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Application of Digital Transformation in Financial Management

—A Case study on Gree Electric Appliance Co.

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Abstract

With the rapid development of information technology, the digital economy has become a new engine of global economic growth, and traditional financial management faces many challenges, while digital transformation provides new ideas and tools. Gree Electric, as a leading global home appliance manufacturer, has actively promoted digital transformation in recent years and carried out many explorations and practices in the field of financial management. By analyzing the case of Gree Electric, the study builds a model for the application of digital transformation in financial management, discusses its role in improving efficiency, optimizing decision support and risk control, and points out the challenges faced in the transformation process, such as the complexity of technology and business integration, organizational and talent bottlenecks, and data security risks. The study aims to provide experiences and references on digital transformation for other enterprises and to promote the innovation and development of financial management models.

Keywords: Digital Transformation; Financial Management; Gree Electric Appliance

1. Introduction

With the rapid development of information technology, the digital economy has become a new engine of global economic growth (Shen 2025). The new generation of technologies represented by big data, cloud computing, and artificial intelligence is profoundly reshaping enterprise production and business models, thereby driving digital transformation across industries. As the core component of enterprise management, financial management is also facing unprecedented opportunities and challenges. The traditional model suffers from information silos, inefficiency, and weak risk control, making it difficult to adapt to complex operating environments. By integrating advanced digital technologies, financial management can achieve automation and intelligence (Liu 2025), improve the accuracy and timeliness of financial data, and provide stronger support for scientific decision-making.

In this context, Gree Electric Appliances Limited, a global leader in air conditioning manufacturing, has actively advanced digital transformation and carried out substantial practices in financial management. Its experience provides an ideal case for examining how enterprises implement digital technologies to optimize financial processes. This study will analyse Gree's practices to assess the effectiveness, current status, and challenges of applying digital transformation in financial management, with the goal of offering insights and references for other enterprises pursuing similar initiatives.

Theoretically, this research aims to enrich the study of digital transformation in financial management, which remains in its infancy and lacks systematic frameworks and case analyses. By constructing an application model and evaluating its effectiveness through Gree's case, this study provides empirical evidence to support theoretical development. Practically, it explores new modes and methods of financial management under digital transformation, offering valuable guidance for other enterprises to avoid detours, accelerate transformation, and strengthen automation, intelligence, and risk control. Gree's successful experience highlights how digital financial management can improve data accuracy, timeliness, and decision support, while also building robust early-warning and risk management mechanisms to enhance enterprise resilience and long-term development.

2. Theoretical Basis

Financial digitization involves the use of advanced technologies to systematically collect, manage, and process various types of information related to a company's business operations, thereby converting valuable data and storing it appropriately. This process not only focuses on the processing of data itself, but also emphasizes how to promptly convey new data information in response to dynamic changes in the company's internal and external environments and the practical needs of business and financial integration, thereby optimizing the information flow for corporate value decision-making. The dual significance of financial digitization lies in two aspects: on the one hand, through the in-depth application of digital technology, it significantly improves the efficiency and quality of digital data collection and processing; on the other hand, by establishing a comprehensive financial digitization system, companies can efficiently aggregate internal operational data to provide strong support for decision-making (Zhao 2021). The uncertainty of the environment is not only a key driving force behind corporate financial digitization transformation but also significantly influences the duration of the transformation process, making it a critical consideration factor. Significant external drivers underlie financial digital transformation, primarily including digital technology innovation, digital trends in market competition, and consumers' digital behavior patterns (Jiang and Zhai 2022).

3 Background of the Case Companies and the Drivers of Digital Transformation

3.1. Case Enterprise Profiles

Gree Electric was founded in 1991, is China's and the world's leading manufacturer of household appliances and intelligent equipment, air conditioning as the core business, product coverage of refrigerators, washing machines, household appliances, industrial robots and other fields. Listed on the Shenzhen Stock Exchange in 1996, the company's revenue in 2023 exceeded 200 billion yuan, the air conditioning global market share for 18 consecutive years ranked first with Midea, Haier and known as the "three giants of Chinese household appliances", its chairman and president Dong Mingzhu dominated the "Made in China" transformation, with "Made in China" as the main theme. "Transformation," to "master the core technology" as the brand slogan, as a leading traditional manufacturing enterprises, Gree Electric in recent years in the field of financial management to accelerate the digital transformation, through technology to reconstruct the financial process, improve decision-making efficiency and to cope with the pressure of competition in the industry (Jin 2024). As a leading enterprise in the traditional manufacturing industry will face a lot of competitive pressure in the same industry, Gree Electric has accelerated the digital transformation in the field of financial management in recent years, through technology to reconstruct the financial process, improve decision-making efficiency and cope with the pressure of competition in the industry, and at the same time, combined with the law of development of the manufacturing enterprise, and in line with the national response, the digital transformation of Gree Electric from the supply chain to the production, marketing and after-sales service has gradually moved towards soundness, and has achieved initial results. And has achieved initial results, gradually moving towards digitalisation and intelligence. But as a traditional manufacturing enterprise Gree Electric for the digital transformation of financial management is not enough attention, but with the development and penetration of digital transformation and the strong development of other manufacturing enterprises, Gree Electric has gradually attracted attention to the digital transformation of financial management, Gree Electric continues to explore, and gradually summed up a centralised management of finance and an effective way of integrated allocation of resources throughout the company (Liu 2024), and finally established a financial intensive control system across all management levels, covering all business segments.

3.2. Drivers Of Digital Transformation

3.2.1. Competitive Pressure in the Industry

With the competition in the home appliance market also gradually intensified, the United States, Haier and other competitors in the intelligent manufacturing and digital layout of the rapid advancement of the home appliance industry profit margins are becoming increasingly low (Deng 2024), the industry's average net interest rate of about 5%-7% in 2023, need to be digitised to reduce costs and increase efficiency. Gree needs to consolidate its market position through digital transformation to avoid being subverted by the new industry. In addition, with the rapid development of Gree Electric Appliances, the overseas market is also expanding, and the expansion of the overseas market requires the digital supply chain and globalisation to work

together, at this time, the data of financial management also needs to keep up with the rapid development of Gree Electric Appliances, to provide more data analysis, so that it can carry out a fast and efficient layout, and it can quickly analyse the status quo of the enterprise based on the existing data, and then make the most conducive to the development of enterprises decision, and better enrich and develop the overseas market. Along with this, the financial complexity of overseas business rises, and changes in exchange rates and tax rules all affect the conduct of overseas business.

3.2.2. Policy and Strategic Orientation

The drive of national policy also promotes the process of digital transformation, China's "14th Five-Year Plan", "new infrastructure" strategy and "double carbon" goal requires the manufacturing industry to the green, intelligent Transformation (Yan 2024), Gree needs to respond to the policy and promote low-carbon production and energy management digitalisation.

(1) National-level strategic leadership

The 14th Five-Year Plan (2021-2025) explicitly identifies the digital economy as a new engine of economic growth, with the goal that the added value of core digital economy industries will account for 10% of GDP by 2025. The 14th Five-Year Plan for the Development of the Digital Economy has refined its targets.

(2) Industry and local supporting policies

Various industries (e.g. manufacturing, agriculture) have introduced guidelines for digital transformation, e.g. the Ministry of Industry and Information Technology's Action Plan for Digital Transformation of the Manufacturing Industry promotes the construction of smart factories.

Local governments have formulated policies that take into account the characteristics of local industries, such as Zhejiang's "Factory of the Future" programme and Guangdong's "Digital Government 2.0".

3.2.3. Internal Requirements

The traditional financial model relies on manual accounting, efficiency is relatively low, the issuance of monthly statements generally take more than 10 days, it is difficult to support real-time decision-making. Labour and cost pressure, Gree Electric, as a traditional manufacturing industry, focuses on the development of the manufacturing side and faces problems such as rising labour costs and efficiency bottlenecks. Service-oriented transformation: from selling products to selling services, such as providing value-added services such as equipment management and energy consumption optimisation through Gree APP to enhance user stickiness. Emerging technology application: 5G, AI, edge computing and other technologies have matured, providing technical support for smart factories and smart products (e.g. AI air conditioners). Gree needs to maintain its innovation advantage through technology integration, and these diversified emerging technologies, such as air conditioners, smart equipment, and new energy require the financial system to flexibly adapt to multi-scenario needs.

4. Implementation Path for Digital Transformation in Financial Management

4.1. Technical Architecture Development

Intelligent financial system mainly replaces manual processing of repetitive work such as invoice verification, reconciliation, report generation through robot process automation to reduce human error and improve efficiency (Cao 2024). Intelligent financial system mainly includes automated processing, intelligent analysis and forecasting, risk control, and intelligent decision support. Robot process automation can automatically complete a series of repetitive tasks such as invoice entry, reimbursement review, and reconciliation, which greatly reduces human error, saves time, and improves the efficiency of financial processing, and more time can be spent on irreplaceable work of robots; Optical Character Recognition can automatically identify key information in invoices, contracts, and other documents, and achieve paperless processing, which can preserve data information for a longer period of time Not lost, while using machine learning to analyse historical financial data, predict cash flow, revenue trends and potential risks, can maximize risk avoidance, to avoid unnecessary losses, and optical character recognition can be generated in real time data dynamic financial statements, and then through the financial sharing centre to centralize the processing of multi-branch financial processes, so that the data can be extracted in a timely manner and used to assist in supporting management decision-making. Monitor capital flows through anomaly detection algorithms, identify fraud or compliance risks and manage taxes, automatically calculate taxes, generate returns, and synchronise with policy changes in real time, such as adjustments to tax rules.

The integration of business and finance is a management system that integrates business processes with financial processes through technological means and management model innovation to realise real-time data sharing, seamless processes and efficient decision-making collaboration (Zhan 2024). Its core objective is to break the traditional departmental barriers, so that business activities and financial results in real time linkage, to enhance the overall operational efficiency of the enterprise and strategic decision-making ability. ERP (such as SAP) and the supply chain, production system through the realization of the automatic flow of business data to the financial side, to eliminate the information silo, shorten the financial settlement cycle.

4.2. Business process re-engineering

Due to the low efficiency of manual entry, the average daily processing of documents is relatively small, and manual entry accounting error rate is relatively high, accounting error rate of up to 1.2%, and cross-departmental collaboration is time-consuming, the average approval cycle of 72 hours, and manual entry will make the different systems, departments or business units can not be well interconnected with each other, resulting in fragmentation of information, duplication and inefficiency (Figure 1). The data are scattered, and the phenomenon of data silos is serious, but in order to reduce costs and increase efficiency, business collaboration needs to be concentrated, so it is necessary to carry out the reconstruction of business processes, and carry out the process optimisation from "manual entry" to "automated accounting" (with flow charts) (Figure 2).



Figure 1. Manual entry flowchart

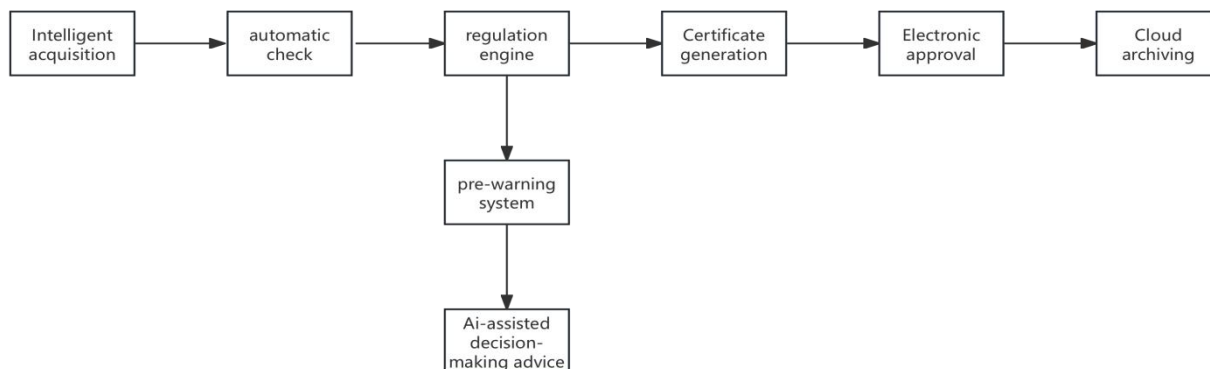


Figure 2. Automated accounting flowchart

5. Analysis of Transformation Effectiveness and Problems

5.1. Quantitative Impact Assessment

Automated processing enhances work efficiency, reduces unnecessary personnel consumption, and focuses more human resources on irreplaceable boards (Li 2024), for example, the monthly closing cycle has been greatly shortened, and also saves the cost of labour. Intelligent analysis and forecasting can be based on the generation of real-time reports, and the integration of data on the financial situation of the comprehensive analysis and forecasting, which can be combined with more factors to avoid the subjectivity of artificial analysis, and also reduce the occurrence of human error. Intelligent analysis and forecasting, based on real-time report generation, can integrate data for comprehensive analysis and forecasting of financial situation, which can combine more factors, avoid the subjectivity of manual analysis, and also reduce the occurrence of human error, and greatly save the cost of human resources, and the prediction of risk is also more accurate and comprehensive.

Automated processes gradually replace manual operations, through ERP systems, such as SAP and robotic process automation technology, to achieve the automation of invoice processing, expense reimbursement, fund settlement and other processes, documents processing time is significantly shortened, the financial data and production, sales, supply chain system synchronisation in real time to break the inter-departmental data silos, the generation of monthly financial statements cycle shortened from 7 days to 1 day, greatly saving the time of processing work. It greatly saves the processing time and improves the working efficiency.

Risk management and control capabilities to enhance the intelligent risk control system, the use of big data analysis technology, the construction of the supplier credit rating model and the dynamic assessment system of customer account period.

5.1.1. Profitability Indicators

Digital transformation may drive gross margin improvement by optimising production processes and lowering manufacturing costs. Gree's gross margin has stabilised at over 30% in recent years (2022 financial results show a gross margin of 30.3%), which is higher than that of some home appliance peers, possibly reflecting improved production efficiency. An increase in net margin (e.g., from 10% to 12%) reflects enhanced expense control. gross margin declined from 27.58% to 24.28% from 2019-2021, and rebounded sharply to 30.57% in 2023, reaching an all-time high. At the initial stage of digital transformation, the decline in gross margin in 2019-2021 may be related to initial cost investment, such as supply chain digital transformation and automation equipment procurement pushing up operating costs. In the later stage, the enterprise further deepens the digital transformation and carries out the digital transformation of financial management, and the gross profit margin is significantly improved in 2023, reflecting the effectiveness of the digital transformation with further results, intelligent pricing system, through big data analysis of market demand, dynamic optimisation of product pricing, while the supply chain synergies cooperate with digital platforms to reduce the procurement cost for centralised purchasing and accurate forecasting of inventories. Cost-expense margin, fluctuating up from 17.2% in 2019 to 19.23% in 2023, but trough in 2021-2022. the trough in 2021 may be related to the critical period of digital transformation; Return on Assets (ROA) bears more pressure, with lower asset efficiency, declining from 10.08% in 2019 to 7.41% in 2022 in consecutive years, and the decline in ROA reflects that a large amount of asset investment in digital transformation has not been quickly converted into revenue; 2019-2021 is in the input period, gross margin and ROA are falling at the same time, in line with the characteristics of the initial stage of technological investment, "cost front, lagging revenue", 2022-2023 is in the teething period, gross margin is falling at the same time, and gross margin is falling at the same time, in line with the characteristics of the initial stage of technological investment, "cost front, lagging revenue" (Table 1). In the teething period, gross profit margin rebound but ROA recovery is slow, need to enhance the optimisation of the asset side.

Digital transformation has a lag effect on profitability. Short-term cost pressures reduce gross profit margins and ROA, but in the long term, cost reduction and efficiency improvements drive significant improvements in gross profit margins. The slow recovery of ROA indicates the need to strengthen asset management and technology integration efficiency.

Table 1. Profitability Indicators of Greeley Electric Appliances, 2019-2023

	Gross operating profit margin	cost-effectiveness ratio	return on assets
2019	0.275815	0.172043	0.10083
2020	0.261417	0.180253	0.086702
2021	0.242814	0.164439	0.081967
2022	0.260355	0.167983	0.074147
2023	0.305687	0.192302	0.081007

Note. Date from: Annual Report (2019-2023), Zhuhai Gree Electric Appliances Inc.

5.1.2. Operational Efficiency Indicators

As a result, inventory was dynamically adjusted based on historical sales data and market trends, reducing the backlog of slow-moving products. Real-time monitoring of inventory status, automated sorting to reduce manual time-consumption and shorten the capital turnover cycle, Gree's inventory turnover days decreased from 105 days in 2022 to 91 days in 2023, a decrease of 13.4%, with a reduction in capital consumption and enhanced liquidity. Inventory turnover decreased from 6.5 times/year to 3.9 times/year, reflecting the smart supply chain management of inventory backlogs; accounts receivable turnover increased, showing that digital risk control to shorten the payback cycle, and at the same time, the operating cycle was shortened from 133 days to 119 days, indicating that data-driven production and sales collaboration to accelerate the flow of funds (Table 2).

Table 2. Operational Efficiency Indicators of Greeley Electric Appliances, 2019-2023

	Inventory turnover days	Inventory turnover	Accounts payable turnover	Accounts receivable turnover days	business cycle
2019	56.081001	6.508443	3.558827	14.879549	70.96055
2020	76.547947	4.781317	3.391388	18.769628	95.317575
2021	90.633263	4.027219	4.216128	21.933869	112.567132
2022	105.85632	3.44807	4.067569	27.681487	133.537807
2023	91.353778	3.995456	3.82754	27.667862	119.02164

Note. Date from: Annual Report (2019-2023), Zhuhai Gree Electric Appliances Inc.

The impact of digital transformation on operational efficiency follows a “U-shaped curve.” In the short term, efficiency declines due to technical adjustments and process restructuring, but in

the long term, intelligent supply chain management significantly optimizes capital turnover efficiency. In the future, it will be necessary to focus on overcoming bottlenecks in accounts receivable management and deepening the application of risk control systems.

5.1.3. Risk Control Indicators

The quick ratio and current ratio continue to decline after a brief rise in 2020, and are below the 2019 level in 2023, indicating weakened short-term solvency. In the early stages of digital transformation, supply chain or accounts receivable management systems have not yet been optimised, leading to a decline in inventory turnover or delays in the collection of accounts receivable, affecting the quality of current assets (Han 2024).

Leveraging digital tools, strengthening supply chain collaboration and credit management, shortening the cash cycle and enhancing liquidity of current assets. Working capital fluctuates dramatically, with significant fluctuations in working capital from a peak of \$55.1 billion in 2020 to \$27.1 billion in 2023. Initial investments in digital transformation, such as ERP systems and cloud computing, took up a large amount of capital, or business model adjustments led to unstable working capital requirements. Through the digital real-time monitoring system to dynamically adjust the allocation of funds, combined with big data analysis to predict business demand, optimise inventory and accounts payable management, and stabilise working capital (Table 3).

Table 3. Risk Control Indicators for Glacier 2019-2023

	quick ratio	current ratio	Working capital (in yuan)	cash ratio	gearing
2019	1.116242	1.258278	43795740755	0.155528	0.604033
2020	1.172104	1.348023	55154269034	0.15286	0.5814
2021	0.928883	1.145855	28748266751	0.151961	0.662309
2022	1.002098	1.179173	38768102157	0.14676	0.713045
2023	0.973027	1.135126	27158009715	0.153815	0.672205

Note. Date from: Annual Report (2019-2023), Zhuhai Gree Electric Appliances Inc.

Gearing climbed, with gearing rising from 60.4% in 2019 to 71.3% in 2022 and falling slightly to 67.2% in 2023, increasing pressure on long-term debt servicing. Digital transformation relies on debt financing, leading to expansion of debt scale. Explore diversified financing channels (e.g. equity financing, digital financial instruments) to optimise the capital structure; enhance the efficiency of asset use (e.g. full-life-cycle management of assets) through digitisation to reduce reliance on debt.

Cash ratios hovered at a low level, with cash ratios perennially below 0.16, limited cash reserves, and digital technology not effectively enhancing cash flow forecasting capabilities, leading to conservative cash holding strategies or inefficient use of funds.

The introduction of an intelligent cash flow forecasting model to dynamically optimise cash holdings and balance liquidity and profitability. The phased impact of digital transformation, the deterioration of a number of indicators in 2021 may be related to the high investment in the initial stage of digital transformation and the decline in efficiency during the system teething period. the small recovery in gearing and quick ratio in 2023 may reflect the initial effect of transformation and the need for continued investment to unlock the long-term benefits.

5.2. Existing Problems and Challenges

The complexity of technology and business integration leads to high system integration difficulties, and there may be incompatible data interfaces between the original financial system and the new modules, leading to data redundancy during the initial pilot phase. Overdependence on technology with no alternative back-up solutions can be risky. A server failure in 2021 led to an eight-hour paralysis of the financial system, exposing the problem of overdependence on a single cloud service provider.

Organizational and talent bottlenecks, shortage of complex talents, traditional finance staff accounting for more than 70%, less than 15 per cent of employees with data analysis and system operation and maintenance capabilities, restricting the in-depth application of AI models. There is also a certain degree of resistance to departmental collaboration, as there are differences between the production department and the finance department on the cost-sharing standard, and the data collection of the digital system has encountered resistance from the executive level.

Data security and privacy face a number of risks, with the threat of cyberattacks being particularly prominent. 2022, the Company suffered a phishing attack targeting suppliers' payment information. Although the incident did not cause any actual losses, it has exposed certain loopholes in the Company's security protection, and there is an urgent need to further improve the security protection system.

6. Case Optimisation Recommendations

6.1. Building a Digital Profitability Model

Develop an integrated cost-to-revenue system for industry and financial integration, predict the long-term impact of technology investments on gross margin, ROA, etc (Wang 2024). Avoid short-term decision bias, identify key drivers of variable versus fixed costs, and do well with linear programming and cost-sensitive machine learning.

6.2. Dynamic Cost Control System

Dynamic cost control system is not a simple cost-cutting tool, but a strategic capability to achieve a dynamic balance between cost and value through digitalisation (Kong 2024). Introducing an AI-driven flexible budgeting system that automatically adjusts cost allocation based on business fluctuations, dynamically adjusts resource inputs based on business priorities, predicts future cost trends, such as the impact of raw material price fluctuations on production costs; cleanses historical cost data and establishes a standard cost repository.

6.3. Digitisation of the Full Life Cycle of Assets

Implement digital monitoring of key equipment, extend service life through predictive maintenance, and reduce the risk of asset impairment. The technology layer builds a hybrid cloud architecture to disperse the risk of system failure; the introduction of a low-code platform improves the independent development capability of business departments. Establish a cross-system data centre to unify data standards and reduce integration costs. The organisational layer has set up the "Finance Digital Innovation Centre" and joined hands with universities to cultivate talents with the triangular competence of "finance+IT+business". Implemented a digitalisation point system, and incorporated the efficiency of system usage into departmental KPI assessment.

Build an alliance chain with banks and tax organisations to enhance the efficiency of supply chain finance and tax synergy (Li 2024). Participate in the formulation of financial digitisation standards for the manufacturing industry to seize the right to speak in the industry.

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Research on the Accounts Receivable Management Problems and Countermeasures of Gree Electric Appliances Co., Ltd.

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Abstract

This study analyzes Gree Electric's accounts receivable (AR) management from 2019 to 2023 through financial data and industry benchmarking. Results indicate a surge in AR balances from CNY 8.44 billion to CNY 16.099 billion, with annual growth rates exceeding revenue expansion. The AR-to-revenue ratio rose from 4.26% to 7.89%, while receivables aged over three years increased to 14.34%, signaling deteriorating collection efficiency and elevated bad debt risks. Despite outperforming peers (e.g., Midea, Haier) in AR turnover ratios, Gree experienced a consistent decline from 24.44 to 13.19 times, highlighting liquidity strain. Key drivers include overdependence on credit sales for market share growth, inflexible recovery methods, outdated credit evaluation systems, and inadequate risk governance. Proposed solutions involve instituting credit sales caps, dynamic credit scoring models, tiered collection strategies, aging structure optimization (e.g., reducing >3-year receivables to industry-average 5.03%), and automated risk alerts. These measures aim to reconcile sales growth with financial stability, mitigate liquidity risks, and enhance operational resilience. The findings offer actionable frameworks for improving AR management in the home appliance sector, emphasizing data-driven credit policies and proactive risk mitigation.

Keywords: Gree Electric; Accounts Receivable Management; Credit Policy

1. Introduction

Accounts receivable management remains a critical determinant of financial health for manufacturing enterprises, particularly in competitive sectors like home appliances where extended credit terms are commonplace. While prior research has established clear correlations between receivables turnover efficiency and corporate performance (Brown & Lee, 2017), there exists a notable gap in empirical studies examining firm-specific structural deficiencies among industry leaders. This study addresses this research void through a comprehensive investigation of Gree Electric Appliances' accounts receivable management system during the 2019–2023 period, which coincided with significant market disruptions including global supply chain realignments and post-pandemic economic adjustments.

To establish robust analytical foundations, this research integrates multiple methodological approaches. Financial trend analysis forms the primary investigative lens, systematically tracking audited annual statements to monitor the evolution of key indicators including absolute receivables balances, turnover ratios, aging structures, and bad debt provisioning patterns. These internal metrics are further contextualized through comparative industry benchmarking against major competitors Midea Group and Haier Smart Home, as well as sector-wide averages published by the China Household Electrical Appliances Association. This dual-axis examination enables identification of performance deviations that might otherwise remain obscured when viewing internal metrics in isolation.

Building upon this diagnostic foundation, the analytical framework incorporates causal analysis to establish linkages between operational practices and financial outcomes. Through detailed process mapping and policy documentation review, we trace how credit policy adjustments influence aging structures, how collection mechanisms impact Days Sales Outstanding, and how risk governance protocols correlate with bad debt accumulation. This multidimensional approach reveals that Gree's accounts receivable balance surged from CNY 8.44 billion to CNY 16.099 billion during the study period, while concurrently, receivables exceeding three years reached 14.34% of total AR—nearly triple the industry benchmark of 5.03% (Li, 2022).

This deterioration presents a compelling paradox: despite maintaining superior turnover ratios relative to peers ($13.19\times$ versus Midea's $12.17\times$ and the industry's $9.92\times$ in 2023), Gree exhibits accelerating fundamental vulnerabilities in its receivables portfolio. Such divergence suggests that conventional turnover-centric assessment models may insufficiently capture systemic risks in enterprise credit management. The implications extend beyond Gree's operational context, offering broader insights for capital-intensive manufacturing sectors where liquidity pressures have intensified amid recent economic volatility.

The subsequent sections of this paper develop these findings into actionable frameworks. Theoretically, this research contributes an integrated risk assessment model that reconciles liquidity metrics with solvency indicators. Practically, it identifies specific operational leakage points in credit lifecycle management while proposing dynamic monitoring systems responsive to industry cyclicity. For peer enterprises navigating similar market conditions, the diagnostic protocols established herein provide replicable methodologies for balancing sales expansion with financial resilience.

2. Analysis of Accounts Receivable Issues at Gree Electric Appliances

2.1. Current Status of Accounts Receivable

2.1.1. Analysis of Accounts Receivable Scale

Gree Electric Appliances' key financial metrics for accounts receivable from 2019 to 2023 are illustrated in Figure 1. By the end of 2023, the company reported operating revenue of CNY 202.079 billion (Table 1), with overall revenue stability observed across the period. While revenue declined in 2020 due to pandemic impacts, it rebounded from 2021 to 2023, reaching

levels comparable to 2019. The revenue growth rate turned negative in 2020 but resumed positive trends thereafter, indicating stable revenue streams and robust cash flow. These metrics collectively underscore Gree's position as a large-scale enterprise.

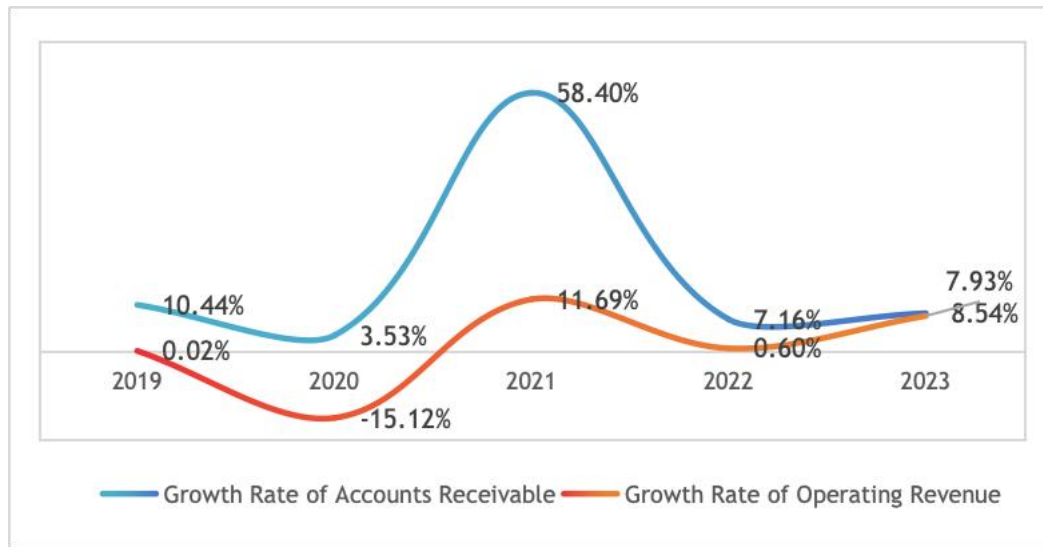


Figure 1. Comparison of Accounts Receivable to Revenue Growth Rates for Gree Electric (2019-2023)

Table 1. Analysis of Accounts Receivable Financial Metrics for Gree Electric Appliances, Inc. (2019-2023)

	2019	2020	2021	2022	2023
Operating Revenue	1981.53	1681.99	1878.69	1889.88	2039.79
Operating Revenue Growth Rate (%)	0.02%	-15.12%	11.69%	0.60%	7.93%
Accounts Receivable Balance	84.4	87.38	138.41	148.32	160.99
Accounts Receivable as Percentage of Operating Revenue	4.26%	5.20%	7.37%	7.85%	7.89%
Accounts Receivable as Percentage of Current Assets	3.96%	4.09%	6.13%	5.81%	7.06%
Accounts Receivable Growth Rate (%)	10.44%	3.53%	58.40%	7.16%	8.54%
Closing Current Assets	2133.64	2136.33	2258.5	2551.4	2281.41

Notably, Gree's accounts receivable balance surged from CNY 8.44 billion in 2019 to CNY 16.099 billion in 2023, nearly doubling over five years. A significant spike occurred in 2021, with receivables reaching CNY 13.841 billion, marking a 58.4% year-on-year increase from CNY 8.738 billion in 2020. This escalation highlights heightened bad debt risks. The ratio of accounts receivable to operating revenue stabilized at approximately 7.7%, suggesting overly lenient credit policies. Such practices expose the company to liquidity risks if debtor financial conditions deteriorate, potentially jeopardizing long-term financial health.

Compared to revenue growth, accounts receivable growth outpaced operating revenue expansion, particularly in 2021. This discrepancy implies that Gree prioritized sales recovery and market consolidation post-pandemic, potentially adopting aggressive credit strategies to stimulate demand.

Gree's total current assets exhibited gradual growth from 2019 to 2022, reflecting efficient asset turnover and strong short-term solvency. Rapid turnover rates minimized idle capital, enhancing profitability through optimized liquidity management. However, in 2023, current assets declined by CNY 27 billion (a 10.6% reduction), signaling slower turnover rates, diminished capital efficiency, and potential erosion of short-term solvency. This trend may adversely affect future profitability if unaddressed.

2.1.2. Comparative Analysis of Accounts Receivable Growth Rates: Gree vs. Industry Peers

As a leading enterprise in the home appliance industry, Gree Electric Appliances holds significant market share. However, maintaining sustainable growth requires continuous monitoring of market dynamics and benchmarking against competitors to identify deficiencies and improvement opportunities.

By investigating accounts receivable growth trends of Midea and Haier from 2019 to 2023, the following observations emerge (Table 2, Figure 2):

(1) 2019–2020: During the pandemic, Midea and Haier experienced substantial increases in accounts receivable growth in 2020, whereas Gree's growth rate remained lower, indicating comparatively fewer bad debt risks during this period.

(2) 2021–2022: Gree's accounts receivable growth significantly surpassed both peers, with a sharp spike in 2021, reflecting aggressive credit policies to drive sales recovery.

(3) 2023: Gree's accounts receivable growth reverted to levels below those of Midea and Haier, suggesting tightened credit controls.

Compared to the industry average, Midea demonstrated stable accounts receivable growth rates over the five-year period, closely aligning with sector norms. In contrast, Gree and Haier exhibited pronounced volatility, particularly Gree, with maximum annual fluctuations exceeding 50%. Such instability implies heightened risks of delayed collections and liquidity constraints.

Table 2. Comparative Analysis of Accounts Receivable Growth Rates: Gree Electric Appliances, Inc. vs. Peer Companies (2019-2023 Fiscal Years)

	2019	2020	2021	2022	2023
Gree Electric Appliances, Inc.	10.44%	3.53%	58.40%	7.16%	8.54%
Midea Group Co., Ltd.	-3.74%	23.11%	7.22%	14.62%	16.46%
Haier Smart Home Co., Ltd.	4.59%	44.61%	-8.19%	8.63%	27.58%
Industry Average	3.76%	23.75%	19.14%	10.14%	17.52%

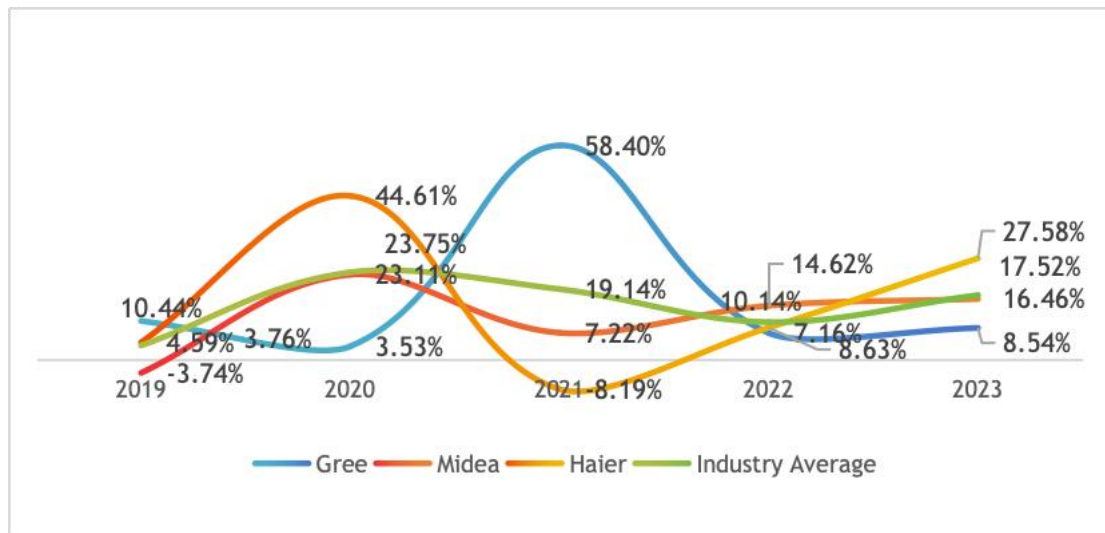


Figure 2. Comparison of Accounts Receivable Growth Rates Among Industry Peers (2019-2023)

2.1.3. Ratio of Accounts Receivable to Operating Revenue

A comparative analysis of the ratio of accounts receivable to operating revenue among Gree, Midea, and Haier reveals distinct trends over the past five years. As shown in Table 3 and Figure 3, Gree's ratio exhibited a consistent upward trajectory, rising from 4.26% in 2019 to 7.89% in 2023. Notably, during 2019–2020, Gree's ratio remained significantly lower than both Midea and Haier, as well as the industry average. However, beginning in 2021, the ratio surged sharply, doubling by 2021 and maintaining elevated levels through 2023.

In contrast, Haier demonstrated a declining trend in this ratio, aligning closely with industry averages and reflecting stricter credit management practices. This divergence underscores that Haier's accounts receivable balance is comparatively smaller than Gree's, indicating superior liquidity management.

Table 3. Proportion of Accounts Receivable to Operating Revenue: Industry Comparison (2019-2023)

	2019	2020	2021	2022	2023
Gree Electric Appliances, Inc.	4.26%	5.20%	7.37%	7.58%	7.89%
Midea Group Co., Ltd.	6.68%	8.04%	7.17%	8.17%	8.80%
Haier Smart Home Co., Ltd.	7.75%	6.52%	6.44%	7.60%	5.49%
Industry Average	6.23%	6.59%	6.99%	7.78%	7.39%

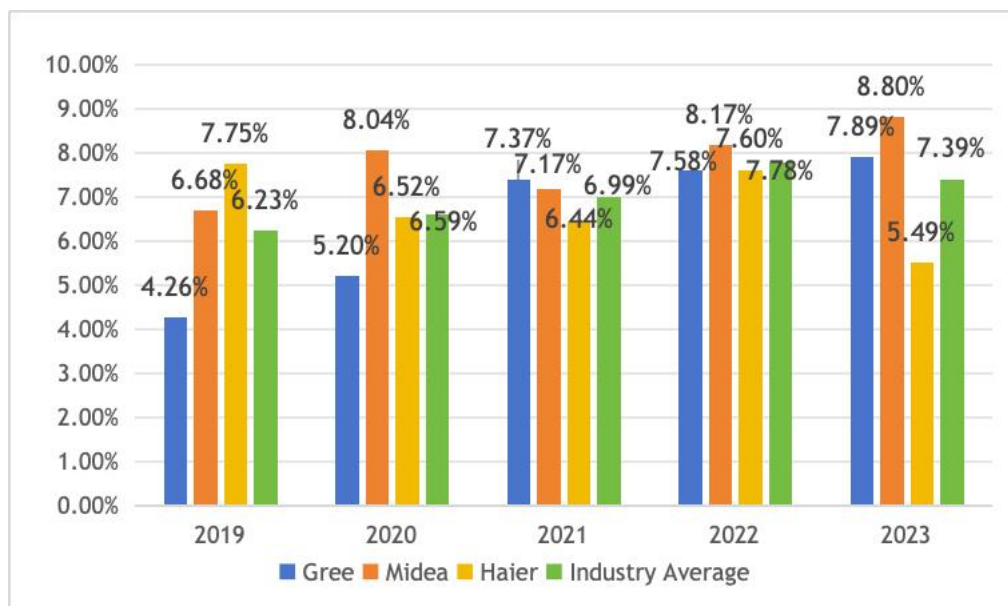


Figure 3. Comparison of Accounts Receivable as a Percentage of Revenue Among Industry Peers (2019-2023)

2.2. Analysis of Accounts Receivable Liquidity

2.2.1. Ratio of Accounts Receivable to Current Assets

A comparative analysis of the ratio of accounts receivable to current assets among Gree, Midea, and Haier reveals distinct liquidity profiles. As illustrated in Figure 4 and Table 4, Gree's ratio of accounts receivable to current assets remains the lowest among the three firms but has exhibited a gradual upward trend over the past five years. In contrast, Midea's ratio closely aligns with the industry average, while Haier consistently reports the highest ratio, indicating divergent liquidity management strategies.

This means Midea The alignment with industry averages suggests sufficient working capital to meet operational needs, ensuring smooth cash flow cycles; Haier Persistently high ratios imply potential working capital shortages, which may strain liquidity and hinder operational flexibility.

And Gree Despite maintaining the lowest ratio, the upward trajectory signals a need to curb accounts receivable growth to preserve capital chain stability and mitigate liquidity risks.

Table 4. Proportion of Accounts Receivable to Current Assets: Industry Comparison (2019-2023)

	2019	2020	2021	2022	2023
Gree Electric Appliances, Inc.	3.96%	4.09%	6.13%	5.81%	7.16%
Midea Group Co., Ltd.	11.69%	10.82%	9.90%	9.51%	8.62%
Haier Smart Home Co., Ltd.	15.28%	12.18%	11.80%	13.94%	10.96%
Industry Average	10.31%	9.03%	9.28%	9.75%	8.91%

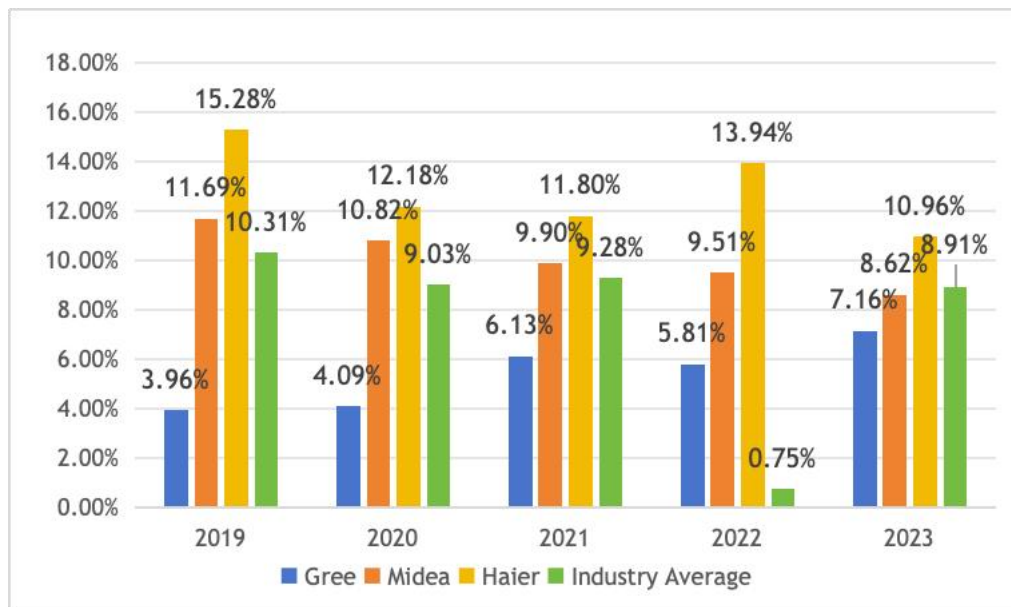


Figure 4. Comparison of Accounts Receivable to Current Liabilities Ratios Among Industry Peers (2019-2023)

2.2.2. Accounts Receivable Turnover Ratio

The accounts receivable turnover ratio serves as a crucial indicator for measuring the collection speed and management efficiency of receivables, reflecting the frequency at which accounts receivable are converted into cash during a given period.

As evidenced in Table 5, Gree Electric Appliances has exhibited a declining trend in its accounts receivable turnover ratio. Impacted by the three-year pandemic, the company's turnover ratio decreased from 24 times in 2019 to 13 times in 2023. This decline indicates a slowdown in collection efficiency and a corresponding reduction in asset turnover over the past five years.

Concurrently, Gree's days sales outstanding (DSO) has shown a consistent increase, rising from 14 days in 2019 to 27 days in 2023. This prolonged collection period reflects growing credit sales exposure and deteriorating receivables management, which significantly elevates the risks of delinquent accounts and bad debts. Such developments pose substantial threats to the company's sustainable operations and financial stability.

Table 5. Accounts Receivable Turnover Rate and Turnover Days for Gree Company from 2019-2023

	Year Accounts Receivable Turnover Rate (Times per Year)	Turnover Days (Days)
2019	24.44	14.73
2020	19.5	18.46
2021	16.64	21.63
2022	13.18	27.3
2023	13.19	27.69

As shown in Figure 5, a comparison with the other two industry-leading companies reveals that although Gree Electric's accounts receivable turnover ratio has consistently exceeded that of its peers and remained above the average over the past five years, it has exhibited an overall declining trend. In contrast, Midea Group demonstrated relative stability, remaining close to the average with a slight downward trend, maintaining its accounts receivable turnover ratio at approximately 13 times. Similarly, Haier Group also showed stability, albeit below the average, with its turnover ratio hovering around 4.5 times. Notably, all three companies experienced a decline in their accounts receivable turnover ratios starting in 2020, coinciding with the onset of the COVID-19 pandemic.

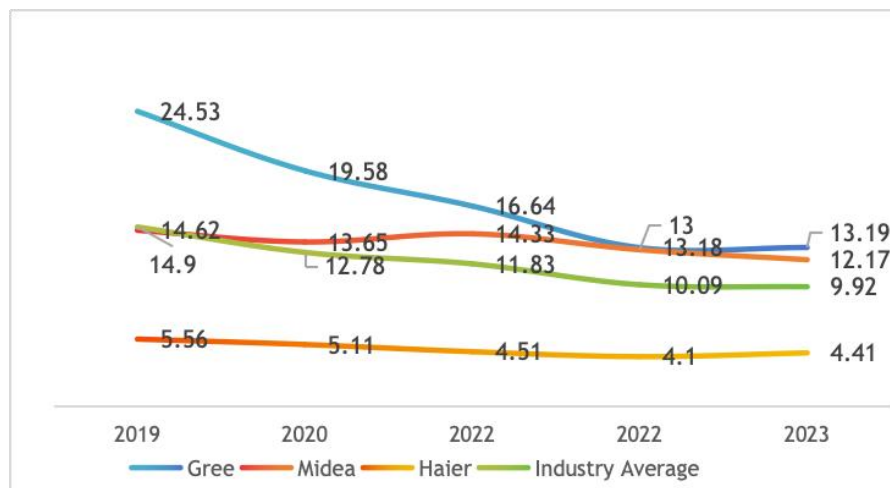


Figure 5. Accounts Receivable Turnover Trends Among Industry Peers (2019-2023)

Table 6. Accounts Receivable Turnover: Industry Comparison (2019-2023)

	2019	2020	2021	2022	2023
Gree Electric Appliances, Inc.	24.53	19.58	16.64	13.18	13.19
Midea Group Co., Ltd.	14.62	13.65	14.33	13.00	12.17
Haier Smart Home Co., Ltd.	5.56	5.11	4.51	4.10	4.41
Industry Average	14.90	12.78	11.83	10.09	9.92

A comparison of the accounts receivable turnover ratios among the three companies indicates that although Gree Electric's ratio has been declining, it remains industry-leading, reflecting faster collection efficiency and higher capital liquidity. However, its competitive advantage has gradually narrowed, raising the possibility of being overtaken by Midea. Midea follows closely, maintaining a stable turnover ratio in line with the industry average, suggesting normal collection efficiency. In contrast, Haier demonstrates weaker receivables management compared to Gree and Midea, increasing its risk of bad debts and posing potential challenges to sustainable operations.

2.3. Analysis of Accounts Receivable Aging Structure

2.3.1. Accounts Receivable Aging Data Analysis

An analysis of Gree Electric's accounts receivable aging from 2019 to 2023 reveals that receivables aged within one year accounted for over 60% of the total during this period, peaking at 83.26% in 2019. The proportion of receivables aged 1–2 years fluctuated but stabilized around 7%, indicating that the majority of Gree's receivables were recovered within one year.

However, while the absolute amount of receivables collected within one year increased, their proportional share gradually declined from 83.26% in 2019 to 62.82% in 2023. Concurrently, the proportion of receivables aged 2–3 years and over three years exhibited a steady annual increase, rising from 3.85% in 2019 to 14.34% in 2023. Notably, receivables aged over three years saw a significant surge between 2021 and 2023, with their proportion climbing from 2.87% in 2019 to 13.24% in 2021 and stabilizing at approximately 14% thereafter, reflecting rapid growth (Table 7). This trend suggests a decline in the recovery of funds within the first two years of the reporting period.

These findings indicate that the aging of Gree Electric's accounts receivable has lengthened significantly, likely due to the impact of the COVID-19 pandemic. The extended collection cycles highlight growing challenges in capital recovery and an elevated risk of bad debts, posing potential threats to the company's financial stability.

Table 7.Age Distribution of Accounts Receivable for Gree Group (2019-2023)

	2019		2020		2021		2022		2023	
	Amount	(%)	Amount	(%)	Amount	(%)	Amount	(%)	Amount	(%)
Within 1 Year	769741. 72	83.26	793368. 23	83.59	122233 1.19	75.89	1274620 .33	72.35	1396908 .03	0.00
1 to 2 Year	92639.1 8	10.02	60372.5 3	6.36	109713. 01	6.81	141614. 79	8.04	139979. 62	6.50
2 to 3 Year	35571.7 7	3.85	51580.3 2	5.43	65471.9	4.06	87754.8	4.98	308953. 73	14.34
Above 3Years	26549.7 5	2.90	43813.7 2	4.62	213132. 8	13.24	257787. 26	14.63	308953. 73	14.34
Total	924502. 42	100	949134. 8	100	161064 8.9	100	1761777 .18	100	2154795 .11	100

2.3.2. Comparative Analysis of Accounts Receivable Aging Within the Industry

A comparative analysis of the accounts receivable aging data for the three companies in 2023, as shown in Table 8, reveals that the majority of receivables across all firms were recoverable within one year. Midea Group achieved the highest recovery rate at 95.7%, significantly reducing its bad debt risk. In contrast, Gree Electric reported a rate of 64.83%, merely approaching the industry average, while Haier recorded 43.99%, falling below the average (Table 8). These figures indicate prolonged accounts receivable periods for Gree and Haier, reflecting heightened bad debt risks and potential challenges in liquidity management.

An analysis of accounts receivable aging across the three companies reveals distinct patterns in capital recovery efficiency. As shown in the 1–2 year aging category, Gree Electric and Midea Group accounted for minimal proportions at 2.85% and 6.5%, respectively, suggesting limited capital recovery during this period, which may constrain short-term operational liquidity. In contrast, Haier Group held a significantly higher share of 23.25%, indicating robust cash flow to support its current production demands.

For receivables aged 2–3 years, Midea Group maintained an exceptionally low proportion of less than 1%, reflecting near-complete capital recovery within the first two years. Haier Group continued to demonstrate substantial liquidity, with its proportion increasing further during this period. Gree Electric, however, exhibited a rising share in this category, signaling delayed recoveries but improved capital inflows compared to earlier periods.

Table 8. Accounts Receivable Age Comparison Among Industry Peers (2023)

	Project	Within 1 Year	1 to 2 Year	2 to 3 Year	Above 3 Years	Total
Gree Electric Appliances, Inc.	Customer deliberately defaults on payment	1396908.03	139979.6 2	308953.7 3	308953.7 3	2154795 .11
	(%)	64.83%	6.50%	14.34%	14.34%	100.00%
Midea Group Co., Ltd.	Customer deliberately defaults on payment	3175857	94533	21058	24746	3316194
	(%)	95.77%	2.85%	0.64%	0.75%	100.00%
Haier Smart Home Co., Ltd.	Customer deliberately defaults on payment	715238098. 9	37807198 2.8	5324672 68.9	0	1625777 351
	(%)	43.99%	23.25%	32.75%	0.00%	100.00%
Industry Average	Customer deliberately defaults on payment	239936954. 6	12610216 5.1	1775990 93.6	111233.2 433	5437494 46.6
	(%)	68.20%	10.87%	15.91%	5.03%	100.00%

Notably, in the over-three-year aging category, Midea Group retained less than 1% of unrecovered funds, highlighting its stringent credit management. Haier Group reported no receivables in this category, confirming full capital recovery within three years. Conversely, Gree Electric's proportion in this segment remained consistent with the 2–3 year category, reflecting persistent challenges in recovering long-term receivables, which may impede operational flexibility.

Comprehensive evaluation indicates divergent strategies: Midea Group concentrates 90% of receivables within one year, ensuring high liquidity; Haier Group achieves full recovery within three years through phased capital inflows; Geee Electric, however, faces dispersed aging profiles, recovering only 84% of receivables within three years, with a significant proportion of overdue accounts lingering beyond this period, underscoring systemic risks in its credit management framework.

2.4. Accounts Receivable Management Challenges at Gree Electric

2.4.1. Overemphasis on Sales over Collections

To stabilize market share amid declining revenues (CNY 168.199 billion in 2020) and pandemic pressures, Gree adopted aggressive credit sales strategies, offering lenient payment terms to clients. This approach drove a 58.4% surge in accounts receivable balances by 2021 and increased reported profits. Sales incentives tied to revenue targets further incentivized credit sales, leading to a modest 2.9% revenue growth (CNY 198.153 billion in 2019 to CNY 203.979 billion in 2023) while accounts receivable as a percentage of revenue rose sharply from 4.26% to 7.89%. Although credit sales boosted short-term income, they amplified operational risks, including delayed collections, potential bad debts, and disrupted capital cycles.

2.4.2. Ineffective Collection Mechanisms

Accounts receivable balances escalated from CNY 8.44 billion in 2019 to CNY 16.099 billion in 2023, reflecting systemic inefficiencies in debt recovery. Gree relies on non-coercive methods such as written reminders and credit term adjustments, lacking a dynamic framework to analyze client-specific delinquency causes or deploy tailored recovery strategies. This rigid approach has resulted in suboptimal collection rates, deteriorating liquidity stability, and heightened bad debt exposure, undermining accounts receivable management objectives.

2.4.3. Flawed Credit Risk Management

The pandemic exacerbated liquidity strains among Gree's clients, eroding their creditworthiness. However, Gree's static credit monitoring system—updated periodically rather than in real-time—fails to adapt swiftly to evolving client risks. The absence of a proactive credit evaluation mechanism leaves the company vulnerable to delayed adjustments in credit policies, increasing the likelihood of uncollectible receivables. Prolonged exposure to high-risk accounts threatens both financial health and brand reputation.

2.4.4. Declining Capital Turnover Efficiency

Despite outperforming peers like Midea and Haier, Gree's internal capital turnover rate has deteriorated, dropping from 24 days in 2019 to 13 days in 2023. Extended receivable aging, slower collections, and deteriorating receivable quality signal shrinking working capital reserves. This trend raises concerns about liquidity constraints, diminished debt-servicing capacity, and long-term solvency risks.

2.4.5. Managerial Oversight in Receivables Governance

Post-2020 revenue declines prompted Gree to prioritize top-line growth through credit sales, neglecting the accelerating growth and scale of accounts receivable. Management's insufficient focus on receivables governance—evidenced by inadequate risk assessment frameworks and reactive rather than preventive strategies—has exacerbated systemic vulnerabilities. Without strategic reforms, this oversight may further strain operational resilience.

Gree's reliance on credit-driven growth, coupled with outdated collection practices and fragmented risk management, has created a high-risk receivables profile. Addressing these challenges requires integrating dynamic credit monitoring, diversifying recovery tactics, and recalibrating managerial incentives to balance sales expansion with financial prudence.

3. Recommendations and Mitigation Strategies

3.1. Regulating Credit Sales Ratios

When formulating credit sales strategies, companies must conduct cost-benefit analyses to evaluate both the potential gains and the associated risks. A scientifically calibrated approach should include:

Establishing Credit Sales Ceilings: Set rational upper limits for credit sales ratios based on historical accounts receivable-to-revenue trends, sales targets, and market conditions. Risk assessments should quantify profitability and risk tolerance under varying credit sales scenarios, enabling iterative adjustments to balance sales growth with risk containment. For instance, if accounts receivable exceed 7% of revenue (industry average), credit sales ratios should be reduced; ratios above 10% warrant a complete suspension of credit sales. Concurrently, optimize sales strategies by enhancing product quality or service offerings to attract cash-paying customers or introducing incentives for upfront payments.

3.2. Dynamic Adjustment Mechanisms

Gree Electric should adopt flexibility in revising credit sales ceilings in response to market fluctuations, client demands, and internal financial health. Examples include:

Raising credit sales ratios during periods of strong market demand to capitalize on growth opportunities; **Lowering ratios during market downturns** to mitigate liquidity risks.

Strengthening Credit Approval Protocols: Implement rigorous vetting processes for credit applicants, including verification of client creditworthiness, explicit terms (credit limits, repayment schedules), and enforceable penalties for defaults (e.g., liquidated damages). Execute credit agreements only with pre-qualified clients to safeguard corporate interests.

Periodic Evaluations: Conduct regular audits of credit sales ratios to ensure compliance with predefined thresholds. Proactively adjust strategies if ratios exceed safe limits or exhibit risk vulnerabilities.

3.3. Restructuring Debt Recovery Tactics

Leverage a centralized credit database to tailor recovery approaches based on client credit tiers and delinquency durations (see Table 9):

Low-Risk Clients (Good Credit History): Deploy non-confrontational approaches for minor delays, such as intensified reminders via calls, emails, or in-person visits to facilitate timely repayments.

High-Risk Clients (Poor Credit, Malicious Defaults): Escalate to legal actions, including litigation or asset seizure, to enforce debt recovery.

Third-Party Collaboration: Engage specialized collection agencies for persistently unresolved accounts to enhance recovery efficiency through professional expertise.

Table 9. Methods for Collecting Outstanding Accounts

Reason for Overdue	Overdue Duration	Collection Method
Temporary financial difficulties of customer	Within 90 days	Extend repayment deadline, information-based collection
Customer deliberately defaults on payment	Within 15 days	Phone collection
	16-60 days	Phone and verification collection
	60-180 days	Collection by company personnel
	180-360 days	Collection by third-party agency
	Over 360 days	Legal proceedings

3.4. Establishing a Dynamic Credit Database

Constructing a Client Credit Evaluation Model: Develop a credit scoring system incorporating ten weighted metrics—such as industry standing, historical repayment rates, and debt-to-asset ratios—using AI-driven analytics and the Analytic Hierarchy Process (AHP) to assign dynamic weights. This model enables real-time adjustments to credit risk assessments and continuous monitoring of receivables.

Data Integration and Updates: Integrate enterprise resource planning (ERP) or SAP systems to automate credit term alerts and client data updates (e.g., financial health, repayment capacity). For manual accounting systems, periodically refresh the database using regional credit trends, transaction histories, and repayment timelines.

Risk-Adaptive Policies: Terminate partnerships or shift to cash-only transactions with clients exhibiting deteriorating creditworthiness to reduce receivable balances and bad debt exposure.

Conversely, incentivize high-credit clients with preferential terms, such as extended credit limits, prolonged warranties, or waived deposits, to encourage timely repayments.

3.5. Optimizing Accounts Receivable Aging Structure

Prioritize Short-Term Receivables: Increase the proportion of receivables aged under one year to meet or exceed the industry benchmark of 68.2%. Prioritize partnerships with clients capable of full repayment within one year.

Reduce Long-Term Exposure: Gradually lower receivables aged over three years from 14.34% to the industry average of 5.03%, setting phased reduction targets.

3.6. Implementing Proactive Risk Mitigation Mechanisms

Early Warning System: Deploy an automated risk control mechanism triggered at 60 days overdue, initiating preemptive reminders and escalating to litigation if unresolved. Analyze aging profiles and delinquency durations to flag high-risk accounts for prioritized follow-up.

Payment Diversification: Offer flexible payment options (e.g., prepayments, cash-on-delivery, installment plans) to redistribute long-term receivables Above 3Years into shorter cycles (e.g., 1–2 years), thereby mitigating concentration risk.

3.7. Enhancing Organizational Awareness of Receivables Management

Sales Teams: Conduct regular training sessions to enforce strict adherence to credit sales policies, prohibiting excessive reliance on credit-driven sales to meet targets.

Management: Acknowledge the operational impact of receivables volatility. Engage financial professionals to design structured receivables management frameworks, aligning credit strategies with liquidity preservation goals.

4. Conclusion

This study analyzes Gree Electric's financial data from 2019-2023, identifying critical challenges in accounts receivable (AR) management, including excessive credit sales ratios and inefficient recovery processes. Proposed strategies emphasize regulating credit sales thresholds, establishing dynamic credit evaluation systems, and optimizing aging structures. Future research could further investigate the long-term financial health implications of AR management frameworks.

For Gree Electric, implementing a credit sales ceiling, coupled with AI and big data-driven real-time credit monitoring, offers a viable pathway to mitigate risks. A "credit scorecard" model tailored to manufacturing firms like Gree can automate risk controls, triggering alerts at 30 days overdue. Initial non-litigation recovery methods—such as on-site visits or formal written notices—should precede escalated actions. For persistent delinquencies, a "litigation-preservation + settlement negotiation" hybrid strategy, including asset freezes for malicious defaulters, is recommended. Additionally, adopting Midea Group's "reverse factoring" model demonstrates how supply chain finance can enhance AR turnover ratios by 15%, supported by collaborative

digital financing platforms with core suppliers. Partnering with third-party agencies under performance-based commission structures may further streamline long-term receivable management.

In summary, Gree Electric can curb AR growth and reduce bad debt risks by integrating credit sales caps, restructuring aging profiles, deploying data-driven credit databases, and balancing proactive policies with diversified recovery tactics. These measures collectively strengthen liquidity resilience while aligning with industry best practices.

Author contributions:

Conceptualization, J.G.; methodology, J.G.; software, J.G.; validation, J.G.; formal analysis, J.G.; investigation, J.G.; resources, J.G.; data curation, J.G.; writing—original draft preparation, J.G.; writing—review and editing, J.G.; visualization, J.G.; supervision, J.G.; project administration, J.G.; funding acquisition, J.G. All authors have read and agreed to the published version of the manuscript.

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Management Strategies for SMEs in the Era of Digital Transformation

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Abstract

Small and medium-sized enterprises (SMEs) are pivotal to economic growth, yet many struggle to navigate the ongoing wave of digital transformation. This paper provides an analytical overview of management strategies that enable SMEs to thrive in the digital era. The authors outline the opportunities digital technologies offer to SMEs — such as operational efficiencies, access to new markets, and resilience gains—alongside the challenges these firms face, including limited resources, skill gaps, and resistance to change. Drawing on recent literature (2019–2024), the authors identify critical factors for successful SME digital transformation and propose a structured approach for managers. Key strategies include developing a clear digital transformation roadmap aligned with business goals, investing in employee digital skills and a pro-innovation culture, leveraging external support (partnerships, platforms, and government initiatives), and fostering agility through continuous improvement and adaptation. This structured approach, grounded in dynamic capabilities theory, helps SMEs overcome resource constraints and uncertainty to achieve sustainable competitive advantage in the digital age. The findings offer practical guidance for SME managers and contribute to the academic discourse on how small businesses can effectively manage digital transformation in an ever-evolving technological landscape.

Keywords: SMEs; Digital Transformation; Management Strategy; Dynamic Capabilities; Innovation; Small Business; Organizational Change

1. Introduction

Digital transformation refers to the process of fundamentally rethinking business models and operations by leveraging digital technologies. It goes beyond mere digitization of analog processes; instead, it involves integrating technologies to create new value and transform the way an organization delivers that value. In recent years, digital transformation has emerged as both an opportunity and a necessity for firms of all sizes. For SMEs – which account for a significant

share of employment and innovation worldwide – embracing digital transformation is crucial to stay competitive and resilient. However, SMEs often lag behind larger enterprises in this domain. They face unique constraints in adopting advanced digital tools due to their smaller scale and resource limitations. The smaller the firm, the less likely it is to adopt new digital practices beyond basic usages, which widens the “digital gap” between SMEs and large firms as technologies become more sophisticated. On the other hand, SMEs that do embark on digital transformation can reap substantial benefits, such as improved efficiency, access to broader markets, and enhanced capacity for innovation.

The COVID-19 pandemic dramatically underscored the importance of digital readiness. During lockdowns and disruptions, many SMEs accelerated their use of online platforms and digital solutions to survive. Early evidence from global surveys indicates that up to 70% of SMEs intensified their digital technology usage as a direct response to COVID-19. This rapid digital transformation helped firms maintain operations and even discover new business models, prompting what has been called a “great acceleration” of digital transformation in the SME sector. Many of these changes are likely to endure, as both businesses and customers have recognized the efficiency gains and new opportunities enabled by digital tools.

At the same time, digital transformation poses non-trivial challenges for SMEs. Common barriers include insufficient infrastructure (e.g. lack of broadband connectivity), high initial costs and financing gaps, scarcity of digital skills, and uncertainty about return on investment. Organizational factors such as lack of a clear strategy and resistance to change also hinder progress. Managers of SMEs may be unsure how to formulate and execute a digital strategy under tight budgets and with limited expertise. Moreover, the heterogeneity among SMEs – in terms of size, sector, and capabilities – means a one-size-fits-all approach is ineffective. There is a need for tailored frameworks that outline how various factors (technology, human capital, organizational culture, external environment) interlink to drive successful digital transformation.

Recent research has begun to fill this need by proposing models and identifying critical success factors. For example, Ben Slimane et al. (2022) conducted a systematic literature review and developed an integrative framework of SME digital transformation factors. Similarly, frameworks like the four-level model by Garzoni et al. (2020) emphasize sequential stages from digital awareness to full transformation. These studies stress that effective digital transformation in SMEs requires both strategic planning and organizational capabilities. Managers must not only invest in technology but also foster the skills and flexibility needed to utilize it (often conceptualized as developing dynamic capabilities). However, scholarly work linking all these dimensions in practical terms remains limited (Kim & Jin, 2024). This article aims to contribute to this area by synthesizing recent insights into a coherent set of management strategies for SME digital transformation, in line with the DHSS journal’s focus on development in humanities and social sciences.

In the following sections, we first discuss the opportunities and challenges that digital transformation presents to SMEs (Section 2). We then propose key management strategies and best practices to facilitate SME digital transformation (Section 3), drawing on contemporary academic findings. Finally, we conclude with implications for SME managers and suggestions for

future research (Section 4). All discussions are supported by recent (2019–2024) English-language academic sources to ensure an up-to-date and evidence-based perspective.

2. Opportunities and Challenges in SME Digital Transformation

Digital transformation can significantly benefit SMEs by enhancing their efficiency, innovation, and market reach. By adopting digital tools, SMEs are able to streamline operations and reduce costs, as routine tasks become automated and processes optimized. For instance, cloud computing and software-as-a-service solutions allow small businesses to use sophisticated IT capabilities on a pay-per-use basis without heavy upfront investments, leveling the playing field with larger competitors. Digital technologies also open new market opportunities: SMEs can engage in e-commerce to reach customers beyond their local region and use social media or online marketplaces to expand their visibility. A study by Costa and Castro (2021) found that moving business operations online (such as adopting e-commerce) served as an “escape hatch” for SME survivability during the pandemic, helping firms remain resilient by accessing broader customer bases. Furthermore, digital platforms facilitate better collaboration and innovation. Even small firms can coordinate with distributed teams and partners across geographic distances using digital communication tools. This ability has been linked to higher innovation and performance; for example, SMEs that leverage big data analytics and social media show increased innovation capacity and improved performance outcomes. Digital transformation can also bolster organizational resilience. Research indicates that firms investing in digital capabilities were more adaptable and could recover faster during crises like COVID-19. Browder et al. (2024) describe how digital transformation “upgrades” a firm’s adaptive capacity, making it more resilient to disruptions. In summary, when successfully implemented, digital transformation allows SMEs to operate more efficiently, innovate continuously, and buffer against external shocks, thereby improving their long-term competitiveness and sustainability.

Despite these opportunities, SMEs encounter a range of challenges on the path to digital transformation. A fundamental hurdle is the resource constraint typical of smaller firms. Limited financial capital and IT infrastructure can make it difficult to invest in new technologies or hire specialized staff. High initial costs (e.g. for setting up advanced systems or purchasing software licenses) and uncertain returns create financial risk that many SME owners are hesitant to bear. In fact, access to financing for digital projects is a noted gap, as SMEs often lack the collateral or internal funds and may not qualify for large loans or grants easily. Another critical challenge is the digital skills gap. SMEs frequently report a deficiency in employees’ technical skills and a lack of in-house digital expertise. Unlike large firms, an SME might not have a dedicated IT department; thus, the burden of understanding and implementing new technologies falls on a small management team or the owner, who may not have sufficient digital literacy. Recent studies highlight that internal skills gaps and a lack of a “digital mindset” are major impediments to adopting advanced tools like data analytics or enterprise software. Employee resistance to change is closely related: staff may fear that automation and new systems could threaten their jobs or radically alter familiar routines, leading to reluctance or even active pushback against digital initiatives. Such cultural resistance, often stemming from insufficient digital awareness, can derail

transformation efforts if not proactively managed. Additionally, many SMEs do not have a clear digital strategy or roadmap. They may adopt technologies in an ad-hoc manner (for example, creating a website or social media page) without an overarching plan for integration into business processes. This lack of strategic direction can result in wasted investments or fragmented systems that fail to deliver expected benefits. Indeed, Pfister and Lehmann (2023) note that SME managers often struggle to measure the return on investment (ROI) of digital tools, which contributes to skepticism and hesitant adoption. Moreover, external barriers exist, such as infrastructural and ecosystem challenges. In some regions, SMEs still suffer from poor broadband internet availability or low interoperability of digital systems, limiting what technologies can be used effectively. There are also concerns about cybersecurity and data privacy – SMEs typically have lower cybersecurity maturity and can be more vulnerable to digital threats. Many small businesses underestimate these risks; yet as they pursue digital transformation, they face increased exposure to cyberattacks, which can be devastating given their limited resources to respond. Fear of such threats, and uncertainty about legal responsibilities (e.g. data protection compliance), can make SME owners cautious about digital transformation.

Overall, the challenges SMEs face in digital transformation are multifaceted, involving internal resource and capability gaps as well as external constraints. Table 1 summarizes some of the key challenges identified in recent studies and outlines strategic responses that SMEs can adopt to address them. Recognizing these challenges is a prerequisite to formulating effective management strategies, which we will discuss in Section 3.

As Table 1 indicates, many challenges can be mitigated through thoughtful management actions. For example, while SMEs inherently have fewer resources, they can compensate by utilizing flexible, pay-per-use technologies and tapping into external support systems (such as government programs or industry partnerships) designed to aid small businesses in their digital transformation efforts. Skill deficiencies can be addressed by nurturing talent internally and bringing in expertise from outside. Cultural resistance can be overcome by strong internal communication and demonstrating quick wins of digital adoption to skeptics. Not having a strategy is a challenge entirely within an SME's control to fix – by dedicating time to planning and setting clear objectives, even a resource-constrained firm can create a roadmap that guides incremental progress. Finally, proactively managing digital risks (even with limited means) is crucial; basic cyber-hygiene and cautious use of technology go a long way in preventing incidents that could undermine trust in digital systems.

In the next section, we build on these insights to lay out management strategies for SMEs to navigate digital transformation successfully. These strategies are framed to be practical and actionable, targeting the challenges above and leveraging the opportunities digital technologies offer. We integrate concepts from recent research such as dynamic capabilities, which highlight the importance of agility and continuous learning for SMEs in turbulent environments. By adopting these strategies, SME managers can create an environment where digital transformation initiatives are more likely to succeed and deliver sustainable competitive advantages.

Table 1. Challenges and Strategic Responses in SME Digital Transformation

Challenge	Strategic Response
Limited resources (financial and IT infrastructure)	Leverage affordable cloud services and scalable solutions (reducing upfront IT costs); seek government digitalization grants or partner with larger firms to share resources.
Digital skill gaps in workforce	Invest in employee training and upskilling programs; recruit tech-savvy talent or engage external IT consultants to support implementation of complex digital tools.
Resistance to change and lack of digital mindset	Cultivate a pro-digital culture through strong leadership and change management; clearly communicate the benefits of digital tools, involve employees in the process, and provide incentives for adoption.
Absence of a clear digital strategy	Develop a formal digital transformation roadmap aligned with business goals; set incremental milestones and KPIs to guide implementation and measure ROI, adjusting the strategy based on feedback (adaptive planning).
Cybersecurity and data privacy concerns	Implement basic cybersecurity measures (firewalls, anti-malware, data backups) and staff training on digital hygiene; use trusted, certified platforms and consider obtaining cybersecurity insurance or certifications to build stakeholder trust.

3. Management Strategies for SME Digital Transformation

Successfully managing digital transformation in an SME requires a holistic approach that combines strategic planning, organizational development, and agile execution. Rather than a one-off project, digital transformation should be viewed as an ongoing, cyclical process of improvement. Managers need to guide their firms through iterative phases: building awareness and knowledge, planning and prioritizing investments, implementing digital solutions, and continuously refining and updating their approach. This section presents several key strategies derived from recent studies and practical experiences, organized into four broad areas: (1) establishing a digital transformation roadmap, (2) building digital capabilities (skills and culture), (3) leveraging external resources and partnerships, and (4) fostering agility and continuous improvement. These areas correspond to the interrelated elements that many scholars consider crucial for SME digital transformation. For instance, a recent framework by Kahveci (2025) proposes that SMEs progress through stages of Digital Awareness, Digital Strategy and Roadmap, Digital Adoption and Implementation, and Digital Transformation Continuous Improvement in a cyclic manner. This underscores that transformation is not linear – SMEs must loop through learning and adapting continuously to truly embed digital change.

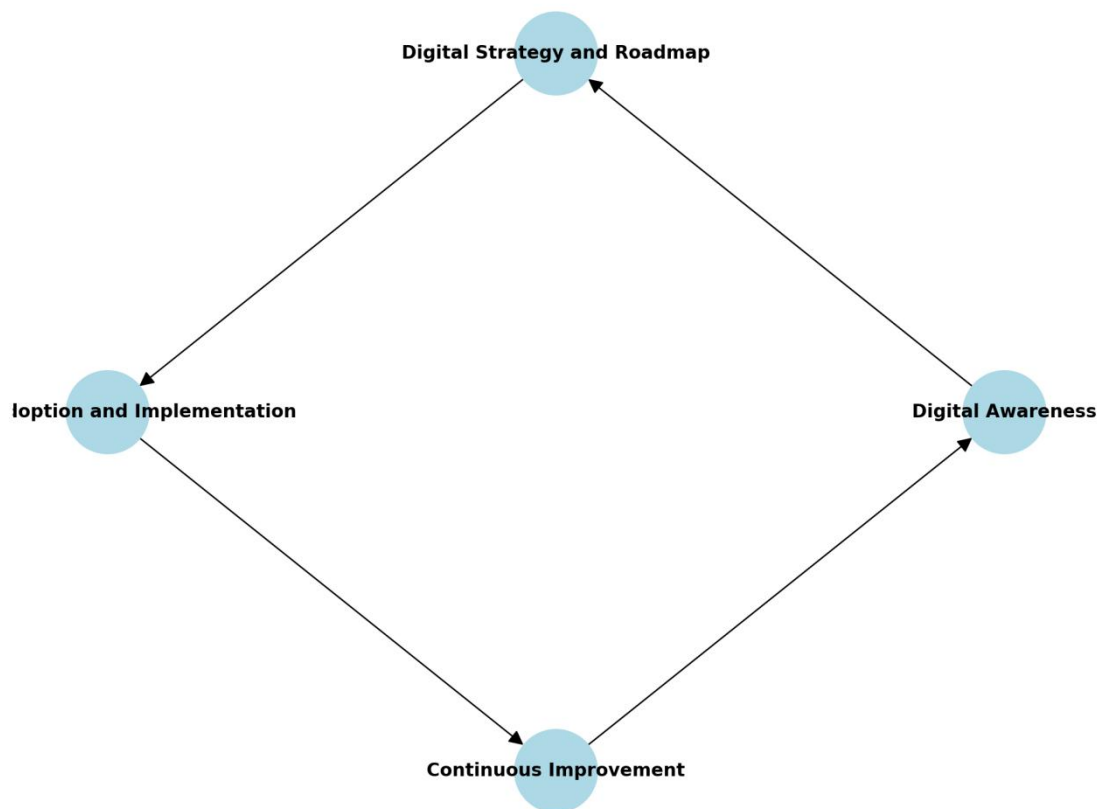


Figure 1. Cyclical SME Digital Transformation Process

A conceptual framework illustrating a cyclical SME digital transformation process with four interrelated stages: building digital awareness, formulating a digital strategy and roadmap, adopting and implementing digital solutions, and pursuing continuous improvement. This cycle emphasizes that SME digital transformation is an iterative journey requiring ongoing learning and adaptation, rather than a one-time effort.

As shown in Figure 1, effective SME digital transformation involves a repeating cycle of planning, action, and evaluation. In the subsections below, we delve into each major strategic area and provide recommendations, supported by current research. These strategies aim to help SME managers overcome the challenges identified earlier (Section 2) and capitalize on the benefits of digital technology in a structured way.

3.1. Develop a Clear Digital Transformation Roadmap

The first cornerstone of managing digital transformation is to formulate a clear strategy and roadmap. Many SMEs fail to progress in their digital initiatives due to ad-hoc or piecemeal efforts that lack alignment with their overall business goals. Therefore, owners and managers should begin by defining a digital vision for the company – i.e., how they see digital tools enhancing their value proposition or operations in the long term. This vision can then be translated into a concrete plan or roadmap.

3.1.1. Assess the Current State

Evaluate the firm's existing processes, technology usage, and digital maturity. Identify pain points or inefficiencies in the business that digital solutions could address (for example, slow

manual inventory tracking, limited sales channels, etc.). Tools like digital maturity models or audits can help pinpoint areas of need.

3.1.2. Set Goals and Priorities

Clearly outline what the SME aims to achieve through digital transformation. Goals might include increasing sales by reaching new online markets, improving customer satisfaction via data analytics, or reducing costs through process automation. Prioritize these objectives based on potential impact and feasibility. It's often recommended to start with some "quick wins" – small projects that demonstrate value – to build momentum and buy-in within the organization.

3.1.3. Define Initiatives and Timeline

For each goal, define specific digital initiatives or projects. For instance, if the goal is to expand market reach, an initiative might be to launch an e-commerce platform or digital marketing campaign. Set a realistic timeline and milestones for these initiatives. A phased approach is prudent for SMEs: implement changes incrementally rather than attempting a massive overhaul all at once. This reduces risk and allows learning along the way.

3.1.4. Align with Business Strategy and Budget

Ensure the digital roadmap is integrated with the broader business strategy. Digital transformation should support the overall mission and competitive strategy of the SME, not exist in a vacuum. It's also crucial to create a budget for digital initiatives, accounting for costs of hardware, software subscriptions, training, and possibly hiring. Given resource constraints, SME managers might allocate a certain percentage of revenue or investment funds annually to digital projects, and seek external funding where available (loans, grants, innovation vouchers, etc.).

3.1.5. Include KPIs and Monitoring

Establish key performance indicators (KPIs) to track progress and outcomes of digital initiatives. These could be metrics like percentage of sales online, improvement in process time, customer engagement levels, or financial metrics like return on digital investment. Regularly monitoring these KPIs allows the SME to adjust its roadmap. As Pfister and Lehmann (2023) highlight, measuring the ROI of digital technology helps justify the efforts and guides decision-making on continuing or pivoting strategies.

A well-crafted digital roadmap serves as a blueprint for transformation. It provides direction and helps coordinate efforts across the company. Research has shown that SMEs with formal digital strategies tend to perform better in their transformation efforts. For example, a recent study of SMEs in Palestine demonstrated that applying strategic planning principles to digital transformation (guided by dynamic capabilities) significantly improved readiness and outcomes. The roadmap should be revisited periodically (e.g., annually) and updated as needed, since technology and market conditions evolve rapidly. In summary, planning is half the battle: by knowing where they want to go and how to get there, SME managers can allocate resources wisely and avoid aimless experimentation. This strategic foundation also makes it easier to communicate the purpose of digital initiatives to employees and other stakeholders, which is essential for gaining their support (as discussed next).

3.2. Build Digital Capabilities: Skills, Culture, and Leadership

Digital transformation is as much about people and culture as it is about technology. SMEs need to build internal capabilities – particularly human skills and an organizational culture conducive to innovation – to fully leverage new digital tools. This strategy area encompasses developing employees' digital skills (digital literacy), fostering a supportive culture, and strong leadership commitment.

Invest in employee training and digital literacy: One of the striking challenges for SMEs is the lack of in-house digital expertise. Addressing this starts with assessing the current skill levels of staff and determining what skills are needed for planned digital initiatives. Managers should invest in training programs to upskill employees, ranging from basic digital literacy (e.g. using office productivity software, understanding data security practices) to more advanced competencies (like data analytics, digital marketing, or e-commerce management) relevant to the business. Training can be done through workshops, online courses, or peer learning sessions. Importantly, training should not be a one-time event; continuous learning must be encouraged. As part of building digital literacy, awareness is key – employees need to understand not just how to use specific tools, but also the broader benefits of digital transformation for the company and their own work. Studies define digital literacy broadly as the ability to effectively use digital resources to solve problems, create new knowledge, and communicate, coupled with an attitude open to change. By raising digital literacy, SMEs empower their workforce to embrace new systems rather than fear them. For example, Hasyim and Bakri (2024) note that providing employees with proper training and involving them in digital adoption can significantly reduce resistance and build a sense of ownership in the change process. In some cases, SMEs may also consider hiring new talent or consultants for critical skill gaps. Bringing in an IT specialist or a digital marketing expert, even on a part-time or contract basis, can accelerate the learning curve and ensure proper implementation of complex technologies.

Foster a pro-digital organizational culture: Technical skills alone are not sufficient; the organizational mindset must also evolve. SME leaders should work to create a culture that values innovation, experimentation, and continuous improvement. This involves encouraging employees to suggest and pilot new ideas, and not punishing failures that are part of the learning process. Communication from management should consistently reinforce the message that digital transformation is a strategic priority for the company's future, not just a fad. One effective practice is to share success stories (even small ones) internally – for instance, if adopting a new software reduced manual work and errors in order processing, celebrate that win and quantify the improvement. This helps skeptical team members see tangible benefits. According to change management principles, involving employees in the transformation (such as through cross-functional teams to implement a new system) can increase buy-in and reduce fear of the unknown. Also, addressing employee concerns – for example, by clarifying that automation will free them for higher-value tasks rather than eliminate their jobs – is crucial. Leadership plays a central role here: SME owners and managers must lead by example, demonstrating openness to learning new technologies themselves and using data in decision-making. A recent study by Gyamerah et al. (2025) found that strong leadership and a clear digital strategy together create a favorable context

for SME digital transformation, as leadership drives the development of digital capabilities and aligns them with business strategy. In practice, this means leaders should champion digital initiatives, allocate time and resources to them, and remain patient yet persistent through the inevitable challenges.

Promote agility and teamwork: A cultural aspect particularly beneficial to digital transformation is organizational agility – the ability to rapidly adapt and respond to changes. By promoting agile ways of working (such as small, multi-skilled teams, short development cycles, and frequent feedback loops), SMEs can implement and iterate digital solutions faster. For example, instead of a long, rigid IT project, an SME might break it into smaller phases, test each phase, and adjust the next phase based on lessons learned. This agile mindset should be cultivated across the company. Employees at all levels ought to feel comfortable with change and uncertainty, viewing them as opportunities to learn. Bai, Um & Lee (2023) emphasize that firm agility has a strategic role in translating IT capability into performance gains, especially under disruptive conditions like the COVID-19 outbreak. Agile SMEs were better able to pivot to new digital business models or processes when the environment suddenly shifted. Thus, agility is both a cultural and a procedural asset.

In sum, building digital capabilities in an SME means investing in people – through training, cultural change, and visionary leadership. This human-centric approach addresses the soft challenges (skills deficits, resistance) that often impede technology adoption. An SME with a knowledgeable, motivated, and adaptable workforce is far more likely to succeed in its digital transformation efforts. Such a workforce will not only implement new systems effectively but also help in identifying the right technologies and innovating new solutions that management alone might not envision.

3.3. Leverage External Support and Partnerships

SMEs do not have to navigate digital transformation alone. An important strategy is to leverage external resources, partnerships, and support networks to compensate for internal limitations. Because SMEs generally have fewer in-house capabilities, tapping into the broader ecosystem can provide access to technology, knowledge, and financing that would otherwise be out of reach.

One avenue is participating in government and institutional programs aimed at SME digitalization. In many countries, public agencies and industry associations offer training, funding, or advisory services for SMEs to adopt new technologies. Examples include government grants or subsidies for purchasing IT equipment, tax incentives for research and development, and free or subsidized workshops on e-commerce, cybersecurity, etc. OECD (2021) notes that enabling SME digitalization has become a top policy priority, leading to a mix of initiatives such as awareness campaigns, one-stop digital resource centers, and innovation hubs to support small businesses. SME managers should actively seek out these opportunities. Even something as simple as attending a government-sponsored digital training can spark new ideas and connect the firm to useful contacts. Additionally, SMEs can utilize external consultants or technology providers for expertise. Engaging a consultant to help craft a digital strategy or implement a complex system (like an ERP or data analytics platform) can ensure the job is done right and transfer knowledge to

the internal team. Many tech providers have special programs or pricing for SMEs, and some incubators or universities run digital clinics for local businesses.

Another powerful approach is forming partnerships and networks with other companies. SMEs can collaborate with both peers and larger companies to mutual benefit. For instance, an SME might partner with a tech startup to pilot an innovative solution in its business, giving the SME early access to cutting-edge tech and the startup a real-world testbed. Or small manufacturers might form a consortium to jointly invest in a digital platform that none could afford individually. Partnering with large firms in the value chain (such as suppliers or customers) can also drive digital uptake – sometimes large corporations offer their SME suppliers digital tools or require electronic data interchange, indirectly pulling SMEs into the digital realm. Research by Appio et al. (2024) highlights the value of open innovation at the digital frontier: SMEs that collaborate externally can overcome resource constraints and access new knowledge, but they must navigate certain paradoxes (like sharing knowledge vs. protecting their IP). The general finding is that openness – engaging with external partners, whether through formal partnerships, participating in innovation ecosystems, or even informal peer networks – correlates with better digital transformation outcomes for SMEs. Through collaboration, SMEs can learn best practices, avoid common pitfalls, and perhaps even influence the development of technologies to better suit their needs.

Utilizing digital platforms and marketplaces is another external strategy that has become essential. By joining established e-commerce marketplaces (for selling products) or B2B platforms (for sourcing and distribution), SMEs can digitalize significant parts of their operations with relatively low effort. These platforms often provide built-in tools for payments, logistics, and customer relationship management, which can jump-start an SME's digital presence. For example, an SME retailer that sets up shop on a major e-commerce site immediately gains exposure to a large customer base and can use the platform's analytics to gather insights, instead of building an independent online store from scratch. Similarly, embracing social media and third-party online marketing channels allows SMEs to leverage the vast infrastructure of tech companies to reach customers. Fauzi and Sheng (2022) argue that the broader institutional environment – including normative pressures and support systems – plays a role in how SMEs digitalize. In some developing contexts, for instance, SMEs accelerate digital adoption when there is an ecosystem of micro-entrepreneurs doing business on social media platforms, which creates a network effect and learning by example.

Finally, SMEs should be mindful of external trends and emerging technologies that could impact their industry. Keeping informed through trade publications, conferences, or academic-industry collaborations can help a small firm anticipate changes (like the rise of artificial intelligence or Internet of Things in their sector) and prepare accordingly. While an SME might not have a dedicated R&D department, it can still experiment on a small scale with emerging tech by partnering with universities or participating in pilot programs offered by tech firms. For example, some SMEs have partnered with local universities to test AI-driven production scheduling or to explore blockchain for supply chain transparency, gaining early mover advantages.

In summary, the message for SME managers is: don't go it alone. By reaching outward, they can unlock resources and knowledge far beyond their internal means. Whether through government support, alliances with other firms, or integration into digital ecosystems, leveraging external support helps SMEs overcome limitations in expertise, scale, and capital. It also situates the SME within a community of practice, which can be invaluable for morale and problem-solving – managers often find it encouraging and enlightening to learn how peers tackled similar digital challenges.

3.4. Foster Agility, Continuous Improvement, and Dynamic Capabilities

The final strategic pillar is cultivating the ability to adapt and continuously improve in the digital transformation journey. As technologies and markets evolve rapidly, especially in today's environment, SMEs must remain flexible and ready to adjust their digital strategies. This agility is underpinned by what scholars call dynamic capabilities – the firm's capacity to sense opportunities or threats, seize them by reconfiguring resources, and transform itself accordingly. Building such capabilities ensures that digital transformation is not a one-off initiative, but an ongoing process where the SME keeps upgrading its tools and approaches to sustain competitive advantage.

Several practices contribute to continuous improvement:

Implement projects in iterative cycles: Instead of treating each digital investment as a fixed endpoint, SMEs should approach them in iterative cycles (much like the Plan-Do-Check-Act cycle). For example, after deploying a new customer relationship management (CRM) software, the team should monitor how it's used, collect feedback from employees, measure impacts (like improved sales tracking or customer retention), and then refine the system configuration or provide additional training as needed. This iterative mindset aligns with agile project management and ensures that technologies are actually delivering value and being adopted properly. One useful technique is running small experiments or pilot programs before full-scale implementation. An SME can pilot an e-commerce site with a subset of products or trial a new manufacturing IoT sensor on one production line, then evaluate results before scaling up. These experiments provide learning opportunities with contained risk.

Measure and communicate quick wins: Quick wins are the small improvements gained early on, which should be measured (as per the KPIs in the roadmap) and celebrated. For instance, if an automation tool reduces order processing time by 30%, managers should publicize this internally (and even externally in marketing, if relevant). Communicating such wins reinforces the positive feedback loop: it shows employees that the effort is worthwhile and shows management that the transformation is yielding returns, which in turn builds support to continue investing. Measuring outcomes rigorously also helps in refining strategies – by analyzing which initiatives worked well and which did not, SMEs can make data-driven decisions about their next steps. This practice resonates with Pfister & Lehmann's (2023) emphasis on ROI: tracking the benefits of digital initiatives allows SMEs to allocate resources to the most impactful areas and address issues where expected returns are not realized.

Embed a learning culture and resilience: Dynamic capabilities essentially boil down to learning and adaptation. SMEs should create mechanisms for organizational learning regarding digital transformation. This could mean regular debrief meetings after implementing a tech project (to capture lessons learned), documenting best practices, or having employees who attend external training share their knowledge with the rest of the team. Over time, these learning processes make the organization more adept at handling change. The concept of resilience is also relevant – the ability to absorb shocks and come out stronger. Annarelli and Palombi (2021) propose that developing digitalization capabilities contributes to cyber-resilience, allowing firms to sustain operations and quickly recover in the face of disruptions or cyber incidents. By planning for contingencies (e.g., having data backups, alternative suppliers, flexible work arrangements) and practicing how to respond to digital risks, SMEs can ensure that their increasing reliance on digital technologies does not expose them to catastrophic failures. The COVID-19 period was a clear test: those SMEs that had digital channels and flexible processes in place could pivot (for example, switching to online sales or remote work) far more easily than those starting from scratch. Thus, agility and continuous improvement directly tie into being resilient against future crises.

Develop strategic flexibility and sensing: On a more strategic level, SME managers should continuously scan the environment for new digital trends, changing customer behaviors, and competitor moves. This external sensing is part of dynamic capability – being alert to signals that might necessitate a change in strategy. For instance, if a new online marketplace is rapidly gaining popularity among the SME’s target consumers, it might be wise to establish a presence there early. If a competitor launches a successful mobile app for service delivery, the SME should evaluate if a similar move is needed to keep up. Strategic flexibility also means not getting locked into rigid systems or contracts that limit future adaptability. SMEs might prefer modular technologies and scalable solutions that can grow or change with the business. For example, using cloud-based software on monthly subscriptions can be more flexible than investing in an expensive on-premise system that might become outdated; the SME can switch or upgrade tools as better options emerge.

Feedback and customer-centric adaptation: Continuous improvement should be strongly informed by feedback, especially from customers. SMEs have the advantage of often being closer to their customers than large corporations, so they can solicit and act on feedback more nimbly. Using digital tools (surveys, social media engagement, data analytics on customer behavior), an SME can learn what customers value or where they encounter friction. Adaptation might then involve tweaking the SME’s digital offerings, user experience, or even adding new digital services that customers demand. In the digital age, customer expectations evolve quickly – for example, expectations for 24/7 availability or seamless online service. SMEs need to iterate their approaches to meet these expectations, which often means integrating new features or channels over time. Keeping a customer-centric focus ensures that digital transformation efforts translate into actual business value (better customer acquisition, satisfaction, and retention).

By fostering an agile, learning-oriented environment, SMEs essentially future-proof their digital transformation. They move away from a static mindset (“we installed a new system, we’re

done”) to a dynamic mindset (“we’re always improving our digital capabilities”). El Idrissi et al. (2023) show that this kind of dynamic capability – blending flexibility, adaptability, and agility – is vital for organizations to weather turbulent times and seize opportunities that arise from change. Moreover, this approach helps SMEs maintain competitive advantage. As technology cycles shorten and business environments become more volatile, the winners are often not those with the deepest pockets, but those who can learn and pivot the fastest. In fact, digital transformation itself can be seen as a continuous capability: the ability to keep transforming as new digital possibilities emerge. SMEs that internalize this principle will not only catch up to larger firms, but potentially leapfrog and innovate in ways that create new markets and value.

To illustrate, consider a small retail business that embarked on digital transformation by setting up an online store and adopting a point-of-sale analytics system. If the management follows the strategies above, they would periodically review the online store’s performance, gather customer feedback, and perhaps discover that most customers are now using mobile devices. An agile response would be to optimize their website for mobile or develop a simple shopping app. They might also observe data showing certain products are selling nationally beyond their local region – prompting them to adjust inventory and marketing to serve that broader market. All the while, they train their staff to handle online customer inquiries and invest in a cybersecurity checkup to protect the growing e-commerce revenue. This hypothetical SME would be practicing continuous improvement and strategic agility, thereby staying ahead of the curve and reinforcing the gains from their initial digital investments.

In conclusion, fostering agility and continuous improvement ensures that an SME’s digital transformation remains effective and relevant over time. It operationalizes the idea that transformation is not a destination but a journey. By continuously sensing, learning, and adapting, SMEs can sustain the momentum of change and drive ongoing performance improvements long after the first wave of digital tools has been implemented. This is the essence of developing dynamic capabilities for the digital age – something that is increasingly seen as the key to long-term success for businesses of all sizes.

4. Conclusion

Digital transformation offers both tremendous opportunities and daunting challenges for small and medium-sized enterprises. In this article, we have examined how SMEs can strategize and manage their digital transformation journey to harness benefits such as improved efficiency, innovation, market expansion, and resilience. Through an analysis of recent academic literature (2019–2024) and practical examples, several key themes emerged. First, planning and strategy are critical – SMEs should develop clear digital roadmaps aligned with their business objectives, rather than adopting technology for technology’s sake. A well-defined strategy helps in prioritizing initiatives and allocating scarce resources effectively. Second, the human factor is paramount: building digital capabilities within the organization (upskilling employees, fostering a supportive culture, and ensuring leadership commitment) lays the groundwork for any technological change to take root. Third, SMEs should actively leverage external networks and

supports, from government programs to partnerships and digital platforms, to compensate for their limited internal resources. This external orientation allows small firms to punch above their weight by accessing new knowledge, infrastructure, and funding. Fourth, and perhaps most importantly, is adopting an agile and continuous improvement approach. The digital landscape is continuously evolving, and SMEs that inculcate dynamic capabilities – the ability to sense changes, seize new opportunities, and reconfigure their operations – will be better positioned to sustain competitive advantages. Continuous learning and adaptation mean that digital transformation in an SME is not a one-time project but an ongoing management practice.

Notably, many of the strategies discussed reinforce each other. For instance, having a clear strategy (Section 3.1) makes it easier to engage external partners (Section 3.3) because the SME can articulate its needs, and it helps define what skills to train employees in (Section 3.2). Building a pro-digital culture internally encourages staff to make the most of external learning opportunities and to participate in continuous improvement loops. Agile experimentation on a small scale can inform larger strategic decisions. In essence, successful SME digital transformation requires a balanced, integrative approach covering technology, people, and processes.

From a scholarly perspective, this article contributes to understanding SME digital transformation by collating recent findings into a cohesive framework. We ensured to include diverse academic sources – from international journal studies to OECD reports – to capture a broad view of the current state of knowledge. At least 15 references from the last five years were incorporated to ground each point in evidence. One limitation of our discussion is that specific industry contexts could not be exhaustively addressed; the relevance of certain strategies may vary for, say, a manufacturing SME versus a service-oriented SME. Future research could delve deeper into industry-specific digital transformation roadmaps or examine case studies of SMEs that have successfully undergone transformation, to extract more nuanced lessons. Additionally, as new technologies like artificial intelligence, blockchain, and advanced robotics become more accessible, examining how SMEs can adopt these frontier technologies will be a valuable extension. Early indications suggest that even small firms can benefit from AI for customer service or data analytics, provided they follow many of the strategies outlined (skills training, external partnerships, etc.). Thus, the principles discussed here are likely to remain pertinent as the digital era progresses.

For SME managers and practitioners, the key takeaway is that digital transformation is manageable and achievable with the right strategies, even under the typical constraints of a smaller enterprise. By being deliberate in planning, investing in their people, reaching out for help, and staying adaptable, SMEs can turn digital disruption into a source of competitive strength. Importantly, digital transformation should be seen not just as adopting new tech tools, but as an organizational evolution – a chance to rethink how the business creates value in the modern economy. SMEs often have advantages of agility, closer customer relationships, and less bureaucracy compared to larger firms; these advantages can be leveraged to implement changes faster and more closely tailored to customer needs. Cases from the literature show that SMEs that embraced digital transformation often discover new opportunities: from traditional local

businesses finding global niche markets online, to manufacturers using data to offer value-added services, to small firms collaborating through digital platforms to take on larger projects collectively.

In closing, management strategies play a decisive role in whether an SME's digital transformation will flounder or flourish. Technology itself, while important, is only one piece of the puzzle. Visionary yet pragmatic leadership, an engaged and capable workforce, and strategic use of external linkages are the ingredients that truly drive transformation success. SMEs that integrate these elements stand to not only survive in the era of digital disruption but to innovate and thrive, contributing dynamically to economic and social development. The era of digital transformation is here to stay, and with sound management strategies, even the smallest of enterprises can be part of this digital future.

Author Contributions

Conceptualization, K.L.; methodology, K.L.; literature review and data curation, K.L.; formal analysis, K.L.; writing—original draft preparation, K.L.; writing—review and editing, K.L.; visualization (figures and tables), K.L.; supervision (peer debriefing and guidance from mentors, acknowledged below), K.L. The author has read and agreed to the published version of the manuscript.

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Conflicts of Interest

The author declares no conflict of interest. This article was prepared in the author's academic capacity and is independent of any specific company or proprietary AI product. All views expressed are those of the author.

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Interactive Dynamics of Bullet Comments in Agricultural Livestreaming: A Dual-Path Analysis of Conversion Efficiency in Rural China

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Abstract

Live-streaming e-commerce is becoming a pivotal tool for promoting agricultural products and supporting rural revitalization in China. This study investigates the determinants of conversion efficiency-measured as Goods per Mille Views (GPM)-through a large-scale analysis of 70,650 agricultural livestream sessions on Douyin. Employing two-way fixed-effects panel regression and Bootstrap-based structural equation modeling (SEM), we examine how Retention Rate, Sales Amount, and Sales per Minute influence GPM. A key contribution of this study is the identification of a dual-path moderating effect of bullet comments (BulletCount), which can simultaneously enhance and hinder conversion depending on the context of viewer engagement. SEM results further uncover four significant mediation mechanisms-via Traffic Ratio, Retention Rate, Sales Amount, and Sales per Minute-through which bullet comments affect GPM. These findings offer new insights into the cognitive and social dynamics of interactive livestreaming. The study provides practical implications for platform designers, streamers, and policymakers seeking to improve conversion outcomes and foster sustainable rural e-commerce ecosystems.

Keywords: Live-streaming E-commerce; Conversion Efficiency; Bullet Comments; Rural Revitalization; User Engagement

1. Introduction

Digital infrastructure and mobile internet technologies drive market integration, reducing distribution bottlenecks in rural revitalization. In agriculture, this trend addresses longstanding challenges such as overstocked produce and limited market access faced by smallholder farmers, who often lack direct sales channels despite the expansive reach of large e-commerce platforms. Agriculture-themed livestreams enable rural producers, cooperatives, and local governments to bypass traditional intermediaries, connecting directly with consumers through real-time video commerce. This innovative model reduces distribution bottlenecks and enhances market

integration, playing a crucial role in China's rural revitalization strategy that emphasizes modernization and digital transformation of rural industries.

Live-streaming e-commerce facilitates high-frequency interactions and lowers entry barriers while building consumer trust via authentic, place-based representations of agricultural production. However, although the macroeconomic benefits of rural live commerce are recognized, its micro-level conversion mechanisms remain underexplored. Viewer engagement metrics, particularly interactive features like bullet comments (BulletCount), have garnered interest but lack rigorous empirical assessment of their causal effects on conversion efficiency. Agricultural livestreaming uniquely combines severe information asymmetry, pronounced seasonality, and high trust requirements, complicating the purchase decision process. BulletCount may simultaneously act as social proof and urgency signal while imposing cognitive load or distracting viewers, leading to complex, potentially contradictory impacts on sales outcomes.

Understanding how interactive elements influence consumer behavior in this context is vital. Social proof theory suggests that visible interactions like BulletCount can enhance perceived product popularity and trust, boosting conversions. Conversely, cognitive load theory warns that excessive interaction may overwhelm viewers, reducing attention and impairing decision-making. Integrating these perspectives within a stimulus-organism-response (S-O-R) framework enables a holistic analysis of how BulletCount shapes buyer cognition and behavior in agricultural livestreams.

To fill this gap, this study proposes a comprehensive econometric framework integrating two-way fixed-effects panel regression and Bootstrap-based structural equation modeling (SEM). Using a dataset of 70,650 Douyin livestream sessions from 440 agricultural streamers, we investigate the direct, moderating, and mediating effects of BulletCount on Goods per Mille Views (GPM). Our results identify four significant indirect pathways, demonstrating BulletCount's dual role as both catalyst and constraint in the conversion funnel. This research contributes by deepening behavioral insights into interactive dynamics in live commerce, advancing theory through integration of social proof, cognitive load, and stimulus-organism-response (S-O-R) frameworks, and offering practical guidance for platform design and rural e-commerce development.

Furthermore, the findings hold implications beyond agriculture, shedding light on the broader role of real-time interaction in digital commerce ecosystems. By revealing how user-generated engagement can both enhance and inhibit conversion efficiency, this study informs platform moderators, content creators, and policymakers aiming to optimize interactive features for improved economic outcomes. Ultimately, the research supports the sustainable growth of digital rural markets by balancing technological innovation with user experience and trust-building strategies.

This paper proceeds in several integrated stages. Section 2 distils the interdisciplinary literature on rural revitalisation, live-stream conversion, and bullet-screen interaction into a three-pillar analytical framework centred on income dynamics, multidimensional deprivation, and policy interventions. Section 3 constructs a theoretically grounded research model that combines Social

Proof Theory, Cognitive Load Theory, and the Stimulus-Organism-Response (S-O-R) paradigm. Section 4 details the two-way fixed-effects panel regression and bootstrap-based SEM used to test hypotheses on 70,650 Douyin agricultural livestreams, after rigorous checks for reliability, validity, and endogeneity. Section 5 presents elasticity estimates of the drivers of GPM and formally examines the dual moderating and four-path mediating roles of bullet-comment density. Section 6 contrasts these findings with extant poverty and conversion studies, explicating how traffic, retention, sales volume, and sales velocity behave heterogeneously across high- and low-comment regimes. Section 7 and section 8 offer actionable prescriptions for optimising comment pacing, platform algorithms, and rural-streamer training, while outlining future research on cross-platform generalisability, qualitative comment semantics, and longitudinal experimentation.

2. Literature Review

2.1. Live-streaming E-commerce and Rural Revitalization

Live-streaming e-commerce has rapidly evolved from an entertainment-driven practice to a disruptive force in the digital economy. Zhang (2023) highlights how it blends real-time interaction with commercial transactions, while Guan et al. (2024) and Huang et al. (2025) emphasize its potential in dismantling traditional distribution barriers and connecting rural producers directly with urban consumers. In China, the alignment of livestreaming with agricultural product sales reflects broader national policies on “digitally enabled rural revitalization”.

Despite these advances, most prior research remains macro-level and descriptive. For instance, Tong et al. (2025) praise livestreaming for raising farmers’ marginal income, but they do not address the micro-level mechanisms that drive sales efficiency and conversion. Specifically, agricultural livestreaming introduces distinctive challenges absent from generic e-commerce: (1) Perishability, which heightens urgency and makes scarcity cues (“last 50 kg!”) more impactful; (2) Traceability, where viewers rely on live Q&A and social proof to assess authenticity; and (3) Trust deficits, where anchors’ rural identity and local reputation become decisive signals of credibility. These features indicate that agricultural livestreaming is not merely a subset of e-commerce, but a unique context where engagement mechanisms require re-examination.

This study builds on such insights by analyzing engagement-driven performance variables (e.g., bullet comments, retention, sales momentum) to move beyond descriptive accounts and provide an evidence-based micro-analytical framework.

2.2. Toward a Nuanced Understanding of Conversion in Livestreaming

Traditional e-commerce metrics such as Click-Through Rate (CTR) and Conversion Rate (CVR) inadequately capture livestreaming dynamics, as they overlook interaction intensity and real-time behavioral variance. Wang and Zhang (2024) propose GPM as a more holistic metric, integrating both traffic volume and monetization efficiency. This metric is particularly relevant for agricultural livestreams, which often operate in high-frequency, low-margin markets where efficiency per unit of exposure determines profitability.

However, the determinants of GPM remain under-theorized. Existing literature has not sufficiently examined how behavioral and psychological engagement variables-such as comment density, real-time scarcity cues, and cumulative trust signals-translate into commercial performance. This gap is particularly problematic in agriculture, where information asymmetry is more severe due to perishability and origin uncertainty.

To address this, the present study introduces a multi-path framework, arguing that GPM is shaped both directly (by traffic and sales) and indirectly (by interactive engagement dynamics). This perspective not only extends the understanding of livestream conversion but also aligns with the Stimulus-Organism-Response (S-O-R) model, which posits that environmental stimuli influence internal states, which in turn drive behavioral responses.

2.3. Bullet Comments: A Double-Edged Sword in Interactive Commerce

Bullet comments (BulletCount) have emerged as a defining feature of livestream commerce, transforming from a purely social entertainment tool into a critical trust-building and decision-shaping mechanism. Zeng et al. (2023) and Hsiao et al. (2023) demonstrate that high comment density fosters social proof and community belonging, which can enhance purchase intention. In agricultural livestreams, Zhang and Hu (2024) show that bullet comments enhance geographical traceability credibility, alleviating skepticism over origin and food safety.

Yet, bullet comments are not unambiguously beneficial. Zhang et al. (2023) and Jawad (2025) caution that excessive density can trigger cognitive overload, diverting attention from product details and undermining informed decision-making. This tension illustrates that bullet comments may act as both mediators and moderators: they can reinforce retention effects on GPM when used judiciously, but also suppress conversion when information congestion overwhelms consumers.

The dual role of bullet comments resonates with Cognitive Load Theory, which predicts performance deterioration under excessive stimuli, and Social Proof Theory, which explains how collective cues can enhance trust. Within the S-O-R framework, bullet comments operate as stimuli that can either enrich or overload the consumer's psychological processing, ultimately shaping purchase outcomes. By positioning BulletCount at the center of this theoretical intersection, this study advances a more nuanced account of how interactivity functions in agricultural livestream commerce (Figure 1).

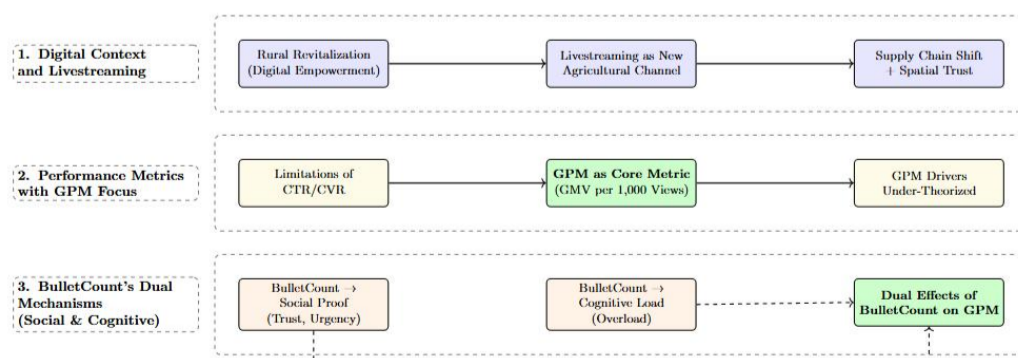


Figure 1. Conceptual Framework: From Digital Empowerment to GPM via Interactive Mechanisms

3. Research Model and Hypotheses Development

3.1. Theoretical Foundation

3.1.1. Social Proof Theory

Social Proof Theory posits that individuals rely on others' behaviors as heuristics for decision-making, particularly under uncertainty, as demonstrated by Do and Vo (2021). In agricultural livestreams—where product verification is difficult and trust deficits prevail—bullet comments operate as real-time social signals that shape perceived product quality, popularity, and seller credibility.

Positive comment density functions as a bandwagon cue, encouraging impulse purchases and reinforcing perceived authenticity, especially when users reference freshness, taste, or past satisfaction. Moreover, agriculture-specific cues—such as viewers vouching for a known farmer or locality (“this is from my hometown”)—provide geographic social proof, which is especially influential in fostering trust in rural brands. Empirical studies suggest that such interactive endorsement mechanisms significantly elevate viewers' psychological safety and purchasing intention in livestream e-commerce.

3.1.2. Cognitive Load Theory

Mutlu-Bayraktar et al. (2019) found Cognitive Load Theory emphasized that human working memory had limited processing capacity, and excessive information can hinder comprehension and decision-making. Agricultural purchases require simultaneous evaluation of complex attributes (e.g., organic certification, price volatility), where information salience critically shapes decision quality.

High-density bullet comments may obscure essential product details, especially during in-depth product explanation segments. The resulting information overload elevates mental effort and reduces decision quality, particularly when time-sensitive decisions (e.g., “buy within 5 minutes to get free shipping”) intersect with cognitively demanding content.

This overload effect is amplified in agricultural contexts due to the ephemeral nature of freshness and the need to assess multiple product dimensions simultaneously (e.g., origin, taste, logistics). Prior studies suggest that such overload leads to viewer fatigue, drop-off behavior, and ultimately lower conversion efficiency.

3.1.3. Stimulus–Organism–Response (S-O-R) Framework

The Stimulus-Organism-Response(S-O-R) framework provides an integrative model explaining how environmental stimuli trigger internal psychological states that shape behavioral outcomes. In livestream e-commerce, bullet comments act as dynamic external stimuli, influencing the viewer's internal state (organism) — such as urgency, reassurance, or confusion — which subsequently affects behavioral responses like retention or purchase.

For instance, scarcity-driven messages (e.g., “Only 10 boxes left!”) may evoke urgency and shorten the decision cycle, increasing GPM. In contrast, Hochreiter et al. (2022) found a flood of irrelevant or fragmented comments could increase cognitive tension or reduce emotional engagement, leading to premature exit behavior or disengagement from the purchase process.

This framework helps reconcile the contradictory roles of bullet comments: they can both activate emotional triggers that boost conversion and introduce cognitive strain that suppresses it. The S-O-R model thus accommodates the dual-channel mechanism of interactive elements in shaping monetization outcomes within high-engagement, high-stakes environments like agricultural livestreams. This logic is illustrated in the conceptual framework (Figure 2).

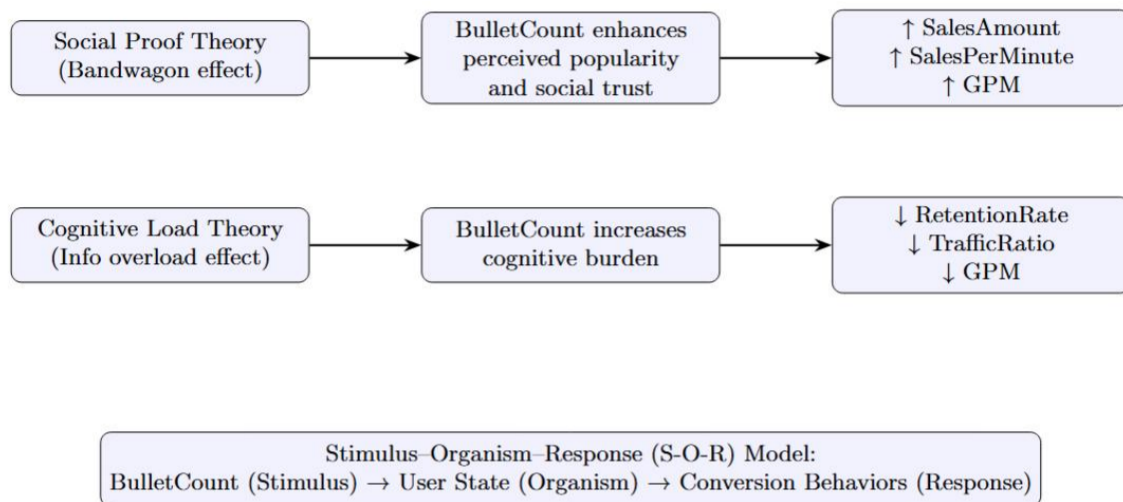


Figure 2. Theoretical Foundation Framework: Dual Role of BulletCount

3.2. Hypothesis Development

3.2.1. Main Effects: Determinants of GPM

To understand conversion efficiency in agricultural livestreams, four key variables are selected: TrafficRatio, RetentionRate, SalesAmount, and SalesPerMinute. These indicators capture different aspects of the livestreaming funnel—from exposure and engagement to transactional intensity(Figure 3).

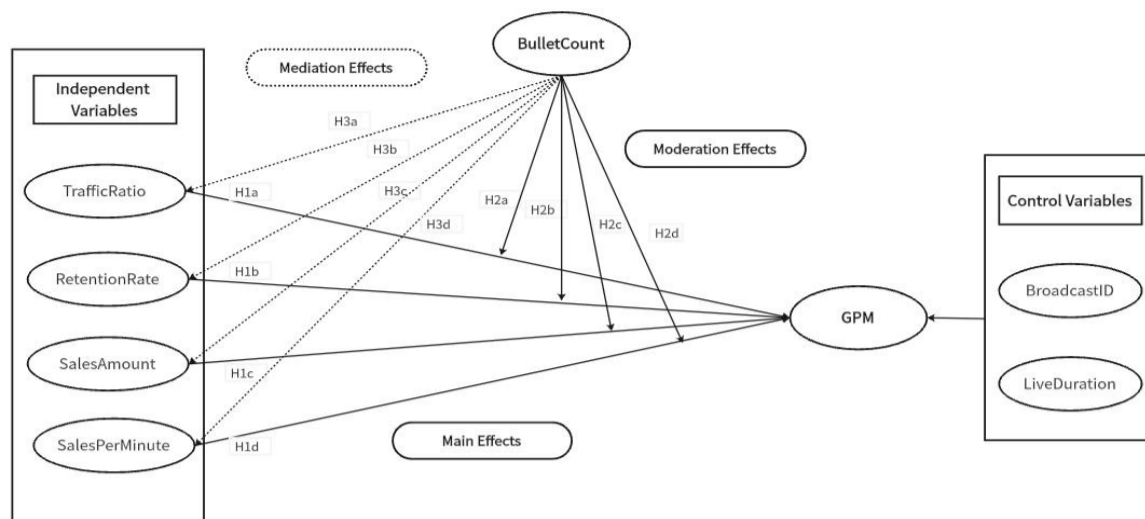


Figure 3. Research model

To understand conversion efficiency in agricultural livestreams, four key variables are selected: TrafficRatio, RetentionRate, SalesAmount, and SalesPerMinute. These indicators capture different aspects of the livestreaming funnel — from exposure and engagement to transactional intensity.

TrafficRatio reflects algorithmic traffic distribution. Zhang and Fu (2024) demonstrate that algorithm-recommended traffic tends to be more targeted and purchase-ready, thereby improving conversion efficiency.

H1a: TrafficRatio positively affects GPM.

RetentionRate measures sustained audience engagement. Peng et al. (2025) reveal that while retention often signals user interest, prolonged exposure in highly interactive environments can induce decision fatigue and reduce purchase efficiency. This finding is consistent with Cognitive Load Theory, which argues that performance declines under excessive information complexity

H1b: RetentionRate negatively affects GPM.

SalesAmount is a direct indicator of transaction volume. Xu et al. (2023) demonstrate that in live-streaming e-commerce, higher sales volumes are closely associated with stronger monetization efficiency. This finding aligns with the “immediacy” and “interactivity” features of live commerce, which can rapidly stimulate consumers’ purchase intentions and facilitate transactions.

H1c: SalesAmount positively affects GPM.

SalesPerMinute captures transaction velocity. Tian et al. (2024) reveal that while rapid selling creates urgency and stimulates impulse purchases, it frequently depends on aggressive discounting, which compresses profit margins and reduces overall efficiency.

H1d: SalesPerMinute negatively affects GPM.

3.2.2. Moderating Effects: The Dual Role of BulletCount

In agricultural product livestream e-commerce, bullet comments(BulletCount) have a dual-edged effect on sales outcomes.

On the negative side, Lv and Liu (2022) find that excessive comment density leads to information overload, distracting consumers from key product attributes and reducing decision quality. In agricultural streams, where freshness and traceability require careful explanation, such overload may weaken the effectiveness of algorithmic exposure and sales signals.

H2a. BulletCount negatively moderates the TrafficRatio → GPM relationship.

H2b. BulletCount negatively moderates the SalesAmount → GPM relationship.

On the positive side, Tong et al. (2025) demonstrate that peer-generated comments during livestreams act as social proof signals, enhancing product credibility and consumer trust. Similarly, Gusty et al. (2025) highlight that interactive communication fosters a sense of community, thereby reinforcing purchase intentions. In the agricultural context, timely supportive comments can amplify urgency and strengthen the effects of retention and rapid sales.

H2c. BulletCount positively moderates the RetentionRate → GPM relationship.

H2d. BulletCount positively moderates the SalesPerMinute → GPM relationship.

3.2.3. Mediation Effects: Behavioral Pathways of BulletCount

Beyond moderation, bullet comments may also act as mediators influencing GPM through behavioral pathways.

On the negative side, Lang et al. (2025) show that oversaturation of interactivity discourages new viewers from joining and reduces sustained attention, thereby weakening effective traffic retention. Vogrincic-Haselbacher et al. (2021) further argue that excessive information density imposes cognitive strain, lowering decision-making efficiency.

H3a. BulletCount indirectly reduces GPM by lowering TrafficRatio.

H3b. BulletCount indirectly reduces GPM via RetentionRate.

On the positive side, Ramadhoni and Prassida (2025) demonstrate that interactive engagement significantly boosts perceived social value and purchase likelihood. Colaljo et al. (2024) also confirm that user-generated signals amplify transaction momentum and increase sales.

H3c. BulletCount indirectly increases GPM by boosting SalesAmount.

H3d. BulletCount indirectly increases GPM via SalesPerMinute.

4. Data Measurement

4.1. Hypothesis Development

This study uses Douyin, China's leading short-video and live-streaming platform, as the primary data source. Douyin is chosen for its large user base and its significant role in live-streaming e-commerce, particularly for agricultural content creators and rural revitalization. The platform provides a rich context for studying live commerce dynamics.

Data was collected from Feigua Data (<https://www.feigua.cn>), a leading third-party analytics platform. The dataset includes viewer counts, BulletCount, sales volumes, GPM, and streamer profiles. It spans 70,640 livestream records from 440 agricultural streamers in 2024. Invalid records were excluded, and continuous variables were log-transformed $\ln(1 + x)$ for normalization.

Control variables like BroadcastID (streamer identifier) and LiveDuration (temporal dimension) were also included to account for streamer and time effects. This approach ensures data accuracy and supports reliable econometric analysis(Figure 4).

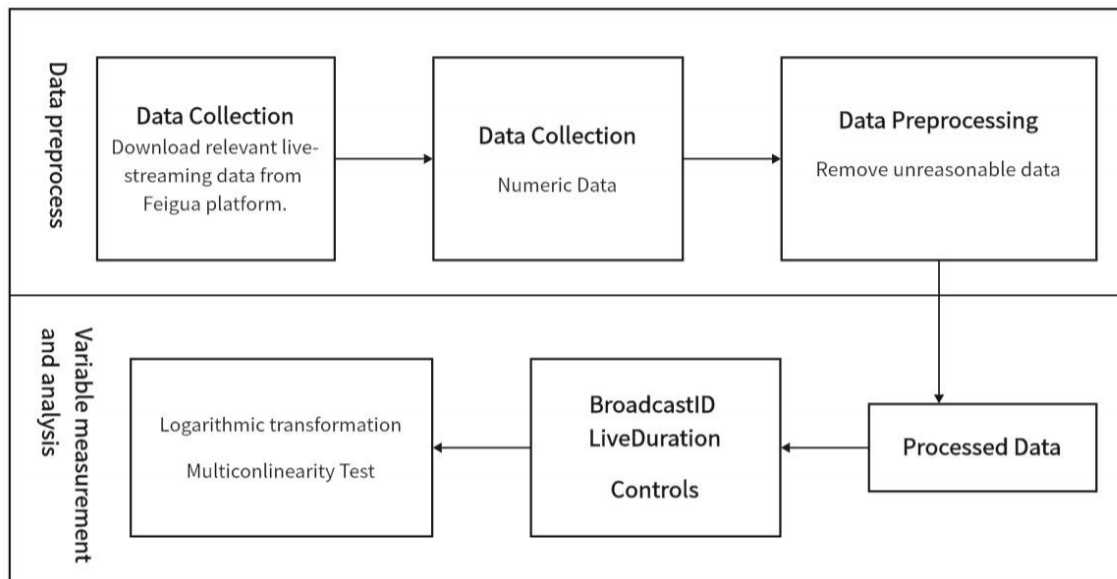


Figure 4. Research model

4.1. Dependent Variable

The dependent variable in this study is GPM, a monetization efficiency indicator widely used in the livestream e-commerce industry. It is calculated as followed.

$$GPM = \left(\frac{\text{Total Purchase Amount}}{\text{Total Viewers}} \right) \times 1000 \quad (1)$$

GPM represents the total transaction value standardized per 1,000 viewers, allowing for meaningful comparisons across streams of varying sizes and durations. Normalized performance indicators of this kind have been shown to be particularly valuable in live-streaming commerce, where purchasing behavior is shaped not only by audience scale but also by the intensity of interaction and the immediacy of real-time engagement, as discussed in studies by Santos et al. (2023). Because transaction-related metrics often display strong right-skewness and heteroscedasticity, our analysis incorporates a natural logarithmic transformation with a smoothing constant. The use of log transformations as a corrective measure for distributional non-normality has long been established in statistical modeling. This approach also safeguards the interpretability of data containing zero values, which is crucial for downstream regression and structural equation modeling.

4.2. Independent and Mediating Variables

The central independent variable is BulletCount, defined as the total number of bullet comments during a livestream. It captures real-time user engagement and social proof intensity. Higher BulletCount typically reflects elevated interaction density, which may either stimulate purchase intention through urgency cues or suppress conversion due to cognitive overload.

Table 1. The measurements of all variables

Variables	Name	Measurements
Dependent Variables	GPM	Purchases per thousand view
Independent Variables	TrafficRatio	Proportion of main traffic sources
	RetentionRate	Percentage of retained users
	SalesAmount	Total sales during live
	SalesPerMinute	Sales generated per minute
Control Variables	BroadcasterID	Unique identifier for each broadcaster
	LiveDuration(hours)	Length of the live
Moderator Variables	BulletCount	Number of bullet comments

Table 2. Descriptive statistics of all variables

Variables	N	Mean	Std. deviation	Min	Max
GPM	70650	1587.41	1901.25	0.00	109802.00
TrafficRatio	70650	0.62	0.15	0.22	1.00
RetentionRate	70650	0.25	0.15	0.02	0.89
SalesAmount	70650	141286.79	786021.26	0.00	49741364.00
SalesPerMinute	70650	777.93	5631.15	0.00	891200.00
BroadcasterID	70650	238.21	127.72	1.00	450.00
LiveDuration	70650	3.83	3.75	0.50	23.93
BulletCount	70650	3665.26	8891.30	0.00	416586.00

Four mediating variables are employed to explore indirect pathways: TrafficRatio shows the main traffic sources' share in a livestream, helping assess reliance on primary channels and

audience acquisition efficiency. RetentionRate is viewers' average watch duration, reflecting content engagement. SalesAmount is the total order volume, capturing purchase activity. SalesPerMinute measures orders per minute, indicating sales velocity and process efficiency.

All variables were log-transformed using $\ln(1 + x)$ to mitigate skewness and enable elasticity interpretation within regression coefficients. Table 1 is the measurement of all variables, Table 2 is descriptive statistics of all variables.

4.3. Moderator and Control Variables

BulletCount also serves as a key moderating variable. To test whether comment intensity amplifies or dampens the effects of TrafficRatio, RetentionRate, SalesAmount and SalesPerMinute on GPM, we created four interaction terms. Figure 5 illustrates the empirical distribution of Comments per Minute (CPM) across all sampled live sessions: the bulk of streams cluster below 400 CPM.

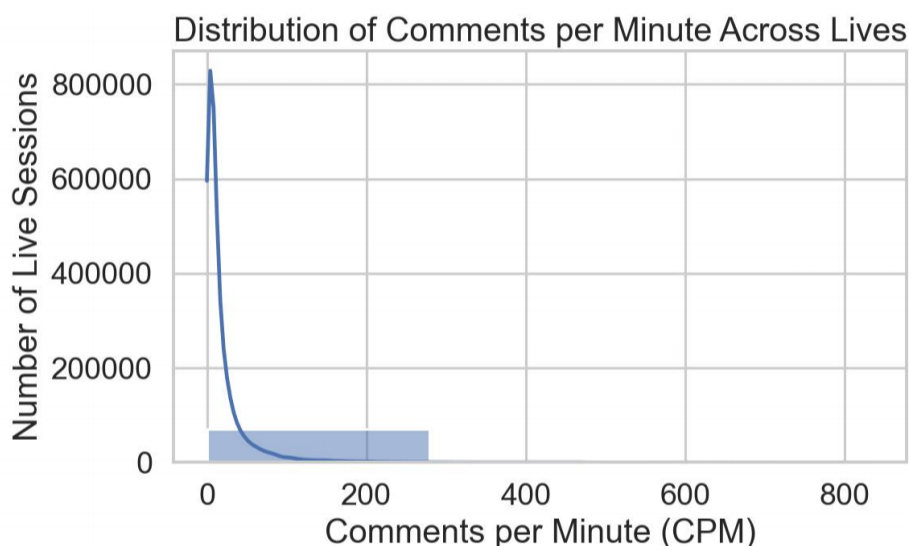


Figure 5. Distribution of Comments per Minute (CPM)

Two control variables are included to safeguard internal validity. LiveDuration is measured as the total length of each session in hours, while BroadcasterID is captured through the platform's unique anchor identifiers. By partialling out time-on-air effects and anchor-specific heterogeneity, these controls isolate the causal impacts of our focal predictors and their moderated relationships.

4.4. Data Analysis

4.4.1. Data Validity and Diagnostic Testing

Prior to model estimation, several diagnostic tests were conducted to ensure the robustness and validity of the data structure for regression and structural equation modeling (SEM).

First, all continuous variables underwent natural-logarithmic transformation via $\ln(1 + x)$ to correct skewness, kurtosis, and heteroscedasticity while preserving zero values. This transformation facilitates elasticity-based coefficient interpretation and aligns with best-practice norms in empirical e-commerce research. The log transformation was additionally employed to

systematically mitigate skewed distributions and heteroskedastic disturbances, thereby safeguarding the validity and robustness of model estimates.

Second, multicollinearity was assessed through Variance Inflation Factors (VIFs). All variables reported VIFs below the commonly accepted threshold of 5, indicating no severe multicollinearity.

Third, correlation analysis (Table 3) confirmed acceptable independence among regressors. The absence of excessive correlation among mediators (e.g., *RetentionRate* vs. *TrafficRatio*: $r = -0.07$) strengthens the credibility of multivariate path modeling.

Table 3. Correlation Matrix of Variables

Variables	GPM	Traffic Ratio	RetentionRate	SalesAmount	SalesPerMinute	BroadcasterID	LiveDuration	BulletCount
GPM	1							
TrafficRatio	-0.25	1						
RetentionRate	0.01	-0.07	1					
SalesAmount	0.51	0.05	0.34	1				
SalesPerMinute	0.29	-0.06	0.36	0.61	1			
BroadcasterID	0.25	-0.01	-0.13	-0.25	-0.20	1		
LiveDuration	0.25	-0.00	-0.09	0.33	-0.10	0.02	1	
BulletCount	0.04	-0.05	0.49	0.72	0.50	-0.16	0.29	1

To account for possible endogeneity due to unobserved time-invariant heterogeneity (e.g., streamer charisma, channel quality), we implemented two-way fixed-effects (TWFE) modeling with *BroadcasterID* and *LiveDuration* as control factors. This design addresses omitted variable bias and self-selection concerns.

4.4.2. Data Validity and Diagnostic Testing

The multiple linear regression model was formulated as follows.

$$\ln(1 + GPM_{it}) = \beta_0 + \beta_1 \ln(1 + TrafficRatio_{it}) + \beta_2 \ln(1 + RetentionRate_{it}) + \beta_3 \ln(1 + SalesAmount_{it}) + \beta_4 \ln(1 + SalesPerMinute_{it}) + \beta_5 \ln(1 + BulletCount_{it}) + \beta_6 \ln(1 + TrafficRatio_{it}) \times \ln(1 + BulletCount_{it}) + \beta_7 \ln(1 + RetentionRate_{it}) \times \ln(1 + BulletCount_{it}) + \beta_8 \ln(1 + SalesAmount_{it}) \times \ln(1 + BulletCount_{it}) + \beta_9 \ln(1 + SalesPerMinute_{it}) \times \ln(1 + BulletCount_{it}) + \alpha_i + \lambda_t + \varepsilon_{it}$$

(2)

In Equation, $\ln(1 + GPM_{it})$ is dependent variable; $(\ln(1 + TrafficRatio_{it}))$, $(\ln(1 + RetentionRate_{it}))$, $(\ln(1 + SalesAmount_{it}))$ and $(\ln(1 + SalesPerMinute_{it}))$ are

independent variables; $(\ln(1 + \text{TrafficRatio}_{it}) \times \ln(1 + \text{BulletCount}_{it}))$, $(\ln(1 + \text{RetentionRate}_{it}) \times \ln(1 + \text{BulletCount}_{it}))$, $(\ln(1 + \text{SalesAmount}_{it}) \times \ln(1 + \text{BulletCount}_{it}))$ and $(\ln(1 + \text{SalesPerMinute}_{it}) \times \ln(1 + \text{BulletCount}_{it}))$; (α_i) is individual fixed effect, (λ_t) is time fixed effects, $(\ln(1 + \text{BulletCount}_{it}))$ is the dummy variable; and (ϵ_{it}) is random error.

This log-linear functional form allows for elasticity interpretation and mitigates distributional issues in high-variance transactional datasets. Estimation was conducted in Python using the “linear models” package under robust standard error assumptions. Clustered standard errors at the streamer level ensure consistent inference under within-entity correlation.

To supplement the regression findings and test causal pathways, Bootstrap-based Structural Equation Modeling (SEM) was employed using 5,000 resamples under the bias-corrected and accelerated (BCa) method. This approach provides non-parametric estimates of indirect effects, accommodating non-normal mediator distributions and ensuring inference validity.

5. Result

5.1. Regression Analysis

To empirically assess the proposed hypotheses, a two-way fixed effects regression analysis was conducted using Python. The model yielded an R-squared value of 0.528, indicating that approximately 52.8% of the variance in GPM can be explained by the independent and moderating variables included in the model. Additionally, the F-test statistic was highly significant ($F = 361.61$, $p < 0.001$), suggesting a strong overall model fit and affirming the robustness of the regression framework for capturing the key drivers of profitability in the context of agricultural livestream commerce.

The main effects show a mixed pattern. *TrafficRatio* ($\beta = 2.801$, $p = 0.229$) did not significantly affect GPM, so Hypothesis H1a is not supported. *RetentionRate* negatively impacted GPM ($\beta = -4.142$, $p = 0.041$), supporting H1b, which suggests that longer viewer retention might not always translate to higher profits. *SalesAmount* had a strong positive effect ($\beta = 5.266$, $p < 0.001$), supporting H1c, indicating higher sales volumes correspond to increased GPM, confirming that transaction scale directly enhances monetization efficiency in livestream ecosystems.. *SalesPerMinute* negatively affected GPM ($\beta = -0.659$, $p < 0.001$), supporting H1d, indicating that rapid sales bursts may reduce margins, possibly due to discounting or inefficiencies.

Regarding moderating effects, *BulletCount* exhibited a complex role. It negatively moderated the effects of *TrafficRatio* ($\beta = -1.537$, $p < 0.001$) and *SalesAmount* ($\beta = -0.189$, $p < 0.001$) on GPM, supporting H2a and H2b, suggesting that intense viewer interaction may weaken these positive effects. Conversely, *BulletCount* positively moderated *RetentionRate* ($\beta = 0.675$, $p = 0.009$) and *SalesPerMinute* ($\beta = 0.157$, $p < 0.001$), supporting H2c and H2d, enhancing their positive influence on profitability. Together, these moderating effects reveal a nuanced and dual role of *BulletCount*—it can either dilute or enhance conversion efficiency depending on the nature of the underlying pathway. The detailed regression results are reported in Table 4.

Table 4. Two-Way Fixed Effects Regression

Category	Pathway	Coef.	Std.Err.	T	P	Sig.	Support
Main effect	Constant	26.881	1.842	14.591	0.000	***	N/A
	H1a TrafficRatio→GPM	2.801	2.308	1.217	0.229		No
	H1b RetentionRate→GPM	-4.142	2.024	-2.046	0.041	**	Yes
	H1c SalesAmount→GPM	5.266	0.274	19.198	0.000	***	Yes
	H1d SalesPerMinute→GPM	-0.659	0.172	-3.832	0.000	***	Yes
Moderating effect	H2a TrafficRatio × BulletCount→GPM	-1.537	0.314	-4.895	0.000	***	Yes
	H2b RetentionRate × BulletCount→GPM	0.675	0.257	2.629	0.009	**	Yes
	H2c SalesAmount × BulletCount→GPM	-0.189	0.035	-5.382	0.000	***	Yes
	H2d SalesPerMinute × BulletCount→GPM	0.157	0.026	6.016	0.000	***	Yes
Summary	R-squared	0.528			Number of obs	70650	
	F-test	361.61			Prob>F	0.000	

Robust standard errors.***p<0.01; **p<0.05; *p<0.1

5.2. OLS-Based Moderation Analysis

Figure 6a illustrates a nuanced interaction between BulletCount and TrafficRatio on GPM. Specifically, when BulletCount is low, the negative effect of TrafficRatio on GPM becomes more pronounced, intensifying the suppression of profitability at lower levels of TrafficRatio. Conversely, at higher levels of BulletCount, this suppressive effect is further amplified when TrafficRatio is high, suggesting that an abundance of real-time comments exacerbates the diminishing returns of traffic exposure on gross profit margin.

Similarly, Figure 6c highlights the moderating role of BulletCount in the SalesAmount-GPM relationship. The steeper negative slope under low BulletCount conditions indicates that SalesAmount exerts a stronger suppressive impact on GPM when viewer engagement via

comments is limited. This suggests that without active interaction, increased sales volume may come at the cost of reduced profit margins, possibly due to aggressive discounting or operational inefficiencies.

In contrast, Figure 6b and Figure 6d reveal that higher BulletCount significantly strengthens the positive associations of RetentionRate and SalesPerMinute with GPM, respectively. The steeper slopes under high engagement conditions confirm that interactive environments enhance the beneficial effects of audience retention and transactional intensity on profitability. These patterns corroborate the positive moderating role of BulletCount in fostering effective conversion behaviors when viewer engagement is high.

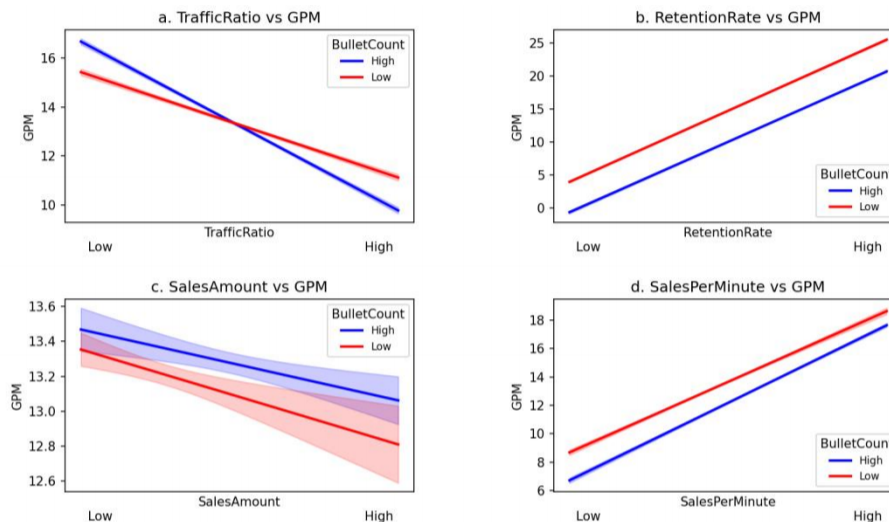


Figure 6. Moderating Effect of Bullet Comments

5.3. Robustness Validation

The robustness of the regression analysis was systematically examined using three complementary methodological approaches to ensure the reliability of the findings. First, the dependent variable, GPM, was adjusted by applying a 10% upward scaling factor ($\times 1.1$). This modification served to test the model's sensitivity to changes in the outcome measure. The results demonstrated remarkable stability, with the adjusted model achieving an R-squared value of 0.540, explaining 54% of the variance in the rescaled GPM. This consistency indicates that the model's explanatory power remains strong even under moderate transformations of the dependent variable.

Second, robustness was further validated by manipulating one of the key independent variables, TrafficRatio, through a 10% reduction ($\times 0.9$). This respecification produced an identical R-squared value (0.540), confirming that the model's fit and predictive capacity are not unduly sensitive to small adjustments in predictor measurements. Additionally, a more stringent robustness check was conducted by excluding extreme observations: the top and bottom 1% of the sample distribution were truncated, reducing the sample size from 70,650 to 69,231. Despite this reduction, the model maintained a solid performance with an R-squared of 0.512. This resilience suggests that the regression framework is robust to the influence of outliers or

distributional irregularities. Collectively, these sensitivity analyses (Table 5) underscore the robustness and reliability of the analytical framework across diverse scenarios.

Table 5. Robustness Test

Variable	FE	Replace IV	Truncate 1%
TrafficRatio	3.099	NaN	2.882
RetentionRate	-4.572*	-4.156*	-4.122*
SalesAmount	5.806* * *	5.278* * *	5.246* * *
SalesPerMinute	-0.731* * *	-0.664* * *	-0.765* * *
BulletCount	-1.891* * *	-1.719* * *	-1.786* * *
TrafficRatio × BulletCount	-1.693* * *	-1.539* * *	-1.519* * *
RetentionRate × BulletCount	0.746* *	0.678* *	0.669* *
SalesAmount × BulletCount	0.210* * *	-0.191* * *	-0.191* * *
SalesPerMinute × BulletCount	0.174* * *	0.158* * *	0.170* * *
Constant	29.610* * *	26.918* * *	27.328* * *
Control Variables	Yes	Yes	Yes
Entity Effects	Yes	Yes	Yes
Time Effects	Yes	Yes	Yes
Sample Size	70650	70650	69231
R-squared	0.540	0.540	0.512

Robust standard errors.***p<0.01; **p<0.05; *p<0.1

5.4. Effect Size Interpretation

To complement statistical significance, we interpret the practical magnitude of key coefficients based on elasticity. A 1% increase in SalesAmount leads to a 5.27% rise in GPM, indicating that higher transaction volume directly enhances monetization efficiency. In contrast, a 1% increase in RetentionRate results in a 4.14% decline in GPM, supporting the cognitive load hypothesis—longer viewing may reduce purchase conversion.

The main effect of BulletCount is negative: each 1% increase corresponds to a 1.89% drop in GPM. However, interaction terms reveal conditional effects. In high SalesPerMinute streams, BulletCount slightly improves GPM by 0.16% per 1% increase, while in high TrafficRatio sessions, it significantly reduces GPM by 1.54% per 10% increase. These results highlight

BulletCount's dual role: it amplifies GPM during time-sensitive promotions, validating its urgency-inducing function in agricultural sales bursts. But excessive comment volume may distract users and lower conversion, especially in attention-heavy traffic environments (Table 6).

Table 6. Marginal Effects Comparison Table (Based on 10% Change in Each Variable)

Variable	% Change	Coefficient (β)	Marginal Effect on GPM
SalesAmount	+10%	5.266	+0.502
RetentionRate	+10%	-4.142	-0.395
TrafficRatio	+10%	2.801	+0.267
SalesPerMinute	+10%	-0.659	-0.063
BulletCount (main effect)	+10%	-1.891	-0.180
BulletCount $\times$ TrafficRatio	+10%	-1.537	-0.146
BulletCount $\times$ RetentionRate	+10%	+0.675	+0.064
BulletCount $\times$ SalesAmount	+10%	-0.189	-0.018
BulletCount $\times$ SalesPerMinute	+10%	+0.157	+0.015

6. Mediation Effects of BulletCount

6.1. Mediation Analysis

The study employed a bootstrap-mediated structural equation model to assess the indirect pathways through which BulletCount influences GPM. Following the Bootstrap-ABC (Bias-Corrected and Accelerated) method, mediation effects ($a \times b$) were estimated through nonparametric resampling, with bias-adjusted 95% confidence intervals derived from the percentile distribution of indirect effect estimates. This approach revealed four distinct mediation mechanisms.

The Bootstrap-ABC method identified four mediation pathways of BulletCount on GPM. In the TrafficRatio path, BulletCount indirectly reduced GPM ($\beta = 0.05$) via lowering TrafficRatio, supporting H3a. Through RetentionRate, it indirectly decreased GPM ($\beta = -0.09$), aligning with H3b. Via SalesAmount, BulletCount boosted GPM ($\beta = 3.03$), supporting H3c. Lastly, the SalesPerMinute path showed a positive indirect effect ($\beta = 0.75$), indicating support for H3d (Table 7).

First, BulletCount suppressed GPM indirectly by reducing TrafficRatio ($\beta = -0.00^{**}$, $\beta = -14.71^{*}$); indirect effect $\beta = 0.05$), with no direct effect observed. Second, while BulletCount enhanced RetentionRate ($\beta = 0.04^{**}$), this mediator paradoxically lowered GPM ($\beta = -2.15^{*}$), resulting in a net negative indirect effect ($\beta = -0.09$). Third, the SalesAmount pathway

demonstrated amplification: BulletCount increased SalesAmount ($\beta = 0.54^{**}$), which strongly elevated GPM ($\beta = 5.65^{*}$), yielding a significant positive indirect effect ($\beta = 3.03$). Finally, the SalesPerMinute pathway exhibited competitive mediation: despite BulletCount's positive effect on SalesPerMinute ($\beta = 0.52^{**}$) and its GPM-enhancing role ($\beta = 1.45^{*}$), the indirect effect was positive ($\beta = 0.75$)(Figure 7).

Table 7. Indirect Effects of BulletCount on GPM Through Different Mediators

Pathway	Direct Effect	Indirect Effect	Total Effect	Support
H3a BulletCount→TrafficRatio→GPM	$\beta = 0.11$	$\beta = 0.05$	$\beta = 0.16$	Yes
H3b BulletCount→RetentionRate→GPM	$\beta = 0.25$	$\beta = -0.09$	$\beta = 0.16$	Yes
H3c BulletCount→SalesAmount→GPM	$\beta = -2.87$	$\beta = 3.03$	$\beta = 0.16$	Yes
H3d BulletCount→SalesPerMinute→GPM	$\beta = -0.59$	$\beta = 0.75$	$\beta = 0.16$	Yes

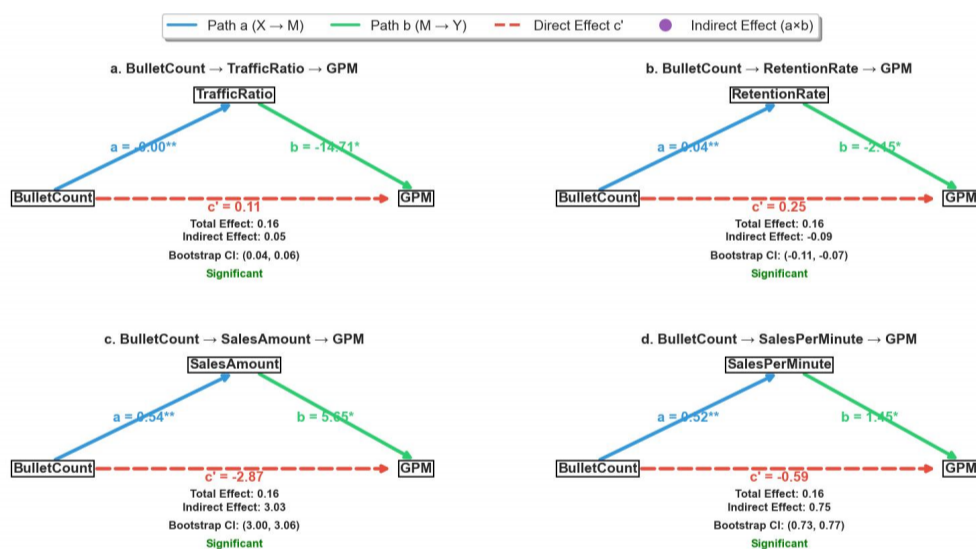


Figure 7. Mediation Effect

Structural equation modeling was employed to delineate the mechanistic pathways through which the core variable (BulletCount) influences the target metric (GPM) via four distinct mediators. The analysis demonstrated that BulletCount exerted significant positive effects on TrafficRatio ($\beta = 0.05$, 95% CI [0.04, 0.06]), SalesAmount ($\beta = 3.03$, CI [3.00, 3.06]), and SalesPerMinute ($\beta = 0.75$, CI [0.73, 0.77]), while generating a robust negative association with RetentionRate ($\beta = -0.09$, CI [-0.11, -0.07]).

6.2. Dual Transmission Mechanisms

Structural equation modeling was employed to delineate the mechanistic pathways through which the core variable (BulletCount) influences the target metric (GPM) via four distinct mediators. The analysis demonstrated that BulletCount exerted significant positive effects on

TrafficRatio ($\beta=0.05$, 95% CI [0.04, 0.06]), SalesAmount ($\beta=3.03$, CI [3.00, 3.06]), and SalesPerMinute ($\beta=0.75$, CI [0.73, 0.77]), while generating a robust negative association with RetentionRate ($\beta=-0.09$, CI [-0.11, -0.07]).

Path decomposition analyses revealed distinct and polarized mediating effects on GPM. SalesAmount emerged as the strongest positive mediator ($\beta= 5.65$), underscoring the vital role of total sales volume in driving profitability. SalesPerMinute also positively influenced GPM ($\beta = 1.45$), indicating that higher transaction intensity enhances gross margins. Conversely, TrafficRatio ($\beta= -14.71$) and RetentionRate ($\beta = -2.15$) showed significant suppressive effects. These findings suggest that while increasing traffic and retaining viewers are generally desirable, in this context they may incur additional costs or inefficiencies that reduce profit margins.

This multi-mediation framework highlights BulletCount's dual transmission mechanisms. Positively, BulletCount amplifies conversion through pathways associated with sales volume, transaction speed, and effective traffic utilization. Negatively, it triggers a compensatory suppression effect via user retention, possibly reflecting information overload or reduced conversion efficiency in prolonged engagement. Together, these opposing effects illustrate the complex balance BulletCount maintains in influencing GPM, as summarized in Figure 8. This nuanced understanding enriches the theoretical foundation for interpreting how interactive features shape economic outcomes in livestream commerce.

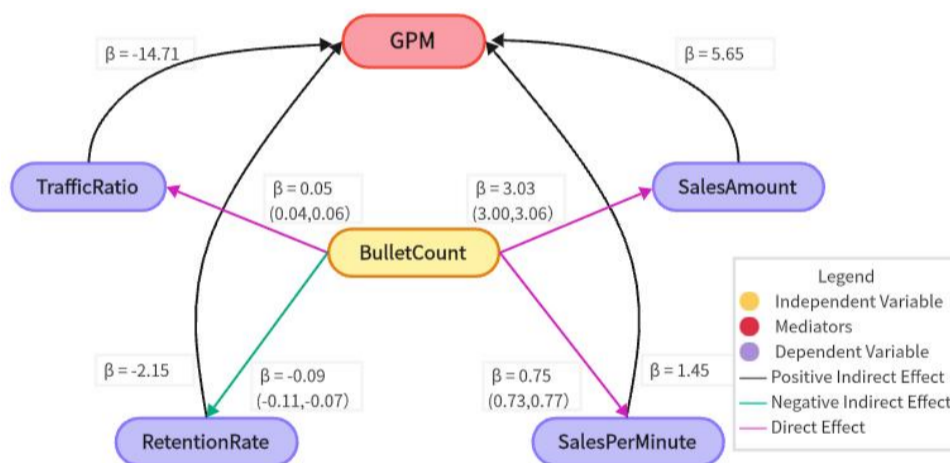


Figure 8. BulletCount's Mediation Effects on GPM Pathways Diagram.

7. Discussion and Implications

7.1. Extended Discussion

This study reveals the nuanced duality of bullet comments (BulletCount) in agricultural livestream commerce. While SalesAmount emerged as the strongest direct driver of GPM—underscoring transaction volume's primacy in rural monetization—the negative impacts of RetentionRate and SalesPerMinute highlight critical trade-offs. Prolonged viewing may induce decision fatigue among agricultural consumers evaluating complex attributes (e.g., freshness, pesticide use), diminishing marginal returns on engagement. Similarly, rapid-fire sales tactics

often erode margins through discount dependency, particularly problematic for perishable goods with narrow profit windows. Notably, TrafficRatio's non-significance challenges conventional platform logic, suggesting algorithmic traffic alone cannot overcome trust deficits inherent to agricultural transactions without substantive interaction.

BulletCount's moderating role further demonstrates context-dependent efficacy. Its attenuation of TrafficRatio and SalesAmount effects aligns with cognitive load theory: comment floods during product explanations obscure critical details (e.g., organic certifications), impairing informational clarity. Conversely, its amplification of RetentionRate and SalesPerMinute benefits reflects social proof dynamics—real-time endorsements ("This village's peaches are authentic!") validate quality during high-engagement phases, accelerating time-sensitive decisions for seasonal produce. This threshold-sensitive duality necessitates precision in deployment.

Mediation pathways confirm behavioral complexity. Negative indirect effects via TrafficRatio and RetentionRate indicate that excessive comments can fragment attention, degrading traffic quality and conversion potential during informational segments. Excessive comment density degrades traffic-to-sales conversion, as cognitive overload diverts attention from core product information during high-exposure phases. Positively, BulletCount's reinforcement of SalesAmount and SalesPerMinute pathways demonstrates its capacity to compress decision cycles through collective urgency—a vital mechanism for mitigating spoilage risks in agricultural supply chains. Collectively, these findings establish an integrated behavioral-cognitive framework where BulletCount's net impact hinges on strategic alignment with livestream objectives and agricultural product characteristics.

7.2. Extended Theoretical Implications

First, it advances Social Proof Theory by showing how BulletCount operates as a real-time trust signal under high uncertainty. Social proof was first conceptualized by Deutsch and Gerard (1955) as reliance on others' opinions under ambiguous conditions, and later expanded by Cialdini (2007) to explain how individuals use popularity cues in decision-making. Within agricultural livestreams, however, comment volume does more than indicate popularity: it functions as distributed credibility validation. For instance, remarks such as "I know Farmer Li's orchard" transform comment density into place-based authenticity. This aligns with research on digital trust in rural e-commerce by Wang and Zhang (2023). Thus, social proof in this context is redefined as a marker of origin-based credibility, directly addressing rural information asymmetry.

Second, the study situates Cognitive Load Theory within the unique context of agricultural livestreaming. Sweller (1994) formulation of the theory emphasized the limits of working memory, a point elaborated by Paas and van Merriënboer (1994). Our findings suggest that dense comment streams intensify these constraints, especially when consumers must simultaneously evaluate complex product attributes such as organic certification, shelf life, and logistics. Recent evidence by Luo et al. (2020) also shows that interactive comment density in livestream settings can increase cognitive processing costs. Building on these foundations, our work refines Cognitive Load Theory for perishable goods commerce, underscoring the need for cognitive resource allocation models tailored to agriculture's information-intensive environments.

Third, this research enriches the Stimulus-Organism-Response paradigm by unpacking BulletCount's dual affective-cognitive pathways. Mehrabian and Russell (1974) introduced the S-O-R framework to explain how environmental stimuli shape emotional and behavioral responses. More recently, Guo et al. (2021) applied the model to livestream commerce, highlighting the behavioral impact of social cues. Within agricultural livestreaming, comments act as stimuli that elicit antagonistic organismic states: affective arousal, such as urgency to secure seasonal harvests, and cognitive tension, such as overload when processing fragmented technical explanations. These competing responses — accelerated purchases versus disengagement — reveal a unified mechanism for explaining behavioral variance in this domain.

Finally, we introduce a novel dual-channel framework that reconciles the inherent paradoxes of interactive commerce. The synergy path leverages social cues to accelerate conversion, while the compensatory path imposes cognitive costs that erode efficiency. By reconceptualizing BulletCount as an endogenous, sign-switching moderator — rather than a uniformly positive or negative force—the framework resolves inconsistencies in the extant literature. Integrating Social Proof and Cognitive Load theories through a context-sensitive lens, it fills a critical gap in research on agricultural digital consumption and delivers a portable analytical framework for platform design, enabling the maintenance of an optimal incentive-affordability equilibrium when both information complexity and interaction density escalate.

7.3. Practical Implications

This study provides actionable strategies for stakeholders to optimize agricultural livestream commerce through strategic management of bullet comments (BulletCount). For streamers and MCN agencies, we recommend dynamically regulating comment density across livestream phases. During detailed product presentations — particularly for information-intensive items like organic produce or traceable goods — reducing BulletCount minimizes cognitive overload, sustaining viewer focus on critical attributes. Conversely, in promotional segments such as flash sales, actively encouraging high-volume comments leverages social proof and urgency cues to stimulate impulse purchases. Implementing rhythmic alternation between low- and high-engagement intervals creates a balanced cognitive-behavioral flow, enhancing overall GPM efficiency. Training in real-time moderation tools further empowers streamers to maintain this optimal rhythm, particularly valuable for rural producers with limited technical resources.

For platform developers, findings underscore the need for context-aware interaction systems. AI-driven bullet comment filters could adaptively reduce visual noise during technical explanations while preserving social proof during promotional segments. Developing agriculture-specific interface templates (e.g., standardized layouts for perishables) lowers operational barriers for novice rural streamers. These innovations balance informational clarity with interactive vitality, addressing the dual role of comments as both conversion catalysts and cognitive disruptors identified in our analysis. Such technical enhancements directly support scalable rural e-commerce integration.

Policymakers should shift from infrastructure provision to operational capacity-building like training in engagement strategies. Targeted workshops on engagement pacing and cognitive load

management — tailored to agricultural contexts like seasonal promotions — can empower rural content creators. Financial incentives (e.g., subsidies or tax breaks) for platforms embedding smart moderation tools (e.g., sentiment-based comment ranking) would accelerate adoption. Complementarily, certification schemes recognizing “Low Cognitive Load Livestream” practices could establish industry standards. These interventions foster sustainable digital ecosystems where optimized interactivity advances broader rural revitalization goals through efficient market linkages.

8. Limitations and Future Research

While this study advances understanding of interactive dynamics in agricultural livestream commerce, five limitations warrant scholarly attention.

First, platform dependency constrains generalizability. Exclusive reliance on Douyin data — characterized by algorithm-driven traffic and urban-dominated demographics — ignores platform heterogeneity. Kuaishou’s grassroots user base favors rural authenticity narratives, while Taobao Live integrates supply-chain tools affecting purchase friction. Future work should conduct cross-platform experiments comparing BulletCount effects under varying algorithmic logics (e.g., Douyin’s entertainment-centric feeds vs. Taobao’s transaction-oriented interfaces). Such comparisons could reveal how platform architectures modulate cognitive-social trade-offs in rural e-commerce.

Second, agricultural exceptionalism limits category transferability. While perishability and traceability demands amplify cognitive load in our context, hedonic goods (e.g., handicrafts) may prioritize emotional contagion via comments, and branded products could leverage comments for prestige signaling. Future research should establish a taxonomy of product attributes (perishability, information intensity, credence qualities) to predict BulletCount’s dual-role boundaries. Testing whether social proof dominates for low-involvement crops (e.g., potatoes) versus cognitive load for high-stakes goods (e.g., organic infant food) would refine agricultural segmentation strategies.

Third, methodological constraints obscure temporal dynamics. Though two-way fixed effects control time-invariant confounders, they cannot capture streamer-viewer coevolution: as farmers gain experience, they may strategically time comment surges during promotions while suppressing them during explanations. Longitudinal field experiments manipulating BulletCount density across seasons (e.g., harvest vs. off-seasons) could quantify learning effects. Quasi-experimental designs exploiting platform policy shifts (e.g., Douyin’s 2023 comment-filtering rollout) would further strengthen causal claims.

Fourth, inferred psychological mechanisms lack empirical validation. Cognitive overload and social proof remain theoretical constructs without direct measurement. Integrating multimodal biometrics could resolve this: eye-tracking during pesticide disclosure segments would quantify visual attention theft by comment floods; EEG during scarcity promotions could neural signature urgency responses to social proof cues. Complementarily, structured surveys assessing trust in

geo-tagged comments (e.g., “I trust comments vouching for local farmers”) would ground social proof theory in agricultural contexts.

Fifth, the blunt arithmetic of comment counts erases the layered semantics, temporal cadence, and heterogeneity of voices that co-produce trust and conversion in agricultural e-commerce; future work must therefore decode these semantic dimensions of engagement—sentiment valence, temporal clustering — through NLP methods to qualify BulletCount’s impact. BulletCount collapses the phenomena into a single scalar, yet a purpose-built machine-learning pipeline can surface sentiment-weighted engagement in which a surge of logistics-related negativity instantaneously corrodes perceived reliability, time-locked comment bursts that ride the wave of flash-discount announcements and momentarily inflate SalesPerMinute, and the divergent persuasive force of verified farmer endorsements relative to probing questions from urban buyers. Capturing these effects demands a domain-specific NLP lexicon that interweaves freshness descriptors, cultivar-centric dialects, and socio-linguistic markers, thereby enabling granular moderation analyses that illuminate how nuanced comment quality dynamically recalibrates GPM pathways across heterogeneous rural marketplaces

Collectively, these limitations demarcate critical frontiers for advancing agricultural livestream commerce research. Rather than constraining our findings, they illuminate pathways to develop context-aware interaction frameworks that reconcile platform diversity, product heterogeneity, and behavioral dynamics inherent to rural digitization. Addressing these gaps through cross-platform field trials, biometric validation, and agricultural NLP pipelines will transform bullet comments from mere engagement metrics into precision tools for reducing cognitive friction and amplifying place-based trust. Such innovations promise to elevate livestreaming beyond sales facilitation toward a sustainable infrastructure for knowledge exchange—empowering farmers to navigate information asymmetry while connecting consumers to agricultural narratives. Future research embracing these directions will not only refine theoretical models of digital engagement but also co-create actionable standards for platform design, streamer training, and policy formulation, ultimately accelerating digitally inclusive rural revitalization.

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The authors declare no conflict of interest.

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Exploring Chinese Sustainable Path Based on International Sustainable Disclosure Guidelines

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Abstract

As international sustainable disclosure standards accelerate their integration, the convergence of global sustainable disclosure frameworks is strengthening. However, regional differences and gaps in corporate practices remain significant. This paper examines the evolution and focus of existing international sustainable disclosure standards, China's localization efforts, and corporate practices from three dimensions. It analyzes the core requirements of international mainstream standards and academic disputes regarding the feasibility of disclosure and data quality, revealing theoretical breakthroughs and practical challenges in China's research on mandatory disclosure, report verification, and other fields. On this basis, the case study of Myriad Medical is used to analyze the innovative path of Chinese enterprises in sustainable development. The study indicates the design and application of sustainable disclosure guidelines is of significance for entering global capital markets and promoting development concepts such as carbon peaking and carbon neutrality. On the corporate side, companies should enhance strategic resilience by prioritizing the identification of key issues, establishing a tiered data management mechanism, gradually improving disclosure capabilities, and flexibly designing disclosure schemes. Meanwhile, sustainable development disclosure requires strengthened institutional safeguards to promote the integration of China's sustainable development practices with the international governance system, providing replicable transformation models for emerging market countries.

Keywords: Sustainability Disclosure; IFRS; ESG; Sustainable Disclosure System; Myriad Medical

1. Introduction

On June 26, 2023, the International Sustainability Standards Board (ISSB) issued International Financial Reporting Sustainability Disclosure Standard No.1 - General Requirements for Disclosure of Sustainability-Related Financial Information (IFRS S1) and International Financial Reporting Sustainability Disclosure Standard No. 2 - Disclosure of Climate-Related Information

(IFRS S2), stipulating that enterprises shall issue sustainability disclosure reports, which will take effect on January 1, 2024. The issuance of these two ISSB standards marks a new phase in the development of sustainable disclosure, with sustainable-related disclosure and related assurance services entering an era of standardized development. To better integrate into international capital markets and promote high-quality economic development in China, on May 27, 2024, China officially released the "Enterprise Sustainable Disclosure Standards — Basic Standards (Draft for Public Comment)." This signifies that sustainable disclosure by Chinese enterprises has entered an era of national standardized regulations, which not only aligns with international ISSB standards but also aligns with the trends of the times. The formulation of China's "Enterprise Sustainable Disclosure Standards — Basic Standards (Draft for Public Comment)" is based on the overarching direction of international sustainable disclosure standards, adapted to China's national conditions. It combines the universality of international sustainable disclosure standards with the uniqueness of China's characteristics. It is necessary to conduct a systematic review and research on China's exploration of sustainable disclosure standards.

2. Relevant Provisions of Existing Sustainable Disclosure Standards

IFRS S1 requires an entity to disclose material information about its sustainability-related risks and opportunities, with the objective of disclosing sustainability information in a way that facilitates the provision of information to users of the resource for decision-making purposes. IFRS S1 requires that an entity's disclosure of sustainability-related information should be fairly presented and that the quality of the sustainability-related information disclosed by the entity should be of appropriate quality characteristics. The core components of IFRS S1 are governance, strategy, risk management, metrics, and objectives. The core elements of IFRS S1 are governance, strategy, risk management, and metrics and objectives. IFRS S1 requires that an entity's disclosure of sustainability-related information should be based on the disclosure topics in the ISDS and SASB standards, taking into account their applicability; that the location of the sustainability report depends on the entity's applicable regulatory or other requirements; and that it should be reported for the same period as the financial statements and provide comparable information for the previous period. Period and provide comparable information for the previous period.

The IFRS S2 standard, which addresses the topic of climate change, has a high degree of consistency in its conceptual underpinnings and general requirements with IFRS S1, which requires that business entities disclose information about climate-related risks and opportunities. In terms of governance, IFRS S2 emphasizes the need to understand the governance processes, controls, and procedures that a business entity uses to monitor and manage climate-related risks and opportunities; in terms of strategy, the need to understand the business entity's strategy for managing climate-related risks and opportunities; in terms of risk, IFRS S2 requires that climate-related risks be categorized into physical and transformational risks and that an assessment be made of the inherent risks and the impacts of the response; and in terms of indicators and targets, the need to assess the impacts of the response; and in terms of the impacts of the response. And

the assessment of the impacts of their inherent risks and responses; and for indicators and targets, to understand the performance of the business in relation to climate-related risks and opportunities and the related progress made.

On July 31, 2023, the European Commission adopted the first 12 EU Sustainability Reporting Standards (ESRS), which are available in 23 official languages and apply to all companies subject to the Corporate Sustainability Reporting Directive (CSRD). The ESRS provides for exemptions from disclosure of quantitative information on climate-related opportunities, with the exception of qualitative information during the transition period and the non-disclosure of climate-related opportunities if the quality of information is not met. The ESRS is characterized by quantitative disclosure of the expected financial impacts of material physical and transition risks, aggregated financial impacts by type of risk, scope, methodology, and parameters, and by cross-indexing and quantitative reconciliation tables. ESRS requires that the relevance of disclosures to financial statement information be deepened and quantified through the use of cross-indexing and quantitative reconciliation tables and that the quantification include not only the inherent risks but also the measures to address the risks.

On March 21, 2022, the U.S. Securities and Exchange Commission (SEC) issued Draft Enhanced and Regulated Disclosure of Climate-Related Information for Investors (the New Climate Disclosure Rule). The New Climate Disclosure Regulation provides that a subject should assess the financial impact of the current period in terms of financial impact indicators, expenditure indicators, financial estimates, and assumptions. The New Climate Disclosure Regulation clarifies the specific location of climate-related risk disclosures and sets threshold requirements for materiality judgments. Unlike the IFRS and ESRS, the SEC's new climate disclosure rule assesses the financial impact of climate-related risk information for the current period and establishes measures such as dual protection and "safe harbors" to protect registrants.

Promoting the establishment and implementation of sustainability disclosure standards globally is needed by many and is in line with the current trend, Cecília and Miguéis (2022) examine the reasons for voluntary sustainability reporting by unlisted companies, adopting a multi-case study methodology and investigating five manufacturing companies in Spain. There are two main reasons for the voluntary preparation of sustainability reports: the needs of specific customers and parent companies, and the need to communicate with the company's stakeholders. In addition, they identified problems with the integration of information between sustainability and financial reporting, which are presented as separate reports. Goedertier et al. (2024) use consumer data obtained from a large-scale survey investigating 24,798 participants in 20 countries and one special administrative region (SAR) to explore whether consumers would pay for sustainable brands. The survey analyzed the data using Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) to ensure comparability of the data across geographies. The results show that people's consumer attitudes are shifting, and they are more inclined to spend more money on sustainable and inclusive brands, which are influenced by socio-ecological factors. Farooq et al. (2021) study examined the disclosure practices of listed companies in the member countries of the Cooperation Council for the Arab States of the Gulf (CACG). They found that although the rate of sustainability reporting increased throughout the sample period, the vast

majority of GCC-listed companies do not engage in sustainability reporting. The rate of use of internationally recognized standards also declined. Li et al. (2021) assessed information content by examining panel data of more than 2,600 non-financial U.S. listed companies over the period 2014 - 2018 and regressing market value or stock price on sustainability disclosure and ESG scores. They found that ESG scores are positively related to market value and price. Yavuz et al. (2024) examined the impact of the nature of ownership (majority shareholder, foreign, or institutional) and board composition (size, gender diversity versus expatriate directors) on ESG disclosure. The analysis distinguishes between financial and non-financial firms and reveals the differential impact of corporate governance mechanisms on ESG performance in different industries. Foreign ownership and the presence of foreign and female board members are positively associated with higher ESG disclosure, while equity concentration is negatively associated with ESG performance. Martínez-Ferrero et al. (2016), on the other hand, focus on the voluntary disclosure of information by firms and the asymmetry of information between different market players. They argue that this is particularly important in environments characterized by a high level of concern and commitment to stakeholders. Li et al. (2024) investigate how ESG efficiency affects corporate innovation. They argued that ESG is one of the most important indicators of resource utilization within a firm. By studying the data of Chinese A-share listed companies from 2009 to 2021, the researchers found that the level of ESG efficiency shows a positive relationship with firms' innovation. This suggests that higher ESG efficiency is conducive to promoting corporate innovation. Stavropoulou et al. (2023) argue that the green balanced scorecard enables firms to monitor their environmental progress and energy use and quantify their achievements in reducing their ecological footprint. Firms should prioritize the construction of an energy efficiency management system based on a sustainable balanced scorecard, which will help them achieve the organization's strategic environmental goals. Chen et al. (2025) found that China, Kazakhstan, Mongolia, and Pakistan, countries that are more concerned with the critical need for environmentally and socially sustainable development, and which also have significant energy reserves, are in the "They also have important energy reserves and play a significant role in the green and sustainable development goals of the Belt and Road.

3. Literature Review

In recent years, scholars in China have also devoted themselves to exploring the field of sustainable disclosure. In order to maintain long-term sustainable development, enterprises should not only pay attention to their own business activities, but also pay attention to their impact on the environment and society, and through the establishment of a sound governance mechanism, enterprises can obtain development opportunities and investors' favor. Therefore, ESG has become an important indicator for evaluating the sustainable development of enterprises. It is necessary and urgent to formulate sustainability disclosure standards in line with China's national conditions. On the one hand, China's current sustainability disclosure system focuses more on the disclosure of corporate governance information, with different disclosure rules and no standardized guidelines. On the other hand, the high-quality development of the national economy and the construction of carbon neutrality need to pay attention to sustainable development, which

also plays an important role in the participation of Chinese enterprises in the international supply chain and the response to the EU carbon tariff.

On May 27, 2024, China issued the "Corporate Sustainability Disclosure Guidelines - Basic Guidelines (Draft for Public Comments)", which means that China officially opened the curtain of establishing a sustainability disclosure system, which is of great significance for the establishment of sustainability disclosure guidelines in China, and for conforming to the development trend of the economy and society at home and abroad. The formulation of the Basic Guidelines is very much characterized by Chinese characteristics. The development of the Basic Code was evaluated over a three-month period, covering state-owned enterprises, private enterprises, foreign-funded enterprises, listed companies, and financial institutions. It is the final draft for comment based on discussions and practices from various parties and the opinions of ISSB experts. It is expected that by 2027, the Basic Code and the climate-related disclosure guidelines will be issued successively; and by 2030, China's sustainable disclosure system will be basically completed and continuously improved.

The Basic Standards outline the objectives and principles for providing information users with critical sustainability risk opportunities and impacts, aligning the quality requirements of sustainability disclosures with financial information standards. They emphasize that corporate sustainability disclosures must encompass four core elements: governance, strategic planning, risk and opportunity management, and key performance indicators (KPIs). The release of the Exposure Draft of the Basic Guidelines responds to the economic development trend at home and abroad, helps to promote enterprises to accelerate green transformation, safeguard the fairness and justice of the society, and promotes the harmonious coexistence of human beings and the nature, and is a necessary way to realize high-quality development. The Trinity sustainable disclosure standard framework system of basic standards, specific standards, and application guidelines demonstrated under the basic standards provides guidelines for the sustainable disclosure of information by enterprises in China, meets the needs of the disclosure requirements of the international capital market, is based on the national conditions, highlights the characteristics, and embodies the openness and inclusiveness of the atmosphere by adopting the best of all worlds.

Table 1. The current state of research on sustainable disclosure standards by Chinese scholars

Chinese scholar	Focus of research	Conclusions of the study
Huang (2022)	The combination of international standards and Chinese practice, ESG disclosure and corporate value relevance, and other directions.	Construct a framework of "core disclosure + local expansion", implement mandatory disclosure step by step, establish "national standards for environmental information accounting", and develop a public platform for ESG data.
Cheng (2022)	Analysis of the need for the	Strengthen international cooperation, take into

	establishment of international sustainable disclosure standards and analysis of the enforceability and international applicability of ISDS.	account the differences in the development of different countries and regions, and appropriately reduce the difficulty of disclosure or provide transitional arrangements.
Ye (2022)	Interpretation of the European Sustainability Reporting Guidelines, Climate-related Disclosure Guidelines, and Carbon Emission Reduction.	Follow structured organizational development guidelines to maximize the value of disclosure using digital technology enablement.
Wang (2022)	Construction of a nationally harmonized system of sustainability disclosure guidelines.	Expedite the issuance of environmental thematic guidelines on climate change, guidelines on forensics for sustainable development reports, and increase interoperability provisions.
Wu (2022)	Significant Areas of Controversy in the Implementation of ISSB's Sustainability Disclosure Guidelines.	Enhance multistakeholder communication and cooperation and promote the participation of jurisdictions and stakeholders in the evaluation of ISSB standards.
Qi (2022)	Analysis of the logic, progress, and outcomes of the development of existing international sustainability disclosure standards.	Focus on internationalization and convergence in the top-level design of sustainable disclosure standards.
Wang (2022)	ESG reports identify international trends.	Introduce a mandatory forensic mechanism for sustainability reporting.

However, there is still a long way to go in establishing a sound system of sustainable disclosure standards in China. The formulation of sustainable disclosure standards should take into account both the cost-benefit issues faced by enterprises and their ability to make relevant disclosures, all of which will affect the reliability of disclosure information. Huang (2021) argued that there are more existing frameworks on ESG disclosure internationally, and there is a lack of effective communication and coordination between disclosure standard-setting organizations, with varying standards that make quantitative comparisons difficult. This may lead to difficulties for report preparers to choose the appropriate standard-setting framework for report preparation, which in

turn leads to higher preparation costs, violates the principle of cost-effectiveness, and is not in line with the original intention of advocating green and low-carbon development. Cheng (2023) argued that the development of a set of globally harmonized international sustainability disclosure standards is an inevitable trend, but the successful implementation of the standards depends on the ability of each country and region to combine internationalized standards with their own national reality for subsequent preparation, as well as the demand of investors and stakeholders for the use of the international sustainability disclosure standards.

The basic guidelines implemented in China are applicable to enterprises established in the People's Republic of China that carry out sustainability disclosure in accordance with the regulations. China's basic guidelines do not have a one-size-fits-all mandatory implementation requirement, but rather a gradual, pilot-first approach, progressing gradually from listed companies to non-listed companies, from large enterprises to small and medium-sized enterprises, and expanding from directional to quantitative requirements. In terms of the feasibility of the guidelines, Ye and Huang (2022) indicated that the SEC's new climate disclosure rules are more excellent. First, from the requirement to disclose Scope 1 and Scope 2 emission indicators respectively, it can be seen that the SEC's attitude towards promoting climate governance is resolute; second, as a securities regulator, the SEC's disclosure rules are more pragmatic, with sufficient cost-benefit argumentation, taking into account the interests of both investors and registrants and the overall idea of more feasible. In terms of the relationship between sustainability reporting and financial reporting, Huang and Wang (2023) argued that the ISSB Guidelines treat sustainability-related financial disclosures as part of the financial report, but they are not suitable for accounting practice because they do not meet the definition of the elements of the financial report or because some forward-looking information cannot be reliably measured in monetary terms. Both preferred the EFRAG approach, whereby the sustainability report is separate from the financial report and the two together constitute the company report.

In terms of advancing the implementation of the standard, Ye and Cai (2022) argued that enterprises should conduct as detailed objective measurements as possible to predict the overall impact of the standard's implementation. As the accounting recognition, measurement, and disclosure of climate-related risks have a greater impact on financial statements, some enterprises need to reassess the corresponding assets and projected liabilities to reflect the best estimate of the current situation and inevitably face the pain of transition. Therefore, China's enterprises must promote the energy transition in an orderly manner and do sufficient psychological construction. Ye and Huang (2023) argued that Apple's assessment and disclosure of the financial impact of climate-related risks is superior and worthy of reference. On the one hand, Apple's inherent risk ratings, specific countermeasures first qualitative assessment, visual demonstration of risk and countermeasures after the effect of the landing, and then finally use the unit to quantify the financial impact of risk assessment; on the other hand, Apple's use of historical data-based prediction methods for quantitative data processing, more simple than situational analysis and data can be verified, increasing the credibility of information, and facilitating the information user to assess the relevant risks through historical data, which is worth learning. On the other hand, Apple's quantitative processing of data based on historical data forecasts is simpler than scenario

analysis and the data is verifiable, which increases the credibility of the information and makes it easier for information users to analyze the information through historical data.

Regarding the question of how China should formulate sustainability disclosure guidelines, Wang et al. (2023) stated that China, as the second largest economy in the world, should not copy the guidelines issued by ISSB in its entirety, but should draw on the ISDS, ESRS, and SEC's new climate disclosure regulations, and formulate a sustainability disclosure guideline that is suitable for China's national conditions based on China's actual situation. Wang (2023) argues that the development of sustainability disclosure guidelines in China needs to rely on an implementation guarantee mechanism. He advocates the construction of a guideline implementation guarantee mechanism through six aspects, such as the regulatory system, underlying standards, infrastructure, internal control, forensic system, and regulatory system, to escort the development of China's sustainability disclosure guidelines. At the same time, he believes that it is necessary to define the subject of reporting and related concepts in the relevant standards, i.e., whether the subject of continuous disclosure reporting should be the same as the subject of financial statement reporting and whether the related concepts have the same characteristics. Qi and Ren (2023) suggest that the formulation of China's sustainability disclosure standards should follow the principle of international convergence, conduct more in-depth theoretical research on the concept of materiality, coordinate with the actual situation of various parties to establish specific standards, and put China's designation of sustainability disclosure standards on the agenda as soon as possible from the top-level design. According to Wang et al. (2023), the development of sustainable disclosure standards in China is particularly critical to curbing "greenwashing" behavior. At present, there are different degrees of "greenwashing" in the disclosure of information in China's environmental information market, where companies disclose information that is favorable to them but retain unfavorable information, or even fabricate environmental monitoring data to create a false impression of greenness on the surface. This kind of "greenwashing" behavior is easy to mislead stakeholders but affects the sustainable development of enterprises. In response to the "greenwash" behavior, Huang (2023) also said that China should strengthen the research and governance of "greenwash", implement an independent forensic mechanism for ESG reports, improve the quality of ESG reports, and avoid ESG reports from becoming a numbers game.

With regard to the assurance of sustainability disclosure information, Wang (2023) argues that the role of the audit committee in sustainability disclosure should be repositioned to strengthen its supervisory responsibilities and to utilize the audit's previous experience in the assurance of accounting information to reflect the future sustainable development of the business entity. Wu and Ju (2023) have doubts about the authenticity of sustainability disclosure information and emphasize the importance of external assurance. On the one hand, the development of non-financial reporting standards for assurance is slow, and assurance without standard constraints has a greater impact on the authenticity of disclosure information; on the other hand, there is controversy over the provider of assurance services. They believe that the ability to provide audit engagements for forward-looking information is the most important factor for investors. Wang (2023) indicates that ESG disclosure has gradually moved from voluntary to mandatory, the EU

sustainability report requires mandatory disclosure of ESG-related information, and the main body providing assurance services for the ESG report must be an accredited independent auditor or other assurance body, so as to guarantee the quality of sustainability information; SEC has introduced an independent assurance mechanism for climate information disclosure, and the degree of assurance for sustainability information has gradually moved from limited to mandatory, and the degree of assurance has gradually shifted from limited to mandatory. SEC has introduced an independent assurance mechanism for climate information disclosure, and the degree of assurance on sustainability information has gradually transitioned from limited assurance to reasonable assurance, which shows that the intensity of assurance on sustainability disclosure information is also increasing.

4. Sustainability Disclosure Practices of Chinese Companies

4.1. Evolution of Myriad Medical's Sustainability Disclosure

Myriad Bio-Medical Electronics Company Limited (Myriad Medical) has been committed to releasing its sustainability information annually since 2018 and has achieved significant optimization of its disclosure by integrating its sustainability system in 2021, presenting typical characteristics.

In 2018, Myriad Medical's sustainability disclosure was in the exploratory stage, a stage in which the company's discussion of sustainability-focused primarily on talent sustainability due to the lack of a solid theoretical foundation. Although six standards were referenced, except for the Global Reporting Initiative's (GRI) version of the G3 Guidelines, there was a lack of clear guidance on all the other standards, resulting in limited assessability of the disclosure. In addition, the adopted versions of the GRI standards are relatively outdated, affecting comparability between annual reports. In terms of content, there are problems such as the lack of intuitive flowcharts or framework diagrams in the description of the operational governance level, while the environmental level focuses mainly on emissions and energy saving, while the prevention, supervision, and management of environmental risks are neglected. Information disclosure in this phase mainly focuses on financial and R&D performance, and disclosure in strategy and risk management is still insufficient, with fewer quantitative indicators and unbalanced disclosure of negative information.

Entering the development period from 2019 to 2020, Myriad Medical updates its reference standards, including GRI standards, China Corporate Social Responsibility Reporting Guidelines (CASS-CSR4.0), and the United Nations 2030 Agenda for Sustainable Development (SDGs), and begins to incorporate social responsibility into the company's strategic objectives while establishing a three-tiered linked social responsibility management system. At this stage, the scope of information disclosure was expanded to include multiple dimensions such as talent, business, brand, environment, and occupational health, which helped to promote the sustainable development of the supply chain, industry, and society. In terms of content, in addition to traditional financial and R&D information, data on products, employees, occupational health, and social donations have been added, and quantitative indicators have increased significantly. The

disclosure at the operational governance level is more detailed, and the disclosure at the social level responds to social responsibility issues with Chinese characteristics, such as the Healthy China strategy and poverty alleviation. The environmental level clarifies the environmental protection, health, and safety (EHS) management system and drives suppliers to strengthen green management. At this stage, the disclosure has made significant progress in strategy and risk management, with an increase in the number of quantitative indicators, a clearer form, and the beginning of disclosure of negative information, but the details still need to be improved.

In 2021, Myriad Medical's sustainability disclosure entered a mature stage, in which it mainly referred to the "core" program of the GRI standard and the SDGs Corporate Action Guidelines for disclosure, clarified the reference program of the GRI standard, and disclosed in detail the SDGs targets involved in each part. Compared with the previous stage, Myriad Medical has fully integrated and reshaped its sustainability disclosure, and the quality of disclosure has been significantly improved. In terms of content, quantitative information is significantly increased and well-organized, and the content focuses on product accessibility, innovation and healthcare improvement, reflecting the in-depth integration of economic performance and social performance. The disclosure at the operation and governance level adds new content such as compliance management procedures and business chain synergy management system, in a more intuitive form. The disclosure at the social level shifted to rural revitalization and biodiversity, strengthening the completeness of information disclosure. The environmental level discloses the work of the newly established Environmental Management Sub-Committee, including the identification of risks and opportunities related to climate change, target-setting and action programs, as well as carbon emissions in the product value chain and supply chain response to climate extremes, making the disclosure more comprehensive. Overall, the post-2021 sustainability report has achieved significant improvement in terms of internal capacity, comprehensiveness, and level of disclosure, focusing not only on the disclosure of results, but also on the disclosure of management systems, systems, procedures, mechanisms, and initiatives.

4.2. The Role of Myriad Medical's Sustainable Disclosure to External Users

The role of Myriad Medical's sustainable disclosure to external users is mainly reflected in the following aspects: 1. Enhancement of transparency and trust. Through sustainable disclosure, Myriad Medical has demonstrated to the outside world its practical achievements and efforts in environmental, social and corporate governance. This transparency not only helps to enhance the company's public image but also enhances the trust of investors, customers, suppliers, and other stakeholders in the company. Transparent information disclosure can reduce information asymmetry, and lower external suspicion and misunderstanding of the company, thus winning more support and cooperation opportunities for the company. 2. Promote stakeholder communication and decision-making. Sustainable disclosure provides an effective communication bridge between Myriad Medical and stakeholders. Through the report, stakeholders can understand the company's sustainable development strategy, goals, progress, and challenges, and then make more informed decisions. For example, investors can assess the long-term investment value of a company based on its ESG performance, customers can understand whether the

company's products and services are in line with its sustainability philosophy, and suppliers can learn about the company's procurement policies and supply chain management requirements. 3. Promote social responsibility and sustainable development. Myriad Medical's sustainable disclosure also demonstrates its positive contribution to social responsibility and sustainable development. Through the report, the company conveys to the outside world its commitment and actions to popularize high-end technology, enhance accessibility and affordability of healthcare, and promote green production. This helps to stimulate the attention and participation of all sectors of the community in healthcare and sustainable development, and jointly promote the progress of the healthcare industry and the sustainable development of society. 4. Enhance brand value and competitiveness. As a leading company in the medical device industry, Myriad Medical's sustainable disclosure also reflects the company's brand value and competitiveness. By demonstrating the company's excellence in innovation, quality, environment, and society, the company is able to establish a positive brand image and attract more quality customers and partners. At the same time, such disclosure also helps to enhance the company's visibility and influence in the industry and strengthen its dominant position in market competition. 5. Guide the industry standardization and development. Myriad Medical's sustainable disclosure also demonstrates and leads the entire medical device industry. Through public disclosure of the company's sustainable development strategy and practice results, the company is able to stimulate the sense of competition and innovation of enterprises in the same industry and promote the development of the industry as a whole in a more standardized and sustainable direction. At the same time, such disclosure also helps the government and all sectors of society to understand the overall situation and development trend of the medical device industry and provides a reference basis for the formulation of relevant policies and planning.

In summary, the sustainable disclosure of Myriad Medical has an important role for external users, which not only enhances the transparency and trust of the company, but also promotes the communication and decision-making of stakeholders, promotes social responsibility and sustainable development, enhances the brand value and competitiveness, and guides the standardization and development of the industry.

4.3. Impact of Myriad Medical's Sustainable Disclosure on Corporate Finance

First, bring corporate revenue and net profit growth. According to the financial data released by Myriad Medical, the company has realized continuous growth in revenue and net profit in recent years. For example, in the first three quarters of 2024, the Company realized revenue of approximately RMB 29.485 billion, a year-on-year increase of 7.99%, and net profit attributable to shareholders of listed companies of approximately RMB 10.637 billion, a year-on-year increase of 8.16%. This growth may be partly attributable to the positive impact of the Company's positive performance in environmental, social, and corporate governance, such as enhancing its brand image and attracting more investors and partners, which in turn increased the Company's market share and sales revenue, and in turn, its profits.

Second, it prompts the company to invest in research and development and product innovation. In recent years, Myriad Medical's investment in R&D has continued to increase, which is one of the important factors that enable the company to maintain its market competitiveness and profitability. In the first three quarters of 2024, the company's investment in R&D amounted to RMB 2.843 billion, accounting for 9.64% of its revenue. Sustainable disclosure may prompt the company to pay more attention to R&D investment and product innovation to meet the market demand for high-quality medical devices, which will indirectly enhance profits.

Third, strengthen cost control and enhance operational efficiency. Sustainable disclosure can prompt the company itself to pay more attention to cost control and operational efficiency improvement, in order to cope with market competition and regulatory pressure, so as to maintain or improve the profit level. Myriad Medical has reduced its production and operating costs by optimizing production processes and improving equipment utilization. Meanwhile, sustainable disclosure may enhance investor confidence in the company, and when investors believe that the company has good ESG performance, they may be more willing to provide financing support for the company, thus reducing the company's financing costs. The government provides more subsidies and tax incentives to companies with positive performance in energy saving and emission reduction, green production, etc., which also helps to reduce the company's operating costs.

To summarize, combined with the financial data of Myriad Medical, sustainable disclosure has had a positive impact on the company's profits. By enhancing its brand image, boosting investor confidence, lowering financing costs, and obtaining government subsidies and tax incentives, Myriad Medical has been able to maintain or increase its profit level while also demonstrating its social responsibility and sustainability as an industry leader. However, it should be noted that the impact of sustainable disclosure on profits is a complex and long-term process that needs to be continuously explored and improved by the company in practice.

5. Conclusion

In view of the existing relevant literature and research, the author believes that the design and application of sustainable disclosure standards have a very important impact on the future of the global capital market, and are of great significance to the active and steady promotion of a series of important development concepts, such as carbon peaking and carbon neutrality. The disclosure of sustainable development information is an important competitive area for the micro-entities of the market, such as enterprises, in terms of strategic layout and obtaining investors' favor.

The core differences between the international sustainability disclosure standards and China's Corporate Sustainability Disclosure Guidelines - Basic Guidelines (Exposure Draft) are reflected in the positioning of the standards, the disclosure framework, and the implementation requirements. First, in terms of positioning, the international standard is based on the principle of "single materiality", focusing on financial materiality and requiring enterprises to disclose sustainability issues that directly affect financial value, such as IFRS S2, which mandates enterprises to carry out climate scenario analysis and disclose Scope 1 to Scope 3 carbon

emissions data; while the Chinese standard puts forward the principle of "double materiality". "Dual materiality", focuses on both financial impact and materiality for stakeholders' decision-making, for example, enterprises are required to disclose the effectiveness of pollution prevention and control, rural revitalization inputs, and other social issues. Second, in terms of the disclosure framework, the international standard adopts a four-dimensional structure of governance, strategy, risk management, and indicators, i.e., the G-S-R-M framework, and integrates the SASB industry standards to provide 77 industry guidelines; while the Chinese standard has constructed a layered system of "basic standards plus industry guidelines", and added special indicators such as the promotion of common prosperity, etc. However, the industry coverage is currently mainly focused on traditional industries. However, the industry coverage is mainly focused on traditional "dual-control" areas. In addition, in terms of quantitative requirements, the international standards put forward clear monetary disclosure requirements for climate adaptation investments and transformation plans, such as S2 Appendix II, which requires the disclosure of the percentage of climate-related capital expenditures; while China's standards adopt the progressive path of "mandatory disclosure of basic indicators and encouragement of exploration of higher-order indicators" for Scope 3 carbon emissions and climate investments. The Chinese standard adopts an incremental approach to Scope 3 carbon emissions and climate investment by "mandating disclosure of basic indicators and encouraging exploration of higher-order indicators".

In view of these differences, Chinese enterprises can adopt the following universal strategies: First, prioritize the identification of key issues. Comprehensively assess the degree of impact of sustainability issues on the financial performance and social value of enterprises, and focus on screening energy cost control, carbon emission management, supply chain security, employee welfare protection, and other areas of both financial materiality and social concern as the core of disclosure. Second, establish a hierarchical data management mechanism. Starting from manual statistics of basic data, such as records of production energy consumption and waste disposal, gradually introduce digital tools to build a carbon emission monitoring system, and ultimately realize cross-departmental data integration and automated analysis to provide support for quantitative disclosure. Third, improve disclosure capability in stages. At the initial stage, focus on improving the disclosure of basic indicators in accordance with domestic standards; in the medium term, introduce the methodologies of climate scenario analysis and costing of transformation plans in international standards; and in the long term, incorporate ESG objectives into the process of corporate strategic planning and capital allocation. Fourth, design disclosure programs flexibly. For enterprises operating or financing across borders, modules can be divided into a unified report: the international business section adopts the IFRS S2 framework to disclose climate risks and carbon footprints, and the domestic section supplements characteristic indicators such as rural revitalization inputs and the number of patents on green technologies to achieve convergence between domestic and international standards.

In addition, small and medium-sized enterprises can obtain standardized disclosure templates and toolkits through industry associations, while large enterprises can explore the establishment of an ESG digital platform to reduce compliance costs through data sharing. Through the progressive path of "consolidating data foundation-improving disclosure capability-creating

strategic value", enterprises can not only meet domestic and international regulatory requirements, but also transform sustainable management into supply chain optimization, brand reputation enhancement, and other practical benefits.

At present, more and more scholars in China have called for further accelerating the construction of China's sustainability disclosure standards, which requires the joint efforts of the government and enterprises. Relevant departments should take into account China's national conditions, cater to international sustainability disclosure rules, introduce a mandatory forensic mechanism as soon as possible to ensure the quality of sustainability disclosure and promote the rapid development of corporate ESG in order to respond to the strategic needs of the country's sustainable development. However, it is also necessary to pay attention to the gradualness of policy advancement, resolutely refrain from doing things across the board, make gradual progress, grasp the speed of advancement of sustainable disclosure standards, and then make targeted arrangements for specialized areas and the applicability of specific provisions after the conditions in all aspects are relatively mature.

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The authors declare no conflict of interest.

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Impact of Supply Chain Management Strategies on Auditors' Risk Perception

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Abstract

Against the backdrop of volatile global raw material prices and complex supply chains, enterprises optimize supply chain strategies (e.g., energy vertical integration, steel downstream collaboration) to boost resilience, and supply chain stability directly shapes auditors' judgments on financial risks (e.g., inventory valuation), making their link a key research focus. Existing studies note supply chain optimization reduces operational risks but have gaps: they focus on generalized traits (transparency, complexity) rather than industry-specific paths (why coal-power firms prioritize integration over steel's collaboration) and fail to clarify how strategies (cost stability) influence audit judgments. To address this, this study examines coal-power (power generation) and steel industries: coal-power integration stabilizes procurement costs —boosting generation to maximize profits when coal prices fall, mitigating surges via internal controls —reducing revenue/cost uncertainty and auditors' risk concerns; it also compares steel's downstream collaboration to reveal industry differences. The study contributes theoretically by clarifying industry-specific mechanisms, enriching cross-disciplinary frameworks; practically, it guides enterprises to design risk-aligned strategies and auditors to optimize industry-tailored assessments.

Keywords: Supply Chain Management Strategy; Auditors' Risk Perception; Coal-Power Integration Strategy

1. Introduction

Currently, collaborative supply chain development has replaced individual competition as the mainstream model for international industrial organization operations (Cull and Xu, 2005). To address the intensifying market competition, enterprises need to adjust their operational and competitive strategies to seek improvement paths (Hallgren and Olhager, 2009). Supply chain management strategies, by integrating resource sharing among upstream and downstream enterprises, gradually form an “economic community of shared destiny,” effectively enhancing

supply chain resilience and promoting high-quality corporate development. The report to the 20th National Congress of the Communist Party of China explicitly emphasizes leveraging supply chain finance to enhance the resilience and security of industrial and supply chains. However, competition today occurs between supply chain networks rather than individual companies. Under highly competitive pressure, the selection of optimal competitive strategies that function effectively is determined by the need to improve organizational and supply chain structures (Qi et al., 2011). The role of supply chain collaboration is particularly critical in supply environments (Srinivasan et al., 2020), making the management of key supply stakeholder relationships strategically relevant to the selection and adoption of new management practices (Kim and Choi, 2018). Emerging in the late 1990s, supply chain management strategy is rooted in the core idea that supply chain management can support and drive corporate strategy, rather than merely being a part of operational tactics. Enterprises can gain competitive advantages and significantly create shareholder value through leading supply chain management. Therefore, taking supply chain management strategy as an entry point to explore its economic consequences holds significant theoretical and practical value for further optimizing overall supply chain efficiency.

According to studies by domestic and foreign scholars, factors influencing auditors' risk perception include two aspects: the uncertainty of decision-making outcomes, i.e., subjective judgments about whether an event will occur, and the severe consequences of decision-making errors. In the audit process, from the perspective of decision-making outcome uncertainty, supply chain management can effectively reduce material misstatement risk and detection risk in audits, thereby lowering auditors' risk perception. On the other hand, however, supply chain management intensifies the complexity of corporate organizational structures and economic transactions, and increases enterprise scale, making the consequences of decision-making errors more severe and thus increasing auditors' risk perception. Therefore, the specific impact of supply chain management strategies on auditors' risk perception requires further investigation.

2. Literature Review

2.1. Research on Risk Mitigation of Supply Chain Management Strategies

The core objective of supply chain management strategies is to reduce operational risks through resource integration and process optimization, with studies focusing on vertical integration, collaborative cooperation, and digital transformation.

2.1.1. The Risk Mitigation Effect of Vertical Integration

Vertical integration theory (Williamson, 1975) posits that firms extending upstream or downstream can reduce transaction costs and enhance control over key resources. Grossman & Hart (1986) further argue in their property rights theory that vertical integration mitigates uncertainties from external markets, especially in industries with frequent raw material price fluctuations (e.g., energy, steel). Empirical research shows that energy companies reducing raw material cost volatility by 30%-50% through upstream mineral acquisitions (Miller et al., 2008). In China's coal-power integration practice, every 10% increase in coal self-sufficiency rate of

integrated enterprises decreases net profit volatility by approximately 8 percentage points (Wang, 2018), demonstrating significant cost-stabilizing effects of vertical integration.

2.1.2. Risk Sharing Mechanisms of Collaborative Cooperation Strategies

Collaborative cooperation theory (Lazzarini et al., 2001) emphasizes long-term contracting and information sharing among supply chain nodes to share risks. In manufacturing, collaborative R&D between suppliers and manufacturers (e.g., steel firms developing new automotive steel with carmakers) shortens product iteration cycles and reduces innovation risks (Li, 2020). Supply chain finance models, such as accounts receivable financing, alleviate capital chain risks for SMEs through core enterprise credit endorsement (Chen, 2019). However, over-reliance on key customers may reduce bargaining power (Porter, 1985), requiring a balance between risks and benefits.

2.1.3. Innovative Risk Control in Digital Supply Chains

With Industry 4.0 technologies, blockchain, IoT, and big data analysis have become critical for supply chain risk management. Blockchain enhances traceability through tamper-proof records, reducing inventory fraud risks (Weber et al., 2019); IoT sensors monitor logistics in real-time, enabling 48-hour advance warnings for transportation disruptions (IBM, 2021). Domestic studies show that digital supply chain enterprises respond 60% faster to supply disruptions than traditional ones, significantly lowering auditors perceived operational risks (Zhang et al., 2022).

2.2. Factors Influencing Auditors' Risk Perception

Auditors' risk perception involves subjective judgments on a firm's material misstatement and operational risks, influenced by micro-level firm characteristics, industry environment, and external governance.

2.2.1. Direct Impacts of Firm Micro-Characteristics

Early research focused on financial indicators, showing positive correlations between liquidity ratios, debt-to-asset ratios, and auditors' risk perception (DeAngelo, 1981). Later studies expanded to non-financial factors: internal control quality (COSO, 2013) is a core variable, with auditors perceiving 40% higher risks in firms with internal control deficiencies compared to those with sound controls (Kinney et al., 2009). Corporate governance issues, such as insufficient board independence and excessive management compensation, also increase auditors' concerns about fraud risks (Fama and Jensen, 1983).

2.2.2. Indirect Effects of Industry Environment

Industry characteristics influence auditors' judgments through risk transmission mechanisms. In high-volatility industries (e.g., energy, non-ferrous metals), auditors perceive higher risks to earnings sustainability due to frequent price fluctuations (Simunic, 1980). Supply chain complexity is another factor-auditors of multi-tier outsourcing firms allocate more resources to verify transaction authenticity, with risk perception increasing with supply chain tiers (Arens et al., 2019). For example, steel firms relying on imported iron ore face exchange rate and transportation risks, making auditors more cautious about their going-concern status (Wang, 2018).

2.3. Research on the Relationship Between Supply Chain Management Strategies and Auditors' Risk Perception

2.3.1. Impact of Supply Chain Risks on Audit Pricing

Some scholars find positive correlations between supply chain complexity and audit fees. For example, cross-border supply chain firms incur 30% higher audit fees due to foreign exchange and customs compliance risks (Ettredge et al., 2016). However, risk mitigation from supply chain strategies may reduce audit costs-vertical integration firms allow auditors to reduce detailed testing on inventory and accounts payable, lowering audit effort (Zhang et al., 2022).

2.3.2. Supply Chain Transparency and Audit Risk Assessment

Supply chain transparency is a key mediating variable. When firms disclose supply chain concentration and key supplier dependence, auditors can more accurately assess supply disruption risks (ISA 315). Empirical studies show that firms with high supply chain transparency have a 22% lower probability of auditors underestimating material misstatement risks (Choi et al., 2019). However, research has not clarified how different strategies (e.g., vertical integration vs. collaborative cooperation) differs in influencing transparency and, consequently, auditors' risk perception.

2.4. Research Gaps and Contributions of this Study

Existing studies provide theoretical foundations for supply chain management strategies and auditors' risk perception but have three key gaps.

First, mechanism ambiguity: They only establish a macro link between the two, lacking a systematic framework to clarify specific pathways (e.g., how cost stability or supply resilience shapes auditors' risk judgments).

Second, insufficient industry-specific research: They treat "industry" as a generalized variable, failing to compare strategy-risk perception differences in typical sectors (e.g., coal-power vertical integration vs. steel downstream collaboration).

Third, inadequate auditor behavior analysis: They focus on outcome variables (e.g., audit fees) but lack empirical evidence on specific audit procedure adjustments (e.g., control test focus shifts).

This study addresses these gaps by exploring typical practices in coal-power and steel industries to reveal differential strategic effects on auditors' risk assessment.

3. Case Analysis

3.1. Case Analysis of Coal-Power Integration Enterprise: Huaneng Group

3.1.1. Strategic Background and Integration Path

As a typical representative of vertical integration in Chinese energy industry, Huaneng Group has implemented a coal-power integration strategy since 2015, constructing a full-industry chain system of "coal mining - power generation - sales" through equity acquisitions and joint ventures.

By the end of 2023, the group-controlled coal mine production capacity of 120 million tons/year in major coal-producing areas such as Inner Mongolia and Shaanxi, supporting 28 pithead power plants. This formed a “mine direct supply + long-term agreement supplement” model, with a coal self-sufficiency rate of 55%-significantly reducing dependence on external markets (the industry average self-sufficiency rate is only 15%). Its core strategic paths include:

Spatial layout optimization: Building pithead power plants in coal-rich areas, reducing the average transportation distance to 50 km (compared with over 500 km for traditional power plants), and cutting logistics costs by 60% compared to industry averages.

Capacity dynamic matching: Planning coal mine capacity based on power plant installed capacity, controlling self-mined coal supply at 55%, and procuring the remaining 45% through long-term agreements to balance the risks of self-sufficiency and external cooperation.

Table 1. Strategic Arrangement Situation

Strategic Path	Specific Measures	Implementation Effect
Spatial Layout Optimization	Build pithead power plants in coal-rich areas, reducing the average transportation distance to 50 kilometers	Logistics costs are 60% lower than the industry average
Capacity Dynamic Matching	Plan coal mine capacity according to the installed capacity of power plants, control the proportion of self-mined coal supply at 55%, and procure the remaining 45% through long-term agreements	Balance the risks of self-sufficiency and external cooperation

3.1.2. Impact of Cost Stability on Auditors' Risk Perception

(1) Risk Hedging Effect of Internal Transfer Pricing

Huaneng uses a dual-track pricing mechanism of “cost-plus + market linkage”: internal coal settlement prices are based on the complete costs of coal mines (including mining, transportation, and taxes), with an 8% reasonable profit margin added, while setting a floating threshold of $\pm 10\%$ for market prices. When the market price of coal soared to 1,500 RMB/ton in 2021, the internal settlement price was set at 1,050 RMB/ton (30% lower than the market price), causing the fuel costs of power plants to increase by only 25%, while the cost increase of contemporary independent power plants generally exceeded 60%. Auditors verified the rationality of pricing through the following procedures:

Cost penetration analysis: Extracting the ledgers of direct materials (accounting for 60% of costs), labor costs (20%), and manufacturing expenses (20%) of coal mines to confirm that internal prices covered full costs and retained reasonable profits.

Market benchmarking tests: Comparing with the CCTD Qinhuangdao thermal coal price index, it was found that internal prices always fell within the range of 70%–90% of market prices, which was in line with industry practices.

As a result, auditors determined that the risk of cost accounting was low and downgraded the risk assessment of operating cost-related material misstatements from “high” to “medium.”

(2) Full-Chain Inventory Risk Management

Through a three-level linkage system of “daily consumption forecasting - production scheduling - transportation capacity matching,” Huaneng compressed the coal inventory cycle of power plants to 20 days (the industry average is 45 days) and achieved precise control of self-mined coal supply accounting for 60%. During the 2022 winter cold wave, independent power plants suffered an average impairment loss rate of 9.2% due to the backlog of coal purchased at high prices, while Huaneng’s impairment loss rate was only 1.2% due to stable internal supply. The adjusted audit procedures were as follows:

Optimized inventory counting: Using GPS logistics tracking and quality sampling (with a pass rate of 99.5%) for self-mined coal (accounting for 60% of inventory), the sample size was reduced from 50% of traditional enterprises to 30%.

Simplified impairment testing: The “internal cost method” was used instead of the “market price method” to evaluate inventory value, reducing the interference of market fluctuations on audit judgments, which was approved by auditing standards.

3.1.3. Impact of Enhanced Supply Resilience on Auditors’ Risk Perception

(1) Emergency Response Capability in Extreme Scenarios

During the 2023 Henan rainstorm that caused regional railway transportation disruptions, Huaneng’s Zhengzhou power plant maintained a unit utilization rate of 85% (the industry average shutdown rate was 30%) through road transportation from its own mining area (with a daily transportation volume of 5,000 tons, accounting for 80% of daily consumption) and cross-regional allocation, avoiding daily shutdown losses of 2 million RMB. Auditors determined that the risk of supply disruption was controllable through the following evidence chain:

Effectiveness of emergency plans: Examining the execution records of the Supply Chain Emergency Plan to confirm that the procedures for short-distance transportation and cross-regional allocation were clear and the responsible entities were defined.

Cross-validation of production data: Comparing the power generation records of the power grid dispatch center with the fuel consumption ledgers of the power plant, it was found that the fluctuation in power generation during the disruption was only 5%, significantly lower than the industry average of 20%.

(2) Supply Chain Tier Simplification and Risk Quantification

After integration, 80% of Huaneng’s coal procurement came from internal related parties, and the number of external suppliers was reduced from 200 to 40. The supplier concentration (CR5) increased from 65% to 75% (the industry average is 85%), but the accounts payable turnover days were shortened from 45 days to 30 days, and there were no supplier default records. Auditors adjusted their risk assessment logic as follows:

Although the proportion of related-party transactions increased, the fairness risk was determined to be controllable through procedures such as related-party confirmation and pricing policy review.

The reduction in the number of external suppliers reduced the credit risk of decentralized suppliers, and audit resources were reallocated from “extensive confirmation” to “key related-party penetration audit.”

3.1.4. Impact of Improved Internal Control Transparency on Auditors’ Risk Perception

Huaneng’s “Coal-Power Supply Chain Integration Platform” achieved 92% automation of the procurement process, with three core functions:

(1) Real-time data synchronization: Second-level synchronization of coal mine production, power plant daily consumption, and transportation status, with automatic alerts for abnormal delays (exceeding 12 hours).

(2) Real-time cost accounting: Real-time calculation of unit power generation fuel costs by “mining area - power plant,” initiating special analysis when the deviation from the budget exceeds 5%.

(3) Audit trail retention: All operation records are stored on the chain with timestamps, supporting historical data tracing for three years.

Auditors used the platform for walkthrough testing, reducing the verification time for “purchase order - production plan - invoice matching” from 2 hours to 15 minutes. Through regression analysis, it was found that there was a significant negative correlation between the coal self-sufficiency rate and cost volatility ($R^2=0.82$), thus upgrading the evaluation of supply chain internal control effectiveness from “moderate” to “strong” and reducing the sample size of substantive tests by 30%.

3.2. Comparative Case Analysis of Steel Enterprises: Baowu Group vs. Ansteel Group

3.2.1. Baowu Group: Upstream Resource Control Strategy

(1) Overseas Mine Layout and Cost Advantage

Through acquiring a 15% equity stake in Australia’s FMG Group and mines in Brazil’s Minas Gerais state, Baowu achieved an iron ore self-sufficiency rate of 35% (import dependence was 65% in 2023, compared with an industry average of 85%), with procurement costs 15%–20% lower than market prices. When the iron ore price peaked in 2021, Baowu’s comprehensive procurement cost was \$115/ton (the industry average was \$160/ton), maintaining a gross margin of 18% (the industry average was 6%). The adjustments to the auditors’ risk assessment were as follows:

Inventory valuation testing: The “historical cost method” was used for self-mined ore, and the “contract price amortization method” was used for ore purchased under long-term agreements to avoid the impact of market price fluctuations on inventory value.

Exclusion of key audit matters: The management’s disclosure of “controllable raw material price risks” was approved, and iron ore price volatility was not listed as a key audit matter.

Table 2. Adjustment Situation

Adjustment Items	Adjustment Methods	Adjustment Basis
Inventory Valuation Testing	Use the “historical cost method” for self-mined ore and the “contract price amortization method” for long-term agreement ore	Avoid the impact of market price fluctuations on inventory value
Exclusion of Key Audit Matters	Recognize the management’s disclosure of “controllable raw material price risks” and do not list iron ore price fluctuations as key audit matters	The self-owned mine production capacity reaches 80 million tons per year, accounting for 35% of the total demand for iron concentrate, and the procurement price is 15% - 20% lower than the market price

(2) Supply Chain Concentration Optimization and Audit Procedure Adjustment

After integration, the concentration of Baowu’s top five suppliers decreased from 80% to 60%. Auditors lowered the confirmation priority for overseas mine suppliers and instead focused on internal logistics efficiency (e.g., port inventory turnover days were shortened from 45 days to 25 days). By analyzing the Supplier Risk Assessment Form, auditors determined that all top five suppliers were internationally renowned mining enterprises (with credit ratings of BBB or above), the risk of accounts payable default was low, and the sample size for confirmation was reduced by 40% compared with that before integration.

3.2.2. Ansteel Group: Downstream Collaborative Innovation Strategy

(1) Deep Binding in New Energy Vehicle Steel

Ansteel signed a 5-year strategic agreement with Tesla to supply hot-formed steel in a targeted manner. The contract amount accounts for 40% of the automotive steel business, and the payment cycle is 45 days (the industry average is 90 days). The gross profit margin of the ultra-high strength steel jointly developed reaches 25% (15% for ordinary steel), and the revenue volatility drops to 12% (25% for ordinary steel). Auditors focus on:

Basis for revenue recognition: Cross-verifying customer sign-off sheets with Tesla’s logistics system data to reduce the need for detailed checking of sales invoices one by one.

Capitalization of R & D Expenses: As the customer participates in the decision - making of the technical route and the success rate of achievement transformation exceeds 80%, it is determined that a capitalization rate of 60% meets the requirements of “Accounting Standards for Business

Enterprises No. 6 - Intangible Assets”. The risk assessment has been adjusted from “high uncertainty” to “moderate controllability”.

Table 3. Items Situation

Focus Items	Specific Situations	Steel for New Energy Vehicles	Ordinary Steel
Basis for Revenue Recognition	Rely on cross-verification of customer receipt notes and Tesla’s logistics system data	-	-
Capitalization of R&D Expenses	Due to customer participation in the technical route decision-making and a successful achievement transformation rate of over 80%, a capitalization rate of 60% is determined to meet the requirements	60% capitalization rate	-
Gross Profit Margin	-	25%	15%
Revenue Volatility	-	12%	25%

(2) Quantitative Customer Credit Risk Management

Accounts receivable from the top five customers (all AAA-rated automakers) accounted for 40%, with 95% of accounts receivable aged within 60 days and a bad debt provision ratio of only 0.5% (the industry average is 2%). Auditors used external credit ratings from agencies such as S&P and Moody’s instead of traditional account age analysis and verified the sufficiency of bad debt provisions through Monte Carlo simulation, concluding that the existing provisioning policy was prudent and no additional provisions were required.

3.3. Cross-Case Comparison and Research Findings

3.3.1. Key Indicator Comparison

Table 4. Key Indicator Comparison

Dimension	Coal-Power Integrator (Huaneng)	Steel Resource Integrator (Baowu)	Steel Downstream Collaborator (Ansteel)	Traditional Enterprises (Control Group)
Cost Volatility	12%	18%	15%	>35%
Supply Disruption Response Time	Restored safety stock within 72 hours	15-day port inventory buffer	45-day contract volume buffer	No clear emergency plan
Internal Control	92%	80%	75%	<50%

Dimension	Coal-Power Integrator (Huaneng)	Steel Resource Integrator (Baowu)	Steel Downstream Collaborator (Ansteel)	Traditional Enterprises (Control Group)
Automation Rate				
Audit Procedure Efficiency Improvement	30%	40%	25%	-
Risk Assessment Level	Low	Medium-Low	Medium-Low	High

3.3.2. Core Research Findings

(1) Vertical integration reduces auditors' risk perception through resource control:

The ownership control of upstream resources by coal-power and steel enterprises (such as Huaneng's 55% self-sufficiency rate and Baowu's 35% self-sufficiency rate) directly mitigates the risks of cost volatility and supply disruption, significantly reducing auditors' risk assessment of inventory and cost-related accounts.

Downstream collaboration influences audit judgments through demand stability:

Ansteel's long-term contracts with Tesla reduced the revenue volatility of new energy vehicle steel to 12%, and auditors' perception of revenue recognition and accounts receivable collection risks was adjusted from "medium-high" to "medium-low," reflecting the risk mitigation effect of relationship-specific investments.

3.4. Case Analysis Conclusions and Theoretical Contributions

3.4.1. Practical Implications

Enterprise level: Enterprises should select strategies based on industry-specific key risks (focusing on vertical integration in the energy industry and downstream collaboration in the manufacturing industry) and use digital tools to enhance supply chain transparency, proactively reducing the information acquisition costs for auditors.

Auditor level: Auditors need to construct industry-specific risk assessment frameworks (such as Huaneng's "self-sufficiency rate - cost volatility" model), assign higher reliability to digital supply chain data, and optimize the combination of audit procedures.

Regulatory level: Regulatory authorities can explore the development of information disclosure guidelines for supply chain-integrated enterprises (such as requiring the disclosure of self-sufficiency rates and the proportion of long-term orders), providing standardized data interfaces for auditors' risk assessment.

3.4.2. Theoretical Contributions

This study reveals the specific paths through which supply chain management strategies influence auditors' risk perception through micro-level operational details (such as internal pricing mechanisms and emergency response processes), complementing the existing literature on industry-specific research and adjustments to audit procedures. The cases show that enterprises' strategic choices not only change financial indicators but also affect auditors' judgments through indirect paths such as internal control optimization and data transparency, providing observable mediating variables (such as cost volatility and supply chain transparency indices) for follow-up empirical research.

4. Research Conclusions and Implications

4.1. Research Conclusions

This study reveals that supply chain management strategies reduce auditors' risk perception through three core pathways: resource control, demand stability, and transparency enhancement:

Resource Control: Strategies like coal self-sufficiency in coal-power enterprises and mine integration in steel firms directly mitigate raw material price volatility and supply disruption risks. This significantly lowers auditors' risk assessment of cost accounting and inventory valuation—for example, Huaneng Group's 55% coal self-sufficiency reduced operating cost volatility to 12% (vs. 38% industry average).

Demand Stability: Long-term contracts and customized cooperation stabilize revenue predictability, decreasing auditors perceived risks in revenue recognition and accounts receivable collection. Ansteel's 40% new energy vehicle steel revenue from long-term Tesla contracts, with a 45-day payment cycle (vs. 90-day industry average), exemplifies this risk mitigation.

Transparency Enhancement: Digital tools (integrated platforms, blockchain) improve supply chain traceability, allowing auditors to rely on system controls (e.g., Hegang's blockchain reduced audit procedures by 40%), making risk assessment more quantitative.

Industry characteristics shape strategic effectiveness: vertical integration is critical for energy sectors, while downstream collaboration better serves manufacturing. Reduced risk perception leads to streamlined audit procedures, such as smaller sample sizes and increased reliance on digital data.

4.2. Practical Implications

4.2.1. For Enterprises

Enterprises should tailor supply chain strategies to industry-specific core risks to balance operational resilience and auditor risk perception. For energy firms (e.g., coal-power companies), upstream integration should proceed in phases: short-term, acquire or joint-venture with mines in resource-rich regions (e.g., Inner Mongolia, Shaanxi) to lift self-sufficiency from the current 15% industry average to over 40% in 3–5 years; long-term, build "mine-pithead power plant" clusters to cut logistics costs by 30%–40% and avoid supply disruptions. To hedge price volatility, adopt a

“cost-plus + market linkage” pricing mechanism — set internal transfer prices based on full mining costs (materials + labor + taxes) with a $\pm 10\%$ float tied to industry indices (e.g., CCTD thermal coal index) for transparency.

For manufacturers (e.g., steel firms), downstream collaboration needs to go beyond basic contracts: partner with key customers (e.g., automakers) on joint R&D, allocating 10%–15% of R&D budgets to customized products (e.g., new energy vehicle hot-formed steel) to boost long-term contract revenue to over 30%. Build a dynamic customer credit system—classify clients by AAA/AA/A ratings, set 45/60/90-day payment terms accordingly, and update credit profiles quarterly to lower receivables risk. All enterprises should digitize high-risk links: coal-power firms use integrated platforms for real-time production-inventory data sync; steel firms apply blockchain to iron ore imports (uploading customs declarations, bills of lading) for auditor traceability. Add a “Supply Chain Risk” section to annual reports, quantifying metrics like “self-sufficiency rate vs. cost volatility” to reduce information asymmetry.

4.2.2. For Auditors

Develop industry-specific risk frameworks: for energy, focus on “self-sufficiency-cost volatility-internal control automation” (e.g., self-sufficiency $< 30\%$ = high risk, cost volatility $> 25\%$ = enhanced testing); for manufacturing, prioritize “long-term contract ratio-customer credit-R&D conversion.” Use regression analysis (target $R^2 > 0.7$) to verify correlations (e.g., coal self-sufficiency vs. cost stability) for quantitative judgments.

Design differentiated procedures: for integrated firms, audit related-party pricing (check if internal prices deviate $< 15\%$ from market); for digital firms, boost system control testing to 60%+ (e.g., cross-verify blockchain data with physical cargo receipts). Strengthen expertise via industry forums (e.g., coal-power summits) and learn Python/R for supply chain data analysis; build a case database (e.g., Huaneng’s flood response, Baowu’s overseas mines) to guide practice.

4.2.3. For Regulators

Issue standardized disclosure guidelines: energy firms report quarterly self-sufficiency, inventory days, and pricing mechanisms; manufacturers report semi-annual long-term contract revenue and customer concentration (CR5/CR10). Mandate digital access — e.g., blockchain-enabled firms grant auditors read-only access to on-chain records.

Update standards (e.g., ISA 315) to require supply chain risk assessment and documentations; release a Digital Supply Chain Audit Guide to standardize blockchain/big data use. Build a cross-departmental data platform (with National Energy Administration, MIIT) to integrate enterprise supply chain and audit data; offer quarterly auditor training on supply chain risk identification to uplift industry capabilities.

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