COSMOS standard provides a quantification path for natural and organic indices through ISO 16128-1/2, but still bases it on mass fraction rather than functional safety. The absence of a definition leads to market signal confusion, with consumers relying on packaging claims for heuristic judgments.

2.2 Consumer Acceptance Theories

The Theory of Planned Behavior (TPB) has been proven to effectively predict green purchase intentions in the field of sustainable beauty, but its explanatory power for the "patent - perceived innovation" path is limited. The Perceived Value Model (PERVAL), emphasizing the three dimensions of functional, emotional, and social value, is more compatible with the emotional premium of clean beauty. Recent studies have proposed the Ingredient Transparency Effect (ITE), which shows that disclosing complete INCI and ingredient tracing can significantly increase purchase intention. A meta-analysis covering 43 empirical studies shows an average correlation coefficient of $r = 0.52$ ($p < 0.001$) between ITE and purchase behavior, but the samples mostly focus on mature European and American brands, lacking situational tests of Chinese original patent formulations.

2.3 Market Potential Assessment Methods

Traditional time-series models (ARIMA, GM(1,1)) perform robustly in short-term predictions but are insufficient in responding to policy shocks and external regulatory events. System Dynamics (SD), which simulates technology diffusion and inventory-sales lags through feedback loops, has been used to assess new energy vehicles and photovoltaic markets but is rarely applied in the cosmetics field, especially lacking dynamic validation of the "patent-sales" coupling degree. The P-S coupling indicator has not yet formed a standardized measurement, with existing studies stopping at static correlations and failing to reveal the time-lag effect and amplification coefficient from patent authorization to retail scanning.

2.4 Review and Innovation of the Study

This study is the first to embed Chinese original patent formulations as intervention variables into US consumer behavior experiments, examining the boundary conditions of ITE in high-tech natural products by controlling NI levels and patent labeling. It then inputs the micro-experimental utility parameters into the system dynamics model, calibrates bidirectionally with the Nielsen retail panel, and achieves vertical integration from "individual

choice - store scanning - market potential." Based on this, the Clean Beauty Adoption Ladder (C-BAL) framework is proposed: Natural Index → Perceived Safety → Patent Trust → Brand Identification → Repurchase Loyalty, providing a new explanatory path and empirical evidence for the transnational technology diffusion of clean beauty.

3. Research Design

3.1 Sample and Data

This study adopts a three-level nested design of "micro-experiment - retail panel - system dynamics," with the authorized patent formulations as the core intervention to empirically test the acceptance path of natural organic cosmetics by US consumers and predict the market potential from 2025 to 2030. The sample composition is as follows: The consumer experiment relies on the Qualtrics US panel, recruiting 1,200 participants (balanced across four census regions, aged 18-55, with 60% females) to test the minimum detectable effect under the conditions of power 1 - $\beta = 0.95$ and $\alpha = 0.05$. The retail data selects 2,847 SKU-level observations from Nielsen RMS during 2021Q1-2024Q4 (Klaschka, U., 2016), covering sales volume, unit price, and promotional intensity. The patent data originates from a joint search of USPTO and CNIPA (keratin AND sulfate-free AND hair growth, inventor Chunhua Zhu), including three authorized and one substantive examination invention patents, used to construct the patent labeling intervention variable.

3.2 Experimental Design

The experimental part follows a three-stage hybrid scheme: First, baseline data on ingredient attention and ESG attitudes are collected through an online questionnaire. Then, a Choice-Based Conjoint (CBC) design is employed, with natural index, price, efficacy patent, and ESG narrative as attributes, each set at three levels, generating 81 virtual products. HB-Hierarchical Bayes estimation is used to estimate attribute utilities and simulate market share. Finally, a sensory home double-blind test (n = 120, 4 weeks) is implemented, with scalp hydration, TEWL, and hair loss count as objective indicators to verify the physiological efficacy of the patented formulations.

3.3 Variable Measurement

The dependent variables include purchase intention (BPW, 7-item scale, $\alpha = 0.87$) and willingness to pay a premium (WTP, open-ended bidding). The mediating variables cover perceived safety, perceived innovation, and brand identification. Control variables involve age, income, frequency of previous clean beauty use, and environmental values (NEP).

3.4 Data Analysis

The CBC results are used to calculate attribute importance and potential market share. Structural Equation Modeling (SEM) combined with 5,000 Bootstrap tests is employed to examine the significance of mediating paths. The retail panel uses a fixed-effects model to identify the net effect of patent labeling on sales. Finally, a system dynamics model is constructed using Vensim, incorporating sensitivity tests and Monte Carlo simulations to predict the evolution trajectory of the US natural organic hair care market and the potential sales ceiling of this formulation from 2025 to 2030. The research plan has been approved by the IRB (Exempt-2024-08-019), and all data have been de-identified to ensure compliance.

4. Results

4.1 Descriptive Statistics

The experimental stimulus of a natural index ≥ 90% increased the mean purchase intention (BPW) by 32.4% ($t = 7.61$, $p < 0.001$, Cohen's $d = 0.68$). When the formulation also carried the efficacy patent label, the willingness to pay a premium (WTP) increased by 18.7% compared to the no-patent condition (95% CI: 16.1%-21.3%), and this increase remained robust after controlling for age, income, and frequency of previous clean beauty use.

4.2 Hypothesis Testing

PLS-SEM results show that the path Natural Index → Perceived Safety → Purchase Intention has a $\beta = 0.49$ ($p < 0.001$), with perceived safety acting as a complete mediator. The path Patent Label → Perceived Innovation → WTP has a $\beta = 0.41$ ($p < 0.001$), with perceived innovation acting as a partial mediator, and the interaction term between patent label and environmental values is significant ($\beta = 0.12$, $p = 0.032$). The chain mediation effect proposed in H3 (Natural Index → Perceived Innovation → Brand Identification → Repurchase Intention) has an effect size of 0.28, with 5,000 Bootstrap 95% CI [0.19, 0.37], not including zero, indicating that the mediation chain is established.

Table 1.

Path Relationship	Coefficient β	p-value
Natural Index → Perceived Safety → Purchase Intention	0.49	<0.001
Patent Mark → Perceived Innovation → WTP	0.41	<0.001
Patent Mark × Environmental Values → WTP	0.12	0.032
Natural Index → Perceived Innovation → Brand Identity → Repurchase Intention	0.28	——

4.3 CBC Market Simulation

Under the optimal attribute combination (natural index 95%, efficacy patent label, ESG narrative, 15% premium), the predicted market share reaches 11.2% (95% CI: 9.8%-12.6%), significantly higher than the benchmark formula ($p < 0.01$). Price elasticity analysis shows that the demand elasticity coefficient in the $18-$22 range is -1.34, indicating that this price band is elastic, and a moderate price reduction can achieve greater market penetration. Further segmented regression reveals that when the natural index increases from 90% to 95%, BPW only increases by an additional 2.1% ($p = 0.08$), far below the 32.4% jump before the 90% threshold, suggesting that the "natural" concept has reached a psychological saturation point at 90%, and subsequent costs should be tilted towards patent technology and ESG narrative rather than continuing to increase the natural index. Moreover, the WTP distribution is right-skewed (K-S $D = 0.12$, $p < 0.01$), with the top 20% of people willing to pay a premium ≥ 30%, whose environmental values score ≥ 5.7 (on a 7-point scale, Cohen's $d = 0.9$) and monthly clean beauty usage ≥ 3 times (OR = 2.3, $p < 0.01$). This can be used to launch a "flagship version" SKU, with a premium of 30%-35%, and ESG stories as the core selling point, locking in high-value customers while avoiding a passive price reduction across the entire product line.

Table 2.

Dimension	Optimal Attribute	Benchmark
	Combination	**Formula**
Natural Index	95%	70%
Retail Price (USD)	21.0 (+15% Premium)	18.3
Price Elasticity of Demand	–1.34	–0.98
Predicted Market Share	11.2%	6.5%

4.4 Panel Data Regression

The fixed-effects model estimates that the sales of SKUs with patent labels are 26.8% higher than the control group without labels ($p < 0.01$), and the promotional sensitivity is reduced by 9.4%. Adding ESG keywords on the front of the packaging can additionally increase sales by 7.3% ($p = 0.018$), validating the external validity of the experimental conclusions. Extending the observation window to 18 months reveals that the sales lift of the patent label reaches a peak of 32.1% in the third quarter and then stabilizes at around 25%, showing a "high plateau" rather than a "pulse" curve, indicating that the premium brought by the patent symbol is not a short-term gimmick but continuously precipitates into brand assets. Further interaction with promotional depth shows that when the discount ≥ 25%, the patent group still reduces 5.7 percentage points less than the non-patent group ($p = 0.022$) (Fonseca-Santos, B., Corrêa, M. & Chorilli, M., 2015), indicating that the patent label acts as a "shock absorber" in price wars, maintaining market share without sacrificing gross profit. The increase from ESG keywords is mainly concentrated in first-tier and new first-tier cities (+9.4%, $p = 0.007$), while it is not significant in the lower-tier market (1.8%, $p = 0.31$), suggesting that green narratives need to match regional consumer values and avoid a one-size-fits-all packaging revision.

Table 3.

Variable/Action	Sales Lift
SKU with Patent Mark vs. Unmarked Control	+26.8%
Reduction in Price Elasticity in Patent Mark Group	–9.4%
Adding ESG Keywords on Front of Packaging	+7.3%

Trend of Patent Mark Sales Lift	Q3 Peak 32.1% → Long-term Steady State ≈ 25%
When Discount ≥ 25% vs. Unmarked Group	5.7 ppt Less Decline

4.5 Sensory Testing

The four-week home double-blind trial shows that the patented formula group's hair loss count decreased by an average of 19.7% (paired $t = 4.63$, $p < 0.001$), and scalp stratum corneum hydration increased by 15.4%, significantly better than the sulfate-containing control group ($p < 0.01$), providing objective physiological evidence for functional claims. After the trial, the hair loss count in the patented group rebounded by only 3.2% during the two-week discontinuation period, far below the control group's 11.5% ($p = 0.012$), indicating that the efficacy has a "memory effect" and can maintain a relative advantage even after discontinuation. The daily usage frequency record of the participants shows that the compliance rate of the patented group reached 96%, higher than the control group's 89% ($p = 0.028$), indirectly confirming that pleasant skin feel and visible efficacy form a positive feedback loop, reducing the risk of discontinuation. Cross-lagged analysis between scalp hydration gain and purchase intention (BPW) shows that for every 1% increase in hydration, BPW increases by 0.42% in the following week ($\beta = 0.42$, $p < 0.001$) (McMullen, R., 2019), indicating that sensory experience can be immediately converted into purchase motivation, providing quantitative support for the subsequent "small sample trial - e-commerce repurchase" fission model.

Table 4.

Specific Indicator	**Patent Formula Group**
Hair Loss Count Change (4 Weeks)	Average Decrease of 19.7%
Increase in Stratum Corneum Hydration of Scalp	Increase of 15.4%
Rebound Rate of Hair Loss Count (2 Weeks after Discontinuation)	Rebound of 3.2%
Daily Usage Frequency Compliance	96%
Scalp Hydration Gain → Purchase Intention (BPW)	For every 1% increase, BPW increases by 0.42%

5. Discussion

5.1 Theoretical Contributions

This study embeds "patent perception" into the Theory of Planned Behavior (TPB) framework, confirming an explanatory increment of $\Delta R^2 = 0.07$ in the context of sustainable beauty, expanding the applicability boundary of TPB's external variables. Meanwhile, the Clean Beauty Adoption Ladder (C-BAL) model is proposed, quantifying the clean beauty technology diffusion mechanism with two parallel paths: "Natural Index → Perceived Safety → Purchase Intention" and "Patent + ESG → Brand Identification → Repurchase," providing a replicable causal chain for subsequent cross-cultural studies.

5.2 Managerial Implications

For US brand owners, Chinese original patent formulations can serve as a differentiated "story package," reducing price sensitivity by 9.4% while maintaining a 15% premium, significantly extending product life cycle. For Chinese manufacturers, prominently labeling "Patented Formula + US Patent No." on the front of the packaging can increase in-store conversion rates, and concretizing ESG narratives (e.g., "zero plastic lining," "refillable pump head") can avoid greenwashing risks. For retailers, incorporating patent labels into electronic screening tags (e-tags) can increase clean beauty shelf turnover rates by over 12%, thereby optimizing category management.

5.3 Policy Recommendations

In addition to the aforementioned mandatory labeling and patent fast-track, the regulatory level urgently needs to establish a cross-border "natural organic whitelist" mutual recognition mechanism, allowing Chinese raw materials that pass ISO 16128 and USDA NOP dual certification to enter the US market through a simplified procedure, significantly reducing compliance costs for small and medium-sized enterprises. The FDA should also extend the MoCRA safety assessment template to the "natural source" category, clarifying the scope of toxicological data exemptions and avoiding redundant animal experiments. In terms of trade

policy, the USTR can grant tariff exemptions for green patent cosmetics under the Section 301 investigation framework to encourage the import of sustainable technologies. State governments can also refer to California's Safer Consumer Products regulations to establish special procurement quotas for "green patent products," pulling the large-scale penetration of Chinese original formulations in the US market through demand-side public procurement.

5.4 Research Limitations and Future Directions

The sensory testing period is only 4 weeks, and long-term efficacy and safety still need to be extended to 12 months and validated in multiple centers. The retail data currently covers Nielsen offline stores, and the penetration of DTC e-commerce (Amazon, brand websites) is not yet complete. Future research can combine fMRI or eye-tracking experiments to explore the activation differences of patent labels on consumer neural pathways and conduct cross-cultural comparisons in the EU, the Middle East, and other markets to construct a comprehensive global clean beauty acceptance index.

6. Conclusion

This study, using the three authorized patents as core intervention variables, employs a 1,200-person random conjoint experiment, four-year Nielsen retail panel, and system dynamics modeling to verify the true acceptance and 2025-2030 sales potential of "Chinese original natural organic formulations" in the US market for the first time. The results show that a natural index ≥ 90% can increase purchase intention by 32.4%, efficacy patent labels bring an 18.7% premium and reduce promotional dependence by 9.4%, the optimal attribute combination predicts a market share of 11.2%, sales of patent SKUs are 26.8% higher than the non-patent control group, and the cumulative NPV@8% over four years reaches $196 million. Sensory testing further confirms that the patented formulations significantly reduce hair loss by 19.7% and increase scalp hydration by 15.4% within four weeks (Caputo, F., Vogel, R., Savage, J., et al., 2021), providing objective physiological evidence for functional claims. Based on the above findings, the Clean Beauty Adoption Ladder (C-BAL) theoretical framework is proposed, integrating "Natural Index - Patent Perception - ESG Narrative" into a unified causal chain, expanding the boundary of the Theory of Planned Behavior in the field of sustainable beauty. At the policy level, it is recommended that the FDA introduce mandatory natural organic labeling regulations, the USPTO establish a green patent fast-track, and through cross-border whitelist mutual recognition and tariff exemptions, reduce compliance costs and provide institutional channels for Chinese original technologies to enter the US market. This study not only provides a replicable empirical paradigm for the overseas differentiated positioning of Chinese manufacturers but also contributes new theoretical and practical evidence for the global diffusion of clean beauty technologies and regulatory governance.

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