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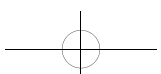


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Current Situation of Urban Energy Consumption Under the Digital Economy Model

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Abstract: The digital economy has injected continuous momentum into the development of urban economy and plays a positive and important role in the transformation and upgrading of urban energy consumption. Specifically, the digital economy can significantly improve the efficiency of urban energy consumption by virtue of its distinctive characteristics of low pollution and high efficiency. Moreover, empowered by the digital economy, the pace of transformation and upgrading of high-pollution traditional industries has been accelerated. Particularly importantly, the urban energy consumption structure has been optimized and adjusted through the indirect role of intermediate factors. From this perspective, studying the current situation and countermeasures of urban energy consumption under the digital economy holds important practical significance both in theory and practice. This paper first briefly summarizes the relevant literature on the impact of the digital economy on the energy consumption structure; then, it focuses on detailed data to explore the current situation of urban energy consumption under the digital economy model; finally, based on the summary of the current situation, it puts forward practical and feasible suggestions, hoping to provide a decision-making basis for the implementation of policies in different types of cities and offer innovative ideas for promoting the high-quality development of urban energy systems.

Keywords: Current situation; Digital economy model; Suggestions; Urban energy consumption

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1. Introduction

In the context of the continuous and in-depth implementation of the “dual carbon” goals, cities, as the engines of national economic growth and the core of energy consumption, have attracted widespread attention from all sectors regarding the optimization and transformation of their energy consumption models. According to the analysis of data from 2023, China’s total energy consumption reached 5.72 billion tons of standard coal, among which fossil energy accounted for as high as 73.6%. In contrast, the proportion of clean energy was less than half of that of fossil energy, only 26.4%^[1]. Studies have shown that on the path to achieving the carbon neutrality goal, the high proportion of fossil energy poses severe challenges to the transformation of China’s energy consumption structure

and is one of the important factors affecting the realization of the carbon neutrality goal. Therefore, this paper focuses on an in-depth analysis of the current situation of urban energy consumption under the digital economy model, hoping to contribute a modest effort to promoting the integrated development of the digital economy and urban energy consumption in the future.

2. Literature review on the impact of digital economy on energy consumption structure

Relevant studies on the impact of the digital economy on the energy consumption structure mainly focus on two aspects: the green energy-saving effect and the energy rebound effect, aiming to analyze the internal impact mechanisms and practical effects of these two dimensions. Studies have shown that the digital economy serves as a crucial engine driving economic growth and provides an effective pathway for the optimization and upgrading of the energy consumption structure. Fundamentally, this relationship is essentially a “game” between the green energy-saving effect and the rebound effect ^[2]. In this game, the improvement of energy efficiency and the optimization of the energy structure represent specific opportunities; however, the total energy consumption may confront unprecedented challenges. To formulate scientific and effective energy policies, it is essential to pay equal attention to both opportunities and challenges, while clearly clarifying the relationship between them.

On one hand, regarding the green energy-saving effect, the digital economy not only triggers a technological revolution but also significantly enhances energy utilization efficiency. Meanwhile, it promotes industrial transformation and upgrading. Through these channels, the energy consumption structure can be optimized, driving it toward low-carbonization, greenization, and cleanization. Zhu et al. (2025) conducted a study using an improved stochastic frontier model and found that the digital economy can substantially improve energy efficiency while exerting a positive driving effect on economic growth. Under the influence of indirect effects, it can effectively reduce energy intensity per unit of output. Nevertheless, part of this energy-saving effect is still offset by the “substitution effect,” “income effect,” and “output effect” ^[3]. Mao et al. (2024), by extensively collecting and analyzing urban panel data, revealed that the digital economy is of great significance to the integration and mutual development of industrial digitalization and digital industrialization. On this basis, energy-intensive industries may be invisibly replaced by technology-intensive industries ^[4]. More importantly, this structural transformation effect is more prominent in cities with low endowments of fossil energy. In addition, the spatial spillover effect—a crucial characteristic of the digital economy—enables its role in optimizing the energy structure to break through geographical constraints, continuously radiate to surrounding regions, drive the optimization and upgrading of energy consumption structures in neighboring areas, and make cross-regional collaborative energy governance possible.

On the other hand, concerning the energy rebound effect, this effect of the digital economy may cause energy conservation and emission reduction outcomes to fall short of expectations. Specifically, as energy utilization efficiency improves, the total energy consumption may show an upward trend. Two primary factors contribute to this phenomenon: first, the decline in energy use costs, and second, the stimulation from economic growth. Some scholars point out that the factors triggering the rebound effect mainly include two aspects: first, the digital economy has an “incomplete substitution effect” on traditional energy sources, meaning it cannot fully replace the use of traditional high-energy-consuming energy; second, the digital economy has spawned a range of new business formats, including digital services and intelligent industries, which further expands energy demand. Relevant calculation data indicate that the current average level of urban energy rebound effect in China is

approximately 56.2%. This figure reflects indirectly that the actual energy-saving effect currently achieved in China is only about 40% of the theoretical value^[5]. The fundamental reason lies in the fact that although the digital economy drives technological innovation and boosts economic growth, it also gradually amplifies the overall demand for energy consumption. Building on theoretical foundations, some scholars have conducted a series of empirical studies. The results show that the popularization of the Internet has dual effects: on one hand, it effectively improves the efficiency of economic operation and stimulates the growth of electricity demand; on the other hand, it may intensify the pressure on energy consumption.

3. Analysis of the current situation of digital economy and energy consumption

3.1. Analysis of the current development situation of the digital economy

From 2012 to 2023, China's digital economy maintained a remarkable growth momentum, with its total volume increasing steadily from the initial 11.2 trillion yuan to 53.9 trillion yuan. This significant leap intuitively demonstrates the important position of the digital economy in China's overall economic system. Over these 11 years, the average growth rate of China's digital economy has remained at a high level, with the specific figure reaching 15.3%. From the perspective of growth rate, in 2023, the digital economy provided solid and strong support for achieving the goal of stable economic growth. The nominal growth rate of China's digital economy in that year was 7.37%, which was 2.73 percentage points higher than the nominal growth rate of GDP in the same period. From the perspective of contribution rate, the corresponding figure reached 66.45%^[6]. This set of data indicates that the digital economy can not only enhance the resilience of China's economic development but also inject a continuous stream of vitality into it.

In the process of the high-quality development of China's digital economy, the internal structure of the digital economy has been optimized. At the same time, a gradual balance has been achieved between digital industrialization and industrial digitalization, and the empowering capacity and integration capacity of the digital economy have been significantly improved. Relevant data show that in 2023, the economic scale of China's digital industrialization sector reached 10.1 trillion yuan, an increase of approximately 0.9 trillion yuan compared with 2022. This growth rate even exceeded the overall growth rate of the digital economy in the same period, which will provide stronger technological and industrial support for the future development of the digital economy^[7].

Finally, an analysis of the data on the development level of the digital economy in various regions of China shows that regional differences may lead to significant variations in the development level of the digital economy across different regions. Among them, the eastern coastal areas take the leading position, while the central and western regions are relatively weak in the development of the digital economy. Although the development level of the digital economy in these two regions still lags behind the national average, the gap in the central region is relatively smaller. From an overall perspective, in recent years, the development level of China's digital economy has been in a continuous growth trend, and the improvement of the national average level of the digital economy has also shown a stable trend across the country.

3.2. Analysis of the current situation of energy consumption

3.2.1. Current situation of total energy consumption

Between 2013 and 2024, China's total energy consumption increased from 4.17 billion tons of standard coal equivalent (SCE) to 5.92 billion tons of SCE, with an average annual growth rate of approximately 3.2%. However, during the same period (2013-2024), the average annual growth rate of China's national economy

was about 6%. Behind these figures lies the fact that China has not only ensured the high-speed development of its economy but also effectively controlled the growth rate of energy consumption. This is not merely a simple “quantity control”; on a deeper level, it reveals that China’s energy efficiency is steadily improving^[8].

3.2.2. Current situation of energy consumption structure

From 2013 to 2024, the consumption of coal—China’s traditional high-energy-consuming energy source—showed an overall downward trend. Relevant data indicate that in 2013, coal consumption accounted for as high as 67.4% of China’s total energy consumption; by 2024, this figure had gradually dropped to 53.2%. These data reflect, from a side perspective, that China’s energy structure is constantly transitioning toward a low-carbon direction. Nevertheless, the role of coal in the power supply system remains significant. Approximately 60% of total coal consumption is used in the field of electricity generation, and its position may be difficult to replace in the short term.

Besides coal, the proportion of oil in the energy consumption structure has remained relatively stable, fluctuating around 18% overall. Compared with oil, the proportion of natural gas in energy consumption showed a continuous upward trend between 2013 and 2024, with the corresponding figures being 5.30% and 8.2% respectively. Owing to its distinct characteristics of cleanliness and high efficiency, natural gas is playing an increasingly important role in the overall energy structure.

In addition, hydropower, wind power, solar power, and nuclear power—important representatives of non-fossil energy—have developed rapidly in recent years, and the proportion of each in the energy structure has increased year by year. Between 2013 and 2024 alone, the total proportion of these non-fossil energy sources achieved a leapfrog development from 10.2% to 21.3%^[9]. This signifies that China’s energy structure is gradually moving toward a new path of greenization and low-carbonization.

4. Suggestions for optimizing urban energy consumption structure under the digital economy model

4.1. Consolidate the foundation of digital infrastructure

To specifically address the unbalanced development of regional digitalization, the government should invest substantial funds, materials, and human resources in digital infrastructure construction. Priority should be given to the central and western regions, as well as regions with low energy endowments. In addition to expanding network coverage and improving network quality, it is also necessary to build a systematic and comprehensive digital financial service system. The core purpose of these measures is to provide convenient network, technical, and other support for the subsequent application of energy digitalization, enabling every region to benefit from digitalization^[10].

4.2. Promote the implementation of intelligent and green transformation

“Industrial intelligent and green transformation” specifically refers to the flexible use of various means to drive the continuous transformation and development of industries towards intelligence and greenization. Under the correct guidance of industrial policies, the integration of the digital economy and traditional industries should gradually shift from “superficial” to “in-depth”—especially for high-energy-consuming industries such as iron and steel, and chemical engineering. Solid and powerful digital technical support should be provided for these industries to achieve intelligent transformation and green upgrading^[11]. At the same time, focus should be placed on fostering

emerging industries such as cloud computing and 5G communications, which are characterized by low energy consumption and high added value. Furthermore, over-reliance on traditional energy sources such as oil and coal should be avoided. This suggestion is put forward from the perspective of optimizing the industrial structure, and its advantage lies in effectively promoting the transformation of energy consumption patterns towards higher efficiency and intensification.

4.3. Support green technology innovation

Greater efforts should be made to research and develop green and environmental protection technologies. To ensure the smooth progress of technology R&D, it is recommended to establish special R&D funds. Moreover, it is necessary to improve financial policies to provide guarantee and support for the development of green credit. For enterprises dedicated to green technology R&D, it is suggested to offer tax reductions and exemptions, as well as provide them with certain financial subsidies^[12]. Additionally, society, schools, and the government should strengthen collaboration, rely on the industry-university-research cooperation platform, and increase efforts in cultivating and introducing high-end talents. This will provide solid talent support for the R&D and innovation of green technologies^[13].

4.4. Implement regionally differentiated strategies

Each region should closely align with its actual conditions to carefully formulate strategies for advancing the development of the digital economy and also establish and improve policies facilitating energy transition. Specific strategies may be formulated in a context-specific manner based on the actual conditions of the eastern, central, and western regions. For instance, the eastern regions should give full play to the advantages of digital technologies and, with an innovative mindset, promote the integrated innovation of these technologies with green energy sources such as wind power and photovoltaic power; the central regions should focus on their local traditional industries, such as manufacturing, fully leverage the enabling role of digital technologies, and assist these traditional industries in advancing toward digitalization step by step; the western regions, on the other hand, should strengthen the construction of digital infrastructure and, more importantly, focus on exploring ways to enhance the effective utilization rate of local energy resources^[14,15]. Such differentiated strategies can enhance the rationality and effectiveness of the transformation of urban energy consumption against the backdrop of the digital economy.

5. Conclusion

To sum up, through various approaches including technological empowerment, industrial adjustment, and consumption transformation, the digital economy can directly change the energy consumption structure and drive its continuous transformation and development towards cleanliness and efficiency. Based on the above research, various regions can promote the optimized transformation of urban energy consumption structure under the digital economy model by taking measures such as consolidating the foundation of digital infrastructure, advancing the implementation of intelligent and green transformation, supporting green technological innovation, and implementing strategies tailored to regional differences.

Disclosure statement

The authors declare no conflict of interest.

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The Effect of Income on Household Time Allocation Among Chinese Couples

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Abstract: Gender equalization has progressed considerably in all areas but has prolonged domestic work. Previous research suggests that income is essential in the distribution of time spent on housework between couples. However, there is still debate about how income works within Chinese households. Therefore, it is necessary to study how income influences the time spent on housework by Chinese couples. This paper uses data from The China Family Panel Studies (CFPS) in 2022 and selected married two-income households aged 18-65 as our study population. Based on the results of the study and the Nash cooperative game ‘divorce-threat’ model, the hypotheses were then regressed using the Tobit model. Robustness tests were then conducted using the OLS regression model and the replacement variables method. Finally, the impact of income on the distribution of household work time of Chinese couples was analyzed, followed by conclusions. Firstly, the allocation of housework time during working days is influenced by income factors, while the distribution of housework time on rest days is not influenced by income. Secondly, individual income is negatively related to own time spent on housework, while the spouse’s income is positively associated with wife/husband time. Thirdly, the wife’s relative income is “U” shaped, and the relative gain of the husband is “inverted U” shaped.

Keywords: Household income; Household time; Tobit model

Online publication: November 5, 2025

1. Introduction

According to the latest data from the Organization for Economic Cooperation and Development (OECD), Chinese men spend far less time on household chores than that of world men average time, only 48 minutes per day on average. Previous studies showed that the inequitable distribution of household time not only hinders gender equality, but also negatively affects the stability of couples’ marriage. Therefore, it is necessary to study the factors that affects the housework time allocation among couples in China.

There has been a lot of literature on the factors affecting housework time allocation among couples. Hence, the influencing factors have been classified into three categories:

- (1) Individual level (age, gender, income, education condition, health condition);
- (2) Family level (family size);
- (3) Social level (cultural value, region).

Among them, the individual-level income factor is the one that has a more significant impact on the distribution of spouses' domestic work, which has been more abundantly studied in Europe and the United States and less so in China ^[1]. Given the different social structures and gender concepts between China, Europe, and the United States, it is necessary to study how income affects the housework time allocation of Chinese couples ^[2]. Most current studies in the field of domestic work in China use regional data, and there is a lack of studies using national survey data. Moreover, previous literature has controversial results on the impact of relative income and considers the implications of less absolute income. Lastly, existing studies have focused on the effect of income on the total time spent on housework and have rarely explored the relationship between income and time spent on workdays and rest days, respectively. This paper was organized to differentiate from these characteristics of previous literature.

2. Model introduction

The China Family Panel Studies (CFPS) is an authoritative, large-scale, comprehensive database. Specifically, it is authoritative because it is funded by Peking University's It985" project and implemented by Peking University's China Social Science Survey Centre. It has successfully conducted six waves of data collection. The target sample size is 16,000 households in 25 provinces/municipalities/autonomous regions, representing 95% of China's population. The database is more comprehensive as it includes data from multiple perspectives, from households to individuals. Therefore, considering the content and purpose of this paper, this paper selected the (CFPS) 2022 survey database for the study.

This paper examines the effect of income on allocating housework time to dual-earner couples. The dependent variable is household time (hours/day), a continuous variable. Considering its existence of a certain proportion of zero, the Tobit model is chosen instead of the OLS regression model used in most studies to make the regression more accurate.

$$y_i = \begin{cases} y_i^* = \beta_0 + \beta_{wi}lw\ income + \beta_{hi}lh\ income + \beta_{rwi}re\ w\ income + \beta_{rhi}re\ h\ income + \\ \beta_{rwi2}re\ w\ income^2 + \beta_{rhi2}re\ h\ income^2 + \eta_i X + \varepsilon_i, & \text{if } y_i^* > 0 \\ y_i^* = 0, & \text{if } y_i^* \leq 0 \end{cases}$$

X : [w age, w health, w urban, h age, h health, h urban]

3. Results and discussion

3.1. Absolute income

The results showed a causal relationship between absolute personal income and the time the wife/husband spent on housework. Firstly, an increase in the personal income of either the wife or the husband reduces the amount of time spent on housework, and the effects of the wife's income are more significant than the effects of the husband's income ^[3]. In addition, personal income has a more substantial impact on the amount of time spent on housework during the working day than on housework during the rest day. It is in line with the findings of the income theory and the individual-centred thinking of the limited time theory ^[4]. Furthermore, according to gender theory, most

women are the primary bearers of household work, while men are primarily the primary bearers of household income ^[5]. Therefore, wives' housework hours are more sensitive to changes in personal income. In addition, the impact of income on rest days is smaller than on workdays because couples' weekday time is mainly allocated to work and household chores ^[6]. In contrast, rest time is mostly given within the household. Thus, income is not affected by the time-limited theory on rest days.

In addition, a spouse's income increases their household work time, and the effects of the wife's household time on the husband's income are more significant than the effects of the husband's household time on the wife's income ^[7]. The impact of weekday household work time is more effective than household work time during rest days, which is consistent with the findings of Nash game theory. Specifically, when the husband's income increases, the wife's housework time increases. Although an increase in the husband's income may improve the overall economic situation of the household and reduce the time spent on housework, an increase in the husband's 'threat point' will increase the wife's time spent on housework ^[8].

Ultimately, the significant increase in the wife's time spent on housework suggests that the 'substitution effect' of an increase in the husband's income is more potent than its corresponding 'income effect'. In addition, since most wives are secondary wage earners in the household, an increase in a wife's income makes a more negligible contribution to the household's total utility, meaning that the wife's 'threat point' is likely not to rise significantly ^[9]. Therefore, an increase in the wife's income does not significantly reduce the husband's hours of housework. Finally, and as noted above, rest day hours are less affected by income and may be influenced by other factors, so an increase in the spouse's income does not significantly increase their rest day hours.

3.2. Relative income

The results showed a causal relationship between relative income and the duration of housework on labour days. First, the wife's relative income and the period of housework showed "U" shaped characteristics ^[5]. Specifically, when the wife's income increases to a certain level of household income, her household work time does not continue to decrease as the wife's income increases ^[10]. Furthermore, the coefficient on the primary term of the wife's relative income is positive, meaning that an increase in the wife's relative income leads to a rise in housework time ^[11]. It is inconsistent with the results of other studies. It may be due to the more significant influence of "gender performance" among the higher-income women in the sample and the deeper traditional Confucianism among the lower-income women.

There is an inverted 'U' shape in the relative income of husbands and the amount of time spent on housework, which is consistent with gender display theory ^[12,13]. Specifically, these husbands who earn less than a certain household income spend less time on housework than other men due to gender performance. It means that men with lower relative incomes perform masculinity by spending less time on housework ^[14]. Also, the negative but insignificant coefficient on the primary term of relative income for husbands is due to the effect of gender theory on masculinity.

This study does not show a significant relationship between relative income and time spent on housework on rest days because the time spent on housework on rest days is not influenced by the exact mechanism as the currently dominant theory and may be affected by other factors. As this paper focuses on the effect of income on hours of housework, this paper will not explore the explanatory mechanisms for hours of housework on rest days.

4. Conclusion

This paper uses CFPS2022 national data to analyze the effect of income on the distribution of domestic work among two-earner couples in China. Regression tests were then conducted using the Tobit model and the robustness check used OLS regression models and substitution variables to ensure the reliability of the results. The conclusions were as follows:

- (1) Income affects the allocation of time for housework during the working day, but has no significant effect on the share of time for housework during the rest day;
- (2) In terms of total income, an increase in one's income reduces one's own housework time, while an increase in one's spouse's income increases one's own housework time. The wife's household time is affected to a greater extent than the husband's household time in absolute income;
- (3) Regarding relative income, the wife's relative income and household work time shows a "U" shape; the husband's relative income and household work time shows an inverted "U" shape.

The contributions of this paper are to use national data to conduct a study in China, test the controversial findings of existing studies and divide the hours of domestic work into working days and rest days to study them separately.

The findings of this paper have some limitations due to objective reasons. Specifically, due to the limitations of the survey data, this paper only considers the nuclear family structure of couples and children. It does not consider other group family structures in China, such as the prominent family and joint families, where couples live with both parents or several generations. The findings of the study may therefore be biased. On top of that, as this paper focuses on the effect of income on couples' time spent on housework, it only concludes that the impact of income on couples' time spent on housework on their rest days is not significant. And the mechanism of other factors on time spent on housework on rest days has not been studied in depth.

Based on the current status of relevant research, future research has the following directions. For instance, to conduct relevant research considering the complexity of Chinese family structure and an in-depth study on the distribution of household work time between couples on their days off.

Disclosure statement

The authors declare no conflict of interest.

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Research on the “Double Helix” Model of Strategic Human Resource Management in the VUCA Era

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Abstract: Enterprises are facing problems such as the dynamic matching of talents and strategies, and the construction of organizational resilience. Based on this, this paper deeply explores the significance of the research on the “Double Helix” model of strategic human resource management in the VUCA era and the practical construction of the “Double Helix” model: the implementation path of key dimensions, aiming to achieve the coordinated progress of the two through strategies such as improving talent density, forging organizational resilience, and promoting the coordinated integration mechanism of the Double Helix, so as to provide scientific human resource management strategies for enterprises, help enterprises enhance their competitiveness in a complex and changeable environment, and achieve sustainable development.

Keywords: Double Helix model; Dynamic coordination; Organizational resilience; Strategic human resource management; Talent density; VUCA era

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1. Introduction

“The Notice of the Ministry of Human Resources and Social Security and the Cyberspace Administration of China on Further Strengthening the Standardized Management of the Human Resources Market” clearly stipulates that human resources and social security departments at all localities shall implement the requirements for building a unified national market, improve the market access system for human resources, standardize the implementation of the notification and commitment system, simplify and optimize administrative licensing, and actively promote electronic certificates. They shall strengthen the interconnection and sharing of regulatory information among departments, and work with the cyberspace administration and other relevant departments to screen and identify websites and platforms (including official accounts, apps, short videos, and Internet groups) that conduct vocational intermediary activities.

Meanwhile, they shall supervise and guide market entities engaged in vocational intermediary activities to apply for licenses in accordance with the law, so as to avoid regulatory blind spots. In addition, they shall

strengthen the verification of the authenticity of matters under the notification and commitment system in conjunction with supervision and inspection as well as special campaigns, and revoke licenses in accordance with the law for those that fail to meet the licensing requirements. For entities that conduct vocational intermediary activities without permission, they shall be shut down or ordered to stop such activities in accordance with the law; if there are illegal gains, such gains shall be confiscated and fines shall be imposed. In cases involving online recruitment services conducted without permission, the cyberspace administration shall handle the relevant websites and platforms in accordance with laws and regulations based on the opinions of the human resources and social security department. Enterprises should comply with national policy documents and follow a development path that aligns with national strategies to cultivate more talents.

2. Significance of research on the “Double Helix” model of strategic human resource management in the VUCA era

2.1. Helping enterprises respond to complex environments and enhance survival capabilities

In the VUCA era, enterprises face multiple internal challenges characterized by volatility, uncertainty, complexity, and ambiguity, while externally, they are confronted with the issue of slow response speed^[1]. The “Double Helix” model of strategic human resource management not only closely integrates talent management with organizational strategy but also enables mutual promotion and coordinated development between the two in this process. By doing so, enterprises can dynamically adjust their talent development strategies in accordance with market changes, thereby better retaining and attracting more talents^[2].

2.2. Promoting the effective implementation of corporate strategies and realizing sustainable development

The “Double Helix” model of strategic human resource management refers to the in-depth integration of talent development with organizational strategic goals. This integration ensures that aspects such as corporate human resource planning, allocation, and development are aligned with the direction of strategic development^[3]. On one hand, enterprises can cultivate a group of outstanding talents by establishing a scientific talent evaluation and selection system, and place the right people in the right positions. On the other hand, enterprises can design personalized training programs based on their development direction, thereby better improving employees’ professional skills and comprehensive quality^[4].

2.3. Promoting the innovation of human resource management and enhancing management efficiency

Traditional human resource management models face numerous limitations in the VUCA era and are difficult to meet the needs of enterprises’ rapid development. The “Double Helix” model of strategic human resource management is an innovative management concept and method. It breaks the single perspective of traditional human resource management and organically integrates talent management with multiple dimensions such as organizational strategy, organizational culture, and organizational structure, forming a systematic and comprehensive management system^[5]. By introducing advanced management concepts and technical means, such as big data analysis and artificial intelligence, this model can realize the digitalization, intellectualization, and refinement of human resource management, and improve management efficiency and the scientific nature of decision-making.

3. The practical construction of the “Double Helix” model: Implementation paths for key dimensions

3.1. Enhancing talent density

3.1.1. Precise talent acquisition and allocation

In the VUCA era, enterprises can use the strategic core capability map to analyze the trend of their strategic development goals and identify the types of talents they may need. By leveraging this model, enterprises can conduct a precise assessment of the quantity, type, skills, and other aspects of the talents required in the future, thereby identifying strategic talents suitable for their own development^[6]. Based on this, during the talent selection process, enterprises should abandon the traditional single experience-oriented interview scenario.

Instead, they should focus on assessing whether candidates have great potential and the ability to learn quickly; whether they share similar values with the enterprise and can better align with the enterprise's development path; and whether they have strong adaptability and can quickly integrate into team collaboration. In addition, enterprises can break down the boundaries between internal and external talents, integrate cross-sector talents, and achieve the optimal allocation of talent resources.

3.1.2. Building a dynamic competence development system

Enterprises can customize learning paths for employees and provide diversified learning resources based on job requirements, career development plans, etc., to meet the learning needs of different employees. For instance:

- (1) Enterprises can break down inter-departmental barriers by establishing an internal talent market, enabling better communication and interaction among employees;
- (2) For employees with high potential, enterprises can assign more complex and challenging tasks, allowing them to enhance their practical capabilities in the process of tackling these tasks and become the core force of the enterprise at an early stage;
- (3) Enterprises can deeply integrate competence development into business processes, enabling employees to apply what they have learned in practice promptly after learning, thereby improving work efficiency and quality^[7].

3.1.3. Digital incentives based on value contribution

On one hand, enterprises can design a differentiated and targeted salary incentive system based on multi-dimensional factors such as employees' project outcomes, skill levels, and actual contributions. For instance, enterprises can utilize digital tools like big data analytics and artificial intelligence to measure employees' value contribution in real time and provide rapid feedback to employees, enabling them to understand the relationship between their work achievements and rewards^[8]. After gaining insight into their work performance, employees can dynamically adjust their work content, which in turn better motivates them to make continuous progress^[9].

On the other hand, enterprises can make employees feel the company's recognition of value contribution by rewarding high performance and encouraging innovative contributions, thereby better stimulating employees' work enthusiasm and innovative spirit, as well as attracting and retaining more outstanding talents^[10]. For example, enterprises can offer material rewards and public recognition to employees who propose innovative ideas and bring tangible benefits to the company. This allows employees to feel the company's emphasis on innovation, thereby attracting more outstanding talents with innovative capabilities to join and stay long-term^[11].

3.2. Forging organizational resilience

3.2.1. Building resilient leadership and culture

In the VUCA era, enterprises can enhance managers' leadership and organizational resilience through various training methods as follows:

- (1) For managers at all levels, enterprises can encourage self-directed learning to help them maintain greater composure in an uncertain environment and accurately grasp the direction of the enterprise's development^[12];
- (2) Enterprises can arrange visits to other enterprises for managers to improve their change leadership capabilities, enabling them to actively adapt to changes within the enterprise and make corresponding adjustments;
- (3) Enterprises can provide training for managers to enhance their resilience, encouraging them to proactively embrace changes, set an example for employees, and inspire employees to face challenges more actively^[13].

Such measures not only improve managers' comprehensive capabilities but also enable ordinary employees to learn from them, thereby better promoting the stable development of the organization.

3.2.2. Optimizing structural and process resilience

Enterprises can reduce organizational levels to ensure that information reaches every manager more quickly and accurately, thereby better enhancing managers' execution efficiency^[14]. For example, enterprises can use big data and artificial intelligence technologies to distribute the specific details of leadership decisions through a platform, and enable managers to communicate and discuss controversial parts online, so as to better improve the execution rate.

Other than that, enterprises can also design processes with redundancy and fault-tolerance space, which can facilitate adjustments and minimize corporate losses. For instance, when designing processes, enterprises should not only back up key nodes but also formulate contingency plans for different scenarios. Furthermore, they should continuously adjust and improve processes based on feedback from employees and managers, so as to better respond to emergencies and enhance the organization's ability to survive and develop in the face of uncertainties.

3.2.3. Data-driven strategic agile decision-making and collaboration

Enterprises can leverage advanced technologies such as big data and AI to build an organizational decision-making system, thereby gaining a better understanding of the dynamic changes of other enterprises. For example, enterprises can collect, analyze, and mine data from similar enterprises and competitors to gain clearer insights into market development trends, competitors' dynamics, and the gaps between their own enterprise and others. Based on this, enterprises can further adjust their development strategies to better promote their own development. Furthermore, enterprises can shorten the decision-making process and improve work efficiency by delegating a certain degree of decision-making authority to managers and personnel in key positions.

3.3. Promoting the dual-helix collaborative integration mechanism

3.3.1. Strategic consensus and goal alignment

In the VUCA era, strategic consensus and goal alignment are key prerequisites for the effective implementation of the "dual-helix" model in strategic human resource management. As two crucial aspects of the "dual-helix," talent density development and organizational resilience development must be closely aligned with the company's overall strategic direction. The goals of talent density development, which include identifying the types of competent talents to recruit and determining how to develop these talents, need to accurately align with the specific human resource requirements of the company's strategy^[15]. For example, if a company's strategy focuses

on exploring emerging markets, talent density development should prioritize recruiting talents with cross-cultural communication capabilities and insights into emerging markets, while enhancing their professional capabilities through targeted training.

The goals of organizational resilience development, such as identifying the types of risks to address and the capabilities to build, also need to serve the company's strategy. For instance, if a company faces the risk of fierce market competition, organizational resilience development should focus on enhancing the ability to respond quickly to market changes and innovate products and services. Only by ensuring that both the goals of talent density development and organizational resilience development clearly align with the company's overall strategic direction can the "dual-helix" avoid operating in isolation, achieve collaborative progress, and provide strong support for the achievement of the company's strategic goals.

3.3.2. Seamless connection of technology platforms

In the VUCA era, the seamless connection of technology platforms serves as a crucial guarantee for promoting the collaborative integration mechanism of the "dual-helix" in strategic human resource management. By leveraging integrated HRIS (Human Resource Information System) or digital management platforms such as Workday, enterprises can break down data silos and achieve the integrated circulation of data including talent maps (competence, potential), performance contributions, organizational effectiveness, and risk early warnings.

Talent map data can clearly present the competence distribution and potential status of the company's existing talents, providing a basis for talent selection, development, and allocation. Performance contribution data can intuitively reflect the work achievements of individuals and teams, facilitating performance evaluation and incentives. Organizational effectiveness data helps assess the operational efficiency and collaboration effects of the organization, identify existing problems, and implement optimizations. Risk early warning data enables the early detection of risk factors that may affect the company's development, allowing timely response measures to be taken. The integrated circulation of these data provides a comprehensive and accurate data foundation for the dynamic management of the "dual-helix."

Through data analysis, managers can gain real-time insights into the status of talent development and organizational resilience, adjust management strategies promptly, achieve precise alignment and collaborative development between talent density development and organizational resilience development, and enhance the company's overall human resource management capabilities and ability to respond to uncertainties.

4. Conclusion

Amid the tides of the VUCA era, research on the "Double Helix" model of strategic human resource management holds profound significance and urgent necessity. This study conducts an in-depth analysis of the model, revealing that it provides strong support for enterprises to cope with complex environments through the dual-driver of talent density and organizational resilience. However, the research still has limitations, as it is difficult to fully capture the dynamic changes in practice. In the future, with the development of the times, it is necessary to continuously deepen the research on this model, integrate emerging technologies and concepts, and constantly optimize and improve it.

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Horizontal Topic of Suzhou Institute of Industrial Technology: Design and Optimization of Digital Salary System

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Analysis of Enterprise Leadership Enhancement Strategies in the Generative AI Era

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Abstract: Currently, the transformation and upgrading of digitalization have become a new task that enterprises urgently need to address. To further enhance the leadership of enterprise leaders, relevant enterprise staff should face up to the infinite possibilities that generative AI brings to enterprise management. Based on this, this paper will briefly analyze the value connotation of generative AI empowering the improvement of enterprise leadership and the relevant influencing factors, and discuss the strategies for enhancing enterprise leadership in the generative AI era, in order to promote the smooth progress of enterprises' digital transformation and upgrading.

Keywords: Enhancement strategies; Enterprise leadership; Generative AI

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1. Introduction

With the rapid development of new-quality productive forces such as artificial intelligence (AI) and big data, markets in fields like collaborative office, online education, and online medical care have developed vigorously, and relevant enterprises are facing new development opportunities and growth points. Against this backdrop, enterprises should explore the positive role of generative AI in enterprise operation and management, and use this digital technology to empower the continuous improvement of enterprise leadership, so as to help enterprises make accurate decisions and promote efficient enterprise operation. This enables enterprise leaders to better perform their functions while freeing themselves from traditional management affairs and devoting themselves to more transformative enterprise strategic development.

2. The value connotation of generative AI empowering the improvement of corporate leadership

2.1. Assisting enterprises in making accurate decisions

The accuracy of decisions determines whether an enterprise can develop and grow. With its powerful algorithmic

computing capacity, generative AI can conduct in-depth mining and intelligent analysis of massive amounts of data. Traditional corporate decisions are usually based on basic financial statements and regular market reports, which not only have limited data samples but also relatively delayed data timeliness ^[1].

After the introduction of generative AI, enterprise leadership can more accurately understand and grasp diversified data such as real-time market dynamics, consumer behavior, and industry development trends, thereby outlining a specific business landscape and providing strong support for accurate decision-making. For instance, based on the big data report on consumer preferences output by generative AI, enterprise leaders can predict the development direction of the industry, lay out the R&D and marketing strategies for new technologies or products in advance, and further enhance the scientificity and foresight of corporate decisions.

2.2. Promoting efficient operation of enterprises

Corporate operation can be described as a complex and high-speed large-scale machine. Each link is interconnected and closely linked, and a delay in any link may affect the overall operation of the enterprise. With its super-strong automation capability and optimization and upgrading effects, generative AI is regarded as a “magician” for enterprise reform and innovation. Generative AI can not only comprehensively analyze the operation processes of an enterprise, identify the repetitive and ineffective parts, but also realize the automation and intellectualization of work processes ^[2].

For example, in terms of supply chain management in the manufacturing industry, by analyzing specific data such as an enterprise’s actual inventory level, production status, and transportation situation, generative AI can automatically generate material procurement plans, production scheduling, and logistics route planning. This helps avoid excessive inventory backlogs, reduce the operating costs of the enterprise, give full play to the positive role of the supply chain, and promote the efficient operation of the enterprise.

3. Influencing factors for the enhancement of corporate leadership in the era of generative AI

3.1. Strategic management level

In the strategic management of an enterprise, leadership undertakes important and specific tasks. These include maintaining the enterprise’s current development momentum and future development standards, defining a clear and compelling vision and mission, appropriately allocating corporate resources to pursue ever-changing market opportunities, continuously monitoring and leveraging the enterprise’s close connection to changes in the external environment, and examining the industry ecosystem to reflect on the enterprise’s core competitiveness ^[3].

However, in practice, for many enterprises, the digital transformation of strategic management is an entirely new task. How to drive enterprises to shift from traditional operation and management thinking to a digital strategic management concept enhanced by generative AI often requires enterprises to “cross the river by feeling the stones” based on their actual circumstances. For most executives and employees, digital technology, generative AI, and digital transformation remain abstract theoretical concepts. How to utilize this new form of productive force in corporate management to improve the quality of enterprise strategic management remains a problem that cannot be perfectly solved in the short term.

3.2. Organizational operation level

Although enterprises continue to reform and innovate their organizational operations, the basic organizational

operation structure still operates within the framework of traditional hierarchical management. Within this management structure, leadership that evolves and innovates tends to form a specific leadership style. However, with the introduction of generative AI, changes in the enterprise's organizational operation model may go beyond such incremental adjustments and could even subvert the long-established hierarchical corporate management structure. Digitalization exerts an all-round impact on every level of the enterprise's organizational operation structure ^[4].

Through the data integration technology of generative AI, enterprise decision-making will shift from developing a single decision-making plan through research to evaluating and selecting among multiple decision-making plans. In particular, with the rapid advancement of natural language technology and machine learning technology, the proportion of manual management in enterprise organizational operations is gradually decreasing, and the organizational structure of enterprises is becoming simpler and flatter. In response to this, corporate leadership must break through traditional paradigms and embrace the changes and opportunities brought about by the era of generative AI.

3.3. Talent team level

The application and implementation of generative AI in enhancing corporate leadership cannot be achieved without the support of professional talent teams. Managers and employees with strong digital literacy are key factors influencing the effectiveness of leadership in applying AI technologies. On one hand, in addition to functional departments and business departments, enterprises should establish new-quality productive forces support departments equipped with technical capabilities such as algorithm development, data governance, and model optimization. This ensures the stable operation and continuous iteration of generative AI within the enterprise ^[5].

If an enterprise lacks professional AI operation and maintenance talents, it will be unable to promptly fix data security vulnerabilities or model failures in its intelligent platforms. This not only disrupts normal operations and causes losses to the enterprise but also undermines leaders' ability to control technical risks. On the other hand, enterprises should cultivate interdisciplinary talents who possess both expertise in generative AI technology and a good understanding of the enterprise's business processes. This helps eliminate "communication barriers" between technical teams and business teams, thereby enabling generative AI to fully exert its value in enhancing corporate leadership.

4. Strategies for enhancing corporate leadership in the generative AI era

4.1. Transform the role positioning of corporate leaders

In the tide of digital transformation, the transformation of leaders' role positioning is the primary step for them to acquire leadership capabilities in the era of generative AI, as listed:

- (1) Enterprise leaders need to recognize that although the effectiveness of leadership in the generative AI era does not merely depend on how leaders apply AI technology, it is more about how to protect the rights and interests of employees;
- (2) To achieve this transformation of role positioning, enterprise leaders need to understand the essence and demands of leadership in the generative AI era, clarify the supporting role of leadership in the enterprise's digital transformation and cultural development, strengthen their digital thinking, and always maintain an open attitude towards generative AI technology. This helps them gain access to cutting-edge technologies

at the earliest opportunity and guide the enterprise's development path ^[6];

- (3) Against the backdrop of the new era, leaders should clarify their own responsibilities and tasks, understand the impact of human-machine collaboration on leadership efficiency, and anticipate issues that generative AI may bring about, such as imbalances in autonomy and a decline in self-efficacy, so as to proactively address challenges in future management work.

In addition, the effectiveness of a leader's leadership is reflected not only in their own transformation but also in their guidance of employees. In daily work, if leaders demonstrate enthusiasm, acceptance, and recognition for generative AI technology, their leadership will receive higher evaluation, which will ultimately affect employees' initiative and enthusiasm in the enterprise's digital transformation. Therefore, enterprise leaders should provide appropriate guidance to employees during the transformation of their role positioning and leverage all available resources to jointly drive the enterprise's digital transformation.

4.2. Optimizing the training system for enterprise leaders

To enhance enterprise leadership in the era of generative AI, a comprehensive and sustainable leadership training system should be established to further improve enterprise leaders' digital literacy and ability to apply generative AI, as shown:

- (1) Leaders' theoretical literacy in AI technology should be strengthened, where enterprises should design a progressive and hierarchical AI technology training system based on leaders' cognitive abilities and development needs, focusing on content such as theoretical knowledge of AI technology, big data analysis technology, and risk prediction and management ^[7]. For instance, in the training of AI technology theory, specific cases of Tesla's AI Factory can be used to help leaders understand the core principles of generative AI—such as large language models and diffusion models—as well as its capability boundaries (e.g., inability to replace human emotional judgment and complex ethical decision-making). This enables leaders to develop a scientific and accurate knowledge system;
- (2) Leaders' practical ability to use generative AI in business scenarios should be enhanced as well. For example, during meetings related to corporate marketing decisions, leaders can be invited to participate in formulating AI-driven marketing plans. This includes, but is not limited to, setting marketing goals for the technical team, clarifying the characteristics of target audiences, and collaborating with the marketing team to evaluate the feasibility of AI-generated marketing plans, make detailed adjustments, and finalize the overall marketing strategy. Through such practices, leaders' ability to solve practical problems using generative AI is gradually improved ^[8];
- (3) The cultivation of leaders' digital literacy should be integrated into the enterprise's long term strategy. For example, in the enterprise's three-year strategic plan, "driving product innovation with generative AI" can be identified as a key development direction and broken down into quantifiable phased goals—such as achieving full coverage of generative AI in raw material procurement and production processes within the first year. This ensures the steady optimization of the leadership training system.

4.3. Building a multi-dimensional talent pool for enterprise leaders

In terms of recruitment, enterprises should increase the introduction of AI professionals such as algorithm engineers and AI product managers, giving priority to candidates with relevant work experience. For talent development, enterprises can establish a "mentor + project" talent growth system, where senior leaders guide

newly promoted leaders to jointly participate in the company's practical projects and provide regular training. This ensures that professionals have the ability to use generative AI to solve practical business problems.

Moreover, enterprises should also select internal employees from the digital technology support team who have business work experience—such as algorithm engineers who have participated in AI marketing projects—to take rotating positions in business departments, so that they can gain an in-depth understanding of customer needs and business processes^[9]. At the same time, select business backbones to study the basic principles and application methods of generative AI in the digital technology support department, so as to improve their ability to express business needs and interpret the output results of generative AI. In addition, enterprises should target practitioners who have been responsible for AI marketing in Internet companies and hire them as the “technology-business liaison personnel” of the enterprise.

Enterprises also need to establish an AI talent echelon to avoid talent gaps. They should cultivate basic-level talents who are proficient in operating generative AI tools and capable of processing basic data; build a middle management team that can lead teams to use generative AI to advance business projects and coordinate technology and business; and for senior corporate managers, require them to formulate AI talent strategies and lead corporate technological innovation. Through the establishment of the above-mentioned talent echelon, enterprises can ensure that there are outstanding talents with good leadership at all levels.

4.4. Improving the governance mechanism for generative AI applications

Enterprises should take the lead with senior leaders, and work together with legal, compliance, technology, and business departments to formulate the Generative AI Application Manual, clarifying usage standards and regulatory provisions as follows:

- (1) There are data privacy protection standards, which include obtaining authorization for user information through the explicit consent of users, encrypting data during storage, conducting regular backups, limiting access rights to specific business purposes, and prohibiting external disclosure. For instance, when using customer data in AI marketing, sensitive information such as ID card numbers must be deleted, and only non-identifiable data like consumption preferences should be retained;
- (2) There are algorithmic fairness guidelines, which aim to prevent biases in training data during the establishment of AI models. For example, when an AI system is used for recruitment, the database of its candidate selection model must include job seekers of different genders, ages, and educational backgrounds; if necessary, audits should be conducted on algorithm results. When the pass rate of a certain group is lower than expected, it is necessary to check whether the model has discriminatory issues;
- (3) There are responsibility delineation standards, which define the responsibilities that various entities should bear in the application of generative AI. When problems arise in AI decisions, the technical team is responsible for improving the model, the business department is responsible for judging requirements, and senior leaders are responsible for making final decisions to avoid mutual shirking of responsibilities.

After the standards are formulated, a dedicated review team for supervision should be established to pre-audit the compliance of projects involving AI-generated content; during the process, relevant technical tools should be used to monitor the application behavior of generative AI in real time, such as conducting keyword monitoring on the conversation content of AI customer service to prevent the leakage of customer privacy; after the event, the review team should take the lead in conducting a comprehensive audit of business projects using generative AI tools, evaluate the management of enterprise leaders on the compliance of AI-generated content applications, and

hold the corresponding leaders accountable if there are non-compliant projects.

5. Conclusion

To sum up, the key to generative AI empowering the improvement of enterprise leadership does not lie in AI technology itself, but in whether enterprise leaders can apply generative AI correctly and avoid its negative impacts. In practical implementation, it is necessary to implement strategies such as transforming the role positioning of enterprise leaders, optimizing the training system for enterprise leaders, building a multi-dimensional talent pool for enterprise leaders, and improving the governance mechanism for generative AI applications. These efforts will encourage enterprise leaders to integrate knowledge and action—based on an innovative concept of AI technology application and enthusiasm for practice—to truly realize the empowerment of generative AI in enhancing enterprise leadership.

Disclosure statement

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Digital Dissemination and Consumption of Cultural Symbols in Lingnan's Traditional Villages

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Abstract: Ancient villages in Lingnan serve as crucial carriers of Lingnan culture. Their abundant cultural symbols now face the dual task of inheritance and innovation in the digital era. Drawing on Stuart Hall's encoding/decoding theory, this study explores how representative cultural symbols of Lingnan's ancient villages are digitally translated and disseminated. By analyzing specific cases, it elucidates the logic of audience interaction and consumption during the decoding of these digital cultural symbols. This study aims to offer valuable insights for revitalizing ancient village culture and informing its sustainable industrial development.

Keywords: Ancient villages of Lingnan; Cultural symbols; Digital dissemination; Encoding and decoding; Symbolic consumption

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1. Introduction

Lingnan ancient villages are important carriers of Lingnan cultural accumulation, and the tangible and intangible cultural heritage they preserve constitutes a distinctive cultural symbol system. According to the Guangdong Province Ancient Village Recognition Criteria, ancient villages must possess characteristics such as being formed before the Qing Dynasty, having abundant historical and cultural remains, and being able to reflect traditional features and folk culture^[1]. With the promulgation of the Outline Development Plan for the Guangdong-Hong Kong-Macao Greater Bay Area, which advocates the strategy of "co-building a culturally vibrant Bay Area", the preservation and dissemination of Lingnan's ancient village culture have been enlisted as a central concern in regional cultural development initiatives^[2].

The advent of the digital wave has established symbolic consumption as a new mode of economic activity. Consequently, cultural symbol consumption has become a key choice for consumers in the new media era. Meanwhile, as consumer demand for cultural experiences grows increasingly diverse, digital media such as short videos and live streaming are progressively supplanting traditional media, reconfiguring the primary channels

through which audiences receive information. Grounded in Stuart Hall's encoding/decoding framework, this study interrogates the process of digital translation of cultural symbols from Lingnan's ancient villages. It further synthesizes the underlying logic of audience interaction and consumption behaviors during the decoding process, thereby furnishing novel approaches for the inheritance and innovation of Chinese traditional culture within the modern context.

2. Cultural symbols of Lingnan ancient villages

As an important part of Cantonese cultural symbols, Lingnan ancient village cultural symbols mainly exist in their tangible and intangible cultural heritage. The tangible cultural symbols are often presented by extracting their design elements and refined through artistic design transformation, while the intangible cultural heritage symbols are more implicit. The audience's recognition of these symbols relies heavily on the creative forms used by the communicators.

In the digital age, the transmission of symbols is no longer confined to the monological communication of traditional media. Instead, it operates through a process where internet communicators digitally encode these symbols, utilizing new media platforms as the interface to reach audiences or consumers, forming a complete "encoding-decoding" circuit. Consequently, dissemination strategies for both tangible and intangible cultural symbols must align with the information reception habits of contemporary audiences by deconstructing and re-encoding these symbols through digital means.

2.1. Tangible cultural symbols

Tangible cultural symbols constitute heritage with a physical presence, ranging from immovable relics (e.g., historic sites, architectural complexes, carvings, murals) to movable items (e.g., representative art and documents). As a fundamental component of ancient village architectural complexes, Lingnan traditional dwellings possess culturally symbolic significance, exemplified by the "Pot-Ear Roof House". Named for its distinctive roof that resembles a pair of upright pot ears, this structure, built from blue bricks and stone slabs since the mid-late Qing Dynasty, epitomizes Lingnan vernacular architecture. The Da Qi Tou Ancient Village in Foshan's Sanshui District boasts the largest preserved cluster of Pot-Ear Roof Houses in the Lingnan region, thereby establishing it as a highly recognizable cultural and visual symbol for the village.

The unique spatial layout "All Alleys Unite, Every Alley Faces the Pond" is an important symbolic feature of ancient village site selection. The ancients believed: "A Hundred Alleys Converging as One, Each Facing the Pond," represents a vital characteristic in ancient village site selection. This practice is rooted in the traditional belief that "Qi disperses with the wind but gathers where water meets" ^[3]. Settlements established with mountains at their back and facing water were believed to harness abundant natural resources while embodying a humanistic philosophy of living in harmony with nature. A quintessential example is the Songtang Ancient Village in Nanhai, Foshan, which utilizes its central pond for ecological regulation, showcasing a hallmark of the Lingnan style.

Furthermore, the academy (Shu Yuan), serving as the physical embodiment of traditional Confucian educational culture, held a position of institutional core within Lingnan's ancient villages. A significant number of these village academies retain the architectural style of the Ming and Qing dynasties, perpetuating the legacy of "emphasizing civility and prioritizing education" ^[4]. This enduring architectural legacy provides the primary source for tangible cultural symbols, and they jointly create the diverse genealogy of Lingnan ancient village cultural symbols.

2.2. Intangible cultural symbols

Intangible cultural symbols are typically manifested as cultural practices, encompassing categories such as traditional crafts, performing arts, and folk festivals. Within Lingnan's ancient villages, these symbols are centered on traditional craftsmanship, showcasing their living cultural heritage. The Lion Awakening (Xing Shi), a quintessential Lingnan performance, derives its symbolism, which is expelling misfortune and attracting prosperity from its core ritual of "Cai Qing", which literally means "picking the green." In recent years, new forms such as female lion dance teams have emerged, giving this traditional symbol characteristics of the times.

Additionally, traditional crafts and culinary culture also constitute significant intangible cultural symbols. Cantonese Embroidery, represented by the Yue Xiu style, is extensively applied in the attire and architectural decorations of Lingnan's ancient villages. Local delicacies such as Boat Congee and Ginger Milk Curd, emblematic of Lingnan, convey regional distinctiveness through the sensory medium of taste. These intangible symbols, relying on oral tradition and practical inheritance, have become the main spiritual core of ancient village culture.

3. Digital encoding: IP collaborations endow ancient village cultural symbols with new meanings

People in modern society live not only in a physical world but also in a symbolic world. As theorized by Stuart Hall, the production of meaning in communication operates through encoding, which is a process wherein an encoder translates information into a message, with the symbol constituting its fundamental vehicle ^[5].

In the current digital context, the dissemination of ancient village cultural codes involves not only formal innovation but, more importantly, leverages new media channels in order to spark audience interest, thereby transforming modes of interaction and consumption. Within the symbolic society, the operational logic of the consumption system no longer relies solely on the fulfillment of material needs but is fundamentally built upon the differentiation and encoding of symbolic meanings ^[6]. In other words, consumers in their purchases often pursue cultural identification, status symbolism, and value resonance. Precisely because of this, IP collaborations have emerged as a pivotal form of digital symbolic encoding for brands.

Through such crossover collaborations with trending IPs to digitally transcode cultural assets, brands can achieve resource complementarity, creating a mutually beneficial outcome where cultural and commercial value are co-created. For example, Foshan's Da Qi Tou Ancient Village forged a lifestyle IP through a collaboration with the coffee brand "Hecaff", distilling the iconic Pot-Ear Roof gable into a "Ripple Logo." This symbol anchors a line of cultural creative products, from coffee sets to mugs, sold via digital markets, integrating symbols with traditional material cultural connotations into the lifestyles of young people.

Similarly, Foshan's Songtang Ancient Village transposed the symbolic layout of "A Hundred Alleys Converging as One" into a cover design for notebooks. Enhanced with illustrative elements depicting the Confucius Birthday Ceremony, the village launched a limited-edition cultural creative gift set. This combination of cultural symbols with modern design exemplifies the vitality of innovating upon and perpetuating its Han Lin (imperial academic) culture. These partnerships create a dual effect, where they channel brand reach to amplify the village's cultural presence, while the unique symbolic narratives significantly enhance the products' value.

Furthermore, a common strategy in the current digital encoding of traditional cultural symbols involves distilling ancient village cultural symbols to create a personified IP, thereby enhancing their distinctiveness. The abstract of the ancient village culture is translated into a tangible IP image, which effectively lowers the cognitive

barrier for audiences regarding specific cultural connotations and facilitates the digital dissemination of the village's cultural symbols. A prime example is the "Dadun Village Tao Dun Dun" IP launched by Lecong Dadun Village in Foshan's Shunde District. The design centers on a pottery jar, clothed in historical attire with peach blossoms adorning its robe and shoes. The peach blossom elements make the image more adorable and tightly connect it with the theme of "Tao Yuan Jie Yi" (Pottery Garden Agreement). This IP is utilized in cultural and creative products to collectively narrate Dadun Village's long history of pottery artistry, carrying profound cultural sedimentation.

4. Communication media: New media as the gateway for cultural symbols

The communication process constitutes an integrated whole, within which the message constitutes merely a part of this entirety^[7]. After cultural symbols are encoded, they must be conveyed through specific media channels. In the contemporary communication context, new media platforms have become the primary conduits for the dissemination of cultural symbols. Compared to traditional media, they not only serve the function of information transmission but, more significantly, intervene deeply in the propagation of cultural symbols through algorithmic recommendations and interactive mechanisms.

As an emerging medium, short-form video platforms facilitate the rapid permeation of cultural symbols through their fragmented nature and highly visual format. A "Pot-Ear Roof House Construction" series on the "Guangfu Ancient Village" Douyin account exemplifies this, combining time-lapse photography of the building process with Cantonese narration, resonating widely and surpassing 8 million views per video. Another case, Foshan's "Lion Awakening Eye-Dotting" video, used close-ups to detail the embroidery and ritual, while physical check-in spots spurred user-generated content and challenges, propelling the video to over 100 million views.

Meanwhile, the rise of "micro-dramas" derived from short videos has garnered significant attention from digital communicators in recent years. Official social media accounts of several ancient villages have begun releasing micro-dramas, activating the historical context behind cultural symbols through narrative storytelling. For instance, Bijiang Ancient Village in Shunde produced a micro-drama based on the legend of its "Gold Tower," transforming gilded wood carvings into "treasure clues" and integrating analyses of architectural craftsmanship within a suspenseful plot. Released on the Tencent Video platform, it achieved over ten million views. Similarly, Da Qi Tou Ancient Village in Foshan's Sanshui District collaborated with a self-media team to produce the series *Mystery in the Ancient Village*, converting the defensive functions of watchtowers into elements of suspense. This allows audiences to understand the symbolic connotations through entertainment, while the lightweight narrative style aligns with modern fast-paced lifestyles, endowing the symbols with storytelling appeal and emotional resonance.

By accurately capturing the core elements of intangible cultural symbols and completing their mediatized encoding, creators utilize platform mechanisms to provide users with new decoding pathways. Consequently, cultural symbols achieve fission-like diffusion through short video platforms. This process illustrates how communication channels not only enhance the visibility of symbols but also shape the patterns of audience engagement.

Furthermore, the instant feedback mechanism inherent in live-streaming technology significantly facilitates two-way interaction, substantially enhancing user participation and encouraging a stronger sense of identity, thereby maximizing the impact of symbolic dissemination. For instance, during a live stream of the "Confucius

Birthday Ceremony” from Guangzhou’s Songtang Ancient Village, the host guided the online audience through ancestral halls while explaining the cultural significance behind inscribed plaques. When viewers posed questions via bullet-screen comments, their inquiries triggered AR effects that visually demonstrated the virtual reconstruction of “Ritual Vessel Arrangements.” This interactive live-streaming format effectively assisted Songtang Ancient Village in integrating traditional cultural symbols into online cultural experiences, thereby transformed into cultural tourism products with clear market value. This demonstrates that live-streaming channels not only affect information accessibility but also complete the transformation of the audience from passive interpreters to co-creators and consumers.

5. Digital decoding: The logic of interaction and consumption in the communication of ancient village cultural symbols

Following the completion of the communication phases involving the IP-based encoding of cultural symbols and their multi-channel distribution, the audience’s “decoding” process becomes crucial in determining the actual effectiveness of communication .

Decoding is a complex and active process of meaning reproduction, wherein the audience is not a passive recipient of information but rather interprets and even reconstructs the message based on their own socio-cultural background and experiences ^[8]. Within the context of digital interaction, this decoding behavior manifests as active engagement, sharing, and consumption, thereby forming the progressive communication chain of “cognition-emotion-action.” It is precisely within this dynamic decoding process that the meaning of ancient village cultural symbols is revitalized and ultimately translated into commodity value.

5.1. Cognition: Popular culture activates symbolic vitality

Traditional cultural symbols of ancient villages often present cognitive barriers for younger audiences due to their spatial and temporal distance. Integrating these symbols into contemporary forms of popular culture provides audiences with a familiar and relatable decoding framework, effectively lowering the barrier to understanding. Online variety shows, as a significant domain of youth culture, activate the vitality of traditional cultural symbols through their entertainment format.

In the past two years, the popular online variety show “Let’s Farm”, leveraging the influence of its “Ten Hardworking Guys” IP, significantly boosted national discourse around agricultural support. During the 2024 Agricultural Support Day period, the show filmed in Foshan, where the “Ten Hardworking Guys” members personally experienced Lion Awakening training and performance. In the program, the majestic lion heads, the resounding gongs and drums, and the members’ clumsy yet earnest learning poses created a dramatic contrast.

This “demystifying” presentation translated complex intangible cultural heritage skills into relatable public entertainment experiences. Subsequently, the program, combined with live-streaming platforms, initiated “Live Streaming for Agricultural Support,” linking the auspicious meanings symbolized by the Lion Awakening, such as “warding off evil, inviting blessings, and bringing prosperity”, with local agricultural products.

Throughout this process, audiences, via the popular cultural form of the online variety show, completed a transformation in their decoding path towards the Lion Awakening symbols: from viewing them as “spectacle” to feeling “resonance,” and ultimately arriving at “value identification.” The entertainment shell packaged and delivered the cultural core of the traditional symbols, effectively enhancing their recognition and affinity.

5.2. Emotion: Collective memory awakens social identity

The profound efficacy of digital decoding lies in its ability to reach the audience's emotional dimension. By awakening latent "Collective Memory" and fostering a sense of ritual, it strengthens the community's identity. Collective memory serves as the emotional bond connecting the individual to the community, while ritualized communication acts as the core mechanism for reinforcing this bond^[9].

The Han Fu fashion show event held at Foshan's Da Qi Tou Ancient Village exemplifies this decoding strategy. The event invited visitors to don Han Fu and walk through the ancient alleys beneath the Pot-Ear gable walls. This act itself constituted a ritual performance transcending time and space. The ancient village's architectural complex, as a tangible cultural symbol, provided an authentic historical setting for the ritual; Han Fu, as a dynamic cultural symbol, became an emotional vehicle for individuals to connect with tradition. When participants shared photos and videos of the event on social media, their decoding behavior surpassed simple "documentation" or personal consumption, this constituted an act of reinforcing their identity as "inheritors of Lingnan culture." through this sense of ritual.

This collective experience transforms symbolic consumption into a cultural statement of "Who we are." When individuals purchase, use, and share products bearing the symbols of Lingnan's ancient villages, they are essentially using consumption to signal their cultural tastes and social identity. For instance, consumers purchasing and showcasing Da Qi Tou Ancient Village's co-branded coffee products on social media not only gain practical value but, more importantly, demonstrate a recognition for both traditional culture and a contemporary youth lifestyle within the digital social sphere, thereby constructing their identity within specific social circles.

Consumption also provides stability through the rationalization of the non-rational, the standardization of difference, and through the precariousness of the human condition^[10]. In other words, the significance of symbolic consumption extends beyond merely "buying a product"; it lies in the reproduction and sharing of symbols, allowing individuals to integrate into a specific cultural community. This logic is precisely the crucial prerequisite enabling emotional identification to further transform into consumer action.

5.3. Action: Scenario-based narratives facilitate consumption decisions

The ultimate objective of digital decoding lies in guiding user action, thereby bridging cultural dissemination and commercial conversion. "Context-Aware Computing" emphasizes that in the mobile internet era, the relevance of information acquisition depends on the perception and construction of "context" (time, location, identity, needs, etc.)^[11].

Live-streaming e-commerce, with its powerful capacity for contextual construction, has become a tool for facilitating immediate consumption decisions. The online live stream "New Year Greetings from the Pi Xiu" launched on the first day of the Lunar New Year in 2025 by Song Jia Ling Village in Zeng Cheng adeptly captured and constructed the specific spatio-temporal context of the "Spring Festival". During the broadcast, the lively and joyous performance of the intangible cultural heritage Pi Xiu dance decoded the collective emotional need for "Ushering in luck and prosperity in the New Year".

Local specialty handicrafts and other New Year goods were displayed and sold within this context, rich with festive atmosphere and cultural meaning. Cultural symbols (Pi Xiu New Year greetings) and consumer symbols (New Year goods) were connected and synchronously decoded within the live stream. The user's live-stream viewing experience was an immersive and continuously stimulated consumption scenario, which channeled their emotional connection to the auspicious culture and festive spirit directly into a desire to purchase the associated

cultural products.

Ultimately, the 336,000 viewership and a 300% increase in sales of local specialties robustly demonstrate the impact of scenario-based decoding on audience consumption decisions, which effectively shortened the consumer decision-making path from cultural understanding to recognition of commercial value.

6. Conclusion

As crucial carriers of Lingnan culture, Lingnan ancient villages are the very root of Lingnan traditional culture. In today's polymorphic media environment, the "re-encoding" and "re-dissemination" of complex cultural codes has become the central challenge for revitalizing ancient villages across the region. The key to addressing this challenge lies in constructing a comprehensive digital communication system that progresses from "symbolic recognition" to "value co-creation." This system requires a systematic curation of cultural symbols and infusing them with contemporary relevance.

The approach is threefold:

- (1) Mastering the digital ecosystem by transforming archaic signifiers into contemporary discourse through IP-centric transcoding;
- (2) Utilizing new media platforms to craft immersive storytelling and contextual experiences;
- (3) Engaging the audience in the decoding process by stimulating cognitive recognition, forging emotional connections, and motivating behavioral responses, thereby closing the loop between cultural appreciation and tangible consumption.

Notably, the revitalization of ancient village culture in the digital age is by no means a simple digital replication, but rather a process of creative translation. Prevention of over-commercialization, superficial homogenization, or even misinterpretation of cultural symbols within the context of consumer society, while ensuring the continuity of their authenticity and cultural significance, will be a core ethical issue determining the sustainable development of traditional culture. Continued exploration of these questions will propel the cultural dissemination of Lingnan's ancient villages from effective revitalization toward sustainable inheritance.

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Analysis of Optimizing Digital Marketing Strategies for EdTech Product Sales in Emerging International Markets

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Abstract: Against the backdrop of deepening globalization and digital integration, emerging international markets, characterized by large populations, rapidly growing educational demands, and progressively upgraded digital infrastructure, have become pivotal hubs for educational technology (EdTech) enterprises to expand their global presence. However, the unique characteristics of these markets, including cultural diversity, divergent consumer behaviors, and uneven digital maturity, pose challenges to traditional digital marketing strategies. This results in EdTech products facing issues such as inefficient user acquisition, insufficient brand awareness, and suboptimal conversion rates. To address these challenges, this paper focuses on optimizing digital marketing strategies for EdTech product sales in emerging international markets. This paper focuses on the optimization of digital marketing strategies for Ed Tech product sales in emerging international markets. Through analyzing the pain points in the application of current strategies, this paper proposes a systematic optimization path from four dimensions: localized content construction, multi-channel coordination and integration, user life cycle operation, and data-driven decision making.

Keywords: Digital marketing; EdTech products; Emerging international markets; Localization; Strategy optimization

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1. Introduction

With the accelerated global digital transformation in education, EdTech products have evolved from auxiliary teaching tools to core platforms driving educational equity and learning efficiency. While mature markets like Europe and America are approaching saturation, emerging markets including Southeast Asia, Latin America, the Middle East, and Africa are becoming new growth engines for EdTech companies. These regions boast significant gaps in basic educational resources, maintain over 10% annual growth rates in mobile internet adoption, and receive stronger government support for digital education initiatives. As the primary channel for reaching users in emerging markets, the effectiveness of digital marketing strategies directly determines product penetration and

sales performance.

However, most EdTech firms still apply mature market-oriented digital marketing models when expanding into these emerging markets. This approach not only fails to align with local cultural perceptions and usage habits but may also trigger user resistance through misinterpretations of cultural nuances and inadequate feature adaptation, ultimately resulting in wasted marketing resources and unmet sales targets.

In this context, optimizing digital marketing strategies for EdTech products in emerging markets holds significant practical importance. On one hand, it enables EdTech companies to accurately grasp the digital marketing patterns in these markets. On the other hand, it provides differentiated marketing approaches for various EdTech products (such as K12 online courses, vocational education platforms, and educational management systems), thereby promoting the healthy development of the entire industry in emerging markets.

2. Current situation and key pain points in the digital marketing of EdTech products in emerging international markets

2.1. Current status overview

EdTech companies currently focus on four primary digital marketing strategies in emerging international markets:

- (1) Social media marketing through platforms like Facebook, Instagram, and TikTok, utilizing short videos and graphic ads to promote products;
- (2) Search engine marketing (SEM) targeting general search engines such as Google to acquire organic traffic;
- (3) Content marketing by creating English-language blogs and publishing industry reports to communicate product value to the public;
- (4) Partner marketing through collaborations with local educational institutions and social media influencers to leverage their channels.

Overall, while some companies have achieved initial user acquisition through these strategies, most remain trapped in a “high investment, low return” dilemma, particularly showing significantly lower performance in user retention and payment conversion rates compared to mature markets ^[1].

2.2. Core pain points

2.2.1. The content lacks local adaptation, and the user cognition threshold is high

The core value of EdTech products lies in their “educational solutions”, yet educational needs carry strong regional and cultural attributes. Specifically, most companies still use generic English marketing content or perform basic language translations without adapting to target markets’ educational systems, teaching scenarios, or cultural customs. For instance, when promoting math-focused EdTech products in Southeast Asia, directly adopting European/American teaching cases and exercises while ignoring local textbook versions and exam syllabi makes users struggle to perceive practical value.

Similarly, marketing content for Middle Eastern markets that fails to account for religious-cultural influences on educational contexts, such as women’s study schedules and content review standards, may trigger user resentment or even damage brand image. Such “cultural disconnect” strategies in content creation erode user trust, significantly reducing the effectiveness of marketing communication and conversion rates.

2.2.2. Single channel selection and lack of coordination, narrow user reach coverage

Beyond global mainstream platforms, numerous regional platforms exist (e.g., Line in Southeast Asia, WhatsApp

Business in Latin America, and Snapchat in the Middle East), each with markedly different user demographics.

For instance, Line's users in Thailand are predominantly teenagers, while WhatsApp Business maintains high penetration among corporate users in Brazil. However, most EdTech companies still focus narrowly on global mainstream platforms, showing insufficient attention to regional platforms. This results in ineffective outreach to potential users in lower-tier markets and a lack of coordination between channels.

Issues like inconsistent content between social media traffic sources and official website product descriptions, as well as disconnects between search engine ads and user landing pages, create "information silos". When users switch between different channels, they experience fragmented experiences that hinder brand recognition, ultimately leading to customer attrition ^[2].

2.2.3. Focus on customer acquisition and neglect retention, lack of user life cycle operation

The conversion process for EdTech products typically involves a "prolonged cycle and high decision-making costs". Users progress through multiple stages, from initial product exposure to final payment, through "awareness, interest, trial, payment, retention, and referral", each requiring distinct strategies.

However, most EdTech companies currently focus their digital marketing efforts on customer acquisition, relying heavily on aggressive advertising to attract clicks. Yet they often neglect systematic operations for post-acquisition phases like trial experiences, payment guidance, and retention activation.

Common issues include users receiving no personalized guidance after registration trials, paid users lacking continuous learning tracking and service feedback, and underdeveloped referral incentive mechanisms for existing customers. This "customer acquisition-first, retention-later" approach not only results in low conversion rates (with trial-to-payment conversion rates below 5% for most companies), but also wastes marketing resources and fails to establish a virtuous cycle of "referrals driving new users".

2.2.4. Weak data-driven ability and lack of scientific basis for strategy adjustment

The core strength of digital marketing lies in its ability to track user behavior through data, enabling strategic optimization. However, EdTech companies in emerging markets face two major data challenges:

- (1) Incomplete data collection: Due to underdeveloped digital infrastructure, these markets struggle with low accuracy in tracking user behavior metrics like page dwell time and feature usage frequency, while lacking comprehensive data on educational needs and learning patterns;
- (2) Insufficient data utilization capabilities: Most companies only perform basic statistical analysis (e.g., click-through rates, sign-ups) without leveraging market-specific characteristics and user profiles for in-depth mining.

This results in situations where they can't determine "which channels demonstrate stronger conversion intent" or "what content better meets target audience needs." Consequently, strategy adjustments rely on experience-based judgments rather than data-driven insights, leaving companies ill-equipped to adapt to the rapidly evolving user demands and competitive landscape of emerging markets.

3. Digital marketing strategy optimization of EdTech products in emerging international markets

3.1. Build a localized content system to reduce the threshold of user cognition and trust

Localization is the cornerstone of establishing brand recognition for EdTech products in emerging markets. In

practice, this requires three key dimensions: language adaptation, cultural integration, and demand alignment, ensuring content seamlessly integrates with local educational contexts and user habits.

3.1.1. Language adaptation

Language adaptation demands moving beyond literal translations to adopt a dual strategy of “official language + dialects” [3]. For instance, in India, content must be available in Hindi, Tamil, and other regional languages alongside English. In Nigeria, primary dialects like Hausa and Yoruba should be included.

Language expression must align with local speech patterns, avoiding complex technical terms, such as rephrasing “personalized learning paths” as “customized courses tailored to your progress” to enhance comprehension.

3.1.2. Cultural integration

Cultural integration involves embedding local elements into marketing content. This requires adapting teaching cases: when promoting writing-focused EdTech products, use local historical events and social trends as writing materials. Visual designs should prioritize regional aesthetics, favoring colors and imagery that resonate locally (e.g., golden and green tones preferred in Middle Eastern markets, avoiding explicit human figures).

3.1.3. Demand alignment

Demand alignment means designing content based on the specific educational challenges of target markets. For instance, to address the “shortage of high-quality teachers” in Southeast Asia’s K12 education market, marketing content could emphasize the product’s “elite teacher-recorded courses + AI tutoring” feature. For Latin America’s vocational education sector with its strong demand for employment-oriented solutions, the focus should be on promoting product collaborations with local enterprises and employment placement services.

3.2. Integrate multi-channel collaborative matrix to achieve full-scenario user reach

Given the digital ecosystem characteristics of emerging markets, EdTech companies should establish a multi-channel synergy matrix comprising “global platforms + regional platforms + vertical channels”.

This approach aims to expand user reach through complementary channels and information coordination, ultimately enhancing brand message consistency and coherence. Regarding channel selection, differentiated strategies should be implemented based on target markets’ platform penetration rates and user profiles.

Specifically, in Southeast Asia, focus on TikTok (primarily targeting young users), Line (strong social features), and local education forums like Malaysia’s Education Malaysia Global Services Forum. For Latin America, prioritize WhatsApp Business (broad coverage for enterprise users and underserved markets), Instagram (effective visual content distribution), and local vocational education platforms such as Brazil’s Veduca. In the Middle East, Snapchat (active among youth users) and LinkedIn (concentrated in vocational education users) should be prioritized alongside partnerships with local educational institutions’ official websites.

Additionally, adjust channel emphasis for different EdTech product types: K12 products should leverage social platforms and short video channels, while vocational education products should focus on LinkedIn and vertical educational forums.

3.3. Optimize the operation of the whole life cycle of users, improve the efficiency of conversion and retention

Given the prolonged sales cycle of EdTech products, it is necessary to take the user life cycle as the core and design differentiated digital marketing strategies in stages, aiming to achieve a closed-loop operation of “customer acquisition, activation, transformation, retention and recommendation”. For instance:

- (1) Awareness Stage: The strategy focuses on attracting user attention through “low-threshold content”. For example, social media platforms can publish free educational videos (like “Master Mathematical Factorization in 10 Minutes”) and launch learning assessment tools (such as “Which Learning Style Is Best for Your Child”). This approach enables users to access product value at minimal cost. Simultaneously, leveraging local KOLs (including education influencers and veteran teachers) for content endorsements enhances brand credibility through authentic user experience sharing;
- (2) Interest-Driven Phase: This stage activates users’ deeper needs through personalized trial programs. Leveraging behavioral data from the awareness phase (e.g., knowledge points browsed and assessment results), we deliver tailored trial content (e.g., recommending “Math Foundation Reinforcement Trial Course” for students struggling with math) and provide one-on-one guidance (via online customer support or community Q&A). These measures help users quickly master product operations while enhancing their overall trial experience;
- (3) Transformation Stage: Implement scenario-based incentives to drive user engagement. This involves creating tailored payment motivations through educational context integration. For example, launch “Mid-Year Exam Sprint Packages” during school seasons and “Team Learning Discounts” for corporate training programs. Additionally, provide flexible payment options including local payment solutions like GrabPay in Southeast Asia and Mercado Pago in Latin America, along with installment payment plans;
- (4) Retention Phase: Enhancing user engagement through “sustained value delivery”. This involves two key strategies: First, delivering personalized learning content (e.g., recommending courses based on progress), organizing online activities (like study check-ins and knowledge contests), and creating community groups (e.g., grade-specific WeChat or Telegram channels) to ensure continuous educational value and social belonging throughout product usage. Second, establishing regular feedback mechanisms (such as satisfaction surveys and suggestion collection) to optimize features according to user needs, thereby strengthening participation and sense of ownership ^[4];
- (5) Recommendation Phase: Leverage incentive mechanisms to drive user virality. This can be achieved through multi-tiered referral rewards (e.g., paying users who successfully refer new customers may receive course coupons, cashback, or free trial periods for newcomers) and streamlined referral processes (such as generating personalized recommendation posters and one-click link sharing features), thereby reducing referral costs for existing users.

3.4. Strengthen data-driven capability to enable dynamic strategy optimization

To ensure digital marketing strategies adapt to emerging market dynamics, a data-driven approach is essential. This requires establishing a robust framework through three key phases: data collection, analysis, and strategy optimization, thereby enhancing both scientific rigor and operational flexibility.

3.4.1. Data collection

The first phase focuses on expanding data coverage, complementing behavioral metrics with demand insights. For behavioral data, tracking tools like Google Analytics and heatmaps enable monitoring of user actions across channels, including clicks, page views, registrations, trial usage, and payments, while integrating platform-specific analytics (e.g., TikTok Analytics and WhatsApp Business API) for precise engagement metrics. Demand data collection involves gathering educational needs, learning patterns, and payment willingness through user surveys, community interviews, and trial feedback, effectively addressing limitations in behavioral data.

3.4.2. Data analysis

The second phase establishes a multidimensional analytical framework encompassing market trends, user behavior, and strategic planning. The market dimension primarily analyzes user growth trends, competitive landscapes, and policy changes across regional markets to identify opportunities and risks. The user dimension stratifies audiences based on profiles (e.g., age, education level, learning objectives, payment capacity), identifying high-value user groups (e.g., those with strong willingness to pay and high retention rates) while analyzing their behavioral patterns and demand preferences.

The strategy dimension evaluates customer acquisition costs, conversion efficiency across channels, content dissemination effectiveness, and user feedback to determine which strategies are effective and which require optimization (e.g., high-cost channels with low conversion rates may need channel investment adjustments or content optimization) ^[5].

3.4.3. Strategy optimization

The third phase involves strategic adjustment, requiring a “rapid iteration” optimization mechanism. This entails periodically (monthly or quarterly) adjusting marketing strategies based on data analysis results, such as increasing investments in high-efficiency channels, optimizing low-performing content, and refining user operations strategies. Additionally, an emergency adjustment mechanism is established for sudden changes in emerging markets (e.g., policy adjustments, platform rule changes, competitor actions) to ensure swift adaptation of strategies.

4. Conclusion

In summary, the optimization of digital marketing strategies for EdTech products in emerging markets is a process characterized by “tailored approaches, dynamic adjustments, and continuous iteration”. Only by prioritizing user needs, leveraging data-driven strategies, and grounding efforts in localized practices can enterprises establish a foothold in fierce market competition. This approach ultimately achieves dual improvements in sales performance and social value, injecting fresh vitality into the global EdTech industry’s development.

Disclosure statement

The authors declare no conflict of interest.

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Digital Economy Empowering New Quality Productive Forces: A Review and Implications

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Abstract: Currently, driven by the accelerated iteration of digital technologies such as big data, cloud computing, and artificial intelligence, the digital economy has become a crucial engine for generating new quality productive forces and promoting industrial upgrading. Building on a systematic review of the theoretical evolution and measurement methods of the digital economy and new quality productive forces, this paper outlines their enabling mechanisms, industrial synergy pathways, and policy practices, and summarizes regional disparities and spatial spillover effects. The main findings are as follows: First, the digital economy reshapes the traditional factor structure and significantly enhances total factor productivity through the permeation of data elements and technological innovation; Second, driven jointly by the consumer internet and the industrial internet, it optimizes supply–demand matching and service models while reducing operating costs and improving production efficiency; Third, policy environments and institutional coordination amplify the enabling effects, as evidenced notably in national big-data pilot zones and the “East Data West Computing” initiative. Looking ahead, empirical research should deepen the exploration of micro-level mechanisms and dynamic panel analyses, construct a measurement system of new quality productive forces that spans macro, meso, and micro scales, and investigate pathways for regional collaborative governance and green digital integration to address the complex challenges of the new era.

Keywords: Digital economy; Enabling mechanisms; Industrial synergy; New quality productive forces

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1. Introduction

In September 2023, General Secretary Xi Jinping first introduced the concept of “new-quality productive forces” during an inspection in Heilongjiang, describing it as an innovation-led, advanced qualitative state of productive forces that emerges from technological breakthroughs, innovative allocation of production factors, and industrial upgrading. At a collective study session of the Politburo in January 2024 this concept was further elaborated: the hallmark of new-quality productive forces is a substantial rise in total factor productivity, and the principal pathways to achieving it include improving workers’ skills and quality, promoting the intelligent transformation of means of labor, integrating digital technologies with equipment, and expanding the objects of labor. To realize its

guiding role, emphasis should be placed on emerging and future industries, while coordinating education, science & technology, and talent policies, and advancing industrial-chain modernization and high-quality development.

The 14th Five-Year Plan designates the digital economy as a key strategic engine. Under common taxonomies, the digital economy comprises “digital industrialization” and “industrial digitalization.” In 2023 China’s digital economy exceeded 40% of GDP; data are identified as a foundational strategic resource and digital technologies as the core drivers of value creation. Through factor empowerment, technological innovation, and industrial-chain collaboration, the digital economy reshapes the traditional production function and gives rise to new industries and business models. General Secretary Xi has stressed the importance of data, and the report of the 20th National Congress of the Communist Party called for deepening the integration of the digital economy with the real economy, an approach consistent with OECD definitions and one that underpins research on China’s digital economy.

From a theoretical perspective, research on the digital economy and new-quality productive forces has advanced systematically, yet separately. Studies on the digital economy concentrate on frameworks, development status, and economic effects ^[1]. Concurrently, research on new-quality productive forces centers on definitions, historical origins, and practical pathways ^[2].

Although the enabling role of the digital economy is theoretically acknowledged, empirical work on this relationship remains insufficient. Current literature often relies on macro-level expositions, neglecting micro-level analysis of how digital technology and data factor allocation translate into new-quality productive forces. Furthermore, a lack of systematic provincial-level panel data testing has limited the understanding of regional heterogeneity and the ability to offer targeted policy recommendations.

Therefore, future research must construct a macro-meso-micro measurement framework. Using dynamic panel models and cross-country comparisons is essential to test micro-level mechanisms, quantify institutional adaptation, and incorporate inclusivity and green transition perspectives. This approach will reveal the causal pathways by which the digital economy fosters new-quality productive forces, providing empirical evidence to inform coordinated policy in technology, institutions, and regional development.

2. Pathways for the digital economy to empower new quality productive forces

2.1. Empowerment mechanisms of the digital economy on new quality productive forces

The empowerment of new productive forces by the digital economy is primarily manifested through the drivers of data as a factor of production and digital technology innovation. New productive forces are constituted by high technology, digital technologies, and innovation capabilities, making them fundamentally distinct from traditional productive forces, which rely on the accumulation of labor, natural resources, and physical capital. In contrast, new productive forces depend more on innovative technologies, information flows, and data as a production factor. As the wellspring of productivity in the new era, the digital economy fosters the generation of new productive forces by optimizing resource allocation and promoting industrial upgrading.

On one hand, the digital economy provides technical support for new productive forces through the expansion of data as a production factor. Zhang points out that the core of the digital economy is data acting as a new factor of production ^[3]. Its integration with traditional factors propels a leap in productivity. Data transforms modes of production and reshapes the very essence of productivity, driving the development of new productive forces by optimizing production processes.

On the other hand, digital technology innovation is a key element in empowering new productive forces. Wang argues that innovation in digital technology drives changes in the allocation of production factors and enhances industrial innovation capacity and economic efficiency ^[4]. For example, the application of technologies such as big data alters industrial structures, facilitates the transformation of traditional industries, and provides the technological foundation for the formation of new productive forces.

2.2. Synergistic effects between the digital economy and industrial upgrading

The digital economy and industrial upgrading share a profound synergistic relationship. The transformation and upgrading of the industrial structure is a crucial pathway for the formation of new productive forces, and the digital economy serves as the core impetus for this process. It facilitates the digital transformation and intelligent upgrading of industries, enhances the competitiveness of traditional sectors, and creates opportunities for the development of emerging industries.

An empirical analysis by Yu found that the promotional effect of the digital economy on new productive forces varies significantly across regions, with a more pronounced enabling effect in the western region and in smaller-scale cities, indicating regional heterogeneity in its impact ^[5]. The widespread application of digital technology promotes the efficient allocation of resources and high-level collaboration across industrial chains, driving the development of new productive forces.

Concurrently, the role of the digital economy in advancing industrial upgrading is also manifested in the optimization of industrial structure and the acceleration of industrial integration. Zhang argues that the rapid development of the digital economy propels the restructuring of industrial chains and fosters industrial convergence, blurring the lines between traditional and emerging sectors ^[6].

This cross-sector integration has become a vital avenue for the generation of new productive forces. Digital technology is driving a paradigm shift in the production models of traditional industries, moving from a reliance on labor and resources to a core focus on technological innovation and information flows. This shift enhances industrial efficiency, resource utilization, and innovation capacity, thereby fostering the formation of new productive forces.

2.3. Interactive relationship between the digital economy and social institutions

The digital economy not only drives the transformation of productive forces but also profoundly impacts social institutions. Its rapid development necessitates corresponding adjustments in social institutions and policy frameworks to accommodate new modes of production. It fosters institutional change by advancing industrial and productivity development. Ren posits that for the digital economy to empower the development of new productive forces, a synergy of technology, economy, and institutions is required, driving a comprehensive upgrade of productive forces, economic structure, and social institutions ^[7].

Under the impetus of the digital economy, institutional change manifests in incentivizing innovation and optimizing resource allocation. Li points out that digital economy policies provide support and safeguards that incentivize corporate innovation, optimize resource allocation, and promote the development of new productive forces ^[8]. For instance, government guidance in infrastructure construction encourages enterprises to utilize digital technologies, thereby enhancing innovation and production efficiency and driving industrial upgrading.

Furthermore, the development of the digital economy requires that government policymaking focuses on cultivating innovation capabilities and rationally allocating resources. The effective implementation of digital

economy policies can foster innovative breakthroughs in enterprises, optimize the environment and support systems, promote the integration of the digital and real economies, and accelerate the generation of new productive forces.

3. Conclusion and prospects

This paper analyzes the theoretical evolution, measurement methods, and enabling mechanisms of the digital economy and new productive forces, drawing the following core conclusions:

- (1) The digital economy reshapes the elemental structure of productive forces. The infiltration of data as a factor of production and the innovation of digital technology profoundly reshape the traditional elemental structure of productive forces. Data transcends the scarcity constraints of traditional factors, driving improvements in total factor productivity. Digital technology provides the technical support for the formation of new productive forces;
- (2) New productive forces exhibit multidimensional characteristics. They are characterized by high-tech, high-efficiency, and high-quality attributes. Their formation relies on the enhancement of laborer quality, the intelligentization of the means of production, and the extended scope of the objects of labor. Empirical evidence reveals regional disparities and spatial spillover effects in their development. The western and northeastern regions, constrained by innovation factors, rely on a “long-board effect,” while the eastern region leads synergistic development through technological diffusion;
- (3) The digital economy empowers new productive forces through a dual-pathway mechanism. In the industrial upgrading pathway, the digital economy promotes the intelligent transformation of traditional industries, reshapes supply-demand matching mechanisms, and achieves cost reduction and efficiency improvement, thereby providing the core impetus for new productive forces. In the institutional synergy pathway, the development of the digital economy necessitates an adaptive policy framework. Government investment enhances corporate innovation momentum and the efficiency of resource allocation, creating a positive feedback loop of “technology-institution-industry.”;
- (4) The enabling effect of the digital economy varies by region. This effect demonstrates a gradient characteristic, with a significant impact on the enhancement of new productive forces in the western region and in smaller-scale cities. Its role in the industrial upgrading of the eastern region is particularly profound.

Policy practices indicate that institutional designs, such as national big data comprehensive pilot zones, can stimulate technological breakthroughs in enterprises. It is necessary to formulate differentiated policies based on regional endowments.

Future research and practice must continue to deeply explore key areas, including the following aspects:

3.1. Research on micro-mechanisms and dynamic evolution

Future research should intensify explorations of micro-mechanisms, delving into causal chains at the enterprise level involving data factor allocation, digital technology adoption, and the generation of new quality productive forces, while integrating case studies and experimental economics methodologies to validate micro-level transmission mechanisms. Concurrently, dynamic panel models should be constructed to capture nonlinear relationships and time-lag effects between the digital economy and new quality productive forces, revealing the

long-term influences of technological iteration cycles and policy interventions.

3.2. Research on institutional adaptability and cross-national comparisons

Regarding institutional adaptability, research should examine the efficiency of productivity empowerment by the digital economy under varying institutional environments, particularly the impacts of disparities in data property rights legislation and cross-border data flow regulations on digital economy development. Through cross-national comparisons, common pathways for institutional optimization should be distilled.

Furthermore, aligned with the objectives of Chinese-style modernization, a policy evaluation framework centered on the three-dimensional synergy of “scientific and technological innovation-institutional innovation-industrial innovation” should be designed to quantify the equilibrium between institutional costs and productivity gains.

3.3. Integration and innovation in measurement systems

Future research should also commit to the integration and innovation of measurement systems, amalgamating novel data sources such as satellite remote sensing and enterprise big data to construct a new quality productive forces index that spans “macro-meso-micro” levels, transcending the limitations of traditional statistical calibers. Simultaneously, models for accounting the “implicit value” of the digital economy should be developed to quantify synergistic effects of data factors, such as platform ecosystem values and efficiency spillovers from algorithmic optimizations.

Disclosure statement

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Research on the Impact of the Construction of Cross-border E-commerce Comprehensive Pilot Zones on China's Export Transformation and Upgrading

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Abstract: Cross-border e-commerce has emerged as a new growth point in foreign trade. While the Dalian comprehensive pilot zone has made some progress, its development is constrained by issues such as the global economic slowdown, the relatively small scale of cross-border e-commerce, a high concentration of export commodities, imperfect information mechanisms, and high overall costs. To address these challenges, this paper explores the importance of the construction of the Dalian comprehensive pilot zone for cross-border e-commerce to the transformation and upgrading of exports. Based on my research project, "Research on Path Optimization of Financial Support for the Development of Advanced Manufacturing Clusters in Dalian," this paper analyzes the current challenges and limiting factors and proposes corresponding countermeasures and suggestions.

Keywords: Cross-border e-commerce comprehensive pilot zone; Cross-border e-commerce; Export transformation and upgrading; Foreign trade export

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1. Background related to cross-border e-commerce comprehensive pilot zones and trade exports

1.1. Introduction to the comprehensive pilot zone for cross-border e-commerce

The cross border e-commerce comprehensive pilot zone is a policy pilot zone established in China to promote the transformation and upgrading of foreign trade and explore institutional innovation in cross-border e-commerce. Since Hangzhou was approved as the first comprehensive pilot zone in 2015, China has established 178 comprehensive pilot zones in eight batches, forming a multi-level open system covering the whole country.

The latest expansion focuses on strengthening border nodes facing Northeast Asia and ASEAN, such as

Dandong and Fang Cheng Gang cities; Hainan Island has become the first provincial-level comprehensive pilot zone in China, relying on the policy advantages of “zero tariffs and simplified tax system” of the free trade port to create an international live streaming e-commerce hub ^[1].

The core task of the comprehensive pilot zone is to promote the deep integration of “Internet plus foreign trade” and build a cross-border e-commerce whole chain ecosystem through policy innovation, technology empowerment and industrial collaboration. At the policy level, the comprehensive pilot zone has piloted tax facilitation measures such as “no ticket tax exemption” and “approved collection of corporate income tax”, and optimized the customs clearance process (such as the “9710” and “9810” regulatory models), significantly reducing the compliance costs of enterprises.

At the service level, relying on the “six systems and two platforms” (six major systems including information sharing, financial services, intelligent logistics, online comprehensive service platform, and offline industrial park platform), we provide one-stop cross-border trade solutions for enterprises ^[2].

1.2. The importance of cross-border e-commerce comprehensive pilot zone construction for export transformation and upgrading

The importance of cross-border e-commerce comprehensive pilot zone construction for export transformation and upgrading are as follows:

- (1) The comprehensive pilot zone has reduced the export costs of enterprises through institutional innovation. The pilot implementation of policies such as “no invoice tax exemption” and “approved collection of corporate income tax” has effectively solved the tax compliance problems of cross-border e-commerce enterprises; The customs supervision models such as “9710” and “9810” have simplified the customs clearance process, enabling small and medium-sized enterprises to participate in international trade more conveniently;
- (2) The comprehensive pilot zone promotes the digital transformation of the industrial chain. By building an online comprehensive service platform and offline industrial parks, integrating supporting services such as payment, logistics, and finance, we aim to assist traditional foreign trade enterprises in transitioning to digital operations;
- (3) The comprehensive pilot zone helps to expand diversified international markets. Each pilot zone has opened up emerging market channels for the “the Belt and Road”, RCEP and other regions in combination with its regional advantages;
- (4) The comprehensive pilot zone has cultivated new competitive advantages in foreign trade. Through the “cross-border e-commerce + industrial belt” model, promote characteristic industry clusters to go global.

2. The current situation of China’s foreign trade exports and cross-border e-commerce development

2.1. The current situation of China’s foreign trade exports

In 2025, against the backdrop of profound changes in the global economic and trade environment, China’s foreign trade exports will show a development trend of both overall pressure and structural upgrading. According to the latest data, the total export volume of goods trade in China increased by 7.2% year-on-year in the first five months of 2025.

Although it maintained positive growth, the growth rate slowed down compared to the same period last year,

and the monthly fluctuations were significant. The monthly export volume in May was 316.1 billion US dollars, a year-on-year increase of 4.8%, a decrease of 3.3 percentage points from April, reflecting a weakening of export growth momentum under the dual pressure of high base effect and weakened global demand.

It is worth noting that the export commodity structure continues to optimize and upgrade: mechanical and electrical products, as the main export force, account for 59.85%, among which technology intensive products perform particularly well - integrated circuit exports increased by 33.4%, automobile exports increased by 13.7%, and the “new three” represented by new energy vehicles, lithium batteries, and photovoltaic products maintained a high-speed growth of nearly 30%. In contrast, traditional labor-intensive products such as clothing and shoes have continued to decline, with a year-on-year decrease of over 5%.

2.2. The current status of cross border e-commerce development in China

China’s cross-border e-commerce industry has entered a stage of high-quality development, showing a sustained growth trend in recent years, with exports occupying an important position in overall trade. Data shows that the total import and export volume of the entire industry will reach 2.63 trillion yuan in 2024, an increase of 1 trillion yuan compared to 2020, with an export contribution rate of up to 74%; In the first quarter of 2025, it will continue to maintain a strong growth trend, with a growth rate of 15.6%, significantly higher than the overall growth rate of foreign trade. In terms of regional distribution, the Yangtze River Delta and Pearl River Delta, as traditional industrial clusters, continue to contribute over 60% of the country’s transaction volume.

However, the central and western regions have shown a rapid growth trend, with key cities such as Chengdu and Xi’an experiencing growth rates exceeding 30%. In terms of business models, the full custody and semi custody models dominate the upgrading of business formats. Platforms represented by Temu, AliExpress, and SHEIN have significantly reduced the entry barriers for small and medium-sized manufacturing enterprises in the international market by integrating one-stop services such as operations, logistics, and after-sales^[3].

3. Restrictive factors for China’s export transformation and upgrading

3.1. The slowdown in global economic growth has a negative impact on the development of foreign trade

According to the latest Global Trade Data and Prospects released by the World Trade Organization (WTO), the global trade volume of goods will only increase by 1.7% in 2025, a decrease of one percentage point from the trade growth rate in 2024, with imports from North America and the European Union both experiencing negative growth.

The World Bank’s “Global Economic Outlook” report released on January 9, 2025 also shows that global economic growth is expected to slow down for the fourth consecutive year in 2025, dropping to 2.4%, lower than the 2.6% in 2024. From 2021 to 2025, the global economy will grow by 2.2%, the weakest five-year growth rate since the early 1990s. It can be seen that the world economy is facing multiple downside risks, and growth remains weak.

At the same time, according to the customs export data, the export scale of Singapore, ASEAN, the United States, China, Taiwan region of China, and other countries and regions has decreased ^[4]. It can be seen that the global economic slowdown and regional policies have posed great challenges to foreign trade, and there is an urgent need to develop other overseas markets.

3.2. The scale of cross-border e-commerce is relatively small and the concentration of exported goods is high

The scale of cross-border e-commerce accounts for a relatively small proportion of the overall import and export scale. From the perspective of exported goods, products are mostly concentrated in integrated circuits, ships, labor-intensive products, agricultural products, basic organic chemicals, etc., accounting for 79.4% of the total export scale in 2023.

The high concentration of exported goods also means high foreign trade risks. With the prevalence of anti globalization and unilateralism, regional wars and political changes, and increasing global trade uncertainty, it may have adverse effects on export markets ^[5].

3.3. The mechanism for government data collection, sharing, and application is not perfect

The imperfect part of the mechanism for government data collection, sharing and application is outlined as follows:

- (1) There are limitations to the collection methods of foreign trade data, manifested in the fact that the data collection and users are mainly government departments, and the external information sharing mechanism is still incomplete. There is a lack of a unified platform for publishing and querying foreign trade information, as well as a database for foreign trade enterprise information, resulting in fragmented and untimely disclosure of publicly available information ^[6];
- (2) The coverage of foreign trade data collection is limited. Foreign trade exports are a full process, multi-dimensional, and diversified business activity. As a third-party regulatory and service organization, although it is difficult for the government to conduct full process and all-round data collection, the current efforts to mine information from overseas consumer markets and local foreign trade industry supply sides are still slightly insufficient;
- (3) Foreign trade enterprises themselves also face problems such as avoiding important information and selectively disclosing information in order to maintain their corporate image, resulting in market information asymmetry ^[7];
- (4) There are information barriers among cross-border e-commerce enterprises, which result in weak collaborative development between cross-border e-commerce and logistics companies, making it difficult to fully utilize each other's advantages and jointly enhance the overall efficiency and level of cooperation.

3.4. High comprehensive costs exacerbate export pressure for cross-border e-commerce enterprises

The overall cost increase has become a major obstacle to the development of cross-border e-commerce, manifested in logistics costs, marketing costs, and overseas warehouse costs ^[8]. For instance:

- (1) It manifests in high logistics costs. The cost of cross-border logistics mainly focuses on warehousing and transportation, including labor costs, rental costs, transportation costs, etc. Cross border logistics involves overseas transportation, outbound customs clearance, cross-border transportation, inbound customs clearance, distribution and delivery, which makes logistics costs even higher. If any two links are not properly connected, additional logistics costs will be incurred;
- (2) It manifests in high marketing costs. When cross-border e-commerce enterprises operate cross-border e-commerce platforms simultaneously, although the basic operating costs of the platform are not high, the basic membership rights in product display and supply information release are limited, resulting in

low inquiry volume for the enterprise. In order to increase traffic, the enterprise needs to continuously purchase additional services. For enterprises, the burden of platform marketing expenses is relatively heavy, and with the growth of brand cultivation and online store ratings, the increase in transaction volume of cross-border e-commerce platforms is a relatively long process^[9];

- (3) This is reflected in the cost of overseas warehouses. The high operating costs of overseas warehouses, high rental fees for overseas warehousing, high labor costs overseas, and high system operating costs have led to high construction and operating costs for overseas warehouses. Small and medium-sized foreign trade enterprises also face problems such as small scale and financing difficulties, making it difficult to establish dedicated overseas warehouses, which hinders the development of cross-border e-commerce business^[10].

4. Conclusion and suggested countermeasures

4.1. Expand market diversification and gain insight into overseas market environments

Relevant departments should take the lead in collaborating with local cross-border cooperation platforms in China, such as AliExpress, Alibaba International, TEMU, SHEIN, etc., to jointly create a fast track to enter emerging overseas markets such as the Middle East, Latin America, and Africa through full custody and semi custody models, reducing dependence on specific markets and avoiding potential market risks^[11]. The demands of emerging market customers are also rapidly changing, with increasing emphasis on product quality and customized services.

In this regard, we should empower both the market and supply chain sides, establish emerging market consumer insight centers in advantageous industries, deeply understand the needs of consumers in Latin America, the Middle East, and Africa, and disclose demand information to enterprises to meet the trend of personalized and differentiated emerging markets, and improve product “experience quality”.

Strategic partnerships with local e-commerce platforms in Southeast Asia such as Lazada and Shopee should be formed, and leverage their platform influence to attract cross-border export business. We should also collaborate with cross-border logistics companies to open a Southeast Asian cross-border e-commerce sea freight express, creating end-to-end full chain services for full container load and bulk shipping. Building a logistics hub in Southeast Asia might help improve cross-border logistics efficiency and reduce logistics costs. Key enterprises visit should be organized and increase participate in cross-border e-commerce markets in Southeast Asia, including Malaysia, Singapore, Brunei, Thailand, Indonesia, etc^[12].

4.2. Innovative reform of cross-border e-commerce supply chain

On the supply chain side, we will establish a new type of cross-border e-commerce supply chain platform and continuously enhance the flexibility of the supply chain. Leveraging the platform’s agglomeration advantage, we will innovate the supply chain platform to bring together cross-border sellers and suppliers. By establishing a centralized manufacturing cross-border flexible supply chain, we will open up vertical supply chains, facilitate rapid integration of upstream and downstream industrial chains, and achieve ecological closure across the entire industrial chain.

We will also build a supporting service system for cross-border e-commerce in various industries, including electromechanical products, integrated circuits, aquatic products, labor-intensive products, agricultural products, and basic organic chemicals. Furthermore, we will cultivate “specialized, refined, unique, and excellent” cross-

border e-commerce industrial parks, each with distinct characteristics and differentiated development ^[13].

4.3. Break down information barriers and enhance the informatization of customs clearance to better serve enterprises

Based on new quality productivity such as big data, cloud computing, the Internet of Things, artificial intelligence, and blockchain, the “data + grid” approach is used to strengthen the collection and application of information among government departments such as industry and commerce, customs, taxation, and ports, and to manage the entire process before, during, and after the event, in order to achieve “traceability from the source, traceability to the destination, risk monitoring, and accountability”.

Realize information sharing and internal circulation nationwide, that is, cross-border data interconnection and intercommunication in comprehensive pilot zones in Northeast, North, South China and other regions, and information interconnection and intercommunication between various cross-border e-commerce comprehensive pilot zones and industrial parks, industrial parks, free trade zones, and bonded zones in real time, realizing internal regional information coordination, and achieving regional coordination and cross-border e-commerce industry coordinated development through external information sharing ^[14].

4.4. Release policy dividends and reduce cross-border operational pressure

We should vigorously develop multimodal transportation and improve the connection between various logistics links. By improving laws and regulations, strengthening the construction of waterway, aviation, and railway infrastructure, promoting the standardization of facilities and equipment, encouraging the integrated development of cross-border logistics enterprises, and strengthening cooperation between cross-border logistics enterprises, we aim to promote the development of multimodal transportation such as “water, road, air, and rail” and strengthen the connection between various transportation modes.

Other than that, we should also launch comprehensive reverse logistics services, clarify tax procedures for returned goods, customs clearance solutions for various types of goods, formulate detailed rules and reverse logistics standards for cross-border e-commerce returns, optimize customs supervision processes, and invite multiple high-quality cross-border logistics service companies to develop comprehensive logistics plans based on different types of goods and export return modes, to safeguard the “home” journey of goods ^[15].

4.5. Encourage traditional foreign trade enterprises to “go global” across borders

We should build a demonstration ecological community of “digital intelligence technology + industrial services”, build a digital intelligence industry symbiotic network around digital infrastructure, strengthen the construction of digital infrastructure such as cloud computing, artificial intelligence, industrial Internet, data center, and guide enterprises to improve the value of traditional brands by digital means. Moreover, we should regularly hold cross-border e-commerce exchange meetings to share new opportunities in the cross-border e-commerce market, and invite cross-border e-commerce platforms such as AliExpress, Alibaba International, TEMU, SHEIN that have already implemented custody models to share one-stop service models such as full custody and semi custody.

Traditional enterprises should be encouraged to carry out overseas trademark registration and international certification of their own brands, give priority to projects and rewards to enterprises that have their own trademarks in the destination country, and promote enterprises to use their own brands to conduct business

Cross-border e-commerce enterprises should participate in domestic and international exhibitions, provide information services and support for market development, and help brands go global. Leading enterprises in

industries such as equipment manufacturing and new energy should be supported to accelerate their digital transformation, vigorously cultivating local vertical platforms, and forming a trend of industry leaders as the core, integrating supply chains, and driving upstream and downstream related enterprises to go global together. Innovative models such as “bonded + live streaming” and “experience store + live streaming”, should be developed and traditional foreign trade and manufacturing enterprises ought to be promoted to use cross-border e-commerce to explore markets, promote internal and external collaboration, and accelerate brand going global.

5. Conclusion

Based on the comprehensive research, it can be seen that the construction of Dalian Cross border e-commerce comprehensive pilot zone has become a key engine for promoting the transformation of Dalian’s export trade from “scale expansion” to “quality and efficiency”. Its empowering role in export transformation and upgrading not only has regional characteristics, but also provides practical reference for similar cities across the country. In the future, Dalian needs to take the cross border e-commerce comprehensive pilot zone as a pivot, further focus on the digital transformation of core industries, strengthen talent cooperation and training with universities and vocational colleges, and optimize the global layout of overseas warehouses, in order to fully leverage the driving role of cross-border e-commerce in export transformation and upgrading, achieve a leap from “Dalian Manufacturing Export” to “Dalian Brand Global Operation”, and provide a more valuable “Dalian Plan” for coastal cities in China to promote high-quality development of foreign trade through cross-border e-commerce.

Disclosure statement

The authors declare no conflict of interest.

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Acceptance of Intelligent Interviews by College Graduates Under AI Empowerment: An SEM Approach

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Abstract: The Master Intelligent interview is based on the Stimulus-Organism-Response (SOR) theory, this study integrates key constructs from the Technology Acceptance Model (TAM) and the Theory of Planned Behavior (TPB), namely attitude and behavioral intention, to develop a dual-path model of how AI empowerment influences college graduates' acceptance of intelligent interview technology. Taking AI empowerment as the independent variable, perceived risk and attitude as mediating variables, and behavioral intention as the outcome variable, the study employs questionnaire surveys and structural equation modeling (SEM) for empirical analysis. The results show that AI empowerment exerts a significant positive impact on attitude, perceived risk, and behavioral intention. Both perceived risk and attitude play significant mediating roles between AI empowerment and behavioral intention. Interestingly, perceived risk does not suppress behavioral intention; instead, it positively promotes it through a "rational trade-off" mechanism. Moreover, perceived risk and attitude form a significant chain-mediated pathway, revealing a continuous psychological transmission mechanism of "rational cognition-emotional adjustment-behavioral decision-making". This study enriches the theoretical framework of AI technology acceptance, extends the application of the SOR model to the context of intelligent recruitment, and provides valuable implications for optimizing university career guidance and enterprise recruitment systems.

Keywords: AI empowerment; Master Intelligent Interview; Technology Acceptance Model; Perceived risk; Structural Equation Modeling

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1. Introduction

The rapid integration of artificial intelligence (AI) into recruitment processes has transformed traditional hiring practices^[1]. Among these innovations, AI-powered intelligent interviews are increasingly adopted by enterprises to enhance efficiency, ensure fairness, and provide data-driven candidate assessments. While these systems offer significant benefits, they also introduce potential challenges, including concerns over algorithmic transparency,

fairness, and privacy. College graduates, as primary users of these technologies during critical job-seeking periods, serve as both direct stakeholders and valuable sources of feedback, making their acceptance crucial for effective implementation. Understanding the psychological mechanisms that drive their adoption of intelligent interview systems is therefore of both theoretical and practical importance.

Based on established technology acceptance theories such as TAM and TPB, existing research has emphasized factors like perceived usefulness, ease of use, and attitude ^[2]. However, these models may not fully explain user behavior in high-stakes contexts such as AI-enabled intelligent interviews, where perceived risks and outcome sensitivity are heightened. To address this gap, this study introduces the SOR framework and integrates the concept of AI empowerment, referring to the enhancement of efficiency, fairness, and analytical depth in intelligent interview systems, into a dual-path theoretical model.

This study integrates AI empowerment, the extent to which intelligent interview systems enhance efficiency, fairness, and analytical depth, into a comprehensive theoretical framework that combines SOR, TAM, and TPB. Within this framework, behavioral intention is influenced via two complementary pathways: an emotional pathway mediated by attitude and a rational pathway mediated by perceived risk. Notably, perceived risk may exert a facilitative, rather than inhibitory, effect in this context, reflecting rational trade-offs in high-stakes job-seeking scenarios.

Accordingly, this research addresses two core questions:

- (1) How do college graduates form intentions to use AI-powered intelligent interview systems under the influence of AI empowerment through the combined effects of perceived risk and attitude?
- (2) What are the underlying mechanisms through which AI empowerment shapes behavioral intention?

To answer these questions, a dual-path model is proposed and empirically tested using SEM, providing a systematic understanding of the psychological logic governing intelligent interview adoption and offering implications for optimizing university career guidance and enterprise recruitment practices.

2. Research hypotheses and model construction

Grounded in the SOR framework, this study integrates the Technology Acceptance Model (TAM) and the Theory of Planned Behavior (TPB) to explore college graduates' acceptance of intelligent interview technology under AI empowerment. AI empowerment, defined as the capability of intelligent systems to enhance efficiency, fairness, and analytical precision, acts as the external stimulus influencing behavioral intention both directly and indirectly through two internal psychological mechanisms: perceived risk (rational cognition) and attitude (emotional evaluation).

Perceived risk reflects individuals' concerns regarding potential negative outcomes, such as technical errors, privacy breaches, or unfair evaluations. While conventional theories suggest that perceived risk suppresses behavioral intention, this study argues that in high-stakes recruitment contexts, risk perception may foster "cautious engagement". Graduates who recognize potential risks may adopt a proactive and well-prepared stance rather than outright rejection, leading perceived risk to exert a positive influence on both attitude and behavioral intention.

Furthermore, AI empowerment may heighten risk awareness through its complexity and algorithmic opacity, prompting rational reflection on potential consequences. Yet, under employment pressure, this rational awareness may transform into adaptive behavior, acknowledging that avoiding AI-based interviews could result in greater opportunity loss. Thus, perceived risk and attitude jointly serve as sequential mediators linking AI empowerment

to behavioral intention.

Based on these theoretical arguments, this study proposes the following hypotheses:

- (1) H1: AI empowerment has a significant positive effect on college graduates' attitudes toward intelligent interviews;
- (2) H2: Attitude has a significant positive effect on college graduates' behavioral intention to use intelligent interview technology;
- (3) H3: AI empowerment has a significant positive effect on college graduates' perceived risk toward intelligent interviews;
- (4) H4: Perceived risk has a significant positive effect on college graduates' behavioral intention to use intelligent interview technology;
- (5) H5: Perceived risk has a significant positive effect on college graduates' attitudes toward intelligent interviews;
- (6) H6: AI empowerment has a significant positive effect on behavioral intention;
- (7) H7: AI empowerment has a significant positive indirect effect on behavioral intention through attitude (i.e., attitude plays a mediating role);
- (8) H8: AI empowerment has a significant positive indirect effect on behavioral intention through perceived risk (i.e., perceived risk plays a mediating role);
- (9) H9: AI empowerment has a significant positive indirect effect on behavioral intention through the sequential mediation of perceived risk and attitude (i.e., perceived risk and attitude play a chain-mediating role).

Overall, the proposed model delineates the pathway from technological empowerment through cognitive and affective evaluations to behavioral intention, providing an integrated framework for understanding intelligent technology acceptance among college graduates (**Figure 1**).

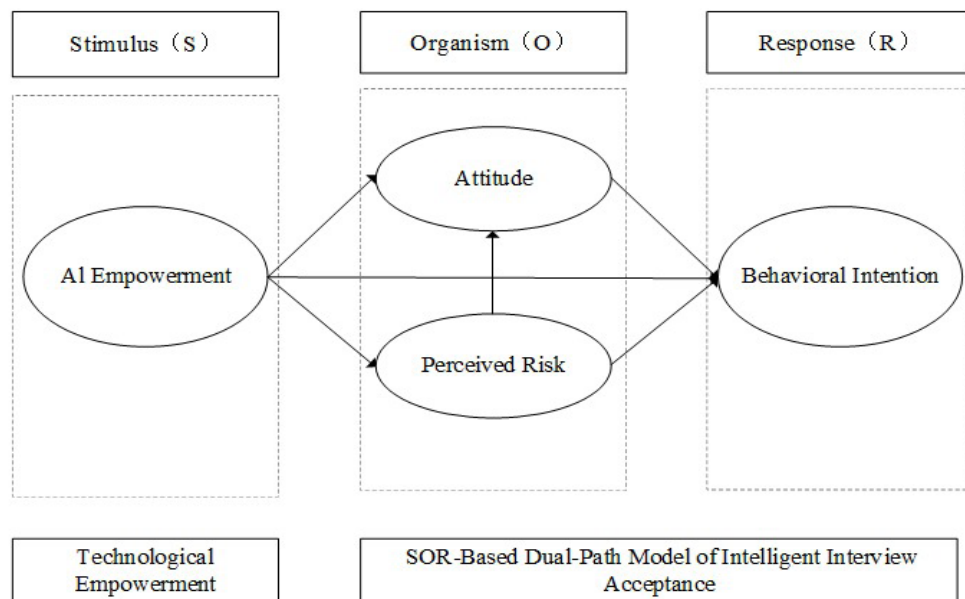


Figure 1. Theoretical framework diagram of college graduates' acceptance of intelligent interviews.

3. Data collection and analysis

3.1. Research subject

This study focuses on Chinese college graduates at the associate, bachelor's, and master's or higher levels. This population is selected for three main reasons:

- (1) Graduates are at a pivotal stage of entering the job market and serve as the primary direct users of intelligent interview technologies; their acceptance critically influences the technology's recruitment effectiveness and provides essential feedback for system optimization;
- (2) While this group is relatively homogeneous in age and employment motivation, ensuring contextual consistency, it also exhibits heterogeneity in educational background, discipline, and institution type, allowing examination of differential effects across subgroups and enhancing analytical depth;
- (3) As the core of the future labor force, graduates' attitudes toward emerging technologies indicate the prospective adoption of intelligent interviews and broader AI applications in future work environments. Thus, focusing on this population offers both theoretical and practical significance.

3.2. Questionnaire design

The study employed a questionnaire survey to collect empirical data. The questionnaire consisted of two sections.

The first section collected respondents' demographic information, including gender, age, education level, and employment status.

The second part focuses on the measurement of core variables. The scale items were revised with reference to mature domestic and international literature and include measurement items for core constructs such as AI empowerment, perceived risk, attitude, and behavioral intention^[3-5].

All items use a five-point Likert scale (1 = 'Strongly Disagree' to 5 = 'Strongly Agree'), and the scale items were revised with reference to mature domestic and international literature.

An online survey was conducted via Questionnaire Star and snowball sampling through graduate social media groups (e.g., WeChat, QQ), targeting college graduates nationwide. A total of 1,351 questionnaires were returned. After removing 13 incomplete or invalid responses, 1,338 valid responses remained, yielding an effective response rate of 99.0%.

Among the respondents, 51.3% were male and 48.7% were female, indicating a balanced gender distribution. Approximately 63.64% reported prior experience with intelligent interviews, indicating high technology penetration. The majority of respondents were aged 18–25 (50%) and 26–35 (27.92%), reflecting a young and middle-aged job-seeking population. Regarding educational background, 77.28% held a bachelor's degree or higher (60.34% bachelor's; 14.94% master's or above), indicating a generally high educational level, which may enhance their acceptance and use of intelligent interview technology.

3.3. Reliability and validity analysis

This study employed SPSS 26.0 and AMOS 26.0 to assess the reliability and validity of the questionnaire data. The results indicated that the overall Cronbach's α for the questionnaire was 0.926, demonstrating excellent internal consistency reliability.

As shown in **Table 1**, the Cronbach's α values for all constructs exceeded 0.7, the composite reliability (CR) values were all above 0.7, and the average variance extracted (AVE) values were all greater than 0.4, collectively confirming good convergent validity for all constructs.

Furthermore, the structural validity of the scale was assessed. The overall Kaiser-Meyer-Olkin (KMO) measure was 0.957, and Bartlett's test of sphericity was significant ($P < 0.001$), indicating that the data were highly suitable for factor analysis and that the scale possessed satisfactory structural validity.

In summary, the scales used in this study demonstrated excellent reliability and validity, confirming the high quality of the data and supporting their suitability for subsequent hypothesis testing and empirical analysis.

Table 1. Short Reliability and validity analysis

Variable Name	CR	AVE	Cronbach's α	KMO
AI empowerment	0.753	0.504	0.751	0.688
Perceived risk	0.733	0.479	0.733	0.684
Attitude	0.763	0.519	0.760	0.694
Behavioral intention	0.728	0.471	0.728	0.684
The overall reliability of the questionnaire Cronbach's $\alpha = 0.926$			KMO = 0.957	
Bartlett's test of sphericity: Approximate Chi-square = 941.262			$P = 0.000$	

3.4. Assessment of model fit

The structural model was evaluated using AMOS 26.0 to assess its goodness of fit.

The results indicate that all fit indices met or exceeded the recommended thresholds: the chi-square to degrees of freedom ratio (CMIN/DF) was 0.755, the root mean square error of approximation (RMSEA) was 0.000, and the goodness-of-fit index (GFI), Tucker-Lewis index (TLI), and comparative fit index (CFI) were all 1.000. Additionally, the normed fit index (NFI) and parsimonious normed fit index (PNFI) were 0.963 and 0.700, respectively.

These values collectively demonstrate an excellent overall model fit, suggesting a high level of consistency between the theoretical model and the empirical data, thereby providing strong support for subsequent path analysis and hypothesis testing.

3.5. Structural equation modeling hypothesis testing

3.5.1. Main effect testing

Using AMOS 26.0, the significance of all path coefficients between latent variables and the factor loadings of observed variables on their respective latent constructs were examined. The results indicate that the first six hypotheses proposed in this study are all supported (**Table 2**).

Specifically, AI empowerment has a significant positive effect on graduates' attitude toward intelligent interviews, perceived risk, and behavioral intention ($P < 0.001$, $\beta = 0.7461$; $P < 0.001$, $\beta = 0.768$; $P < 0.001$, $\beta = 0.338$), supporting H1, H3, and H6.

Perceived risk has a significant positive effect on both graduates' attitude toward intelligent interviews and behavioral intention ($P < 0.001$, $\beta = 0.408$; $P < 0.001$, $\beta = 0.247$), supporting H4 and H5. Additionally, attitude has a significant positive effect on behavioral intention ($P < 0.001$, $\beta = 0.345$), supporting H2.

These results confirm the hypothesized main effects and indicate that AI empowerment, perceived risk, and attitude play significant roles in shaping graduates' behavioral intention to use intelligent interview technology.

Table 2. Structural model test results

Hypothesis	Path relationship	Path coefficient	Standard error (SE)	T-value (CR)
H1	AI Empowerment → Attitude	0.461	0.072	6.397
H2	Attitude → Behavioral Intention	0.345	0.069	4.831
H3	AI Empowerment → Perceive Risks	0.768	0.051	14.957
H4	Perceived Risk → Behavioral Intention	0.247	0.069	3.487
H5	Perceived Risk → Attitude	0.408	0.073	5.655
H6	AI Empowerment → Behavioral Intention	0.338	0.070	4.668

3.5.2. Mediation effect test

The bootstrap resampling method (with 5,000 repeated samples) was employed to estimate the path coefficients and indirect effects of the mediation model. The results are presented in **Table 3**, which reports the point estimates of each effect as well as their 95% bootstrap confidence intervals.

Table 3. Results of mediation effect testing

Effect type	Path relationship	β	LLCI	ULCI	P
Total effect	AI Empowerment → Behavioral Intention	0.768	0.675	0.861	0.000
Direct effect	AI Empowerment → Behavioral Intention	0.433	0.302	0.564	0.000
Indirect effect	AI Empowerment → Attitude → Behavioral Intention	0.335	0.253	0.440	0.000
Total effect	AI Empowerment → Behavioral Intention	0.678	0.675	0.861	0.000
Direct effect	AI Empowerment → Behavioral Intention	0.481	0.347	0.614	0.000
Indirect effect	AI Empowerment → Perceived Risk → Behavioral Intention	0.287	0.198	0.407	0.000
Total effect	AI Empowerment → Behavioral Intention	0.768	0.675	0.861	0.000
Direct effect	AI Empowerment → Behavioral Intention	0.327	0.187	0.467	0.000
Direct effect	AI Empowerment → Perceived Risk	0.758	0.657	0.859	0.000
Direct effect	AI Empowerment → Attitude	0.463	0.318	0.607	0.000
Total indirect effect	AI Empowerment → Perceived Risk → Behavioral Intention	0.183	0.086	0.300	0.000
Total indirect effect	AI Empowerment → Attitude → Behavioral Intention	0.154	0.086	0.244	0.000
Total indirect effect	AI Empowerment → Perceived Risk → Attitude → Behavioral Intention	0.104	0.056	0.170	0.000

The total effect of AI empowerment on behavioral intention was 0.768 (95% CI [0.675, 0.861]), indicating a strong and significant positive influence in the absence of mediators. After introducing perceived risk and attitude as mediators, the direct effect remained significant ($\beta = 0.327$, 95% CI [0.187, 0.467]), suggesting partial mediation and confirming that AI empowerment affects behavioral intention both directly and indirectly through psychological mechanisms.

Specifically, the indirect effect via attitude was 0.154 (95% CI [0.086, 0.244]), supporting H7 and highlighting attitude as a critical emotional pathway linking AI empowerment to behavioral intention. The indirect effect via perceived risk was 0.183 (95% CI [0.086, 0.300]), statistically significant but opposite to the negative direction predicted by H8, indicating that perceived risk acts as a facilitative rather than suppressive mediator.

Additionally, the sequential chain mediation via perceived risk and then attitude was 0.104 (95% CI [0.056, 0.170]), supporting H9 and validating a sequential psychological transmission mechanism: rational risk evaluation → emotional adaptation → behavioral decision-making.

Overall, the total indirect effect (0.441) accounted for 57.4% of the total effect, with the chain mediation path explaining 13.5%, confirming that graduates' decision-making in AI-powered interviews involves a complex, sequential psychological adaptation rather than a simple stimulus-response process.

4. Conclusion

Originated from the SOR framework, this study develops a dual-path model to examine how AI empowerment influences college graduates' acceptance of intelligent interview technology. The empirical findings demonstrate that AI empowerment has a significant positive impact not only on behavioral intention but also on attitude and perceived risk, highlighting the comprehensive psychological and behavioral influence of AI-driven recruitment technologies. Both attitude and perceived risk play significant mediating roles between AI empowerment and behavioral intention, with indirect effects accounting for 57.4% of the total effect. This underscores that psychological mechanisms constitute the primary pathway through which AI empowerment shapes technology acceptance.

Interestingly, perceived risk exerts a positive mediating effect, contrary to traditional risk-aversion assumptions. This finding reflects a rational trade-off mechanism in high-stakes employment contexts, where job seekers perceive that the certain loss of rejecting AI interviews outweighs the potential risks associated with their use. Thus, heightened awareness of technological risks paradoxically enhances willingness to adopt AI interviews, revealing the complex nature of risk-based decision-making in technology acceptance.

This study contributes to theory by extending the SOR model to explain AI adoption in high-stakes decision contexts and by uncovering a reversed risk-intention dynamic. Future research may expand the sample beyond college graduates, incorporate contextual and cultural variables, and explore the evolving impact of AI advancements on users' acceptance models over time.

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The Partial Centralization Decision for ClosedLoop Supply Chain Coordination with Trade-In Strategy

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Abstract: To explore the impact of partial centralization on supply chain performance, this study constructs a two-period game model of a closed-loop supply chain involving a manufacturer and an online retail platform participating in the trade-in strategy. Through mathematical modeling and numerical simulation methods, the optimal decisions were analyzed under conditions where the manufacturer partially owns the retail platform's partial equity. This study finds that partial centralization yields the highest profits, followed by full centralization, with decentralized decisions yielding the lowest profits. Moderate centralization enhances overall profits by optimizing incentive mechanisms, whereas excessive ownership concentration reduces the flexibility of the retail platform, leading to a decline in profits. Additionally, product durability and trade-in subsidy significantly influence supply chain profitability: high-durability products reduce renewal frequency, while trade-in subsidy effectively stimulates consumer demand and increase overall profits. This study provides theoretical support and practical guidance for companies implementing the trade-in strategy.

Keywords: Closed-loop supply chain; Coordination; Partial centralization; Trade-In

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1. Introduction

In 2024, the State Council of China issued the “Action Plan for Promoting Large-Scale Equipment Upgrades and Trade-In Programs for Consumer Goods”, thereby launching a new round of trade-in initiatives aimed at stimulating domestic demand and advancing green transformation. The plan particularly encourages the replacement of high-value durable goods such as new-energy vehicles and electronic products. Trade-in programs are closely related to the closed-loop supply chain (CLSC), which manages the full product lifecycle, from design and production to use, recycling, and remanufacturing, and serves as a vital mechanism for resource circulation and product reuse^[1].

In the implementation of trade-in initiatives, two problems are critical: on the demand side, providing incentives and constraints to encourage consumers to return used products; and on the supply side, achieving

coordination and governance among manufacturers, online retail platforms, and recycling actors.

The existing literature on trade-in primarily examines firms' adoption decisions, the design of pricing and subsidy schemes, and the choice of implementation models. Studies compare organizational structures such as centralized recycling, retailer-led recycling, and manufacturer-led recycling, and further analyze how second-hand and peer-to-peer (P2P) markets affect pricing, product quality, and intertemporal decisions ^[2-5]. In parallel, the supply chain governance literature has long focused on the efficiency trade-offs between centralization and decentralization ^[6]. More recently, research highlights "partial centralization" typically established through equity participation, as a hybrid governance mode that facilitates information sharing and coordination ^[7,8]. In particular, Li et al. developed a multi-period dynamic model encompassing centralized, decentralized, and partially centralized supply chains, providing a unified analytical framework for comparing these governance structures ^[9].

Against this backdrop, this paper investigates the collaborative decision-making problem between a manufacturer and an online retail platform under a trade-in program. This study constructs a two-period game-theoretic model, where the manufacturer's equity stake in the platform captures the degree of partial centralization. Within the settings of full centralization, full decentralization, and partial centralization, we derive the optimal pricing and ordering strategies of both parties and compare supply chain performance. Furthermore, product durability, the intensity of trade-in subsidies, and the presence of a second-hand market are incorporated into the unified framework to examine their joint effects on pricing, recycling, and ordering decisions.

2. Model description and assumption

This study considers a two-period game model in CLSC involving a manufacturer and an online retail platform, both participating in a trade-in program. The manufacturer holds a share of ownership in the platform, denoted by θ . The platform transfers a proportion of its profit to the manufacturer based on θ , where $\theta = 0$ represents a fully decentralized structure and $\theta = 1$ indicates full centralization.

The manufacturer is responsible for the production of new products, with products durability denoted by δ ($0 < \delta < 1$). The online retail platform is responsible for retail sales and the execution of the trade-in in the second period, including the collection and remanufacturing of returned products. Scenarios *C*, *D* and *P* represent fully decentralized, fully centralized, and partially centralized decision-making structures, respectively. For simplicity, manufacturer profit from remanufacturing, production cost, and discount rates are set to zero ^[10].

Assuming rational consumers, their utility from new and remanufactured products varies. In a two-period model, each consumer's valuation v for new products is uniformly distributed over $[0,1]$, with the market size normalized to 1. First-period buyers may continue using the product or participate in the trade-in program.

Consumer behavior is classified as follows:

- (1) BH: buy in the first period and keep in the second;
- (2) BR: buy in the first period and trade in the second;
- (3) NB: skip the first period and buy in the second;
- (4) NN: no purchase in either period.

It is assumed that the retail platform offers products in both periods and that consumers choose the option maximizing their total utility. The decision sequence follows:

- (1) The manufacturer first determines the wholesale prices w_t , $t \in [1,2]$;
- (2) The online retail platform determines the order quantities q_t , $t \in [1,2]$ and the trade-in quantity q_3

Based on the solution approach used by Li et al., the inverse demand functions for both periods can be expressed as follows (1)–(3) ^[9]:

$$p_1 = 1 - q_1 + b \quad (1)$$

$$p_2 = 1 - q_1 - q_2 \quad (2)$$

$$p_3 = (1 - \delta) (1 - q_3) \quad (3)$$

b is the subsidy for the trade-in product, i.e., the residual value.

Since the manufacturer holds a partial ownership share in the online retail platform, a proportion of the platform's profit is transferred to the manufacturer accordingly. In the second period, the profits of the retail platform and the manufacturer are given by (4),(5):

$$\pi_{R2} = (1 - \theta) [(p_2 - w_2) q_2 + (p_3 - w_2) q_3] \quad (4)$$

$$\pi_{m2} = w_2 (q_2 + q_3) + \theta \{q_3 [(\delta - 1) (q_3 - 1) - w_2] - q_2 (q_1 + q_2 + w_2 - 1)\} \quad (5)$$

The retail platform, the manufacturer and supply chain system's profits are given by (6)–(8):

$$\pi_m = \pi_{m1} + w_1 q_1 + \theta (1 - q_1 + b - w_1) q_1 \quad (6)$$

$$\pi_r = \pi_{r1} + (1 - \theta) (p_1 - w_1) q_1 \quad (7)$$

$$\pi^i = \pi_m + \pi_r \quad (8)$$

3. Equilibrium results and analysis

3.1. Equilibrium results

This study adopts the method of backward induction and verifies the negative definiteness of the Hessian matrix to derive the equilibrium solutions under centralized, decentralized, and partially centralized decision-making scenarios. To ensure that the decision variables are strictly positive, the relevant parameters must satisfy the following conditions: $0 < b \leq 0.675$.

(1) Proposition 1:

(i) Under centralized decision-making, the equilibrium solution:

$$q_1^c = (1 + 2b) / 3; q_2^c = (1 - b) / 3; q_3^c = 0.5;$$

(ii) The profit of the supply chain system under centralized decision-making:

$$\pi^c = [7 + 4b (1 + b) - 3\delta] / 12;$$

(2) Proposition 2:

(i) The overall profit of the supply chain under decentralized decision-making:

$$w_1^D = \frac{1}{112} [95 + 52b + \frac{63}{-2 + \delta} - \frac{24(-1 + b)}{-13 + 7\delta}], w_2^D = \frac{[47 + 4b(-2 + \delta) - 25\delta][1 - \delta]}{4(-2 + \delta)(-13 + 7\delta)}, q_1^D = \frac{-5 + 4b(\delta - 2) + 3\delta}{-26 + 14\delta},$$

$$q_2^D = \frac{1}{56} [-3 - 4b - \frac{21}{-2 + \delta} + \frac{32(b - 1)}{-13 + 7\delta}], q_3^D = \frac{1}{8} [4 + \frac{3}{\delta - 2} - \frac{4(b - 1)}{-13 + 7\delta}];$$

(ii) The profit of the supply chain system under decentralized decision-making:

$$\pi^D = \frac{(43\delta - 79)[2b(\delta - 2) + (3\delta - 5)]b}{8(13 - 7\delta)^2} + \frac{\delta\{20293 + \delta[(5651 - 784\delta)\delta - 15793]\} - 10087}{64(13 - 7\delta)^2(\delta - 2)};$$

(3) Proposition 3:

(i) Under partial centralization, the equilibrium solution:

$$w_1^P = \frac{(\theta-1)\{A_5 + A_2[A_4 - 25 - 7(\theta-4)\theta + \delta[13 + 4(\theta-4)\theta]]\}}{[2(\delta-2)(\theta-2)^2 A_1]}, q_1^P = \frac{10 - A_2 + 4(\theta-3)\theta + \delta[(8-3\theta)\theta-6]}{A_1},$$

$$w_2^P = \frac{(\delta-1)(\theta-1)(94 + A_2 + A_6)}{(\delta-2)(\theta-2) A_1}, q_2^P = \frac{74 - A_2(\delta + \theta - 3) + A_3}{2(\delta-2)(\theta-2) A_1}, q_3^P = \frac{114 + A_2(\theta-1) - 2\theta[92 + \theta(9\theta-50)] + A_1}{2(\delta-2)(\theta-2) A_1},$$

(ii) Under partial centralization, the total profit of the supply chain:

$$\pi^P = \frac{1}{4(-2+\delta)(-2+\theta)^2} \{(\theta-1)[4 + \delta(-4 + \delta(-2 + \theta)^2) - \frac{3A_9}{A_1^2}] - \frac{A_8}{A_1}\}.$$

Due to space limitations, the values of the parameters A_7 - A_9 and the calculation process of the inference results are provided below.

3.2. Analysis

The analysis of the equilibrium results are as follows:

(1) Corollary 1:

(i) $q_1^D < q_1^C$;

(ii) When $0 < \delta < \hat{\delta}$, $q_2^D < q_2^C$;

(iii) $q_3^D < q_3^C$, where $\hat{\delta} = \frac{3(-29+26b)}{-65+44b} - 2\sqrt{\frac{316-116b+25b^2}{(-65+44b)^2}}$;

Under centralized decision-making, the retail platform's orders for both phases and trade-in volumes are higher than under decentralized systems. Centralization enhances supply chain efficiency by aligning manufacturer and retail platform decisions, improving demand forecasting, enabling more rational ordering, and supporting more attractive trade-in subsidies, which boost consumer participation and second-phase recovery. Thus, the coordination and information sharing in centralized decision-making result in higher product orders and trade-in volumes compared to decentralized systems.

(2) Corollary 2:

(i) $q_2^i + q_3^i > q_1^i$, $i \in \{C, D, P\}$;

(ii) $w_1^i > w_2^i$, $i \in \{D, P\}$;

Across all decision-making structures, second-phase products have lower wholesale prices but higher total orders than first-phase products, driven by reduced durable-goods pricing and the trade-in program, which lowers consumers' net cost and boosts demand. As a result, second-phase products gain a pricing advantage, significantly increasing overall order volume.

(3) Corollary 3: $\pi^C > \pi^D$;

The profits of centralized decision-making exceed the decentralized decision-making. When the manufacturer and the retail platform make decisions together, they can coordinate activities across all stages, thereby optimizing the overall performance of the supply chain. For example, the manufacturer can set wholesale and retail price based on market demand and production costs, while the retail platform can correspondingly adjust order quantities and the promotional strategy.

(4) Corollary 4: $\frac{\partial w_1^P}{\partial b} > 0, \frac{\partial q_1^P}{\partial b} > 0, \frac{\partial w_2^P}{\partial b} < 0, \frac{\partial q_2^P}{\partial b} < 0, \frac{\partial q_3^P}{\partial b} > 0;$

Old-product subsidies create expectations of future rebates through the trade-in, lowering consumers' effective replacement costs and stimulating first-phase demand. This allows manufacturers to raise wholesale prices and retail platform to increase orders. In the second phase, higher trade-In prompt the manufacturer and retail platform to reduce wholesale prices to accelerate turnover and prevent excess inventory. The coordinated subsidy approach strengthens supply chain coordination, enhances competitiveness, and leverages economies of scale.

(5) Corollary 5:

(i) $\frac{\partial w_1^P}{\partial \theta} < 0, \frac{\partial w_2^P}{\partial \theta} < 0, \frac{\partial q_1^P}{\partial \theta} > 0, \frac{\partial q_3^P}{\partial \theta} > 0;$

(ii) If $0.4 < \delta \leq 0.75, \frac{\partial q_2^P}{\partial \theta} > 0;$

As ownership increases, wholesale prices for new products in both phases decrease, while first-phase orders for new and trade-in items rise. When product durability exceeds a threshold, second-phase new-product orders also increase, reflecting the residual value that attracts consumers who delay purchases. Greater ownership enables the manufacturer to lower prices, stimulate demand and trade-in participation, and align pricing, subsidies, and supply-chain operations, thereby expanding market volume and boosting second-phase orders. Firms could prioritize durable designs and adjust ownership levels to optimize market strategies.

(6) Corollary 6: $\frac{\partial w_1^P}{\partial \delta} > 0, \frac{w_2^P}{\partial \delta} > 0, \frac{\partial q_1^P}{\partial \delta} < 0, \frac{\partial q_2^P}{\partial \delta} > 0, \frac{\partial q_3^P}{\partial \delta} < 0;$

Wholesale prices for new products in both phases rise with durability, yet first-phase and trade-in order quantities decline, while second-phase orders increase. Enhanced durability raises perceived value and justifies premium pricing, causing consumers to retain the first stage purchases longer, reducing immediate replacements but later driving demand for high-quality durable goods in the second stage.

4. Numerical simulation

This section uses Mathematica for numerical simulations to examine how product durability, ownership level, and rebate rate affect decisions and profitability, with non-negativity constraints and the following parameter settings: $b = 0.4, \theta = 0.5, \delta = 0.45$.

Through numerical simulation, supply chain profits rank as follows: $\pi^P > \pi^C > \pi^D$.

Under partial centralization, profit sharing and retained autonomy encourage platform investment and flexibility, while lower coordination costs enhance efficiency. Full centralization removes double marginalization and gains scale economies but reduces flexibility and may raise coordination costs. Decentralization, hindered by conflicting goals and information asymmetry, yields the lowest profits.

As shown in **Figure 1**, under partial centralization, supply chain profit follows an inverted-U pattern with ownership level: moderate ownership enhances alignment and coordination, improving pricing and ordering efficiency, whereas excessive ownership erodes autonomy, slows response, and raises coordination costs, reducing profits.

As shown in **Figure 2**, greater product durability negatively affects profitability. Longer usage reduces demand for new products and trade-ins, lowering orders and recovery volumes. Although higher prices may

signal better quality, weaker demand offsets these gains and narrows margins. Increased durability also prolongs replacement cycles and slows market turnover, further suppressing profitability.

From **Figure 3**, trade-in subsidies enhance supply chain profits across all decision structures, with larger subsidies yielding higher gains. By reducing consumers' purchase costs, subsidies boost demand and order volumes, lower wholesale prices, and improve competitiveness. Increased orders raise revenues for both parties, while greater trade-in participation enhances recovery and remanufacturing, thus improving resource utilization and overall profitability.

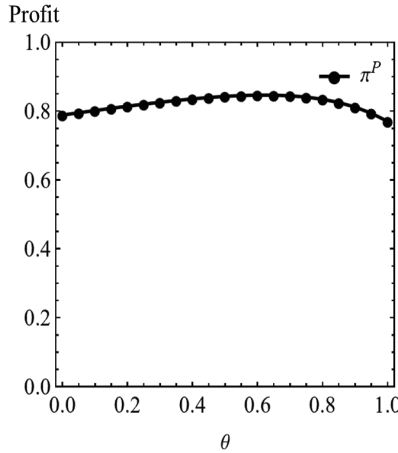


Figure 1. Effect of ownership level on profit.

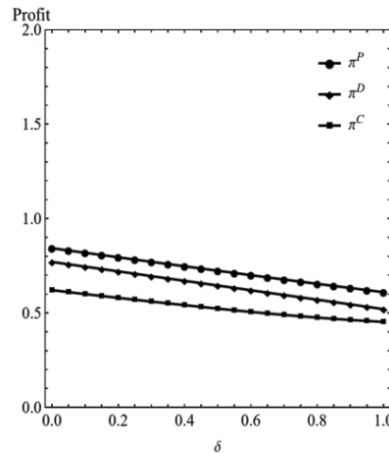


Figure 2. Effect of product durability on profits of supply chain member.

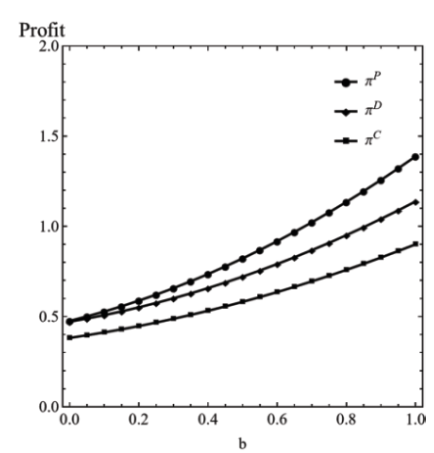


Figure 3. Effect of old product subsidies on of supply chain member.

5. Conclusion

This study develops a two-period game-theoretic model of a closed-loop supply chain in which a manufacturer and an online retailer jointly operate a trade-in program, and compares system performance under decentralized, partially centralized, and fully centralized decision structures. The results show that partial centralization achieves superior outcomes by balancing coordination efficiency with retailer autonomy: at moderate ownership levels, it maximizes overall profit, whereas excessive ownership reduces platform flexibility and responsiveness, leading to profit decline. Product durability exerts a negative effect on profitability, while higher durability signals better quality, it extends replacement cycles and suppresses demand, thereby reducing system revenue. In contrast, old-product subsidies stimulate consumer purchases by lowering effective prices, expanding orders and trade-in participation, and ultimately improving both resource utilization and supply chain profit.

This study offers several managerial insights for firms implementing trade-in strategies. Manufacturers should balance product durability and replacement demand, adopt moderate equity participation, and coordinate dynamic subsidy and pricing strategies. Retailers should enhance responsiveness and collaboration to improve performance. Limitations include simplified assumptions, exclusion of third-party recyclers, and a two-period scope; future work should consider realistic costs and multi-stage dynamics.

Disclosure statement

The author declares no conflict of interest.

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Research on the Influence of Financial Status of Benxi Steel Sheet Material on Stock Price Under the Perspective of Big Data

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Abstract: Based on the financial data and stock price information of Bengang Steel Plates Co. Ltd. from 2004 to 2023, this paper uses SPSS 26 software, combined with DuPont Analysis and Wall Score Method, to explore the correlation between stock price and nine key financial indicators selected from three dimensions: profitability, development capability, and operating capability, including fixed asset growth rate, price-to-book ratio (P/B ratio), and gross profit margin. Through correlation analysis, multiple regression analysis, and curve fitting, the study finds that: fixed asset growth rate, P/B ratio, and gross profit margin show a significant positive correlation with stock price; return on equity (ROE), operating income, and accounts receivable turnover days show a significant negative correlation with stock price; earnings per share (EPS) and net profit growth rate do not show a significant correlation with stock price. The research results indicate that the stock price of Bengang Steel Plates Co. Ltd. is greatly affected by its asset scale and market valuation, while some profitability indicators have not been effectively transmitted to the stock price. Finally, countermeasures and suggestions are put forward from the aspects of cost control, technological innovation, market expansion, and financial structure optimization, so as to provide references for corporate operation and investment decisions.

Keywords: Bengang Steel Plates Co. Ltd.; Financial indicators; Stock price impact

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1. Introduction

The steel industry occupies a pivotal position in China's industrial sector. Studying the relationship between Bengang Steel Plates Co. Ltd.'s (hereinafter referred to as "Bengang Steel Plates") stock price and its financial information, conducting an in-depth analysis of key financial indicators, understanding the underlying economic implications and market logic, and revealing the enterprise's operational status, profitability, solvency, and future development potential, all while using financial analysis tools to predict fluctuations in the company's stock price,

can help investors seize investment opportunities amid stock market volatility.

This research also provides references for enterprises to gain insights and make precise decisions in the complex and ever-changing market environment, thereby contributing to the development of the hometown.

2. Methodology

2.1. Data selection

The sample data in this paper are obtained from the financial indicators and closing price information of Bengang Steel Plates on the Sina Finance platform. For the case analysis, financial indicators within the time span from 2004 to 2023 are selected as the research objects, and all data are summarized on an annual basis. Since the adopted data are entirely derived from the annual reports publicly disclosed by the listed company, the consistency of statistical standards is ensured, thereby enhancing the comparability of the data. In the data processing stage, this paper mainly relies on SPSS 26 software to conduct scientific and standardized processing of the above indicator data.

With fundamental analysis as the core, a comprehensive evaluation is systematically carried out from three dimensions: profitability, development capability, and operating capability.

To ensure the comprehensiveness and accuracy of the analysis, the DuPont Analysis and Wall Score Method are selected as the analytical methods. Combined with the research results of relevant scholars, nine key financial indicators are further identified, including fixed asset growth rate, price-to-earnings ratio (P/E ratio), net profit margin on sales, EPS, gross profit margin, operating income, net profit growth rate, inventory turnover rate, and accounts receivable turnover days.

Through a comprehensive analysis of these indicators, this paper strives to fully and objectively reveal the enterprise's financial status and operating performance.

2.2. Research hypotheses

Through literature research, this paper finds that with the continuous maturity of the market and the increasing improvement of the securities regulatory system, the role of financial information in stock returns has become increasingly prominent ^[1]. In this context, if there are no significant differences in control variables such as policy factors and macroeconomic environment, the financial status of listed companies will have a significant impact on their stock returns ^[2,3].

To further explore the intrinsic connection and degree of influence between different financial indicators of listed companies and stock price trends, this paper proposes the following nine hypotheses based on the implications of the indicators and existing research on the relationship between relevant indicators and corporate performance:

- (1) H10: There is no positive impact relationship between the fixed asset growth rate (financial indicator) and stock price;
H11: The fixed asset growth rate (financial indicator) has a positive impact on stock price.
- (2) H20: There is no positive impact relationship between the price-to-book ratio (P/B ratio, financial indicator) and stock price;
H21: The price-to-book ratio (P/B ratio, financial indicator) has a positive impact on stock price;
- (3) H30: There is no positive impact relationship between the return on equity (ROE, financial indicator) and

- stock price;
- H31: The return on equity (ROE, financial indicator) has a positive impact on stock price;
- (4) H40: There is no positive impact relationship between earnings per share (EPS, financial indicator) and stock price;
- H41: Earnings per share (EPS, financial indicator) has a positive impact on stock price;
- (5) H50: There is no positive impact relationship between the gross profit margin (financial indicator) and stock price;
- H51: The gross profit margin (financial indicator) has a positive impact on stock price;
- (6) H60: There is no positive impact relationship between operating income (financial indicator) and stock price;
- H61: Operating income (financial indicator) has a positive impact on stock price;
- (7) H70: There is no positive impact relationship between the net profit growth rate (financial indicator) and stock price;
- H71: The net profit growth rate (financial indicator) has a positive impact on stock price;
- (8) H80: There is no positive impact relationship between the inventory turnover rate (financial indicator) and stock price;
- H81: The inventory turnover rate (financial indicator) has a positive impact on stock price;
- (9) H90: There is no positive impact relationship between accounts receivable turnover days (financial indicator) and stock price;
- H91: Accounts receivable turnover days (financial indicator) has a positive impact on stock price.

2.3. Data analysis process

2.3.1. Correlation analysis

This study uses SPSS 26 software to conduct an in-depth analysis of the data and explores the correlation between various indicators and stock price through the Pearson test.

The test and analysis show that three indicators of Bengang Steel Plates: fixed asset growth rate, P/B ratio, and gross profit margin exhibit a significant positive correlation with stock price. At the same time, three other indicators: ROE, operating income, and accounts receivable turnover days show a significant negative correlation with stock price.

However, it is worth noting that the significance levels of net profit growth rate and EPS are higher than 0.05, so they do not show an obvious correlation with stock price. Finally, the inventory turnover rate is correlated with stock price, but the degree of correlation is relatively low, resulting in a minimal impact on stock price.

2.3.2. Multiple regression analysis

The goodness of fit of the model is 0.872, indicating that the sample representativeness is generally good. The adjusted R^2 value is 0.867, which also shows that the model has a good goodness of fit. The Durbin-Watson value is 1.917, which is close to 2. This usually means that the residuals are randomly distributed and do not show obvious autocorrelation. Therefore, the model residuals follow a normal distribution, and the explanatory power of the model is strong.

Five out of the seven financial indicators are included in the multiple regression model. Among these five indicators, fixed asset growth rate, ROE, inventory turnover rate, operating income, and accounts receivable

turnover days show a significant correlation with stock price. The formula is as follows:

$$Y \text{ (Closing Price)} = 3.423X \text{ (Fixed Asset Growth Rate)} - 3.352X \text{ (ROE)} - 3.325X \text{ (Operating Income)} + 0.921X \text{ (Inventory Turnover Rate)} - 2.669X \text{ (Accounts Receivable Turnover Days)} (3-6)$$

Specifically, there is a significant positive correlation between fixed asset growth rate and stock price. This means that as the fixed assets of Bengang Steel Plates continue to appreciate, positive signals are released, and the stock price is driven by scale. Thus, the stock price will show a synchronous upward trend. This finding reflects the positive impact of fixed asset growth on the company's stock price and demonstrates the market's recognition of the company's asset appreciation.

However, three indicators: ROE, operating income, and accounts receivable turnover days exhibit a significant negative correlation with stock price. This indicates that as these indicators change, the stock price will show an opposite trend. These negative correlations reflect that the enterprise drives its stock price not through its core strength but through scale expansion, reminding investors to consider multiple factors comprehensively when paying attention to the company's financial status.

2.3.3. Curve analysis

In the regression analysis, in addition to the variables already included in the model, there are two variables that are significant but not included. These two variables are the P/B ratio and gross profit margin, which reflect Bengang Steel Plates' market performance and operating efficiency. The P/B ratio represents the relationship between the market value and book value of the company's stock, and it is one of the important indicators for investors to judge whether a company is undervalued or overvalued. The gross profit margin, on the other hand, reflects the company's profitability in the production or sales process and indicates the effectiveness of the company's cost control and pricing strategies.

The P/B ratio curve of Bengang Steel Plates shows different influence trends in different ranges. Specifically, when the P/B ratio is in the range of 0.5 to 1.5, its impact on the company is relatively significant. This means that within this range, small changes in the P/B ratio will significantly affect the company's stock price. However, when the P/B ratio enters the range of 1.5 to 2.5, its impact becomes moderate. Within this range, the increase or decrease in the P/B ratio will have a relatively small impact on the company's performance.

The gross profit margin curve of Bengang Steel Plates shows different influence characteristics in different ranges. Specifically, when the gross profit margin is in the range of 0% to 60%, its impact on the stock price is relatively moderate. However, when the gross profit margin rises from 60% to 105%, its impact begins to become significant. This means that the increase in the gross profit margin has a more positive driving effect on the overall stock price of Bengang Steel Plates.

2.3.4 Analysis of research results

Table 1. Verification results of assumed relationships for this steel plate

Hypothesis	Result
H11: The fixed asset growth rate (financial indicator) has a positive impact on stock price	Supported
H21: The price-to-book ratio (P/B ratio, financial indicator) has a positive impact on stock price	Supported
H30: There is no positive impact relationship between the return on equity (ROE, financial indicator) and stock price	Supported
H40: There is no positive impact relationship between earnings per share (EPS, financial indicator) and stock price	Supported
H51: The gross profit margin (financial indicator) has a positive impact on stock price	Supported
H60: There is no positive impact relationship between operating income (financial indicator) and stock price	Supported
H70: There is no positive impact relationship between the net profit growth rate and stock price	Supported
H80: There is no positive impact relationship between the inventory turnover rate and stock price	Supported
H90: There is no positive impact relationship between accounts receivable turnover days and stock price	Supported

The verification results of H11 clearly reveal a positive correlation between stock price and the fixed asset growth rate of Benxi Iron and Steel Plate Co. Ltd.

Similarly, the verification results of H21 also indicate a positive correlation between stock price and the P/B ratio of the company. Furthermore, the verification results of H51 demonstrate a positive correlation between the gross profit margin of Benxi Iron and Steel Plate Co. Ltd. and its stock price.

This finding suggests that when investors pay attention to the fundamentals of Benxi Iron and Steel Plate Co. Ltd., they are placing increasing emphasis on the impact of the company's profitability on its stock price. As a crucial indicator for measuring a company's profitability, an increase in gross profit margin is often capable of attracting more investors' attention, thereby driving up the stock price. Therefore, for investors, closely monitoring changes in the gross profit margin of Benxi Iron and Steel Plate Co. Ltd. will help them better seize investment opportunities.

3. Conclusion: Policy recommendations

Investors base their decisions on in-depth analysis and rational investment, aiming to pursue steady returns. In their considerations, a company's profitability has always been a key focus. It not only serves as a critical indicator for evaluating a company's comprehensive competitiveness but also constitutes an important factor determining investment value. Therefore, for enterprises like Benxi Iron and Steel Plate Co. Ltd., continuously enhancing their own profitability is undoubtedly a core mission in daily operations.

Benxi Iron and Steel Plate Co. Ltd. should improve its profitability through refined cost control. By implementing a series of measures such as optimizing production processes, reducing raw material procurement costs, and enhancing equipment utilization efficiency, the enterprise can effectively reduce production costs, thereby expanding profit margins. In addition, the enterprise should also attach importance to technological innovation, increase R&D investment, and continuously launch new high-value-added products to further strengthen its profitability.

In terms of market expansion, Benxi Iron and Steel Plate Co. Ltd. also has the potential to improve profitability. The enterprise should actively explore overseas markets and establish long-term and stable strategic cooperative relationships with well-known international iron and steel enterprises. Through diversified marketing

activities such as participating in international exhibitions and holding product promotion conferences, it can continuously enhance brand awareness and market influence, thus laying a solid foundation for improving profitability.

In terms of financial management, Benxi Iron and Steel Plate Co. Ltd. can take measures to strengthen internal controls to achieve an appropriate P/B ratio. This not only helps ensure the accuracy and reliability of financial information but also provides investors with a clearer financial perspective, thereby guiding them to make more informed investment decisions.

The rational allocation of debt and equity financing is an important means to reduce financial risks and improve a company's debt-servicing capacity and credit rating. Benxi Iron and Steel Plate Co. Ltd. can formulate a reasonable financing strategy based on the company's operating conditions and market environment. In terms of debt financing, the company can raise funds by issuing bonds, obtaining bank loans, and other methods; however, it should pay attention to controlling the scale of debt and debt costs to avoid excessive borrowing that may increase financial risks. In terms of equity financing, the company can attract investors by issuing new shares, implementing equity incentives, and other approaches to enhance its capital strength.

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Strategies for Enhancing the Competitiveness of Retail Chain Pharmacies in China in the Era of Pharmaceutical E-Commerce

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Abstract: With the rapid growth of the “Internet + Healthcare” model, pharmaceutical e-commerce has swiftly gained a substantial market share in China’s pharmaceutical retail sector, thanks to its competitive prices, convenient purchasing channels, and online consultation services. This has put considerable pressure on traditional retail chain pharmacies. This paper provides an overview of the current state of pharmaceutical e-commerce, and analyzes the main challenges faced by retail chain pharmacies, including intense price competition, changes in consumer habits, insufficient digitalization and severe homogenized competition. Drawing on industry practices and case studies, the paper proposes strategies to enhance competitiveness, such as promoting digital transformation and online-offline (O2O) integration, strengthening pharmacist services and health management capabilities, optimizing supply chain management, building differentiated brand advantages, and proactively responding to policy and regulatory requirements. The study argues that, while leveraging their advantages in specialization, community-based operations, service orientation and retail chain pharmacies, should actively embrace digitalization and industrial collaboration in order to achieve sustainable development in the context of e-commerce. This research provides theoretical references for the strategic transformation of retail chain pharmacies and offers practical significance for the high-quality development of the pharmaceutical retail industry.

Keywords: Competitiveness; Digital transformation; Pharmaceutical e-commerce; Retail chain pharmacies; Strategic pathways

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1. Introduction

In recent years, the “Internet + Healthcare” strategy has advanced further and the policy environment for pharmaceutical e-commerce has gradually become more relaxed. These changes have led to profound transformations in China’s pharmaceutical retail industry. Platforms such as AliHealth, JD Health and Ping An Good Doctor have rapidly attracted large numbers of consumers by offering competitive prices, convenient

purchasing channels and a range of health services, resulting in the continuous growth of the e-commerce market.

According to public data, the market size of pharmaceutical e-commerce in China exceeded hundreds of billions of Chinese Yuan by 2023 and continues to grow steadily. This trend has not only transformed residents' drug-purchasing habits, but also put traditional retail chain pharmacies under considerable pressure.

Against the backdrop of intensifying competition, retail chain pharmacies are facing multiple challenges. On the one hand, e-commerce platforms use large-scale procurement and internet technology to reduce sales costs significantly, leading to increasingly fierce price competition. On the other hand, consumers have gradually become accustomed to an integrated "drug purchase + consultation" experience through online channels, resulting in a continuous diversion of foot traffic from traditional pharmacies.

At the same time, retail chain pharmacies generally suffer from shortcomings in digital infrastructure, supply chain integration and service innovation, resulting in serious competition and insufficient overall competitiveness. Without timely strategic adjustments, the survival space of traditional pharmacies will be further compressed. However, e-commerce does not only pose a threat; it also creates new opportunities for the transformation and modernisation of retail chain pharmacies.

As important community-based health service providers, pharmacies have unique strengths in offline channels, pharmacist services and doctor-patient interaction that cannot easily be replicated by e-commerce platforms in the short term. Achieving online-offline (O2O) integration through digital empowerment, enhancing the professional value and service capacity of pharmacists, and building differentiated brand advantages through supply chain optimisation and brand development have become urgent issues for retail chain pharmacies.

In this context, this paper uses the impact of pharmaceutical e-commerce as its research background. It provides a systematic review of the sector's development trends, analyses the competitive pressures and practical dilemmas faced by retail chain pharmacies, and explores strategic pathways for enhancing competitiveness through case studies. The aim is to provide a reference for the digital transformation and strategic upgrading of retail chain pharmacies, offering theoretical and practical value in promoting the high-quality development of China's pharmaceutical retail industry.

2. The development of pharmaceutical e-commerce and the impact on retail chain pharmacies

2.1. The development status of pharmaceutical e-commerce in China

In recent years, the maturity of internet technology and national policy support have driven the rapid development of pharmaceutical e-commerce in China. Since the State Council issued the 'Opinions on Promoting the Development of the Health Service Industry' in 2014, the sector has gradually gained regulatory flexibility, particularly as the National Medical Products Administration has explored ways to sell prescription drugs online, creating favourable conditions for industry growth.

After 2020, the 'Internet + Healthcare' policy, coupled with the catalyst of the pandemic, drove a surge in demand for online drug purchases, significantly increasing the penetration rate of pharmaceutical e-commerce^[1]. According to data from iiMedia Research and the National Health Commission, the market size of pharmaceutical e-commerce in China exceeded 300 billion Chinese Yuan in 2023, with projections indicating continued double-digit growth over the next three years.

In terms of market structure, leading platforms such as AliHealth, JD Health and Ping An Health hold

significant market shares and are expanding beyond single drug retailing to offer integrated services, including “drug purchase + consultation + chronic disease management + health insurance”. Meanwhile, some traditional retail chain pharmacies have begun to establish their own online platforms or collaborate with internet companies to explore O2O models, thereby enhancing market coverage and customer loyalty ^[2].

As shown in **Table 1**, the development of pharmaceutical e-commerce in China is characterised by an increasingly relaxed policy environment, rapid market growth, growing industry concentration and expanding service boundaries. This makes it an indispensable part of the pharmaceutical retail industry.

Table 1. Development of China’s pharmaceutical e-commerce market and major platforms (2019–2023)

Year	Market size (100 million RMB)	Annual growth rate	Industry penetration (share of total retail sales)	Major platforms & market share (approx.)
2019	1350	18%	3.8%	AliHealth 28%, JD Health 24%, Ping An Health 10%
2020	1850	37%	5.5%	AliHealth 30%, JD Health 25%, Ping An Health 12%
2021	2300	24%	6.7%	AliHealth 29%, JD Health 27%, Ping An Health 13%
2022	2700	17%	7.3%	AliHealth 28%, JD Health 28%, Ping An Health 14%
2023	3100+	15%	8.1%	AliHealth 27%, JD Health 29%, Ping An Health 15%

3. The current situation and problems of the competitiveness of retail chain pharmacies in China

3.1. The development status of retail chain pharmacies in China

In recent years, the number of retail chain pharmacies in China has continued to grow, and the industry has become more concentrated. According to statistics from the China Association of Pharmaceutical Commerce, the total number of retail chain pharmacies nationwide exceeded 600,000 by 2023.

Leading enterprises such as China National Pharmaceutical Group (Guoda Pharmacy), LBX Pharmacy, Yifeng Pharmacy and Dashenlin have expanded rapidly, increasing their nationwide presence. The CR5 (the market share of the top five chain enterprises) has exceeded 30%, indicating a trend towards large-scale development. At the same time, continuous efforts have been made at the national level to promote compliance and professional management in the circulation of medicines. This has led to improvements in drug quality assurance and the allocation of licensed pharmacists in retail chains ^[3]. Some large chain enterprises have also begun experimenting with cooperating with internet platforms, exploring “online ordering, offline delivery” O2O models to cope with competition from e-commerce.

Overall, as shown in **Table 2**, retail chain pharmacies in China have certain advantages in terms of channel coverage, brand influence and pharmacist resources. They have become an integral component of the pharmaceutical retail sector, playing a distinctive role in areas such as chronic disease management and community health services ^[4].

Table 2. Scale of China's retail chain pharmacies and leading enterprises (2023)

Indicator	Data/Status
Total number of retail chain pharmacies nationwide	Over 600,000
Industry concentration (CR5)	Over 30%
Major leading enterprises	Guoda Pharmacy, LBX Pharmacy, Yifeng Pharmacy, Dashenlin, Jianzhijia
Number of Guoda Pharmacy outlets	10,000+
Number of LBX Pharmacy outlets	9,000+
Number of Yifeng Pharmacy outlets	7,000+
Number of Dashenlin outlets	6,500+
Industry development trends	Rapid channel expansion, accelerated digital exploration, gradual promotion of O2O models

3.2. Major problems at the current stage

Although retail chain pharmacies continue to expand in size, they remain insufficiently competitive in the face of e-commerce, as reflected in several areas as outlined:

- (1) Their level of digitalisation is relatively low. Most pharmacies are behind the times when it comes to building information systems, managing member data and applying intelligent marketing tools. They have yet to develop mature digital operating models, which makes it difficult for them to compete with the data-driven, precise marketing strategies employed by pharmaceutical e-commerce platforms ^[5];
- (2) Their supply chain integration capabilities are inadequate. Compared with e-commerce platforms, retail chain pharmacies generally have weaknesses in terms of procurement bargaining power, logistics efficiency and inventory management. This results in relatively high drug costs and low circulation efficiency, which constrains both price competitiveness and the customer experience;
- (3) Service capabilities need improvement. Although pharmacies have an advantage in terms of professional pharmacist services, these functions are often weakened in practice, with the focus remaining mainly on 'selling drugs' rather than extending to health management, chronic disease intervention and personalised medication guidance ^[6]. This makes it difficult to build long-term customer loyalty. In addition, there is serious homogenised competition within the industry. Most pharmacies offer similar products, use similar promotional methods and have similar store layouts, lacking distinctive value propositions or brand personalities. Consequently, consumers often base their choices primarily on price, which further intensifies low-level competition;
- (4) Adaptation to policies and regulations is insufficient ^[7]. The pharmaceutical retail industry is greatly affected by policy. Changes such as the sale of prescription drugs online and the inclusion of retail pharmacies in medical insurance settlement systems can have a direct impact on business models. Some chain pharmacies still demonstrate shortcomings in terms of compliance management, medical insurance settlement and drug traceability systems. This undermines their capacity for sustainable development.

In summary, while retail chain pharmacies in China have certain advantages in terms of scale and channels, they still suffer from significant deficiencies in digital transformation, supply chain efficiency, service specialisation and differentiated competition. These issues leave them relatively passive in the face of pharmaceutical e-commerce and highlight the urgent need for transformation and upgrading ^[8].

4. Strategic pathways for enhancing competitiveness

Retail chains should empower licensed pharmacists by expanding their remit beyond drug dispensing to include chronic disease management, health consultations, rehabilitation guidance and other value-added services. This would gradually enable pharmacies to evolve into community health service centres ^[9].

By organising health seminars, offering personalised pharmaceutical guidance and conducting regular follow-ups, pharmacies can increase patient trust and loyalty, thereby creating service barriers that distinguish them from e-commerce platforms. Furthermore, supply chain optimisation and industrial collaboration are important ways of enhancing competitiveness. Traditional pharmacies generally have weak bargaining power in procurement and low logistics efficiency, resulting in less competitive drug prices and slower circulation. Therefore, chain pharmacies should reduce costs by centralising procurement, sourcing directly, and establishing regional logistics centres. At the same time, they should promote the development of intelligent warehousing and cold-chain systems to ensure the safe and timely distribution of drugs.

At an industry level, pharmacies could collaborate with hospitals and internet healthcare platforms to create integrated ‘diagnosis-purchase-follow-up’ health management ecosystems. This would enable them to share resources, complement each other’s value, and enhance their overall service capacity and industry standing. Meanwhile, brand building and differentiated competition are crucial strategies for overcoming homogenisation.

As most pharmacies in the industry have similar product assortments and promotional approaches, which can lead to price wars, pharmacies must develop unique brand identities and distinctive services to stand out from the competition ^[10]. For example, they could position themselves as ‘chronic disease management pharmacies’ or ‘elderly health specialty pharmacies’ to meet the needs of specific segments of the population.

Additionally, public welfare activities, corporate social responsibility initiatives and community engagement can strengthen brand recognition and consumer trust. Finally, in the face of increasingly strict policies and regulations, pharmacies must proactively improve compliance as a baseline requirement, building on a foundation of drug safety and quality management. Pharmacies should fully implement drug traceability systems and licensed pharmacist coverage to ensure safety and reliability throughout the sales and usage process.

On the other hand, they should align with electronic medical insurance vouchers and internet-based reimbursement systems to improve consumer access to medical insurance settlements and enhance the purchasing experience. At the same time, they should establish cooperative channels with medical institutions to expand the prescription drug market and seize policy opportunities, such as the trend of ‘prescription outflow’.

It is foreseeable that retail chain pharmacies can only effectively enhance their competitiveness under the impact of pharmaceutical e-commerce and establish sustainable strategic support for long-term development by simultaneously advancing digital transformation, service innovation, supply chain integration, brand development, and regulatory compliance.

5. Case analysis

In order to further validate and enrich the strategic pathways for enhancing competitiveness that were proposed earlier, this paper selects two representative enterprises from among China’s retail chain pharmacies, LBX Pharmacy (Laobaixing) and Yifeng Pharmacy to examine their recent transformation practices. It explores how they have responded to the impact of pharmaceutical e-commerce, and it draws insights from their experiences.

5.1. LBX pharmacy: Diversified layout and digital transformation

As one of China's leading pharmacy retail chains, LBX Pharmacy has actively promoted digitalisation in recent years. The company has established its own "LBX Online Mall" and joined platforms such as JD Daojia and Meituan Pharmacy, achieving online-offline channel integration and meeting consumer demand for "immediate delivery". In terms of supply chain management, LBX Pharmacy has reduced operating costs and improved distribution efficiency through centralised procurement and the construction of regional logistics centres.

In addition, LBX Pharmacy is emphasising the extension of its professional services by setting up 'chronic disease management zones' that provide added-value services such as blood sugar and blood pressure monitoring, as well as health consultations. This enhances customer loyalty. To build its brand, the company leverages public welfare activities and community health lectures to enhance its social image and create competitive advantages. This case study shows that digitalisation and enhanced service capacity are effective ways for retail chain pharmacies to strengthen their competitiveness in the face of e-commerce.

5.2. Yifeng pharmacy: Regional focus and differentiated services

Yifeng Pharmacy's development strategy places greater emphasis on a regional focus and differentiated positioning. The company has established a strong network of stores in central and eastern China, enhancing customer loyalty through membership-based operations. In terms of digitalisation, Yifeng has developed an intelligent management system that integrates procurement, inventory and sales. It has also promoted personalised marketing and health management services by analysing member data.

In terms of service models, Yifeng Pharmacy emphasises the value of pharmacists by launching "Pharmacist-to-Home" services, which provide drug delivery and medication guidance for elderly patients and those with chronic conditions. At the same time, Yifeng has introduced the "Yifeng Health +" platform, which integrates health consultations, drug deliveries and membership services to create a comprehensive, differentiated service system.

This case study demonstrates how retail chain pharmacies can establish unique characteristics in e-commerce competition by leveraging regional advantages, strengthening service innovation and deepening membership operations.

5.3. Case insights

An analysis of LBX Pharmacy and Yifeng Pharmacy reveals that they have undergone similar transformations in response to the impact of e-commerce as listed below:

- (1) Both companies prioritise digital transformation, utilising online platforms to extend the scope of their services;
- (2) They both strengthen pharmacist services and health management, thereby highlighting the irreplaceable value of offline professional services;
- (3) They both continuously invest in supply chain integration and brand building to create cost advantages and achieve competitive differentiation.

These experiences demonstrate that retail chain pharmacies are not merely "vulnerable groups" in the context of e-commerce. Instead, they can explore development pathways suited to their own circumstances through strategic adjustments and business model innovation. This allows them to achieve differentiated competition and even complementary collaboration with pharmaceutical e-commerce.

6. Countermeasures and recommendations

Under the continuous impact of pharmaceutical e-commerce, retail chain pharmacies in China must overcome current challenges and achieve sustainable development by coordinating efforts across the industry, enterprises and policymakers to drive transformation and upgrading. At the industry level, promoting standardisation and digitalisation is an inevitable trend. The current pharmaceutical retail market suffers from incomplete drug traceability systems, inconsistent service standards and uneven digitalisation.

Industry associations and regulatory authorities must provide stronger guidance, promote the creation of unified standards for pharmaceutical distribution and pharmacy services, and speed up the development of comprehensive digital traceability systems to ensure the safety and quality of drugs. Building industry-wide data-sharing platforms and promoting interconnectivity between pharmacies can improve supply chain efficiency, share resources, and foster collaborative development within the industry, thereby creating a favourable ecosystem for digital transformation.

At the enterprise level, developing unique competitive advantages is crucial for retail chain pharmacies to overcome e-commerce challenges. On the one hand, chain pharmacies should actively promote the integration of online and offline services by developing their own platforms or collaborating with internet companies to create more extensive and convenient O2O models that meet the diverse needs of consumers. Conversely, they should empower licensed pharmacists by expanding their services beyond traditional drug guidance to include chronic disease management, rehabilitation follow-up and health consultations. This will gradually transform pharmacies into community health service centres, enhancing customer loyalty.

At the same time, enterprises should focus on supply chain integration and cost control by enhancing centralised procurement capabilities and establishing intelligent warehousing and cold-chain logistics systems. This will narrow the gap with e-commerce in terms of price and efficiency. In terms of brand building, retail chain pharmacies should avoid engaging in pure price competition. Instead, they should create a differentiated position and offer innovative services. For example, they could specialise in chronic disease management or elderly health services to meet the needs of specific market segments.

Public welfare activities, corporate social responsibility and community engagement can also enhance brand influence and customer trust. At the policy and regulatory level, the government should create a more flexible and favourable environment for the transformation and development of retail pharmacies while ensuring drug safety. The medical insurance settlement system should be improved and the full application of electronic medical insurance vouchers in retail pharmacies promoted to lower consumers' purchasing thresholds and enhance pharmacies' attractiveness. Restrictions on online prescription drug sales should be relaxed to enable pharmacies to expand their prescription drug market share through integration with internet healthcare. Meanwhile, the government should introduce targeted support policies to encourage retail chain pharmacies to pilot digital transformation projects and explore innovations in smart supply chains, intelligent marketing and health services. Tax incentives or financial subsidies could be provided to reduce transformation costs.

In terms of regulation, the quality of drugs and the services provided by pharmacists should be supervised more strictly to ensure the healthy and orderly development of the industry. This would provide institutional guarantees for the transformation and upgrading of retail chain pharmacies. In conclusion, enhancing the competitiveness of retail chain pharmacies in China depends not only on internal reform and innovation, but also on industry-wide standardisation and supportive policy frameworks.

Only by advancing along multiple pathways: digitalisation, service innovation, differentiation and compliance,

can retail chain pharmacies establish new competitive advantages in the face of the dual pressures of the impact of e-commerce and industry transformation, ultimately achieving high-quality, sustainable development.

7. Conclusions

The rapid development of pharmaceutical e-commerce is profoundly reshaping China's pharmaceutical retail landscape, impacting retail chain pharmacies in multiple ways, including price, channels and services. This paper analyses the current state of pharmaceutical e-commerce and the problems faced by chain pharmacies. It also presents representative cases and proposes pathways for enhancing competitiveness. These include taking digital transformation as the core driver, providing professionalised services as a competitive barrier, optimising the supply chain and building the brand as differentiation strategies, and managing compliance and securing policy support as guarantees. The study shows that retail chain pharmacies are not simply weak players in the face of e-commerce; rather, they can achieve online–offline integration and create unique value through proactive transformation, thereby securing a position in the competitive landscape. Looking ahead, as digital technologies become more widely applied and regulatory frameworks improve, the relationship between retail chain pharmacies and pharmaceutical e-commerce is expected to evolve towards complementarity and collaboration. This will promote the high-quality development of the pharmaceutical retail industry.

Disclosure statement

The authors declare no conflict of interest.

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Research on the Sustainable Development of Event Tourism in Luoyang from the Perspective of Sports-Tourism Integration

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Abstract: As a renowned historical and cultural city, Luoyang boasts a wealth of tourism resources, including sports venues, natural landscapes, and cultural heritage sites, laying a solid foundation for the integrated development of the tourism industry and sports events in recent years, with remarkable achievements in practice. However, from the perspective of sports-tourism integration, Luoyang's event tourism still faces a prominent issue of uneven development: a surge in tourists during peak seasons, leading to overcrowded attractions, and a scarcity of visitors during off-peak seasons, resulting in idle resources. This not only leads to inefficient resource utilization but also restricts the enhancement of economic benefits and hinders sustainable development. In light of this, this paper comprehensively employs literature research, case analysis, and fieldwork methods to systematically analyze the current development status of event tourism in Luoyang within the context of sports-tourism integration. The aim is to provide theoretical and practical support for achieving high-quality and balanced development of local event tourism, offering valuable references for addressing the issue of uneven development and moving towards a sustainable future.

Keywords: Event tourism; Luoyang; Sports-tourism integration; Sustainable development

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1. Introduction

1.1. Research background

In recent years, the global sports tourism market has shown a vigorous development trend, with a growing variety of products such as sports event tourism, outdoor sports tourism, and sports-themed vacations, attracting a large number of tourists. In China, sports tourism has also received strong support from national policies. The "Several Opinions of the State Council on Accelerating the Development of the Sports Industry and Promoting Sports

Consumption” explicitly proposes to vigorously develop sports tourism and create influential sports tourism boutique routes and events. Leveraging its resource base and policy support, Luoyang has witnessed thriving development in event tourism.

However, compared with some advanced event tourism destinations at home and abroad, Luoyang’s event tourism still faces some problems and challenges during its development, such as insufficient brand influence of events, inadequate tourism support services, and insufficient integration of events and tourism.

1.2. Research objectives

The primary objective of this study is to comprehensively analyze the current development status of event tourism in Luoyang. Specifically, this includes the following aspects:

- (1) To sort out the development history of event tourism in Luoyang, analyze the basic conditions of current event tourism, such as types, scales, and participant demographics, and understand its position and role in the tourism market;
- (2) To conduct an in-depth analysis of the problems and causes in the development of event tourism in Luoyang from multiple dimensions, including event brand building, tourism support facilities, the degree of integration between events and tourism, and marketing;
- (3) To draw on the experiences of successful event tourism cases at home and abroad, and, in combination with the actual situation in Luoyang, propose innovative strategies and recommendations suitable for the development of event tourism in Luoyang;
- (4) To provide theoretical support and practical guidance for the sustainable development of event tourism in Luoyang, helping Luoyang become an event tourism destination with international influence.

1.3. Literature review

Scholars both domestically and abroad have conducted in-depth research on issues related to the development of the event tourism industry, which can be broadly categorized into four main areas: market development of the event tourism industry in Luoyang, as well as the relationships between event tourism and residents, culture, and industry. Among these, literature research on the relationship between event tourism and residents accounts for the largest proportion, while there is relatively little research on the regional event tourism industry in Luoyang.

From the perspective of market development in Luoyang’s event tourism industry, scholars such as Sun et al. conducted relevant research in 2021 using SWOT analysis to examine the development of the sports tourism industry in the Luoyang region. They provided a detailed analysis of its current status and future development issues, offering a comprehensive conceptual framework for the development of outdoor sports event tourism in Luoyang and proposing corresponding development recommendations^[1].

Regarding research on the relationship between event tourism and residents and participants, scholars such as Zhou et al. took marathons as an example in 2023, collecting data through interviews and using grounded theory to analyze the liminal experiences of participants in mass sports events. They found that the liminal experience of marathon participants is a growth process that includes anticipation, release, inversion, transcendence, and self-breakthrough^[2]. This enriches the research content of liminal theory and reveals the experience construction mechanism of participants.

In 2020, scholars such as Hu et al. studied the motivations and influencing factors of sports event tourists through questionnaires and statistical analysis. They found differences in motivations among tourists of

different genders, ages, education levels, and occupational statuses, and proposed corresponding development recommendations ^[3].

From the perspective of cultural integration and development in event tourism, in 2023, scholar Yu explored the role of experiential sports tourism in the inheritance of intangible cultural heritage of traditional ethnic sports. She proposed suggestions for establishing activity venues, cultivating talent, strengthening institutional construction, and increasing publicity ^[4].

From the perspectives of event tourism, industry, and value co-creation, scholars Wang and Wu studied the development status of China's sports event tourism industry in the context of all-for-one tourism in 2020. They pointed out issues such as inadequate industrial synergy systems and imperfect resource development systems, and proposed optimization paths such as platform optimization and resource optimization ^[5].

In summary, research by numerous scholars both domestically and internationally has covered multiple perspectives, including the relationships between event tourism industry and residents, culture, and industry, as well as various aspects such as sports tourism, event experiences, cultural heritage preservation, and event impact assessments. However, there is relatively little regional research on event tourism in Luoyang, particularly analyses concerning the balanced development of event tourism in Luoyang.

On one hand, Luoyang has been continuously increasing its efforts to develop the tourism industry in recent years, with event tourism experiencing rapid growth and exhibiting significant market potential. On the other hand, event tourism can also achieve integrated development with various industries such as culture, health, and agriculture, continuously promoting the expansion of emerging industry market sizes.

Therefore, this study on the sustainable development of Luoyang's event tourism industry contributes to promoting balanced development in the regional tourism industry.

2. Main text

2.1. Development status

2.1.1. Overview of Luoyang's tourism resources

In terms of natural tourism resources, Luoyang is characterized by its topography, which is higher in the west and lower in the east, with diverse landscapes featuring both mountains and waters. To the north lies Xiaolangdi, a benchmark for Yellow River management and a global challenge in water conservancy; to the south stands Baiyun Mountain, with 98.5% forest coverage, 37 peaks over 1,500 meters, and Yuhuangding Peak at 2,216 meters, the highest in Central China, offering a blend of sightseeing, summer retreat, scientific research, and exploration.

In terms of cultural heritage, Luoyang shines even brighter. The Longmen Grottoes represent the largest and most prolific stone carving treasure trove, hailed by UNESCO as the "pinnacle of Chinese stone carvings"; the White Horse Temple is China's first officially sponsored Buddhist temple, known as the "Ancestral Court" and the "Origin of Buddhism." Additionally, Luoyang boasts numerous historical and cultural relics such as the Sui and Tang Dynasties Luoyang City National Heritage Park, the Yingtian Gate Site Museum, and Guanlin, all of which are invaluable resources for developing event tourism in Luoyang.

2.1.2. Achievements in the development of sports event tourism

In recent years, Luoyang has achieved remarkable results in the development of sports event tourism. It has hosted large-scale comprehensive events such as the Henan Provincial Games and the UCI Junior Track Cycling World Championships, as well as professional events like the CBSA Ding Junhui vs. Ronnie O'Sullivan Masters and

the China National Track Cycling League. Additionally, there are mass events such as the “Luoyang Table Tennis King” tournament and the New Year’s Day Long-Distance Run and Half Marathon. The hosting of these events has attracted a large number of athletes, spectators, and tourists, laying a solid foundation for the development of sports event tourism in Luoyang.

Taking the 14th Henan Provincial Games in 2023 as an example, the opening ceremony was held at the Yingtianmen Gate Site of the Sui and Tang Dynasties Luoyang City. The unique venue selection and splendid cultural performances drew significant attention. During the event, the number of visitors to nearby attractions such as the Luoyi Ancient City increased substantially, leading to a notable rise in tourism revenue.

Through media coverage of these events, Luoyang’s city image and cultural characteristics have been widely disseminated. The CBSA Ding Junhui vs. Ronnie O’Sullivan Masters, held at the Longmen Grottoes Scenic Area, featuring two of the world’s top snooker players showcased their skills at this UNESCO World Heritage Site. This event attracted global media attention, showcasing the highlights and unique features of the Longmen Grottoes to a worldwide audience. It achieved a “two-way empowerment” and “mutual pursuit” between the event and cultural tourism, significantly enhancing Luoyang’s international visibility. More and more people have come to know Luoyang through these events, developing a strong interest in the city and being attracted to visit, further driving the development of sports event tourism in Luoyang.

2.1.3. Case analysis of sports event tourism

(a) The 14th Henan provincial games

In 2023, Luoyang hosted the 14th Henan Provincial Games, showcasing unique innovations in various aspects, particularly with the opening ceremony held at Yingtianmen Gate, which became a major highlight. Against the backdrop of the city and with historical sites as the stage, a dazzling “Ancient Capital Runway” was created, transforming the entry “ceremony” into an entry “into the city” ceremony. This transformed the millennia-old “major historical site” into a stylish and vibrant “reception hall,” presenting a carnival that vividly blends “sports events” with “cultural tourism and creativity.” Innovative use of new technologies such as 3D without glasses provided the audience with a realistic and stunning visual experience, creating a highly attractive light and shadow show that perfectly balanced atmosphere and ceremony.

During the opening ceremony, the online click-through rate exceeded 200 million. Through reports by major media outlets and dissemination on social media, Luoyang’s city image was widely promoted. In terms of tourism promotion, Yingtian Gate has become a popular tourist attraction in Luoyang. The tourism facilities around Yingtian Gate have also been further improved, with the catering, accommodation, shopping, and other service industries seizing development opportunities. Additionally, the hosting of the provincial games has driven the development of other tourist attractions in Luoyang, such as the Longmen Grottoes and the White Horse Temple, which have also seen an increase in visitor numbers, promoting the overall development of Luoyang’s tourism industry.

(b) CBSA Ding Junhui vs. Ronnie O’Sullivan masters match

In 2024, the CBSA Ding Junhui vs. Ronnie O’Sullivan masters match was held at the Longmen Grottoes scenic area in Luoyang, serving as a classic example of the “mutual empowerment” between sports events and cultural tourism. During the event, global media focused on the Longmen Grottoes, showcasing the scenic area’s magnificent scenery, rich history, and unique culture to audiences worldwide. Through television broadcasts, online live streams, and other means, the popularity of the Longmen Grottoes soared, attracting more attention

from domestic and international tourists. Many people who previously knew little about the Longmen Grottoes developed a keen interest because of this event and began planning visits.

From the perspective of enhancing tourism appeal, the hosting of the masters match brought a large number of tourists to the Longmen Grottoes scenic area. In addition to fans who came to watch the matches, many visitors were drawn by the unique atmosphere of the event's integration with culture. Besides watching the matches, they explored the Longmen Grottoes scenic area in depth, admiring the exquisite Buddha sculptures and learning about the historical and cultural background of the grottoes.

(c) New Year's day long-distance run and half marathon event

The New Year's day long-distance run and half marathon event, a key initiative in Luoyang, has become a widely influential sports event in the region. Taking the year 2025 as an example, this competition attracted over 15,000 runners from across the country, with more than half of them hailing from outside Luoyang. During the event, the organizing committee worked closely with local tourism departments and businesses in Luoyang to provide foreign runners with a rich tourism experience.

From the perspective of disseminating urban culture, the New Year's day long-distance run and half marathon event has provided an excellent platform for the promotion of Luoyang's urban culture. The event route was meticulously designed, passing by numerous iconic buildings and historical and cultural landmarks in Luoyang. Additionally, the event featured performances by local folk artists, such as dragon and lion dances and Heluo Grand Drum performances, allowing runners and spectators to appreciate the unique charm of Luoyang's traditional culture.

From the perspective of promoting the integrated development of sports and tourism, the New Year's day long-distance run and half marathon event has played a positive and exemplary role. By attracting tourists through the event, it has stimulated tourism consumption while enriching the event experience with tourism resources, achieving mutual promotion and common development between sports and tourism. During the event, Luoyang's hotel, catering, transportation, and other industries experienced a peak in consumption, contributing to the local economy. Tourism enterprises have also actively developed tourism products related to the event.

2.2. Research on development challenges

2.2.1. Inadequate product development

Currently, the types of event tourism products in Luoyang are relatively limited, primarily consisting of spectator and participatory event tourism products, lacking innovation and distinctiveness. In terms of spectator event tourism, most offerings involve watching traditional sports events such as basketball, football, and table tennis, with relatively conventional event formats and content that lacks innovative activities capable of attracting tourists' attention.

Among the participatory event tourism products, outdoor sports such as marathons and mountain climbing are the most common, leading to a severe problem of product homogenization. Many cities are hosting marathon events, and Luoyang's marathon event fails to stand out with differentiated competitive advantages in terms of product design and experience creation, making it difficult to meet the diverse needs of tourists. Meanwhile, for some emerging participatory event tourism projects, such as e-sports tourism and extreme sports tourism, Luoyang's development efforts are insufficient and fail to keep up with market trends.

2.2.2. Shallow integration depth

There is a lack of synergy in resource integration between events and tourism. Luoyang boasts abundant

tourism resources and conditions for hosting sports events. However, in actual development, communication and collaboration between the sports and tourism departments are not close enough, failing to form an effective resource integration mechanism. The organization and operation of sports events often focus solely on the events themselves, neglecting the integration with tourism resources and failing to fully consider how to leverage events to attract tourists and drive tourism consumption. On the other hand, when developing and promoting tourism products, the tourism department also fails to adequately plan and promote sports events as important tourist attractions.

In terms of service support, the integration of events and tourism is also inadequate. During event periods, tourists' demand for tourism services such as accommodation, dining, and transportation significantly increases. However, Luoyang currently has shortcomings in terms of service support for event tourism. Accommodation facilities around some event venues are insufficient, especially during peak tourist seasons and large-scale events, when hotels are in short supply and prices are excessively high, affecting tourist satisfaction. In terms of transportation, the connection between event venues and tourist attractions is not smooth enough, and public transportation capacity is insufficient, causing inconvenience for tourists.

2.2.3. Inadequate facilities and services

Luoyang's transportation infrastructure still faces some issues in the development of event tourism. Due to the influx of a large number of tourists attracted by events, the traffic volume on urban roads has surged, yet Luoyang's transportation network appears inadequate in handling such peak traffic flows.

In terms of accommodation, there is a certain gap in both quantity and quality of Luoyang's lodging facilities. During the event period, the sudden increase in tourist numbers has led to a significant rise in accommodation demand, which Luoyang's lodging facilities cannot fully meet, especially in terms of a relative shortage of mid-to-high-end accommodation resources. Regarding catering, although Luoyang boasts a rich culinary culture, the quality and distinctiveness of catering services have not been fully showcased in event tourism services. Catering venues around the event venues often primarily offer fast food and snacks, lacking the supply of main courses with local characteristics.

2.2.4. Limited brand influence

There are numerous issues in the brand construction of Luoyang's event tourism, resulting in low brand awareness and reputation. In terms of brand positioning, Luoyang's event tourism lacks a clear and unique brand identity.

Regarding brand communication, the promotion efforts for Luoyang's event tourism are insufficient, with limited communication channels and methods. Meanwhile, the content of event tourism brand communication lacks appeal and fails to fully demonstrate the unique charm and value of Luoyang's event tourism, making it difficult to stimulate tourists' interest and desire.

2.3. Analysis of balanced development strategies

2.3.1. Innovative development of event tourism products

Fully tapping into Luoyang's unique historical culture, natural landscapes, and folk customs, and developing themed event tourism products with local characteristics are key measures to promote the development of Luoyang's event tourism. Leveraging abundant cultural resources, the development of cultural experience-based event tourism products enables tourists to gain an in-depth understanding of Luoyang's historical culture while

participating in events.

An “Ancient Capital Cultural Marathon” could be organized, integrating marathon events with Luoyang’s historical and cultural landmarks. A unique race route could be designed, allowing runners to traverse the millennia-old ancient capital, experiencing the stone carving art of the Longmen Grottoes, the Buddhist culture of the White Horse Temple, and the architectural style of the Sui and Tang Dynasties Luoyang City, among other attractions. Meanwhile, cultural display points could be set up along the race route to showcase Luoyang’s traditional handicrafts and folk performances, enabling runners and spectators to immerse themselves in Luoyang’s cultural charm up close during their downtime. Additionally, a “Cultural Exploration Orienteering Race” could be introduced, using Luoyang’s historical and cultural sites as checkpoints. Participants would earn points and complete the race by fulfilling various culture-related tasks, such as answering questions about cultural relics and experiencing traditional crafts.

2.3.2. Deepening the integrated development of events and tourism

Strengthening the deep integration of events and tourism in terms of resources, industries, and markets is a crucial approach to enhancing the competitiveness of Luoyang’s event tourism. In terms of resource integration and collaboration, sports and tourism departments should establish close cooperation mechanisms, jointly formulate event tourism development plans, and integrate sports event resources with tourism resources to achieve resource sharing and complementary advantages.

When organizing sports events, full consideration should be given to the utilization of tourism resources, combining event venues with tourist attractions to create event tourism routes.

For instance, when hosting the “Luoyang Table Tennis King” competition, the venue could be set near the Longmen Grottoes, allowing participants and spectators to conveniently visit the grottoes after the event. Simultaneously, when developing tourism products, the tourism department should fully incorporate elements of sports events, launching event-related tourism packages such as “event viewing + scenic spot tours” and “event participation + tourism vacations” to meet the diverse needs of tourists. Furthermore, resources from event organizers, tourism enterprises, scenic spots, and other parties could be integrated to jointly plan and promote event tourism activities, forming a synergistic effort to enhance the influence of event tourism.

2.3.3. Improving the infrastructure and service system

Strengthening the construction of transportation facilities, improving the quality of accommodation and catering services, and optimizing event and tourism services are the foundations for enhancing the quality of event tourism in Luoyang. The improvement of infrastructure is crucial for the development of event tourism.

During the event period, in order to alleviate urban traffic congestion, Luoyang should strengthen traffic planning and management. Upgrade and renovate the main roads leading to event venues and tourist attractions, increase the number of lanes, improve road conditions, and reduce traffic congestion. Increase public transportation routes, especially those leading to event venues and tourist attractions, extend operating hours, and increase the frequency of departures to facilitate tourist travel. Additionally, Luoyang can increase investment in accommodation facilities to expand the supply of lodging, particularly mid-to-high-end accommodation resources. They can also encourage social capital to invest in the construction of star-rated hotels, boutique homestays, etc., to enhance the quality and service standards of accommodation facilities. Meanwhile, Luoyang should strengthen the management and supervision of accommodation facilities, standardize the order of the accommodation market,

and ensure the safety and hygiene of accommodation facilities. In terms of catering, explore and inherit Luoyang's food culture, and create catering brands with local characteristics by encourage catering enterprises to innovate dishes and introduce more delicacies that cater to tourists' tastes.

2.3.4. Strengthen brand building and marketing promotion

Luoyang should deeply explore its own historical and cultural heritage, natural scenery, and sports event characteristics to clarify the positioning of its event tourism brand. Combining Luoyang's city image as the "Millennium Ancient Capital, City of Peonies," position the event tourism brand as an "event tourism destination where historical culture and sports passion coexist," highlighting the unique charm of Luoyang's event tourism. Around this positioning, create an event tourism brand with differentiated competitive advantages by integrating historical and cultural elements into sports events.

In terms of traditional media, strengthen cooperation with newspapers, television, radio, and other media to place advertisements for the event tourism brand, report on event activities and tourism resources, and increase brand exposure. Advertisements for Luoyang's event tourism can be placed on media outlets such as China Central Television and Henan Television to showcase Luoyang's historical and cultural heritage, natural scenery, and exciting moments from sports events. In terms of new media, fully utilize social media, short video platforms, etc., for brand dissemination. Establish official Weibo, WeChat public accounts, Douyin accounts, etc., for Luoyang's event tourism, and regularly release event information, travel guides, exciting videos, and other content to attract user attention and interaction.

3. Conclusion

In summary, Luoyang's event tourism has achieved remarkable results under the dual support of resource endowment and policy-driven initiatives. However, deep-rooted structural contradictions still need to be resolved through systematic strategies. Therefore, this paper proposes the following paths to promote balanced development:

- (1) By strengthening the deep integration of events and tourism in terms of resources, industries, and markets, we aim to improve supporting services, coordinate promotional efforts, deepen the integrated development of events and tourism, and enhance the integration of sports and tourism;
- (2) We seek to improve transportation infrastructure, elevate the quality of accommodation and catering services, and optimize event and tourism services to provide visitors with a better travel experience;
- (3) By clarifying brand positioning, formulating communication strategies, and conducting marketing activities, we aim to strengthen brand building and marketing promotion, enhancing the visibility and influence of Luoyang's event tourism.

In the future, research on the development of Luoyang's event tourism can be expanded along three major dimensions:

- (1) Construction of a quantitative evaluation system through the establishment of a Sports-Tourism Integration Index (STII) to accurately measure the collaborative efficiency of sports and tourism through big data analysis of tourist sentiment.
- (2) Pathways for county-level collaborative development by exploring the model of "event attraction in core scenic areas, diversion and accommodation in surrounding counties" (e.g., outdoor events at Baiyun

Mountain driving tourism to health and wellness destinations in Ruyang County).

- (3) Dual-track research on technology and ethics by paying attention to the substitution effect of VR event experiences on physical tourism and establish ethical guidelines for digital participation in cultural heritage.

By applying these technologies in Luoyang's event tourism, we aim to explore how to leverage new technologies to enhance visitor experiences and innovate event tourism products and service models, thereby promoting high-quality and sustainable development of Luoyang's event tourism.

Disclosure statement

The authors declare no conflict of interest.

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Advances and Identification Challenges in Micro-Econometric Models of Firm Productivity

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Abstract: Firm-level productivity analysis serves as a cornerstone for understanding the micro-foundations of economic growth, industrial competitiveness, and efficient resource allocation. This comprehensive review synthesizes and critically evaluates the primary statistical and econometric methodologies employed in the measurement and analysis of productivity at the firm level. We systematically delineate the evolution from traditional parametric techniques, such as production function estimation and Stochastic Frontier Analysis (SFA), to non-parametric approaches, including Data Envelopment Analysis (DEA) and the Malmquist Productivity Index. A significant focus is placed on addressing pervasive micro-level challenges, notably firm heterogeneity, measurement error, and endogeneity biases, which are endemic to firm-level data. The paper further explores recent methodological innovations, highlighting the integration of machine learning, quantile regression, and network analysis into the productivity research arsenal. By providing a structured guide for selecting and applying appropriate statistical tools, this review aims to equip researchers with the knowledge to conduct robust micro-level productivity analyses. Finally, we outline promising future research trajectories, emphasizing the potential of novel data sources and computational methods to deepen our understanding of productivity determinants.

Key words: Efficiency analysis; Firm productivity; Microeconomics

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1. Introduction

The analysis of productivity at the level of the individual firm is indispensable for unpacking the black box of macroeconomic performance. While aggregate productivity figures illustrate broad economic trends, it is the microeconomic investigation of firms that reveals the fundamental mechanisms, such as innovation, managerial efficiency, and technology adoption, through which growth and competitiveness are genuinely forged. The dispersion of productivity across firms within the same industry is often substantial, underscoring the limitations of representative agent models and highlighting the critical importance of firm-level analysis. Statistical and econometric methods are the primary instruments for quantifying these micro-level dynamics, translating raw data

on inputs and outputs into meaningful inferences about efficiency and technological change.

The central objective of this paper is to provide a systematic and detailed overview of the statistical techniques prevalent in the empirical literature on firm-level productivity. We delve into the theoretical foundations, practical implementation, relative strengths, and limitations of each major approach. The discussion is structured to guide researchers through the complex landscape of methodological choices, from basic production function estimations to sophisticated models designed to correct for identification problems. Furthermore, this review synthesizes recent advancements and proposes directions for future inquiry, reflecting the dynamic nature of this field. By bridging economic theory with cutting-edge methodological practice, this paper seeks to enhance the rigor and relevance of empirical research on firm productivity.

2. Measurement of firm productivity: Core methodological frameworks

2.1. Parametric approaches

Parametric methods require the researcher to specify a functional form for the production technology, which is then estimated using statistical techniques. This structure allows for hypothesis testing and the derivation of economic elasticities but imposes assumptions that may not hold universally. The cornerstone of parametric productivity analysis is the production function, which relates a firm's output (typically revenue or value-added) to its inputs (e.g., capital, labor, materials). The most common specifications are the Cobb-Douglas and the more flexible Translog forms. The core estimation model involves decomposing output into contributions from observable inputs and an unobserved residual term interpreted as productivity.

A significant challenge in this estimation is the endogeneity of input choices: firms likely adjust their inputs based on their knowledge of their productivity, which is unobserved by the econometrician. This leads to correlation between inputs and the error term, biasing standard Ordinary Least Squares (OLS) estimates. Seminal solutions to this problem include Fixed Effects (FE) models, which control for time-invariant unobserved firm heterogeneity but assume productivity shocks are not correlated with input changes over time.

Instrumental Variables (IV) methods require valid instruments that affect input choices but are uncorrelated with productivity shocks, which are often difficult to find. More advanced control function approaches, such as those that use intermediate inputs (e.g., materials or investment) as proxies for the unobserved productivity shock, allowing for more robust identification of the production function coefficients.

SFA extends traditional production function estimation by explicitly modeling the deviation from the production frontier as a combination of inefficiency and statistical noise. Introduced by SFA allows for a more nuanced understanding of how individual firms differ from best-practice performance. The key advantage of SFA is its ability to separate inefficiency from random noise, providing direct estimates of firm-specific efficiency scores. However, the results can be sensitive to the chosen distributions for the inefficiency and error terms.

2.2. Non-parametric approaches

Non-parametric methods eschew specific functional forms, instead constructing a production possibilities set based directly on the observed data. This flexibility is particularly useful when the underlying technology is complex or poorly understood. DEA, rooted in operations research, uses linear programming to envelop the data and construct a linear production frontier. Firms on the frontier are deemed fully efficient (efficiency score = 1), while the efficiency of other firms is measured by their distance to this frontier. DEA is highly flexible, accommodating

multiple inputs and outputs without requiring a priori weights. Its major drawbacks are its deterministic nature (it attributes all deviation from the frontier to inefficiency, ignoring noise) and its sensitivity to outliers.

The Malmquist index, often implemented using DEA, measures the change in a firm's total factor productivity (TFP) between two periods. It decomposes productivity growth into two components: efficiency change (catching up to the frontier) and technical change (a shift in the frontier itself). This decomposition is particularly valuable for panel data analyses aimed at understanding the sources of productivity dynamics over time. A recent application by developed a robust nonparametric framework to analyze profits, prices, and productivity for French meat-processing firms in a dynamic context, using "m-out-of-n" bootstrapped DEA to obtain robust estimates and confidence intervals.

3. Addressing micro-level challenges in estimation

3.1. Modeling firm heterogeneity

Firms are inherently heterogeneous in their technologies, management quality, market power, and responses to external shocks. Ignoring this heterogeneity can lead to severely biased estimates and misleading policy conclusions. The recognition of this diversity has shifted the focus from representative firm models to frameworks that explicitly account for variation across firms.

Panel data techniques are fundamental for controlling unobserved heterogeneity. FE and Random Effects (RE) models are standard tools that control for time-invariant, unobserved firm characteristics. While FE models provide consistent estimates under the assumption that the unobserved heterogeneity is correlated with the explanatory variables, they cannot estimate the effect of time-invariant covariates. RE models are more efficient but rely on the stronger assumption that the unobserved effects are uncorrelated with the regressors. The Hausman test is typically used to guide the choice between these two models.

Beyond these standard methods, random parameters models and latent class models represent significant advancements. These techniques allow the production function coefficients to vary across firms or groups of firms, explicitly modeling technological heterogeneity. For instance, a study on Chinese export enterprises revealed that multiple forms of heterogeneity, including firm location, age, size, innovation capacity, brand strength, capital structure, and human capital, collectively explain competitiveness better than productivity differences alone. This finding challenges the conventional wisdom from Melitz-type models that productivity is the primary determinant of export behavior and suggests that "multiple heterogeneity" rather than singular "productivity heterogeneity" drives firm performance in certain contexts.

Another critical dimension is accounting for spatial heterogeneity. Research on Chinese digital enterprises from 2001 to 2019 has shown significant regional variations in TFP growth patterns. Eastern regions demonstrated sustained leadership with converging productivity levels among firms, while central regions exhibited expanding disparities, and western regions faced more turbulent development paths with increasing internal inequality. Such spatial patterns necessitate geographical fixed effects or spatial econometric techniques in empirical models to prevent biased inference.

The evolution of firm-level databases, such as longitudinal establishment surveys and comprehensive administrative data, has enabled researchers to implement these sophisticated approaches. However, new challenges emerge with larger and more detailed datasets, particularly concerning computational complexity and the risk of overfitting. Bayesian methods, which incorporate prior information through regularization, offer

promising avenues for handling complex heterogeneity structures without exhausting degrees of freedom.

3.2. Tackling endogeneity and measurement error

Endogeneity and measurement error constitute the most formidable obstacles to causal inference in firm-level productivity analysis. These issues arise from multiple sources and require specialized identification strategies.

The simultaneity problem (or productivity shocks problem) occurs when unobserved productivity shocks influence firms' input decisions, leading to correlation between inputs and the error term in production function estimations. As noted, control function approaches (OP/LP methods) use intermediate inputs as proxies for these shocks. Recent refinements to these methods include correcting for revenue-to-quantity bias when output is measured in revenues rather than quantities, and accommodating dynamics in the productivity process.

Selection bias represents another endogeneity concern, particularly when analyzing productivity premia of specific firm behaviors like exporting or innovating. Firms self-select into these activities based on expected benefits, creating non-random samples. Heckman-type selection models with instrumental variables are commonly employed, though finding valid exclusion restrictions remains challenging. Recent studies on Vietnamese enterprises, for example, have addressed the selection into formalization and its effect on innovation and productivity, revealing complex hump-shaped relationships and threshold effects.

Measurement error in input and output variables plagues firm-level data, especially from financial statements where misreporting may occur for tax or strategic reasons. This error typically attenuates coefficients toward zero, biasing productivity estimates downward. Instrumental variables approaches and the use of alternative data sources (e.g., electricity consumption as a proxy for capital utilization) can mitigate this issue. A comparative study of TFP estimation methods for Chinese digital enterprises found that LP (Levinsohn-Petrin), WRDG, and MrEst methods more effectively alleviated endogeneity and sample selection problems compared to OP (Olley-Pakes) and related approaches.

Dynamic panel data estimators, particularly the System Generalized Method of Moments (SYS-GMM), have gained prominence for addressing these issues simultaneously. SYS-GMM exploits internal instruments from lagged levels and differences of the variables, making it particularly useful when external instruments are weak or unavailable. An application of SYS-GMM to Chinese A-share listed manufacturing firms from 2011–2020 demonstrated dynamic productivity persistence and revealed that R&D expenditures initially suppress productivity before generating positive effects after two periods, with significant heterogeneity across regions and ownership structures.

Recent advances in non-parametric bounding approaches offer alternative strategies when traditional identification assumptions are questionable. Applied to study gender diversity's effect on firm performance, this method provides more credible inference in the presence of heavy-tailed firm-level data. Furthermore, the challenge of measuring intangible inputs like R&D and innovation has prompted methodological innovations.

4. Recent methodological innovations and future research avenues

The field of firm-level productivity analysis is undergoing rapid transformation, driven by computational advances, novel data sources, and interdisciplinary cross-fertilization. These developments are expanding the methodological frontier beyond traditional econometric approaches.

4.1. Integration of machine learning techniques

Machine learning (ML) algorithms are increasingly applied to productivity measurement, offering flexible, non-parametric alternatives to conventional production function estimation. Random forests and neural networks can capture complex interactions and non-linearities in the production process without imposing restrictive functional form assumptions. These techniques are particularly valuable for prediction tasks and feature selection when dealing with high-dimensional data. However, their “black box” nature often complicates economic interpretation, prompting research on explainable AI (XAI) methods that maintain predictive power while offering insights into variable importance.

ML methods also show promise in addressing fundamental identification problems. For instance, causal forests extend random forests to estimate heterogeneous treatment effects, potentially helping to uncover how productivity responses to policies or managerial practices vary across firms. Similarly, ML techniques can improve propensity score matching for creating valid counterfactuals in policy evaluation studies, leveraging their superior pattern recognition capabilities to achieve better covariate balance.

4.2. Distributional methods and heterogeneity analysis

Growing recognition that average treatment effects may mask important distributional patterns has spurred interest in methods that examine productivity relationships across the entire conditional distribution. Quantile regression techniques allow researchers to estimate how inputs affect output at different points of the productivity distribution, revealing, for example, that the returns to R&D may be substantially higher for already highly productive firms compared to median performers.

4.3. Network analysis and spillover effects

Productivity is increasingly understood as interdependent across firms through supply chains, knowledge flows, and labor mobility. Network analysis provides tools to model these interdependencies and estimate spillover effects. Spatial econometric techniques have been extended to incorporate general network structures, allowing researchers to test whether a firm’s productivity is influenced by the characteristics or behaviors of its network neighbors.

For example, studies have examined how a firm’s position in global value chains affects its productivity growth trajectory, with implications for industrial policy. Similarly, analyzing co-patenting or inventor mobility networks can reveal knowledge spillovers that contribute to productivity convergence or divergence within clusters and regions.

4.4. Non-parametric causal inference with complex data

As illustrated recent advances in non-parametric causal inference are improving the robustness of productivity studies. Their concATE method provides finite-sample valid confidence bands for treatment effects without assuming functional forms for the production technology or selection process. This approach is particularly valuable when studying complex interventions like organizational changes (e.g., workforce diversity policies) where traditional parametric assumptions are untenable .

The application to 945 listed firms revealed threshold effects in the relationship between gender diversity and firm performance (Tobin’s Q), with benefits materializing only when representation exceeded approximately 30% in growth sectors and 65% in cyclical sectors . Such nuanced findings demonstrate how modern causal inference

methods can generate more actionable insights for managers and policymakers.

4.5. Future research directions

Several promising trajectories emerge for future research:

- (1) The integration of rich micro-level datasets, including firm surveys, transaction-level data, satellite imagery, and digital footprints, with advanced statistical models will enable more granular and timely productivity measurement. Studies like the analysis of Vietnamese formal and informal enterprises point to the value of specialized surveys that capture diverse business arrangements;
- (2) Dynamic general equilibrium modeling with heterogeneous firms is increasingly incorporating micro-econometric estimates to improve policy counterfactuals. Closing the loop between micro estimation and macro aggregation remains a frontier challenge with significant implications for growth theory;
- (3) The measurement and valuation of digital capital and intangible assets require new approaches as these factors become more important drivers of productivity. Research on Chinese digital enterprises represents an initial foray in this direction, but more work is needed to properly account for data as a production factor and platform business models;
- (4) Bridging the gap between productivity analysis and strategic management through interdisciplinary studies could yield valuable insights. Understanding how managerial practices, organizational design, and strategic choices map onto productivity distributions represents a fertile ground for future research with both academic and practical significance.

5. Conclusion

The statistical analysis of firm-level productivity stands as a dynamic and critically important field, providing the essential micro-foundations for understanding macroeconomic growth, industrial competitiveness, and the efficacy of resource allocation. This review has systematically traversed the extensive methodological landscape, from the foundational parametric and non-parametric frameworks to the cutting-edge approaches designed to tackle the inherent complexities of microdata. The central thesis that emerges is that there is no single, universally superior method; rather, the selection of an appropriate statistical tool is a nuanced decision that must be carefully aligned with the specific research question, the nature and quality of the available data, and the particular econometric challenges at hand.

The evolution of methodological best practices has been largely driven by the relentless pursuit of causal identification in the face of persistent obstacles. As discussed, the core challenges of firm heterogeneity, endogeneity, and measurement error are not merely technical footnotes but fundamental issues that can dictate the validity of empirical findings. The progression from basic OLS and fixed effects models to sophisticated control function approaches (OP/LP) and dynamic panel estimators (SYS-GMM) represents a concerted effort to isolate the true effect of inputs and practices on productivity from spurious correlations. The recent integration of machine learning techniques promises to further this agenda by offering unparalleled flexibility in modeling complex, non-linear production technologies, though it also introduces new questions regarding interpretability and causal inference.

A paramount insight from recent literature, which this review has underscored, is the necessity of moving beyond average effects to fully appreciate the distributional dimensions of productivity. The application of quantile

regression and other heterogeneity-analysis techniques has revealed that the relationships between inputs, policies, and productivity outcomes can differ dramatically between high-performing and low-performing firms. Studies on Chinese exporters and digital enterprises, for instance, demonstrate that competitiveness and growth patterns are shaped by a “multiple heterogeneity” of factors, including innovation capacity, spatial location, and human capital, rather than by productivity alone. This recognition necessitates a more granular approach to both research and policy, acknowledging that one-size-fits-all recommendations are likely to be ineffective.

Looking forward, the future of firm-level productivity research is exceptionally promising, propelled by several convergent trends. The explosion of novel data sources, from detailed administrative records and real-time digital footprints to satellite imagery and specialized firm surveys, offers an unprecedented opportunity to measure inputs, outputs, and firm behaviors with greater accuracy and frequency. The challenge and opportunity lie in integrating these diverse data with robust causal inference strategies, such as the non-parametric bounding approaches exemplified to generate more credible and actionable insights. Furthermore, the growing emphasis on intangible assets and digital capital demands continued methodological innovation to properly account for the drivers of productivity in the modern, knowledge-based economy.

In conclusion, the statistical toolkit for analyzing firm productivity is richer and more powerful than ever before. By judiciously applying these methods, with a clear-eyed understanding of their assumptions and limitations, researchers can continue to unlock the secrets of firm-level performance. The implications extend far beyond academic circles; robust micro-econometric analysis provides indispensable evidence for managers seeking to optimize operations, for investors allocating capital, and for policymakers designing programs to foster innovation, competition, and sustainable economic growth. The ongoing dialogue between economic theory, methodological innovation, and empirical application will undoubtedly remain the lifeblood of this vital field of inquiry.

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Financial Performance Evaluation of Proya Company from a Stakeholder Perspective

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Abstract: The continuous growth in per capita national disposable income has propelled the global cosmetics industry to significant growth over the past decade. Taking Proya Cosmetics Co., Ltd. as an example, this paper adopts a stakeholder perspective. By selecting financial indicators from Proya's annual reports from 2017 to 2022, standardizing the data using SPSS software, and applying factor analysis, a series of financial performance evaluation models for Proya were constructed. A total of 15 listed companies in the same industry and Proya's financial indicators over the past six years were selected for horizontal and vertical comparative analysis and evaluation. The analysis reveals that creditors, employees, and the government are the primary stakeholders influencing Proya's financial performance. Based on these findings, corresponding strategies are proposed: safeguarding creditor interests from multiple angles; prioritizing value creation to enhance employee satisfaction; and strengthening social responsibility awareness while actively cooperating with government initiatives.

Keywords: Factor analysis; Financial performance evaluation; Proya; Stakeholders

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1. Introduction

As people's pursuit of beauty continues to rise, domestic cosmetics consumption has maintained robust growth momentum. The rapid development of e-commerce platforms in recent years has also opened up significant growth opportunities for the cosmetics industry. By the end of 2025, China's cosmetics market is projected to exceed 580 billion Chinese Yuan, accounting for approximately 14.5% of the global market share and ranking second worldwide.

This growth is underpinned by a confluence of factors: rising disposable incomes, the 'Guochao' (or 'China Chic') trend favoring domestic brands, and sophisticated digital marketing strategies that leverage live-streaming and social media. In January 2021, the State Council approved the implementation of the "Regulations on the Supervision and Administration of Cosmetics" along with a series of supporting secondary regulations.

This signifies stricter requirements for cosmetic safety and efficacy, significantly strengthening oversight and penalties for violations. This will not only further standardize market competition within the industry and eliminate non-compliant small and medium-sized enterprises but also impose higher standards on well-known brands like Proya. The new regulatory environment effectively raises the cost of compliance and demands greater transparency, making robust financial management and stakeholder trust more critical than ever.

As a leading Chinese cosmetics brand, Proya possesses R&D innovation centers that rival international standards. It has also established a long-term partnership with the National Deep Sea Base Management Center, securing valuable resources for its products. Since its inception, the company has consistently engaged in public welfare initiatives, from building Hope Primary Schools to donating to disaster-stricken areas, truly shining as a beacon of domestic brands. The new regulatory framework further requires Proya to prioritize enhancing product quality and safety while safeguarding consumer rights. Therefore, Proya should seize this opportunity to continuously improve product quality and expand its future market share.

However, the question remains: is Proya's current financial and operational strategy holistically sustainable? Are there hidden vulnerabilities in its relationships with key partners beyond its consumers and shareholders? Consequently, this paper selects Proya as its research subject. From a stakeholder perspective, it conducts horizontal and vertical comparisons of the company's financial performance to identify key factors influencing its financial outcomes. Targeted strategies are proposed to support Proya's continued growth. This approach allows for a diagnostic evaluation of the company's strengths and weaknesses across its entire ecosystem of influence.

2. Literature review

2.1. International research status

2.1.1. Research on financial performance evaluation

In 1954, Peter E. Drucker, known as the "Father of Modern Management," first introduced the concept of performance management in *Management Practice*. It was not until 1977 that Aubrey Daniels from the United States revisited performance management. This sparked a series of studies by scholars both domestically and internationally. The evolution of performance evaluation has since expanded from basic financial ratio analysis to sophisticated multi-dimensional frameworks.

Notably, the Balanced Scorecard incorporated non-financial perspectives, while Economic Value Added (EVA) focused on true economic profit. Factor analysis, the method employed in this study, is particularly valued for its ability to objectively reduce data dimensionality and identify latent constructs that drive observed financial patterns, thus avoiding the subjectivity of arbitrary weight assignments ^[1].

Wang analyzed 2019 financial data from 20 enterprises in coastal cities using factor analysis. The results indicated significant differences across various levels within the traditional Chinese medicine industry, yet relatively minor disparities in overall rankings ^[2].

2.1.2. Research on stakeholders

The term "stakeholder" originated in a 1963 memorandum from the Stanford Research Institute. Ansoff et al. provided early theoretical definitions of stakeholders, but these lacked empirical grounding and thus received limited attention at the time. It wasn't until Freeman's seminal 1984 work on stakeholders that the field gained scholarly prominence and entered a new phase of development. "Freeman's seminal work, *Strategic Management: A Stakeholder Approach*", argued that firms must manage relationships with all groups that can affect or are

affected by their objectives, fundamentally challenging the primacy of shareholder value.

Subsequent research, such as Rowley (1997) RDAP (Reactive, Defensive, Accommodative, Proactive) typology, helped classify corporate responses to stakeholder claims. In the 21st century, stakeholder theory has increasingly converged with the Environmental, Social, and Governance (ESG) movement, positioning effective stakeholder management as a core component of risk mitigation and long-term value creation ^[3]. Additionally, Emmerson et al. verified the positive correlation between ESG performance and corporate financial performance in South Africa, highlighting the need to validate this conclusion in China's cosmetics industry ^[4].

2.2. Domestic research status

2.2.1. Studies on financial performance evaluation

Du employed factor analysis to construct a financial performance evaluation system for listed steel companies in the same industry using four years of financial data. By selecting indicators based on four core competencies, the study evaluated the financial performance of MG Co., Ltd. Findings revealed relatively weak profitability requiring further enhancement ^[5]. Similar methodological applications are found in studies of other sectors, such as logistics (Hou) and rare earth enterprises (Liu & Zhong), confirming the widespread applicability of factor analysis in the Chinese academic context for deriving composite performance scores ^[6,7]. Other domestic studies have applied the stakeholder lens to corporate governance (Shen) and internal pay structures (Wang) ^[8,9].

However, a discernible gap exists in the literature. For instance, few studies systematically apply a comprehensive stakeholder-financial indicator framework to conduct a dual-faceted (horizontal and vertical) performance evaluation of a single, prominent company within the fast-moving consumer goods (FMCG) industry. This study aims to fill this gap by providing an in-depth case analysis of Proya.

2.2.2. Research on stakeholders

He and Lu analyzed the strategic behaviors adopted by four core stakeholders in ecological and environmental governance based on stakeholder theory, focusing on their self-interest. The study concluded that stakeholders' differing perspectives necessitate tailored strategies from multiple angles ^[10].

3. Introduction to Proya and research design

3.1. Introduction to Proya

Proya Cosmetics Co., Ltd. (hereinafter referred to as Proya) was established in 2003 and successfully listed on the Shanghai Stock Exchange in 2017. Headquartered in Hangzhou, it is an integrated company encompassing R&D, production, and sales. Proya primarily focuses on three major categories: skincare, color cosmetics, and hair care, building a multi-category, multi-brand matrix. Its brand portfolio includes the core 'Proya' brand focused on skincare science, the acquired color cosmetics brand 'Color Key', and the personal care brand 'Off & Relax'.

This diversified structure mitigates risk and captures value across different consumer segments. After going public, Proya gradually transitioned toward e-commerce to adapt to the new environment. The company primarily relies on online channels while maintaining offline channels in parallel. This 'online-first' strategy has been pivotal to its recent growth, allowing it to leverage data-driven insights and direct-to-consumer engagement, though it also increases its dependence on digital platform dynamics and marketing expenditures.

3.2. Selection of financial performance evaluation indicators

3.2.1. Principles for selecting financial performance indicators

(a) Authenticity

To ensure accurate conclusions, the authenticity of financial performance indicators is paramount. All data analysis relies on reliable metrics, necessitating rigorous verification of indicator authenticity. All data in this study were sourced from official annual reports and audited financial statements published on the Shanghai Stock Exchange and National Equities Exchange and Quotations (NEEQ) platforms.

(b) Feasibility

Key considerations during indicator selection include: whether analysis can achieve expected outcomes, maintain smooth workflow, and ultimately be implemented. This requires advance prediction, derivation, and experimental validation. This principle guided the selection of widely recognized, consistently reported financial ratios that are directly calculable from disclosed financial data, ensuring the model's replicability and practical utility.

3.3. Analysis of financial performance indicator selection

For sustainable growth, companies require stakeholder support while stakeholders play a supervisory and regulatory role. Financial statements serve as a primary source for understanding corporate performance. This paper, grounded in stakeholder theory, identifies key stakeholders of the company. By organizing and analyzing data from Proya's annual financial reports and other sources, we conduct an in-depth examination of these stakeholders. The stakeholders closely related to the enterprise selected for this analysis include shareholders, suppliers, creditors, employees, customers, government, and society. Eleven indicators were chosen from these seven stakeholder groups for subsequent analysis. The selection rationale for each group is elaborated below, linking the chosen indicators to the core claims and concerns of each stakeholder.

3.3.1. Shareholders

Shareholders form the cornerstone and a vital component of a company's development. The capital raised or invested by shareholders reflects a company's favorable operating environment, strength, and decision-making capabilities, enabling it to achieve greater longevity in a market economy. We have listed multiple banks and companies holding shares as shareholders, demonstrating greater support for Proya and reflecting widespread trust in the company.

As primary investors seeking returns, shareholders are most concerned with corporate performance. Stronger business development ensures returns on their capital investment. Therefore, this analysis uses earnings per share (EPS) and return on equity (ROE) to reflect shareholder returns. EPS measures the portion of a company's profit allocated to each outstanding share, directly impacting stock price, while ROE gauges the efficiency of generating profits from shareholders' equity, a key metric for investor evaluation.

3.3.2. Creditors

Creditors are indispensable to a company's normal operations and development, making their role significant. Creditors focus on recovering principal and interest upon maturity, leading them to closely monitor a company's cash flow. Thus, this study examines Proya's short-term and long-term borrowing status from 2018 to 2022.

Creditors prioritize timely repayment of principal and interest upon maturity. This paper thus examines the debt-to-equity ratio, current ratio, and quick ratio. The current and quick ratios indicate a company's short-term

debt repayment capability, with higher values signifying stronger short-term solvency. A lower debt-to-equity ratio demonstrates greater protection of creditors' interests. The quick ratio, being a more stringent measure than the current ratio as it excludes less liquid inventory, provides a conservative view of immediate liquidity.

3.3.3. Employees

Sustainable corporate development requires valuing employees' contributions. Therefore, we analyze Proya's employee headcount over the past five years. While Proya's workforce has grown alongside its production scale expansion, overall fluctuations remain minimal, indicating stable staffing levels.

The employee compensation ratio is calculated as the ratio of cash paid to employees to operating revenue. A higher value indicates greater employee satisfaction with the company. Only with such satisfaction can employees better progress alongside the company and contribute their strengths. This metric serves as a proxy for the company's investment in its human capital relative to its revenue generation. A declining trend could signal underinvestment in talent, potentially leading to higher turnover and lower productivity.

3.3.4. Customers

Customers serve not only as reliable support for a company's long-term development but also play a crucial role in monitoring product quality. According to the 2022 annual report, sales to the top five customers totaled 798.3137 million yuan, accounting for 12.55% of Proya's annual sales. While this relatively low concentration indicates minimal dependency risk, it highlights the company's need for greater customer diversification.

Customers represent a vital asset for enterprises, with their focus centered on brand image and product quality. Only by enhancing customer satisfaction can a company sustain sound development. Therefore, selecting the revenue growth rate as an indicator is appropriate, as higher values signify improvements in the company's core competitiveness and product/service offerings. Sustained high revenue growth is a strong market signal of brand health, customer acceptance, and effective marketing strategies.

3.3.5. Suppliers

Suppliers and enterprises maintain a sound cooperative relationship. Timely payment receipt is a key concern for suppliers. Therefore, the accounts payable turnover ratio is selected as an indicator. A higher value indicates the enterprise's ability to effectively manage and recover accounts payable within a short timeframe. Conversely, a higher cash-to-accounts payable ratio signifies stronger repayment capacity. An excessively high accounts payable turnover ratio, however, might indicate overly aggressive payment terms that could strain supplier relationships, while a very low ratio could signal potential cash flow problems.

3.3.6. Government and society

The government oversees enterprises to ensure lawful tax compliance. The tax-to-assets ratio is thus selected as an indicator. This metric reflects an enterprise's tax payment status: a higher value indicates better tax compliance and greater contribution to tax revenue.

As members of society, enterprises should contribute back to society while benefiting from its resources. This paper uses the donation ratio to reflect the fact that a higher proportion of donation expenditures relative to operating revenue indicates greater contribution to charitable causes.

Government and enterprises maintain a mutually beneficial relationship. The government provides

development guidance and fosters a harmonious, stable environment, while enterprises must comply with all legal regulations and actively pay taxes in accordance with the law. As members of society, enterprises should not blindly pursue profit maximization but instead contribute to social stability and build a positive brand reputation. In the modern context, these indicators align closely with the ‘Social’ and ‘Governance’ components of the ESG framework, which is increasingly influencing investment decisions and consumer preferences.

3.4. Construction of the financial performance evaluation model

3.4.1. Data selection and processing

Proya operates within China’s cosmetics industry. To ensure data accuracy and the feasibility of factor analysis, data from 15 listed Chinese companies in the same sector were selected as the research sample, excluding those with ST designations. This screening ensures that the peer group consists of financially healthy companies, providing a more meaningful benchmark for comparison. The final sample represents a cross-section of the industry, including both established players and emerging challengers.

This study selected 11 stakeholder-related indicators for analysis. Each dataset was complex and lacked common characteristics for direct comparison. Therefore, SPSS 25.0 software was employed to standardize the 11 indicator datasets.

The standardization process, often referred to as Z-score normalization, transforms the raw data for each indicator to have a mean of 0 and a standard deviation of 1. This is a critical step as it eliminates the influence of different measurement units and scales, allowing for the composite and comparable analysis of variables like ratios, percentages, and absolute growth rates.

3.4.2. Feasibility test for factor analysis

To assess the validity of factor analysis, this study selected 11 indicators from the 15 peer companies. Using SPSS 25.0 software, KMO and Bartlett’s tests were conducted to establish an effective financial performance evaluation model. After standardizing the data, they were input into the KMO and Bartlett’s tests.

Results indicate that the KMO sampling adequacy measure of $0.513 > 0.5$ confirms the selected sample data are suitable for factor analysis, enabling further analysis. While a KMO value of 0.513 is considered mediocre, it is above the minimum threshold of 0.5, deeming the sample adequacy as acceptable.

More importantly, Bartlett’s Test of Sphericity was highly significant ($\text{Sig.} = 0.000$), which robustly rejects the null hypothesis that the correlation matrix is an identity matrix. This confirms that the correlations between the variables are sufficiently large for factor analysis to proceed meaningfully.

3.4.3. Extracting common factors and determining factor number

Common factor variance calculated using SPSS 25.0. All 11 selected indicators achieved extraction rates exceeding 60%, indicating that the extracted common factors reflect over 60% of the information from the original variables, with a high degree of information retention. This ‘Communalities’ table is crucial; for instance, if an indicator like Return on Equity (X2) has an extraction value of 0.892, it means that 89.2% of its variance is captured by the extracted common factors, which is an excellent result.

To examine factor contributions to variable explanation and determine principal component numbers, this study employed PCA to derive a total variance explained table. The cumulative variance contribution reached 83.12%, indicating that the extracted four principal components explain 83.12% of the information in the selected

11 fundamental financial indicators. This reflects high-precision analytical results and demonstrates effective factor analysis. The decision to retain four factors was based on Kaiser's criterion (eigenvalues greater than 1). The scree plot exhibited a distinct inflection point after the fourth factor, providing intuitive validation for this selection. The cumulative explained variance of 83.12% represents an exceptionally high level in social science research, indicating that the four-factor model comprehensively summarizes the original data.

3.4.4. Factor naming and scoring

To facilitate factor naming and enhance data clarity, the matrix was rotated using Kaiser's maximum variance normalization method. Varimax rotation, an orthogonal rotation method, was applied to simplify the factor structure. This rotation maximizes the variance of the squared loadings of a factor on all the variables, resulting in a pattern where each variable loads highly on only one factor, making the factors more distinct and interpretable.

According to the software calculations, common factor F1 exhibits significant loadings on indicators X3 (current ratio), X4 (quick ratio), X5 (debt-to-equity ratio), and X10 (asset tax rate). Therefore, the Creditors and Government Factor is named F1. The combination of solvency ratios and the tax rate is intriguing. It suggests a latent factor representing the company's 'Financial Prudence and Social Compliance', encompassing its ability to meet short-term obligations while fulfilling its fiscal duties to the state.

Common factor F2 exhibits substantial loadings on indicators X1 (Earnings Per Share), X2 (Return on Equity), and X9 (Cash to Accounts Payable Ratio). Therefore, the shareholder factor is named F2. This factor clearly encapsulates 'Profitability and Shareholder Value Creation.' The inclusion of the Cash to Accounts Payable ratio suggests that strong cash flow generation is perceived by the model as part of a healthy financial profile that benefits shareholders.

Common factor F3 shows significant loadings on indicators X8 (Accounts Payable Turnover Ratio) and X7 (Revenue Growth Rate). Consequently, the supplier and customer factor is named F3. This factor represents the 'Market Dynamism and Supply Chain Efficiency'.

High revenue growth (customer focus) is linked with the management of payables (supplier relations). A negative loading on payables turnover might imply that faster growth can sometimes lead to longer payment cycles as companies utilize supplier credit to fund expansion.

Common factor F4 exhibits significant loadings on indicators X6 (Employee Compensation Ratio) and X11 (Donation Ratio), hence the F4 factor is named the Employee and Social Factor. This factor is clearly aligned with 'Human Capital and Social Investment', reflecting the company's commitment to its workforce and its role as a corporate citizen.

Finally, SPSS 25.0 software was used to analyze and derive the final factor score coefficients, presented in matrix form.

The calculation formulas for each common factor are derived from the component score coefficient matrix:

- (1) $F1 = -0.072ZX1 - 0.11ZX2 + 0.317ZX3 + 0.322ZX4 - 0.298ZX5 - 0.004ZX6 - 0.076ZX7 + 0.051ZX8 + 0.001ZX9 + 0.208ZX10 - 0.084ZX11;$
- (2) $F2 = 0.381ZX1 + 0.351ZX2 - 0.076ZX3 - 0.058ZX4 - 0.003ZX5 - 0.086ZX6 + 0.177ZX7 + 0.056ZX8 + 0.259ZX9 - 0.122ZX10 - 0.134ZX11;$
- (3) $F3 = 0.021ZX1 + 0.124ZX2 - 0.036ZX3 - 0.109ZX4 + 0.166ZX5 + 0.027ZX6 + 0.475ZX7 - 0.52ZX8 - 0.251ZX9 + 0.194ZX10 + 0.026ZX11;$
- (4) $F4 = 0.09ZX1 - 0.066ZX2 + 0.041ZX3 - 0.037ZX4 + 0.257ZX5 - 0.587ZX6 + 0.148ZX7 + 0.093ZX8 +$

$$0.088ZX9 + 0.239ZX10 + 0.404ZX11.$$

Based on the four formulas above, a comprehensive score for financial performance evaluation can be calculated. The specific calculation formula is as follows:

$$F = (29.827\% F1 + 24.49\% F2 + 15.241\% F3 + 13.563\% F4) / 83.12\%$$

This comprehensive score (F) is a weighted average based on the proportion of variance each factor explains. Factor F1, being the most influential, carries the highest weight (29.827%), followed by F2 (24.49%). This weighting scheme ensures that the composite score reflects the relative importance of each underlying latent dimension in explaining the total variance among the companies.

3.5. Financial performance evaluation results for Proya company

3.5.1. Horizontal comparison results

Based on the comprehensive scoring formula for financial performance factors outlined above, this study systematically applied standardized data samples from 15 cosmetics companies to conduct horizontal comparative analysis. Factor scores were calculated and ranked accordingly.

Six companies achieved positive composite financial performance scores, indicating sound financial health. Nine companies recorded negative scores, suggesting less-than-ideal financial performance requiring improvement. A positive score indicates performance above the industry average (mean of zero), while a negative score indicates below-average performance.

Among them, Juzu Biotech and Fierjia achieved notably high composite scores within the industry. Juzu Biotech ranked first with a composite score of 1.05, with all individual factor scores placing within the top two positions. Fierjia recorded positive scores across all factors, indicating strong evaluations from various stakeholders for both companies. The success of Juzu Biotech, for instance, can be attributed to its high-profit-margin business model centered on recombinant collagen technology, which likely drives strong performance across all stakeholder factors, particularly profitability (F2).

In 2022, Proya achieved a composite score of 0.35 within the industry, ranking fifth overall and positioning itself in the upper-middle tier of the sector. Specifically:

- (1) F2 (Shareholders) ranked second with a score of 1.22;
- (2) F3 (Suppliers, Customers) ranked third with a score of 1.00.

This indicates high prioritization of shareholders, suppliers, and customers, resulting in strong stakeholder satisfaction. Proya's strong F2 and F3 scores are a direct reflection of its successful 'big product' strategy and dominant e-commerce presence, which drive revenue growth and profitability, delighting shareholders and customers alike.

Conversely, F1 (Creditors, Government) ranked 11th with a low score of -0.6, reflecting poor financial performance. F4 (Employees, Society) ranked seventh, also relatively low, indicating insufficient emphasis on creditors, government, employees, and society. Overall, while maintaining focus on shareholders, suppliers, and customers, Proya should also address the financial performance concerning creditors, government, employees, and society. This lopsided performance profile reveals a strategic trade-off. Proya's aggressive growth and marketing investments, while successful in capturing market share, may be straining its liquidity (affecting creditors) and diverting resources from employee compensation and social contributions.

3.5.2. Longitudinal comparison results

After conducting a horizontal financial performance evaluation of Proya and its industry peers from a stakeholder perspective, we next applied the financial performance evaluation indicators identified above. Using the same methodology, we selected Proya's financial performance data from 2017 to 2022 to derive scores and rankings for each indicator, enabling a longitudinal comparison.

To ensure comparability between the horizontal and longitudinal analyses, the factor scoring model derived from the industry-wide analysis (i.e., the component score coefficient matrix) was applied to Proya's longitudinal data. This means that Proya's financial data from 2017 to 2022 were standardized and then substituted into the same factor formulas (F1, F2, F3, F4) established in section 3.4.4 to calculate the scores for each year. This approach allows for a direct and consistent evaluation of Proya's performance over time against the industry benchmark. Substituting the 2017-2022 financial data into the calculation formula yields Proya's financial performance scores and rankings:

It can be concluded that, Proya's financial performance level was low in 2020, with a composite score of only -0.65 points, ranking last. All factor scores were negative. The 2020 annual report indicates that 180 million Chinese Yuan in freight costs were recognized under cost of sales due to implementing new revenue recognition standards.

Additionally, the severe economic conditions in 2020 resulted in operating revenue of only 3.752 billion Chinese Yuan. These factors collectively contributed to Proya's last-place ranking in financial performance evaluation. The year 2020 serves as a stress test, highlighting Proya's vulnerability to external shocks (pandemic) and internal accounting policy changes. The across-the-board negative scores indicate a systemic impact that affected all stakeholder groups.

In contrast, Proya achieved the highest overall score and ranking in 2022, with all factor scores positive, indicating improved financial performance across all stakeholder dimensions. Specifically, its F2 (Shareholders) and F3 (Suppliers and Customers) scores were 0.16 and 0.17 respectively, ranking 1st and 2nd (driven by higher ROE and revenue growth); while its F1 (Creditors and Government) score of 0.39 placed 3rd (reflecting improved short-term solvency and stable tax contribution). Proya's 2022 annual report reveals the company's ongoing efforts to optimize organizational structure, implement a unified brand planning model across all levels, and refine its performance management system. These initiatives demonstrate tangible effectiveness. The 2022 recovery underscores Proya's operational resilience and the effectiveness of its strategic adjustments post-2020. However, it's critical to note that even in its best year, the scores, while positive, are not exceptionally high, suggesting there is still significant room for improvement, particularly in making these gains sustainable.

Analysis indicates that Proya's overall scores were negative for most years (only two years showed positive results), reflecting significant volatility in its stakeholder-related financial performance. Specifically:

- (1) F4 (Employees and Society) recorded negative scores in five out of six years (2017-2022)—a chronic issue stemming from persistently low employee compensation ratios and limited charitable donations, even amid revenue growth;
- (2) F1 (Creditors and Government) showed negative scores in four out of six years, primarily due to unstable short-term solvency (fluctuating current ratios) and a declining asset tax rate over time. This indicates that Proya's ability to balance the interests of shareholders (high returns) with those of creditors (financial safety) has been inconsistent, potentially due to cyclical investment and leveraging strategies.

3.5.3. Comprehensive evaluation

Based on the above horizontal and vertical comparisons, Proya's financial performance is closely linked to its stakeholders:

- (1) In horizontal comparisons with the cosmetics industry, Proya's financial performance evaluation was weaker for F1 (Creditors and Government) and F4 (Employees and Society);
- (2) In vertical comparisons of financial performance from 2017 to 2022, the weaker evaluation levels were observed for F1 (Creditors and Government) and F4 (Employees and Society).

Therefore, it can be concluded that Proya Company has underperformed financially in terms of its stakeholders: creditors, employees, and the government. The triangulation of evidence from both the cross-sectional (peer comparison) and time-series (self-comparison) analyses provides robust and convergent validity to this conclusion. It paints a picture of a company that is an effective market competitor but has yet to build a consistently robust and balanced foundation for long-term stakeholder value creation.

4. Risks facing Proya company

Based on horizontal and vertical comparisons, this paper will analyze these three aspects to explore the factors influencing the company's financial performance: insufficient debt-repaying capacity, low employee satisfaction and room for improvement in government relations.

4.1. Insufficient debt-repaying capacity

As indicated by the preceding analysis, creditors assess solvency through the current ratio, quick ratio, and debt-to-asset ratio. Per the 2022 financial statements, Proya reported total assets of 5,778,071,824.19 Chinese Yuan and total liabilities of 2,240,848,493.9 Chinese Yuan at the reporting period's end. The debt-to-asset ratio stood at 38.78%, reflecting a higher proportion compared to previous years. A higher debt-to-asset ratio indicates stronger reliance on creditor investment for operations, while simultaneously reducing the security of timely loan repayment and weakening the company's debt repayment capacity. This reliance on external financing creates financial risk.

In a rising interest rate environment or a credit crunch, Proya could face significantly higher financing costs or difficulty refinancing maturing debts. Furthermore, weak solvency ratios limit its financial flexibility to seize strategic acquisition opportunities or weather unexpected economic downturns, potentially ceding competitive ground to more fiscally conservative rivals.

4.2. Low employee satisfaction

Employees represent the most critical resource within an enterprise, and their satisfaction directly impacts corporate performance. Employee compensation ratios provide a more intuitive measure of the proportion of cash paid to employees annually relative to operating revenue, thereby reflecting employee satisfaction with the company. Employee compensation ratios exhibit a declining trend year-on-year.

Although a slight increase occurred in 2022, this phenomenon warrants attention. In the knowledge-intensive cosmetics industry, which relies heavily on R&D innovation and marketing creativity, high employee turnover is particularly costly. Low satisfaction can lead to a 'brain drain,' loss of institutional knowledge, decreased productivity, and a decline in the quality of customer service and product innovation. This erodes the very core competencies that Proya has worked hard to build. The slight uptick in 2022 is a positive sign but must be part of a

sustained reversal of the trend to mitigate these long-term risks.

4.3. Room for improvement in government relations

Analysis of Proya's financial performance indicators over the past six years reveals fluctuations in its asset tax rate. The rate peaked at 0.166 in 2017 but dropped to 0.026 in 2022. Past financial reports consistently reveal that government documents, such as the "Wuxing District People's Government Office Notice on Issuing Implementation Opinions for High-Quality Development of Manufacturing in Wuxing District", indicate substantial government support for Proya. This includes allocations of enterprise development subsidies, technological advancement grants, and patent funding.

Given the government's sustained commitment to fostering business growth, Proya must not only prioritize creating a favorable development environment but also actively contribute to national economic progress. This necessitates heightened attention to government relations and proactive cooperation with governmental initiatives. A declining asset tax rate, while potentially optimized for shareholder value, can be perceived negatively by government stakeholders.

It may signal a lower-than-expected contribution to public finances relative to the company's asset base and the support it receives. This could make Proya more vulnerable to stricter regulatory scrutiny, reduced access to future subsidies, and a weakened position in policy dialogues. In an era of increasing emphasis on 'Common Prosperity,' a poor track record on tax contribution and social responsibility can also attract public criticism and damage brand reputation.

5. Recommendations for enhancing Proya company

5.1. Safeguarding creditor interests from multiple perspectives

Both the company's operational performance and debt levels impact creditor interests. Therefore, the company should establish a scientific financial control system internally, integrate financial objectives into long-term planning, develop comprehensive sustainable budgets and financial control measures, and strictly manage all expenses and costs to ensure rational allocation and utilization of funds. This includes implementing robust rolling cash flow forecasts and establishing clear target ranges for key solvency ratios (e.g., maintaining a current ratio above 1.5), making them part of management's KPIs.

The company should conduct annual internal asset restructuring to reallocate resources efficiently.

This includes reassessing inventory management and capital investment decisions to maximize asset utilization and liquidate non-essential assets to reduce debt. Specifically, Proya could adopt Just-In-Time (JIT) inventory management techniques to minimize working capital tied up in stock and conduct post-investment appraisals for major capital projects to ensure they deliver projected returns.

The 2023 revision of the Company Law of the People's Republic of China emphasizes protecting creditors' interests through the doctrine of piercing the corporate veil. Consequently, companies should periodically establish dedicated task forces to proactively investigate whether shareholders abuse the company's legal independence or limited liability to evade debts, thereby harming creditors. This approach not only safeguards creditors' interests from multiple angles but also effectively prevents internal misconduct that could compromise corporate interests. Beyond compliance, Proya should engage in transparent communication with its creditors, providing regular business updates beyond mandatory reporting, thereby building trust and potentially securing more favorable

lending terms.

5.2. Prioritizing value creation and enhancing employee satisfaction

Proya can enhance financial performance by valuing employee contributions through improved work environments and advancement opportunities, thereby boosting satisfaction using strategies as outlined:

- (1) Actively listen to employee needs by establishing an anonymous feedback platform to gather opinions and address reasonable requests, increasing employee well-being. To be effective, this platform must be coupled with a visible and timely action plan demonstrating that feedback is heard and acted upon;
- (2) Establish a platform for employee skill training and career development while addressing employees' evolving career needs at different stages. Through systematic training programs and targeted development pathways, it can unlock employee potential, enabling them to better adapt to market changes and company growth requirements, thereby comprehensively valuing employee contributions. Proya should create a 'Proya University' offering courses in digital skills, leadership, and industry trends;
- (3) Implementing a dual-track career system (managerial and technical/experts) would allow employees to advance without being forced into management roles, recognizing and rewarding specialized expertise;
- (4) Develop personalized career plans by deeply understanding employees' career aspirations and strengths, tailor-made development roadmaps can be created alongside abundant learning resources and opportunities.

These boosts work motivation, fostering a win-win scenario where employees and the company grow together. This requires training managers to become effective coaches who regularly conduct career development conversations. Linking a portion of managerial bonuses to employee development and retention metrics can further incentivize this cultural shift.

5.3. Strengthen social responsibility awareness and actively support government initiatives

As a key stakeholder, government relations form the core of external coordination for enterprises. Therefore, strengthening social responsibility awareness and actively cooperating with government initiatives will help establish and maintain competitive advantages. For instance:

- (1) Proya should proactively assume greater social responsibilities. This includes establishing foundations, actively engaging in charitable endeavors, and prioritizing environmental protection;
- (2) The company should also respond to national calls by deepening industrial and employment assistance programs to help governments address job creation. Such actions not only bolster government performance and public image but also foster a favorable public opinion environment and cultivate an exemplary corporate culture;
- (3) Proya should move beyond ad-hoc donations and develop a strategic CSR framework aligned with its brand identity, such as focusing on women's empowerment and environmental sustainability (e.g., reducing plastic packaging). Publishing an annual sustainability report following international standards (like GRI) would formalize and communicate these commitments;
- (4) Proya must also conscientiously comply with laws and regulations, ensuring all profit-seeking or risk-averse actions align with national interests. Strengthening communication with the government requires designating dedicated personnel or departments to coordinate governmental relations. Proactively obtaining relevant policy information and accurately grasping the government's major policies and

macro-level intentions enables timely adjustments to corporate decision-making. Additionally, voluntarily reporting operational status to relevant government departments fosters understanding and support;

- (5) Proya should establish a dedicated Government Relations & Public Policy department. This team would be responsible for policy monitoring, interpreting new regulations' impact on the business, and ensuring the company's strategy is aligned with national initiatives like 'Made in China 2025.'

Building a relationship based on transparent dialogue and partnership, rather than mere compliance, is key to securing long-term government support.

6. Conclusion

Corporate financial performance evaluation serves as a vital tool for effective management. With the emergence of the stakeholder perspective, integrating stakeholder requirements into performance evaluation systems has become an inevitable trend. Corporate financial performance evaluation should not only serve shareholder returns but also aim to integrate the interests of all parties for mutual benefit. This study has operationalized this principle by constructing a factor analysis model based on stakeholder-defined financial indicators, providing a quantifiable and comparative method for such integration.

Evaluating financial performance for stakeholders requires comprehensive measurement and analysis to ensure more accurate, objective, and holistic outcomes. The case of Proya vividly illustrates that a high composite score can mask significant vulnerabilities in key stakeholder relationships. The horizontal and vertical analysis revealed that its strong market performance is counterbalanced by weaknesses in financial prudence (creditors), human capital investment (employees), and social compliance (government).

Corporate managers must consistently maintain a stance of harmonious coexistence with all stakeholders to achieve long-term success. The recommendations provided, ranging from sophisticated financial controls and strategic human resource development to proactive government engagement, offer a concrete roadmap for Proya to rebalance its priorities. For the broader cosmetics industry, this study serves as a cautionary tale and a demonstration of a methodological framework. It highlights that in an era of heightened regulatory scrutiny and social consciousness, sustainable growth is inextricably linked to a company's ability to nurture trust and create value for its entire stakeholder ecosystem, not just its shareholders.

This study is subject to several limitations that also present opportunities for future research as listed:

- (1) The horizontal analysis was limited to a sample of 15 peer listed companies, which may not fully capture the diversity of the entire cosmetics industry, particularly by excluding influential unlisted enterprises;
- (2) The evaluation framework relies exclusively on financial indicators, omitting critical non-financial dimensions, such as consumer brand loyalty, employee turnover rates, or environmental impact, that are integral to a comprehensive assessment of stakeholder value creation.

Future studies could address these constraints by expanding the peer sample and integrating both financial and non-financial metrics to construct a more holistic and robust stakeholder performance evaluation model.

Disclosure statement

The authors declare no conflict of interest.

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Digital Transformation Drives the Upgrade of Corporate Accounting Functions: The Transformation Path from Transactional to Value Management-Oriented

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Abstract: The global wave of digitalization has accelerated the process of corporate digital transformation, placing higher demands on financial and accounting management. Since then, accounting work has shifted from the traditional transactional model to a modern value management-oriented model, leading to a transformation of accounting functions. As corporate managers, they must advance their work proactively, empower the modernization and innovation of financial accounting with digital technology, and transition to management accounting to ensure enterprises keep pace with the times. Therefore, this paper explores the current status of corporate financial and accounting work amid the digital wave, identifies the challenges in the transformation of accounting from transactional to value management-oriented, and finally proposes several feasible and effective improvement strategies, aiming to provide more references for relevant practitioners.

Keywords: Accounting functions; Digitalization; Enterprises; Transactional (accounting); Value management-oriented (accounting)

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1. Current status of corporate financial and accounting work amid the digital wave

Corporate financial and accounting work is undergoing profound changes, and the wide application of various cutting-edge technologies has greatly transformed traditional work models. Digital technologies represented by cloud computing, big data, artificial intelligence, and blockchain have fully penetrated all aspects of financial and accounting work. In the field of accounting, automated software can process massive transaction data quickly and accurately, automatically generate accounting vouchers, account books, and financial statements, significantly improving accounting efficiency and accuracy. Financial shared service centers have realized the centralized

management of financial processes through cloud computing.

By building this platform, many enterprises have integrated financial businesses scattered in different regions, unified accounting standards, reduced repetitive work, and lowered operating costs. At the same time, big data analysis technology helps enterprises deeply tap the value behind financial data, providing strong support for budget preparation, cost control, performance evaluation, etc., and making financial decisions more scientific and forward-looking^[1-3].

During the digital transformation process, corporate financial and accounting work also faces many challenges. On the one hand, the rapid iteration of technology requires enterprises to continuously invest a large amount of funds in system updates, maintenance, and employee training, which is a heavy burden for some small and medium-sized enterprises with weak financial strength. Moreover, compatibility issues between different digital systems occur from time to time, leading to poor data flow and affecting work efficiency. On the other hand, data security risks have become a major concern for enterprises.

With the digital storage and transmission of financial data, security incidents such as cyber-attacks and data leaks occur frequently. Concerns regarding integrity, confidentiality, and availability of financial data to build a sound data security protection system has arise for enterprises to solve. Even more, digital transformation puts forward higher requirements for the capabilities and qualities of financial and accounting personnel, exposing problems and challenges in multiple aspects and restricting the digital process of enterprises.

2. Problems in the transformation of corporate accounting from transactional to value management-oriented

2.1. Formalization of financial department work

In the process of accounting transformation, the transaction-centric mindset remains difficult to completely correct, and some financial and accounting work still suffers from formalization. Although financial processing and report preparation are basic tasks, mastering methods to flexibly apply information technology for efficiency improvement is still lacking in current financial and accounting work. Furthermore, rigid accounting standards and financial data evaluation from a single perspective restrict the digital transformation of financial accounting^[4]. There are still cases where cost accounting neglects business information identification and cost management, and financial work lacks reflection, instead wasting such scientific and objective information resources. These issues require in-depth reflection to avoid formalization and one-sidedness in financial department work.

2.2. Difficulty in providing basis for corporate decision-making

The transformation of traditional transactional accounting to value management-oriented accounting, supported by digital technology, provides accurate guidance for corporate strategic and operational decisions, and will certainly bring new opportunities for sustainable and high-quality corporate development. However, currently, most enterprises still struggle to achieve this grand goal and need careful planning during digital transformation.

On one hand, the focus on information output by the financial department remains at a static level, focusing only on costs, revenue, and other indicators. The neglect of market trend forecasting and analysis of internal and external environmental changes makes it obviously difficult to achieve value management^[5-7]. On the other hand, financial data is isolated from business data, and business activities are disconnected from financial results. The decision-making level fails to maintain balance and result orientation, making it naturally difficult to sustain high-value growth.

2.3. Reducing corporate competitiveness

The lack of financial functions caused by delayed accounting transformation directly exerts a negative impact on corporate competitiveness. Since the financial department fails to identify irrationalities in resource allocation through value management, enterprises face efficiency shortcomings in capital utilization, cost control, asset operation and other aspects. Nowadays, the commercial market is highly competitive. Enterprises need to use financial data to observe and gain insights into situations, analyze market opportunities and optimize strategic layouts. However, transactional accounting is relatively unable to make up for this gap and provide in-depth support. This also easily leads to enterprises struggling to grasp business strategies and market responses, and failing to balance product innovation, cost control and market expansion. Eventually, their core competitiveness decreases, resulting in a “domino effect” of overall losses.

3. Paths and strategies for digital transformation to drive the upgrade of corporate accounting functions

3.1. Building an integrated digital financial platform to break data barriers

Data fragmentation is a major problem faced by many enterprises in their transformation today, which is particularly prominent in accounting work and also restricts the development of accounting functions towards a comprehensive value management-oriented model. In response, enterprises must establish an integrated digital financial platform, connect data chains and business chains, provide the most basic support, and lay a solid foundation for modernized and comprehensive development. On one hand, enterprises should integrate existing resources, add interfaces between financial and business systems, define unified data standards, realize the synchronization of work between the two sides, effectively complete cost accounting, revenue statistics and other tasks, and guide the orderly progress of business-end work.

In this way, adjustments to production, orders and other aspects can be made based on financial data, a balance can be achieved in complete value and price management, and decision-making deviations caused by data silos can also be avoided. On the other hand, enterprises should set up a dedicated management team, including maintenance and security personnel, to manage the operation of the platform system. Here, financial personnel are supported to retrieve data according to management needs to provide support for value management. A data quality verification module is also embedded to automatically identify (data issues) through algorithms, laying a reliable foundation for subsequent value analysis. In short, digital transformation drives the upgrade of corporate accounting functions, which gains support from an integrated digital financial platform to break data barriers and avoid data silos, this is worthy of in-depth exploration and practice ^[8–11].

3.2. Reshaping financial processes and strengthening the orientation of value management

Transactional accounting focuses on ex-post recording, which is completely different from the comprehensive support and balance involved in value management. Currently, enterprises need to rethink and optimize financial processes around value management goals to promote business empowerment. Specifically, focusing on process adjustments, enterprises can advance the nodes of financial control. In the budget preparation process, they should integrate big data to analyze market trends and industry benchmark data, and formulate dynamic budget plans.

Many enterprises involve cost management in their work; similarly, with the support of advanced technology platforms, they can accurately capture data information and identify room for cost optimization. It is necessary to adjust the cumbersome and unreasonable parts of these processes. For example, Robotic Process Automation (RPA)

technology can replace manual work in completing standardized tasks such as invoice verification, accounting voucher generation, and tax declaration, freeing up financial personnel to focus on value management ^[12]. Enterprises should gradually form a complete closed-loop financial process, conduct regular reviews and in-depth reflections, and explore more possibilities for digitalization to drive the upgrade of corporate accounting functions and transform from transactional to value management-oriented.

In short, reshaping financial process design is crucial. Only by truly recognizing the problems in the work of the financial department itself can enterprises take targeted measures, truly take value management as the orientation, form new work systems, plans, processes and activities, and truly gain more new development opportunities with the support of cloud computing, big data, the Internet of Things and artificial intelligence.

3.3. Strengthening the business-finance collaboration mechanism and deepening the penetration of value management

Based on the previous content, we can see that business-finance integration is a major development trend, and a number of work initiatives are oriented towards business-finance integration and scientific guidance to promote the in-depth transformation of accounting towards value management. In fact, insufficient business-finance collaboration can easily lead to the failure of value management to be implemented effectively. Enterprises must establish a normalized business-finance collaboration mechanism to ensure that the concept of value management is implemented throughout the entire process of financial accounting work.

To this end, enterprises need to form cross-departmental collaboration teams, with members covering positions in finance, business, technology, etc., and clarify the responsibilities of each role in value management ^[13]. For example, financial personnel need to participate in the preliminary planning of business projects and provide professional suggestions from the perspectives of cost-benefit calculation and capital allocation; business personnel need to promptly feedback dynamic business data to help the financial department accurately capture value creation nodes. At the same time, with the help of an integrated digital financial platform, enterprises should establish a mechanism for real-time sharing and linked analysis of business and financial data. When there are order fluctuations, production adjustments and other situations on the business side, the financial system can automatically trigger data early warnings and analysis, generate comprehensive reports including financial impacts and market trends, and provide real-time support for business decisions ^[14].

In addition, regular business-finance collaboration meetings should be held to jointly discuss value loss points and profit growth points in business processes. For instance, by analyzing material consumption data and financial cost data in the product production process, enterprises can optimize supply chain procurement strategies; by combining sales business data and financial revenue data, they can adjust product pricing and market promotion plans. Through this in-depth business-finance collaboration, the barriers between finance and business are broken, enabling financial value management to extend from backend accounting to frontend business planning and execution. This truly realizes business optimization driven by financial data and financial decision-making supported by business dynamics, promotes the improvement of the overall value of the enterprise, and provides strong support for the transformation of accounting functions towards value management.

3.4. Cultivating compound financial talents to consolidate the foundation for transformation capabilities

The key to upgrading accounting functions lies in the iteration of talent capabilities. It is necessary to build a

compound talent training system integrating “financial expertise + digital skills + business awareness” using strategies as follows:

- (1) Enterprises should formulate hierarchical training plans: For basic financial personnel, conduct training on digital tools such as RPA and financial system operation to ensure they can efficiently complete automated accounting work. For middle-level financial managers, focus on training in big data analysis tools and business intelligence applications to enhance their ability to interpret data and mine value. For example, identifying inefficient assets and optimizing capital turnover rate through data analysis. For senior financial leaders, strengthen training in strategic thinking and business insight. Arrange for them to participate in business department management through job rotation mechanisms to understand business logic and ensure financial decisions are closely aligned with corporate strategies;
- (2) A talent incentive mechanism should be established through the incorporation of the mastery of digital skills and contributions to value management into performance appraisals to encourage financial personnel to take the initiative in transformation. At the same time, introduce external expert resources, conduct special lectures and case studies, share transformation experiences of industry benchmark enterprises, broaden the horizons of financial personnel, and help them adapt to the role positioning of value management-oriented accounting.

In short, talents, namely human resources, are the most important support for enterprise transformation and development. Even with the introduction of digital technology, it still needs to be implemented by professional teams and personnel. By strengthening internal training, promotion management and welfare benefits, and enhancing external talent introduction, enterprises will definitely build a high-level and professional financial team, laying the foundation for the future sustainable development of the enterprise.

3.5. Improving the data security and governance system to ensure compliant and orderly transformation

Against the background of in-depth digital transformation, the security and compliance of financial data are the prerequisites for value management, which requires enterprises to build a comprehensive protection system from three aspects: technology, system and management.

At the technical level, adopt a dual protection model of “cloud-native security + local backup”. Deploy data encryption, access permission control and abnormal behavior monitoring systems in the cloud to prevent data leakage or tampering; establish a local disaster recovery center and regularly back up core financial data to respond to extreme cyber security incidents.

At the system level, formulate the Financial Data Security Management Specifications, clarify data classification standards and access permission levels, and establish a data usage traceability mechanism. Use blockchain technology to record data retrieval and modification traces to ensure the traceability of data flow.

At the management level, set up a cross-departmental data governance team. Led by the financial department, work with IT and legal departments to conduct regular data security audits, identify security vulnerabilities, and at the same time pay attention to the requirements of laws and regulations such as the Data Security Law and Personal Information Protection Law to ensure the compliance of financial data management and provide a safe and stable environment for the transformation of accounting functions to value management ^[15].

It is believed that through unremitting efforts, the data management and information security system will be improved, allowing enterprises to carry out accounting digitalization and transform towards value management

without worries. This still requires joint efforts from all of people.

4. Conclusion

Based on the above analysis, it is clearly pointed out that digital transformation is an inevitability for enterprise development, as well as a new opportunity and challenge for the upgrading of accounting functions. As relevant practitioners, we should recognize that traditional transactional accounting only has the “accounting” function, which is single-dimensional, one-sided and rigid. Only by identifying a modern, high-level and intelligent new management model can enterprises seize development opportunities through accounting and lay a solid foundation for their modernized and comprehensive development. Enterprises should also grasp the opportunity of digital transformation, continuously optimize the accounting function system, and gain more opportunities to stand out in the fierce market competition. This is worthy of our in-depth exploration and practice.

Disclosure statement

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Analysis on How Digital Transformation Enhances Enterprise Supply Chain Resilience

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Abstract: In recent years, with the advent of the digital era, digital transformation has become a mainstream social trend. As a powerful driving force, digital transformation is profoundly changing the operation mode and management method of enterprise supply chains. Enterprises should seize this opportunity to continuously enhance supply chain resilience. Enhancing enterprise supply chain resilience based on digital transformation can not only improve the supply chain's resistance and recovery capabilities, but also further enhance its innovation capability. This helps enterprises better respond to various unstable factors and provides protection for promoting the sustainable development of the supply chain. In this regard, this paper first expounds the multi-dimensional value of digital transformation in enhancing enterprise supply chain resilience, and then puts forward effective paths, aiming to provide certain reference for relevant researchers.

Keywords: Digital transformation; Enterprise; Supply chain; Resilience

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1. Multi-dimensional value of digital transformation in enhancing enterprise supply chain resilience

1.1. Facilitating the improvement of supply chain resistance capacity

In recent years, the social market environment has shown complex and volatile characteristics, and supply chains also face unstable factors such as trade frictions and natural disasters. Digital transformation can build a strong and powerful “shield” for them, further enhancing the resistance capacity of supply chains.

With the help of digital technologies, enterprises can monitor supply chains in real time and make dynamic adjustments to them. For example, enterprises use technologies such as artificial intelligence and the Internet of Things (IoT) to monitor supply chains in a multi-level and all-round manner, and grasp various data generated in warehousing, procurement, production and sales in a timely manner. When abnormal data is detected, enterprises will promptly formulate response plans, such as finding new suppliers, improving logistics and transportation routes, or readjusting production plans, thereby reducing the impact of unstable factors on the supply chain ^[1].

Digital transformation can enhance the effect of collaborative cooperation among cooperative enterprises in the supply chain. Through digital platforms, enterprises can establish in-depth cooperative relationships with distributors, manufacturers and suppliers, achieving collaborative innovation, resource complementarity and information sharing. At the same time, when resisting risks, all cooperative enterprises can communicate quickly, coordinate actions and jointly respond to various challenges faced, so as to continuously improve the stability of the supply chain ^[2].

1.2. Facilitating the improvement of supply chain recovery capacity

Enterprises' flexible use of digital means can significantly reduce transaction costs. In traditional supply chain transactions, not only the operation process is cumbersome, but also a large number of paper documents are generated. This will increase the risk of data errors, waste costs such as time and funds, and lead to a continuous rise in costs. With the steady advancement of the digital transformation process, enterprises will use automated order processing systems, online payments and electronic contracts in transactions. The transaction process will become more efficient and simple, and the investment in costs such as material and human resources will be reduced, thereby further reducing transaction costs ^[3].

At the same time, digital transformation can also enhance the coordination capacity of core enterprises. In the supply chain, core enterprises play an important role in overall planning and coordination. Through digital platforms, core enterprises can achieve closer connections and more efficient communication with upstream and downstream enterprises. Core enterprises can grasp the dynamic information of each node in the supply chain in real time, detect problems in a timely manner and coordinate all parties to solve them. When facing risks, core enterprises can rely on digital means to quickly organize forces from all parties, jointly formulate response strategies, and ensure the stable operation of the supply chain ^[4].

1.3. Facilitating the improvement of supply chain innovation capacity

In the context of the digital era, enterprises can use various digital technologies to conduct all-round data mining and analysis. By mining and analyzing massive data in the industrial chain, enterprises can accurately grasp the weak links of the supply chain, customer preferences and market demands. Based on these more valuable and practical data, they can carry out targeted innovation activities. At the same time, enterprises will also take the initiative to innovate the existing supply chain model, and actively jointly develop innovative projects with partners and suppliers to achieve complementary advantages and resource sharing, thereby promoting the sustainable development of the supply chain ^[5].

Meanwhile, enterprises can use digital platforms to obtain industry information and market dynamics in real time, and make targeted adjustments to supply chain strategies. In order to better respond to the complex and changeable market environment, enterprises can adjust logistics and distribution plans, production plans and product structures according to market changes, continuously improve their adaptability and flexibility, fully activate the innovation momentum of the industrial chain, and constantly enhance the influence of enterprises in the industry ^[6].

2. Multi-dimensional paths for digital transformation to enhance enterprise supply chain resilience

2.1. Deepening the operational reform of digital supply chains

In the warehousing link, enterprises should actively introduce advanced algorithms and automated equipment

to build an intelligent warehouse management system. This system enables efficient storage, rapid sorting, and accurate distribution of goods, thereby reducing human errors and labor costs. At the same time, building an intelligent transportation management system allows enterprises to monitor the driving position, status of vehicles, and conditions of goods in real time. They can adjust transportation routes based on actual situations to comprehensively improve transportation safety and efficiency^[7].

In the procurement link, enterprises should actively build digital platforms to ensure the standardization and transparency of procurement processes. Through these digital platforms, enterprises can achieve effective connection with suppliers and share procurement information in real time, making procurement decisions more timely and accurate. Meanwhile, enterprises can also use big data technology to evaluate and manage suppliers, screen out high-quality suppliers, establish stable and long-term cooperative relationships, and create a high-quality procurement environment.

In the production link, promoting the development of smart manufacturing is the key to deepening the operational reform of digital supply chains. Enterprises can introduce technologies such as industrial Internet and the IoT to realize interconnection and data sharing among production equipment. This allows real-time monitoring of various indicators in the production process, enabling timely identification and resolution of problems in production. By implementing smart manufacturing, enterprises can achieve flexible and customized production, quickly respond to changes in market demand, and improve production efficiency and product quality^[8].

In the sales link, to accurately understand and grasp market trends and enterprise demand, enterprises should flexibly use digital marketing platforms and tools. These tools help accurately identify target groups and develop exclusive marketing plans for them. Enterprises can also use social media and e-commerce platforms to communicate with customers in real time, provide better services to enhance customer satisfaction, and continuously increase the enterprise's market share and sales volume. Additionally, in-depth mining and analysis of sales data can provide strong support for formulating procurement decisions and production decisions^[9].

2.2. Strengthening monitoring and management of supply chain risk links

There is a close connection between various value links in the supply chain. Problems in a single value link may have a huge impact on the entire supply chain, and in severe cases, lead to the breakdown of the entire supply chain. Therefore, while improving the overall resilience of the enterprise supply chain, it is also necessary to strengthen the monitoring and management of each value link of the supply chain, extend the enterprise supply chain horizontally and vertically, and integrate more suppliers and distributors to ensure that enterprises in the supply chain can obtain corresponding resources in a timely manner^[10].

Enterprises should focus on the operation of the supply chain, proactively introduce technologies such as the IoT, big data, and artificial intelligence, and build an intelligent monitoring and automated early warning system to identify potential risks in the supply chain in a timely manner. For example, enterprises use the IoT technology to connect staff, circulating products, and production equipment in the supply chain, share and monitor operational data generated in the supply chain in real time, and issue timely warnings and formulate corresponding countermeasures when abnormal data is found. Enterprises rely on big data technology to identify abnormal data in a timely and accurate manner, such as sudden decreases or increases in supply volume and market sales volume, and promptly determine whether there are problems in the production and sales links^[11].

In addition, the supply chain risk monitoring and management system should be evaluated and optimized regularly. With changes in the market environment, the expansion of enterprise business, and the continuous

advancement of technology, the original monitoring systems and management methods may no longer be applicable. Therefore, enterprises should conduct a comprehensive review of the entire system regularly, checking whether the monitoring indicators are reasonable, whether the early warning mechanism is sensitive, and whether the response measures are effective. Based on the evaluation results, the system should be adjusted and improved in a timely manner to ensure that it can always monitor and manage supply chain risks accurately and effectively, providing a solid guarantee for enhancing the resilience of the enterprise supply chain.

2.3. “Chain Leader” enterprises proactively innovating supply chain technologies

In the supply chain, core enterprises occupy an important strategic position, and the digital transformation of core enterprises will have a relatively direct impact on the entire supply chain. Therefore, to enhance the resilience of the enterprise supply chain, it is necessary to improve the “chain leader system”, clarify the main responsibility for improving the resilience of the enterprise supply chain, confirm the “chain leader” status of the core enterprise in the supply chain, and rely on the core enterprise to drive the digital construction and intelligent upgrading of upstream and downstream enterprises, as well as guide the technological innovation and operation model innovation of the entire supply chain ^[12].

Core enterprises should use advanced digital technologies to collect, integrate, and analyze various data in the supply chain. This enables them to gain a deeper understanding of the problems and risks existing in each supply chain, accurately identify opportunities for further development, optimize supply chain development strategies, and thereby promote the sustainable development of upstream and downstream industrial chains. At the same time, core enterprises can also use intelligent algorithms and machine learning to predict risks such as inventory backlogs, optimal logistics and transportation routes, and market demand, thereby maximizing the accuracy of upstream and downstream supply chains.

To promote transparency in the entire supply chain process, core enterprises should fully rely on the advantages of blockchain technology and build a sound accountability mechanism. This not only makes each link in the supply chain more transparent but also enhances the trust between various industrial chains and enterprises. In addition, core enterprises can use digital twin technology to build supply chain models based on actual conditions, simulate and predict the future operation status of the supply chain, and regularly simulate and predict risks. This continuously strengthens the supply chain’s defense capabilities and effectively resists various unstable factors ^[13].

2.4. Cultivating an innovative ecosystem for digital supply chains

Enterprises should build an intelligent collaborative platform for supply chains, and set up modules such as R&D innovation, warehouse management, and production management in the collaborative platform. This breaks down data barriers between different business segments and enables cross-business and cross-system collaborative development. For example, enterprises can use integrated automation technology to develop an intelligent warehouse management system, which automatically updates and stores information on incoming and outgoing products, materials, and equipment.

The system can also proactively connect with other business segments, intelligently adjust production plans based on changes in warehouse inventory and throughput, and promptly feedback market trends and production plans to upstream enterprises. Upstream enterprises then adjust their equipment and material procurement plans and production schemes based on the feedback data, ensuring the rationality of product circulation and warehouse

reserves, thereby further enhancing the flexibility of the supply chain ^[14].

Enterprises should strengthen the development of digital talent teams. They should closely align with the development status and needs of the supply chain, focus on carrying out diversified talent training, and supply high-quality management talents, innovative talents, and R&D talents to the supply chain. At the same time, enterprises should improve the promotion channel mechanism for employees to create a favorable development and promotion environment within the enterprise.

In addition, efforts should be made to enhance employees' digital skills and thinking. Regular activities such as seminars and knowledge competitions themed on digital transformation should be held. These diverse activities fully stimulate employees' interest in learning, comprehensively improve their digital literacy, and cultivate them into digital talents truly needed by the enterprise's supply chain, injecting inexhaustible talent momentum into the sustainable development of the supply chain ^[15].

3. Conclusion

In summary, digital transformation has multi-dimensional value for enhancing the resilience of enterprise supply chains. It can improve the supply chain's resistance, recovery, and innovation capabilities, helping enterprises resist risks, reduce costs, and achieve innovative development in a complex and volatile market environment. To this end, enterprises can start with paths such as deepening the operational reform of digital supply chains, strengthening the monitoring and management of supply chain risk links, promoting supply chain technology innovation by "chain leader" enterprises, and cultivating an innovative ecosystem for digital supply chains. These paths provide specific practical directions for enterprises to enhance supply chain resilience. In the future, with the continuous advancement of science and technology and the constant changes in the market environment, digital transformation will become an inevitable path for enterprises to enhance supply chain resilience. Enterprises should fully recognize the importance and urgency of digital transformation, actively respond to challenges, seize opportunities, continuously explore and innovate the models and methods of digital transformation, and promote the digital transformation and resilience enhancement of their supply chains.

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VAT Neutrality and Corporate Social Responsibility: Evidence from China's 2018 VAT Credit Refund Reform

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Abstract: Taking China's 2018 value-added tax (VAT) credit refund reform as an exogenous shock to improve VAT neutrality, we use a difference-in-differences approach to explore how the reform affected corporate social responsibility (CSR). We find that the reform motivated firms to improve CSR performance. The reform has a "resource" effect, increasing internal funds and reducing financing costs, thereby enhancing firms' ability to undertake CSR. The reform also has a "reputation" effect, stimulating firms' willingness to engage in CSR to improve their reputations. CSR following the reform increases firm values and reduces bankruptcy risk. Our study provides fresh insights into VAT neutrality theory and is a reference for tax reform in emerging economies.

Keywords: Corporate social responsibility; Reputation effect; Resource effect; VAT credit refund reform; VAT neutrality

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1. Introduction

In June 2018, China promulgated the "Notice on the tax policy related to the refund of VAT credit for some industries in 2018" to refund the VAT credit for certain industries. This reform has smoothed the reimbursement chain and substantially improved VAT neutrality. As China's largest tax, the VAT has extensive and far-reaching effects on businesses. China previously implemented tax rate and tax deduction policies. Previous studies have extensively examined these policies' effectiveness. However, the effects of the 2018 VAT credit refund policy, a tax system reform aimed at tax neutrality enhancement, on firm decision-making have rarely been discussed.

Given the urgency of climate change, ecological imbalances, and other social problems, corporate social responsibility (CSR) engagement has become an unavoidable business practice. Moreover, CSR is vital for firms' long-term development and competitiveness^[1]. Therefore, to fill the research gap, we examine the effects of the VAT credit refund reform on firms' CSR-related decisions.

Using the VAT credit refund reform as a quasi-natural experiment, we adopt a difference-in-differences (DID) method to explore how the reform affects CSR. This study makes three main contributions:

- (1) Our research is novel as we examine how the VAT credit refund reform affects CSR engagement, enriching the literature on VAT neutrality theory;
- (2) We pioneer the exploration of tax neutrality's impact on firms' ability and willingness to undertake CSR, complementing research on the driving forces of CSR from a novel perspective;
- (3) We provide a practical reference for other countries considering implementing VAT reform.

2. Hypothesis

The VAT credit refund reform is expected to exert “resource” and “reputation” effects. The “resource” effect enhances firms' ability to fulfill CSR. The reform smooths the chain of VAT deductions and returns to activate enterprise VAT credits and increase internal cash flow, while mitigating the resource allocation distortion of non-neutral tax policies^[2]. Reducing the distortion can reduce cash flow volatility and financial risk, thereby enhancing enterprises' external financing ability. According to idle resources theory, CSR engagement largely depends on whether a firm has surplus resources. Several studies note that financing constraints are key to inhabiting firms' CSR investments^[1,3]. Therefore, the reform will promote enterprises' ability to participate in CSR practices by enriching their resources.

Furthermore, the “reputation” effect stimulates firms' willingness to undertake CSR. The reform gives full play to the tax neutrality principle, optimizes the business environment, and strengthens the market's role in resource allocation. Therefore, after the reform, firms will focus more on building their reputations. Extant literature notes that CSR helps enterprises win stakeholders' trust and provides a strategic method for establishing a good reputation^[4]. Hence, the reform can motivate firms to improve CSR performance to improve their reputations.

Therefore, we propose the following hypothesis: The VAT credit refund reform has a positive impact on firms' CSR performance (Hypothesis 1).

3. Sample and methods

3.1. Sample

China extended its VAT credit refund policy to eligible manufacturing enterprises in 2021 and added seven more industries in 2022. Therefore, we selected A-share listed companies from 2013 to 2020 as our research sample.

We excluded financial industry, ST, or IPO firms, and firms with missing data, abnormal profit rates or asset-liability ratios. All continuous variables are winsorized at the upper and lower 1% levels. The final sample includes 16,769 firm-year observations from 2,773 firms. The data are from the China Stock Market and Accounting Research Database (CSMAR) and Wind Database.

3.2. Model specification

According to the reform, our treatment group includes advanced manufacturing, modern services and power grid enterprises. The policy time-point is 2018. We used DID to examine how the VAT credit refund reform affects CSR. **Eq. (1)** describes our model as follows:

$$CSR_{i,t} = \beta_0 + \beta_1 Treat_i \times Post_t + \sum Controls_{i,t} + \sum Firm_i + \sum Year_t + \varepsilon_{i,t} \quad (1)$$

CSR refers to corporate social responsibility, which is the sum of environmental and social scores from the Huazheng ESG index system^[5,6]. *Treat* is a dummy variable equal to 1 for enterprises in the treatment group and 0 for those in the control group. *Post* is a dummy variable representing time equal to 1 for the years between 2018–2020 and 0 otherwise. *Controls* includes all control variables.

We control for firm-fixed and year-fixed effects and cluster regression coefficient standard errors at the firm level.

4. Empirical results

4.1. Summary statistics

Table 1 provides the full sample descriptive statistics. The CSR mean and median are 1.347 and 1.342, respectively. Although distribution is relatively uniform, the overall level is low ^[5,6]. The mean of *Treat* × *Post* is 0.258, indicating that the treatment group comprises 25.8% of the total sample. The control variables are within reasonable ranges.

Table 1. Full sample descriptive statistics

Variables	Obs	Mean	SD	P25	Median	P75
CSR	16769	1.347	0.147	1.243	1.342	1.448
Treat × Post	16769	0.258	0.438	0.000	0.000	1.000
Size	16769	22.504	1.280	21.613	22.325	23.242
Age	16769	2.498	0.534	2.079	2.565	2.996
Lev	16769	0.448	0.201	0.291	0.442	0.599
Inv	16769	0.147	0.142	0.057	0.110	0.181
Inta	16769	0.048	0.053	0.018	0.034	0.058
OCF	16769	0.048	0.066	0.010	0.047	0.086
Turno	16769	0.603	0.418	0.329	0.508	0.745
Divp	16769	0.712	0.453	0.000	1.000	1.000
Grow	16769	0.145	0.408	-0.044	0.081	0.230
ROA	16769	0.029	0.059	0.011	0.031	0.058
SOE	16769	0.414	0.492	0.000	0.000	1.000
EBITsd	16769	0.058	0.156	0.014	0.026	0.051
Dual	16769	0.236	0.425	0.000	0.000	0.000
Board	16769	2.133	0.197	1.946	2.197	2.197
Indra	16769	0.376	0.054	0.333	0.364	0.429

Table 2 illustrates the differences in CSR before and after the reform, where the treatment group had lower CSR than the control group prior to the reform. However, this reverses afterward.

Table 2. Subsample descriptive statistics test

Variables	Time-point	Treatment (1)	Control (2)	(1)–(2)	T-test dif	Dif in Dif (T-test)
CSR	Before-policy	1.320	1.328	-0.008	-2.738***	0.041
	Post-policy	1.377	1.374	0.003	0.716	(15.856***)

t-statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.2. Baseline findings and robustness tests

Table 3 shows the baseline findings. The dependent variables in columns (1)–(3) are *CSR*, environmental

responsibility (*Environ*), and other social responsibility (*Social*), respectively.

The coefficient of $Treat \times Post$ is 0.12 and significant at the 1% level, thereby supporting hypothesis 1. Economically, relative to unaffected firms, the CSR performance of affected enterprises increased by 0.89%, indicating that the reform improves tax neutrality and thus motivates firms to undertake CSR activities. Both environmental and other social responsibility performance increased.

Table 3. Baseline findings

Variables	(1) CSR	(2) Environ	(3) Social
Treat \times Post	0.012*** (2.895)	0.005** (1.968)	0.007** (2.194)
Size	0.032*** (9.071)	0.008*** (3.903)	0.025*** (9.734)
Age	0.018 (1.535)	0.016** (2.437)	0.005 (0.493)
Lev	-0.008 (-0.669)	-0.006 (-0.963)	-0.005 (-0.529)
Inv	0.020 (1.154)	-0.003 (-0.318)	0.022* (1.647)
Inta	0.099** (2.273)	0.032 (1.263)	0.064* (1.895)
OCF	-0.028* (-1.914)	-0.003 (-0.356)	-0.028** (-2.106)
Turno	0.022*** (3.355)	0.003 (0.856)	0.019*** (3.582)
Divp	0.011*** (4.225)	-0.000 (-0.122)	0.011*** (5.065)
Grow	-0.010*** (-4.693)	-0.003*** (-2.718)	-0.006*** (-3.738)
ROA	-0.004 (-0.184)	-0.019* (-1.872)	0.015 (0.980)
SOE	0.002 (0.376)	0.008* (1.784)	-0.007 (-1.206)
EBITsd	0.011 (1.167)	0.003 (0.886)	0.008 (0.941)
Dual	0.001 (0.453)	0.002 (1.365)	-0.000 (-0.165)
Board	-0.006 (-0.518)	-0.011* (-1.832)	0.005 (0.532)
Indra	0.013 (0.369)	-0.010 (-0.548)	0.025 (0.906)
Constant	0.569*** (6.431)	0.414*** (8.407)	0.133*** (2.064)
Firm	Yes	Yes	Yes
Year	Yes	Yes	Yes
r2_within	0.024	0.008	0.023
N	16769	16769	16769

t-statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

We tested for parallel trends before the reform and possible policy delays (**Figure 1**). Before the reform, the coefficients were not significant, satisfying the DID model's parallel trends assumption. A placebo test rules out omitted-variable bias. **Figure 2** illustrates the estimated coefficients' probability density distribution. The random sampling estimate distribution is concentrated around 0, which is below the benchmark estimate coefficient of 0.013; thus, unobserved factors do not affect the basic conclusions.

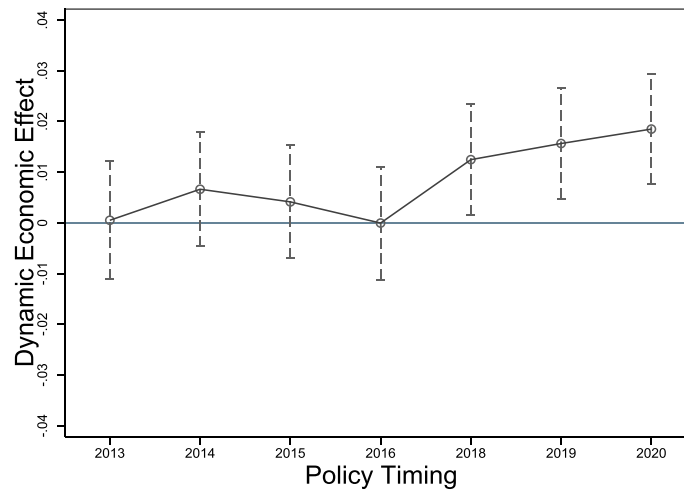


Figure 1. Parallel trend test.

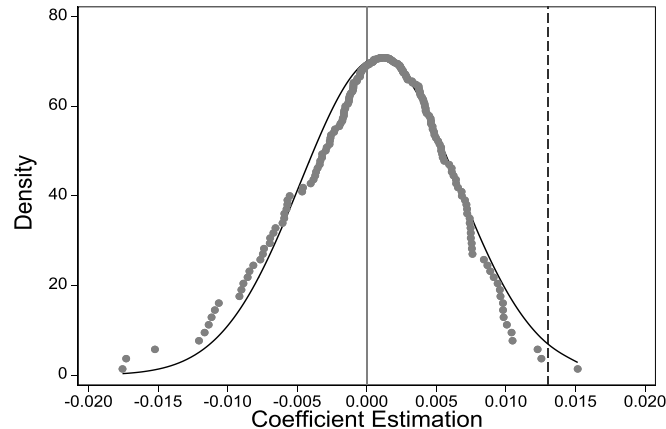


Figure 2. Placebo test.

Table 4 reports the robustness test results. In the first test group, we replace key variables. Column (1) shows the results of replacing *Treat* with 1/2 in 2018. Column (2) shows the results of replacing *CSR* with charitable giving (*Don*). In the second test group, we control for potentially missing variables. Column (3) reports the results of controlling for the actual VAT burden in the previous period (*Vatb*). Column (4) shows the results of controlling for the VAT credit to be deducted (*Ucvat*). Column (5) presents the results of considering the effect of an A-tax-rating (*RA*).

Table 4. Robustness Test

Variables	(1) CSR	(2) Don	(3) CSR	(4) CSR	(5) CSR
TP	0.014*** (2.934)	0.058* (1.865)	0.012*** (2.897)	0.012*** (2.923)	0.005 (1.343)
Vatb			0.001 (0.346)		
Ucva				0.276* (1.715)	
TP × RA					0.010*** (2.671)
RA					0.002 (0.829)
Constant	0.569*** (6.429)	-2.980*** (-5.107)	0.569*** (6.430)	0.572*** (6.439)	0.568*** (10.194)
Controls	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Prov	No	No	No	No	No
r2_within	0.024	0.024	0.024	0.025	0.025
N	16769	16769	16769	16769	16769

t-statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. TP refers to $Treat \times Post$.

4.3. Economic implications

We examine the economic consequences of CSR following the reform by adopting the model in **Eq. (2)**:

$$TQ_{i,t}/Zscore_{i,t} = \lambda_0 + \lambda_1 Treat_i \times Post_t \times CSR_{i,t} + \lambda_2 CSR_{i,t} + \lambda_3 Treat_i \times Post_t + \sum Controls_{i,t} + \sum Firm_i + \sum Year_t + \varepsilon_{i,t} \quad (2)$$

where TQ refers to firm value and $Zscore$ indicates bankruptcy risk.

Table 5 presents the results. In columns (1) and (4), the coefficient of $Treat \times Post \times CSR$ is significantly positive. Actively engaging in CSR following the reform can increase firm value and reduce the probability of bankruptcy. Moreover, the positive effects on TQ and $Zscore$ are more significant in highly capital-intensive firms (PPE_high).

Table 5. Economic consequence analysis

Variables	(1) TQ	(2) PPE high TQ	(3) PPE low TQ	(4) Z score	(5) PPE high Z score	(6) PPE low Z score
Treat × Post × CSR	0.889*** (5.537)	1.185*** (5.324)	0.419* (1.925)	4.402*** (5.449)	4.841*** (4.638)	2.738** (2.343)
CSR	-0.275*** (-2.865)	-0.313** (-2.429)	-0.107 (-0.779)	-1.202** (-2.463)	-1.558** (-2.535)	-0.008 (-0.010)
Treat × Post	-1.386*** (-6.067)	-1.761*** (-5.574)	-0.714** (-2.330)	-6.895*** (-5.984)	-7.439*** (-4.972)	-4.566*** (-2.765)
Constant	16.790*** (14.614)	14.179*** (9.942)	16.529*** (9.625)	50.126*** (9.899)	37.427*** (6.179)	62.564*** (6.731)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
r2_within	0.107	0.089	0.089	0.228	0.194	0.236
N	16769	8235	8534	16769	8235	8534
p-value		0.000			0.000	

t-statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5. Conclusions

In 2018, China implemented a VAT credit refund reform, providing an appropriate scenario for examining tax neutrality. Therefore, based on this unique background, this study verifies that VAT neutrality positively affects CSR. Specifically, the reform has both “resource” and “reputation” effects, increasing firms’ ability and willingness to enhance their CSR performance. Moreover, undertaking CSR following the reform was shown to significantly increase firm value and reduce bankruptcy risk.

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Disclosure statement

The authors declare no conflict of interest.

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Research on the Theoretical Logic and Development Path of Artificial Intelligence Audit

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Abstract: With the deep integration of digital technology and the real economy, AI auditing has emerged as a core paradigm that breaks through the pain points of traditional auditing, such as “sampling limitations, post-event lag, and reliance on manual labor”. This paper systematically reviews the theoretical connotations of AI auditing, reveals its current practical status, deeply analyzes four core challenges: data quality, ethical compliance, talent adaptation, and institutional synergy, and proposes feasible development paths from four dimensions: technological optimization, institutional construction, talent cultivation, and industry synergy. The research indicates that AI auditing needs to be “based on data elements, driven by technological innovation, with institutional guarantees as the bottom line, and talent adaptation as the core”, and achieve an upgrade from “tool assistance” to “governance synergy” under the promotion of new productive forces.

Keywords: Artificial intelligence audit; Audit quality; Digital transformation; New-quality productivity

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1. Introduction

1.1. Research background

1.1.1. Digital transformation drives the transformation of audit paradigm

The global digital economy has grown from \$22.5 trillion in 2016 to \$53.3 trillion in 2024. While digital technology reshapes business models, it also expands the scope of audit from “structured financial data” to “structured + unstructured + real-time streaming data”. Liang et al. pointed out that new-quality productivity reconstructs audit production relations through “data elements + technological innovation”, driving the transformation of auditing from “sample verification” to “full-scale intelligent analysis” - traditional manual auditing of annual reports of listed companies, which requires 30 people per week, can be completed by an AI audit system within 48 hours for full data verification^[1].

1.1.2. Industry demand drives the implementation of AI auditing

From the perspective of enterprises, Xu's research shows that 85% of listed companies prioritize "improving audit quality and reducing compliance risks" as their core needs ^[2]. The "real-time monitoring" feature of AI auditing can solve the pain point of "irreversible discovery after the fact" in traditional auditing. From the perspective of audit institutions, Li pointed out that small and medium-sized accounting firms are facing the dual pressure of "30% increase in labor costs and low audit efficiency", and AI has become the key to reducing costs ^[3].

1.1.3. Policy support to guide the development of AI auditing

The "14th Five Year Plan for the Development of Digital Economy in China" clearly proposes to promote the digital transformation of auditing and enhance intelligent auditing capabilities. The EU's Digital Services Act (DSA) requires platform enterprises to conduct compliance audits using AI technology; The Public Company Accounting Oversight Board (PCAOB) of the United States will release the "AI Audit Guidelines" in 2024 to standardize the application of AI in auditing. The policy dividend provides institutional guarantees for AI auditing.

1.2. Research significance

1.2.1. Theoretical significance

This study aims to fill the theoretical gap of "integration of new quality productivity and auditing". Existing audit research mostly focuses on the application of a single technology, and there is insufficient exploration of systematic changes in audit models under new quality productivity. This article introduces the theory of new quality productivity into the field of auditing, constructs a four-dimensional framework of "data technology system talent", and explains the impact of new quality productivity on the form of audit data, technological logic, institutional system, and talent demand, providing a new perspective for the cross integration of the two theories.

Additionally, this study serves to enrich the theoretical foundation of auditing. Although the current responsible innovation perspective supports audit risk management, there are gaps in subject behavior and governance boundaries. This study also introduces the theory of holistic governance, clarifies the positioning of auditing in organizational governance, clarifies the collaborative boundaries with other management functions, and improves the theoretical system of auditing.

1.2.2. Practical significance

The practical significance are as follows:

- (1) Provide industry standard references for policy-makers;
- (2) Regarding the lack of digital standards for auditing, it is suggested to clarify the data quality threshold;
- (3) Require audit firms to publicly disclose method logic and data compliance proof to avoid "black boxes method";
- (4) Establish a digital tool filing system, clarify the scope of application and risk control measures, and promote standardization in the auditing industry.

1.3. Research innovation points

One of the innovation points of this research is its theoretical innovation, where we are constructing a four-dimensional framework for auditing driven by new quality productivity and breaking through the limitations of traditional audit theory's single dimension, guided by the theory of new quality productivity, and starting from the core elements.

Under the new quality productivity in the “data” dimension, it emphasizes the clarification of data collection and governance standards. In the “technology dimension”, the focus lies on sorting out the path, such as process automation to enhance audit efficiency. The “system” dimension aims to refine the definition of audit responsibilities and to optimize the design of quality control mechanisms, thereby reinforcing accountability and consistency across the audit process. Conversely, the “talent” dimension defines the digital capability needs of auditors, proposes a training system approach, and achieves deep integration of the two theories.

The second is its practical innovation, through proposing a “low-cost transformation path” for small and medium-sized audit institutions. In response to the difficulty of transformation for small and medium-sized institutions, it is recommended to prioritize the introduction of low threshold process automation tools (such as voucher verification systems) to replace manual labor and improve efficiency. After resource accumulation, upgrade data analysis technology and transform in stages to reduce costs and risks.

2. Literature review

2.1. Theoretical connotation research

Cui et al. defined AI auditing as a “new model based on big data to achieve process automation, risk intelligence, and clear accountability” from the perspective of responsible innovation, and proposed a three-level accountability boundary of “AI model developers auditors enterprise management”^[4]. Fang et al. constructed an “AI audit boundary recognition model” based on the theory of holistic governance, clarifying the criteria for dividing the “manual review process” and the “AI autonomous decision-making process”^[5].

2.2. Technical application research

Li et al. used DeepSeek as an example and confirmed that its accuracy in identifying abnormal transactions reached 92%, which is 35% higher than traditional models^[6]. Xu et al. added that DeepSeek can parse the Enterprise Accounting Standards through natural language processing to generate a “revenue recognition compliance report”^[7]. Yun proposed the “RPA + AI combination model”, which, after being applied by a manufacturing enterprise, improved the efficiency of “procurement approval verification” by 85% and reduced the error rate from 5% to 0.3%^[8]. Xu pointed out that this model can cover 70% of repetitive audit tasks^[9].

According to a survey conducted by Ni et al., 38% of manufacturing companies identified issues such as “abnormal equipment shutdown” and “energy waste” through “IoT device collection of production data + AI analysis”, resulting in an 18% increase in production efficiency in a certain automobile factory^[10].

2.3. Review of domestic and foreign research

From the current research status in the field of auditing at home and abroad, there are several research consensus in academia:

- (1) At the technical level, it is widely recognized that digital technology has a positive effect on improving audit efficiency and optimizing risk identification accuracy. It is believed that the application of automation tools and data analysis technology can effectively break through the efficiency bottlenecks and risk blind spots of traditional manual auditing;
- (2) At the challenge level, uneven data quality, blurred ethical and compliance boundaries, and mismatched talent capabilities and technological applications have become common problems that constrain the digital development of auditing. It is necessary to focus on data governance, compliance control, and talent

cultivation;

- (3) At the institutional level, it is proposed to improve the regulatory system and industry standards in the field of auditing, providing clear institutional guidance for digital auditing practices. However, there are still three shortcomings in existing research: at the theoretical level, there is insufficient exploration of the deep integration of cutting-edge theories such as new quality productivity and holistic governance with audit practice, making it difficult to fully explain the systematic changes in audit models under the new development background;
- (4) At the practical level, there is a lack of differentiated research on the audit characteristics of different industries, and customized audit plans that are suitable for the needs of various industries have not been formed, resulting in limited guidance value of general research conclusions for specific industry practices;
- (5) At the empirical level, domestic research mainly focuses on single case analysis, lacking large-scale questionnaire surveys and statistical tests covering multiple industries and institutions. The universality and persuasiveness of research conclusions need to be improved.

Based on this, the research positioning of this article focuses on the integration of new quality productivity and audit theory, and the coordinated development of system technology talent, aiming to fill the existing research gap.

3. Theoretical basis and definition of connotation

3.1. Theoretical basis

3.1.1. Theory of new quality productivity

The core of new quality productivity is “led by technological innovation, promoting the reconstruction of production factors and the transformation of production relations”. This theory is reflected in three aspects in auditing: at the level of production factor reconstruction, data becomes the core audit element, gradually replacing the traditional audit model of “labor + sampling data”, achieving full coverage and deep mining of audit data sources, and providing data support for accurate identification of audit risks.

At the level of production relations transformation, the audit subject has expanded from a “single audit institution” to a diverse collaborative entity of “audit institution + technical model developer + regulatory agency”. Each entity needs to clarify their rights and responsibilities, such as technical model developers being responsible for ensuring the reliability of tools, audit institutions being responsible for standardizing the use process, regulatory agencies being responsible for supervising overall compliance, and jointly ensuring the standardized promotion of audit processes.

At the level of productivity improvement, the application of digital technology breaks through the “upper limit of manual efficiency” and realizes the audit mode of “full data + real-time analysis”, significantly shortening the audit cycle and improving the timeliness and accuracy of risk identification.

3.1.2. Responsible innovation theory

The theory of responsible innovation emphasizes that “technological innovation needs to take into account ethical, legal, and social values.” Its specific application in audit practice includes: the dimension of ethical responsibility, which requires the use of technical models in audits to avoid algorithmic discrimination. For example, in credit audit scenarios, it is necessary to prevent unreasonable evaluation bias towards small and micro enterprises by optimizing evaluation indicators, balancing data samples, and other methods to ensure fair and impartial audit

results.

In terms of legal responsibility, it is necessary to clarify the responsible parties for “technical model errors”. For example, model developers should bear 30%–50% of the responsibility, and audit institutions should be responsible for the compliance of the model application process to avoid audit risks that cannot be traced due to unclear responsibility definitions.

In terms of social responsibility, audit work needs to serve the dual goals of “corporate compliance + social governance”, and accurately identify illegal activities such as “money laundering” and “tax evasion” through technological empowerment, providing audit support for maintaining market order and social fairness.

3.1.3. Holistic governance theory

The theory of holistic governance emphasizes “cross departmental and cross level collaboration to solve fragmentation problems”, and its application in auditing is mainly reflected in three aspects of collaboration:

- (1) Cross-departmental collaboration: Audit institutions need to work with the internal finance IT, establish a collaborative mechanism among business departments, break down departmental data barriers, obtain comprehensive data covering the entire process of enterprise operations, and ensure the integrity and relevance of audit data;
- (2) Cross-level collaboration: National, provincial, and municipal audit institutions need to establish a technical tool and data sharing mechanism. For example, a province needs to build a “provincial digital audit platform” to integrate audit resources across the province, covering audit services in 16 cities, and achieve efficient sharing of experience in technology application, data analysis, and risk identification between upper and lower level audit institutions;
- (3) Cross-subject collaboration: Audit institutions need to establish a collaborative linkage mechanism with regulatory agencies (such as the China Securities Regulatory Commission and the China Banking and Insurance Regulatory Commission) to timely synchronize the clues of corporate violations discovered during the audit process to regulatory departments, and receive key regulatory direction guidance from regulatory departments, forming a “audit supervision” linkage force and enhancing the overall efficiency of market supervision and audit supervision.

3.2. Definition of connotation

3.2.1. Definition of refactoring

Based on the above theory, this study defines AI auditing as a new auditing model driven by new quality productivity, based on big data, and utilizing technologies such as machine learning, RPA, and the Internet of Things (IoT) to achieve automated auditing processes, intelligent risk identification, and collaborative governance. It needs to consider both ethical compliance and accountability, and serve the creation of enterprise value and social governance.

3.2.2. Comparison with traditional auditing

Table 1. Comparison of traditional auditing and artificial intelligence audit

Comparative dimension	Traditional auditing	Artificial intelligence audit	Increase margin
Scope of data processing	Sampling data (1%–5%)	Full data (100%)	Risk identification omission rate reduced from 15% to 2%
Audit efficiency	30 people per week	48 hours (AI system)	Efficiency increased by 95%
Risk identification type	Explicit risk (such as incorrect amount)	Explicit and implicit risks (such as concealment of related party transactions)	Hidden risk identification rate increased by 80%
Audit timeline	Post audit (such as annual audit)	Real-time + post audit	Risk response time reduced from 3 months to 1 hour
Personnel skill requirements	Auditing standards + financial Knowledge	Auditing standards + finance + AI technology + business knowledge	The demand for composite talents has increased by 120%
Cost structure	The main cost is labor (accounting for 80%)	Technical cost + labor cost (technology accounts for 40%)	Long-term cost reduction of 30% (after economies of scale)

4. The current practice status of artificial intelligence auditing

4.1. Industry application penetration rate

The AI application rate in the national audit industry is expected to reach 58% by 2025, an increase of 42 percentage points compared to 2020. The financial industry has the highest penetration rate (85%), followed by government auditing (72%), manufacturing (55%), retail (48%), and small and medium-sized accounting firms (32%). The penetration rate in the eastern region is 75%, significantly higher than the 45% in the central and western regions. The core reason is the difference between “technology investment capability” and “talent reserve”.

4.2. Technical application preferences

The application rate of basic technologies such as simple machine learning reaches 80%, mainly used for “repetitive task automation”. The application rate of advanced technologies such as deep learning and big models reaches 45%, mainly concentrated in the fields of finance and government auditing. The application rate of AI + blockchain and other integrated technologies reaches 25%, mainly used in “high-risk scenarios” such as credit audits and tax audits.

4.3. Preliminary feedback on implementation effect

Table 2. Satisfactory feedback upon the implementation of artificial intelligence auditing

Effect dimension	Very satisfied (%)	Satisfaction (%)	General (%)	Dissatisfied (%)	Average satisfaction
Audit efficiency improvement	45	40	13	2	4.2
Risk identification accuracy	38	42	18	2	4.0
Cost reduction	25	35	35	5	3.6
Operational convenience	20	40	35	5	3.4
Interpretability of results	15	30	45	10	3.0

5. Core challenges faced by artificial intelligence auditing

5.1. Data level challenges

The data level is a fundamental obstacle for artificial intelligence auditing, manifested in four major problems:

- (1) Low data quality, including the problem of original vouchers not being digitized in enterprises, inconsistent data formats across multiple systems, a certain error rate in manual input, and lagging updates to enterprise data;
- (2) Data security risks, such as unencrypted storage of sensitive data by audit institutions, lack of encrypted channels for enterprise audit data transmission, and lax control over enterprise data access permissions. A certain institution was fined 2 million Chinese Yuan for violating the Personal Information Protection Law due to data leakage (2024 case);
- (3) Difficulties in data sharing, such as internal data silos within enterprises, lack of sharing mechanisms between audit institutions and banking, taxation and other departments, and cross-border data restrictions on international audit projects;
- (4) High cost of data, with an average annual cost of 500000 to 2 million Chinese Yuan for enterprise digital transformation, 100000 to 500000 Chinese Yuan for professional data cleaning tools, and 50000 to 200000 Chinese Yuan for massive data storage, which small and medium-sized institutions find difficult to afford.

5.2. Technical challenges

The technological constraints on the large-scale application of AI auditing are reflected in four aspects:

- (1) The problem of “black box” models, where deep learning models (such as DeepSeek and GPT) have difficulty tracing the decision-making process and lack a complete evidence chain in their output, which conflicts with auditing standards;
- (2) Poor technical adaptability, as generic models cannot meet industry needs (such as financial anti-money laundering and manufacturing production efficiency auditing), with recognition accuracy within a certain range. Customized models have high costs, and the technology iterates every 6-12 months;
- (3) Insufficient technical stability, where some enterprises have experienced audit interruptions due to the collapse of AI models, and the accuracy of some models has decreased after 6 months of use. AI has a certain misjudgment rate for new types of violations;
- (4) Lack of technical standards, where the model accuracy is within a certain range but there is no qualified threshold, there is no unified standard for data quality, and there is confusion in enterprise selection.

5.3. Ethical and legal challenges

The ethical and legal aspects have sparked compliance disputes, with four core issues:

- (1) Algorithmic ethical risks and data bias leading to algorithmic discrimination, auditors overly relying on AI to shift responsibility, and AI excessively collecting information that violates privacy;
- (2) Legal gap, with no clear regulations on the proportion of responsibility for “AI model errors”, no unified standard for the acceptance of AI audit evidence, and cross-border audits facing conflicts between Chinese and foreign regulations (such as China’s Personal Information Protection Law and the EU GDPR);
- (3) Compliance costs are high, with audit firms spending over 100000 Chinese Yuan annually to learn AI regulations and enterprises spending over 500000 Chinese Yuan to upgrade their AI systems;

- (4) Lag in regulation, with no regulations on model filing and algorithm transparency. Regulatory agencies lack professional tools, and multiple departments have overlapping responsibilities and inefficient collaboration.

5.4. Talent level challenges

The talent level is a key bottleneck for the implementation of AI auditing, manifested in four aspects:

- (1) Shortage of composite talents, whereby auditors have good compliance with the “audit + finance” ability standards, but poor compliance with the “AI technology + business knowledge” ability standards. There are relatively more composite talents in the financial industry, and there are fewer composite talents in small and medium-sized institutions. Most auditors lack data preprocessing and model optimization capabilities;
- (2) Training system is not perfect, with a low proportion of AI courses in auditing majors in universities. Students need 1–2 years of training after graduation, and the average annual training budget for small and medium-sized institutions is less than 50000 Chinese Yuan. Training in large institutions is mostly based on basic operations, and there is little cooperation between universities and enterprises, resulting in insufficient practical experience for students;
- (3) Serious talent loss, with AI audit talents receiving higher salaries than traditional ones, and the competitiveness of audit institutions being lower than that of technology companies. Some composite talents have left due to unclear career development, and the intensity of AI audit work is relatively high, resulting in a serious turnover situation;
- (4) Personnel resistance, such as auditors worrying about AI replacing manual labor, believing that AI system operations are complex, and not believing in AI results.

Even if AI recognizes abnormalities, it still requires 100% manual review, which fails to leverage efficiency advantages.

6. Development path of artificial intelligence audit

6.1. Data level: Building a “high-quality, secure, and shared” data ecosystem

At the data level, three measures need to be taken simultaneously:

- (1) To improve data quality, enterprises should establish a “cleaning verification labeling” process, and link the evaluation of “completeness, accuracy, and timeliness” with KPIs;
- (2) To ensure data security by building technical defenses through “transmission + storage encryption”, “minimum permission control”, and “anomaly monitoring”, formulating the “AI Audit Data Security Management System”, and conducting regular compliance audits;
- (3) To promote data sharing, integrate data from multiple departments through enterprise data platforms, build federated learning platforms across enterprises, and participate in international rule making across borders.

6.2. Technical aspect: Achieving “transparency, adaptability, and standardization”

Breaking through the bottleneck at the technical level requires three points:

- (1) Cracking the “black box” of the model, using explainable AI technologies such as LIME and SHAP, requiring AI to generate an evidence chain containing transaction records and related evidence, and 100%

- manual review of major risk issues;
- (2) To improve adaptability, develop industry-specific models and scenario based modules, and iterate the models every 3–6 months;
 - (3) To improve standards, starting from industry associations to take the lead in formulating the “AI Audit Technology Standards”, establishing a “compliance + security + effectiveness” certification system, and issuing selection guidelines.

6.3. Ethical and legal aspects: Building a governance system of compliance, fairness, and collaboration

We need to make three-dimensional efforts in ethics and law:

- (1) Strengthen ethical governance, conduct regular algorithmic fairness audits, formulate the “AI Audit Ethics Guidelines”, and establish an ethics review committee;
- (2) To improve the legal system, introduce the “AI Audit Legal Responsibility Regulations”, clarify the standards for the acceptance of AI audit evidence, and participate in international legal coordination;
- (3) To optimize supervision, with regulatory agencies using AI monitoring tools, establishing an AI audit filing system and regular regulatory audits, and building a multi departmental collaborative platform.

6.4. Talent and industry level: Creating a “composite and ecological” pattern

Talents and industries need to be driven by two wheels. On the talent side, universities should reform audit courses and establish training bases, industries should provide graded training and promote vocational certification, and enterprises should establish mentorship and rotation mechanisms; Optimize incentives by promoting, simplifying operations, and piloting to reduce resistance.

On the industry side, they should promote tripartite cooperation in developing solutions, organize exchanges with associations, and collaborate on research and development between industry, academia, and research. In addition, it is essential to establish a technology, service, and talent ecosystem, participate in ISO rules internationally, export technology, and promote mutual recognition of certifications.

7. Conclusion

Artificial intelligence auditing is a core paradigm that breaks through the pain points of “sampling limitations, post audit lag, and manual dependence” in traditional auditing. Its development needs to be based on “data elements, driven by technological innovation, with institutional guarantees as the bottom line, and talent adaptation as the core”, and upgraded from “tool assistance” to “governance collaboration” with the help of new quality productivity.

From a practical perspective, the AI application rate in the national audit industry is expected to reach 58% by 2025, but there are significant industry and regional differences. The financial industry and the eastern region have higher penetration rates, while small and medium-sized accounting firms and the central and western regions have lower penetration rates; In terms of technological application, basic technologies are widely used, while advanced and integrated technologies are concentrated in high-risk areas; The implementation effect has high satisfaction in audit efficiency and risk identification accuracy, but low satisfaction in interpretability of results.

The current artificial intelligence audit faces four core challenges: data, technology, ethics and law, and talent. Data quality and security issues are the fundamental obstacles, while technical “black boxes” and adaptability

issues constrain large-scale applications. Ethical compliance and legal gaps have sparked controversy, and the shortage of composite talents is the key bottleneck for implementation.

To promote the development of artificial intelligence auditing, efforts need to be made from four dimensions: data, technology, ethics and law, talent and industry. This includes building a high-quality data ecosystem, achieving technological transparency and standardization, establishing a compliant and fair governance system, creating a composite talent pattern, and working together from multiple dimensions to overcome development obstacles.

Disclosure statement

The authors declare no conflict of interest.

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Research on the Impact of Green Technology Innovation by Muyuan Group on Corporate Performance

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Abstract: Against the backdrop of global climate change and tightening resource constraints, sustainable agricultural development has emerged as a central issue for countries worldwide in addressing environmental challenges. As a major agricultural nation, China's livestock industry accounts for over 35% of the total agricultural output value, serving as a crucial pillar for ensuring national nutritional security and rural economic development. However, traditional farming models have long relied on high-density rearing, excessive use of chemical inputs, and end-of-pipe pollution control measures. These practices have resulted in greenhouse gas emissions accounting for 45% of the agricultural total, an annual generation of over 3 billion tons of livestock manure, and a resource utilization rate of less than 60%. This "high-input, high-emission, low-efficiency" development path has not only exacerbated ecological issues such as soil degradation and water eutrophication but also undermined the industry's international competitiveness and consumer trust due to food safety hazards like antibiotic residues and heavy metal contamination. In this context, Muyuan Group has actively pursued green technology innovation to achieve simultaneous enhancement of economic and ecological benefits.

Keywords: Corporate performance; Green technology innovation; Livestock farming

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1. Literature Review

1.1. Impact of green technology innovation on corporate economic performance

Most scholars generally agree that green technology innovation significantly promotes corporate economic performance in terms of economic outcomes. However, a small number of scholars hold the opposite view. Using a sample of Shanghai and Shenzhen A-share listed companies from 2007 to 2021, Guo found that green technological innovation can significantly enhance a company's economic performance, leading to an increase in its return on assets^[1]. Based on her research, Miao concluded that the implementation of green technological innovation has multiple positive impacts on the performance of highly polluting enterprises^[2]. Nevertheless, Zhou

posited that the process of technological innovation undergoes significant dynamic changes, and investment in innovation does not always directly result in improved corporate performance ^[3].

1.2. The impact of green technological innovation on corporate environmental performance

Current research generally agrees that green technological innovation significantly and positively promotes environmental performance. Zhai believes that it helps companies reduce the costs of complying with environmental regulations, thereby avoiding substantial fines and reputational damage that may result from non-compliance ^[4]. Xue et al. argued that by optimizing production processes and introducing advanced energy-saving equipment, companies can effectively enhance energy efficiency and reduce resource waste ^[5].

1.3. The impact of green technological innovation on corporate social performance

Green technological innovation significantly and positively influences social performance through multiple pathways, such as enhancing corporate image, strengthening environmental compliance, optimizing resource utilization efficiency, promoting harmonious stakeholder relationships, and driving sustainable social development. Zhang et al. found that implementing green innovation strategies can effectively enhance a company's reputation, gain social recognition, and thereby promote its long-term development ^[6].

2. Overview of green technological innovation at Muyuan

2.1. Company introduction

Muyuan Foods Co., Ltd. was established in 1992 and successfully went public in 2014. Nowadays, the company has established a full-chain pork industry layout that encompasses feed processing, pig breeding, pig farming, and slaughter processing. Guided by the core vision of “enabling people to eat safe pork,” Muyuan has always been dedicated to supplying society with high-quality pork products that are safe, delicious, and healthy, thereby helping to enhance the quality of life for the public and safeguarding their wonderful lives. The company has delved deeply into its primary pig farming business and innovatively adopted a “fully self-bred, full-chain, and intelligent” farming model. This approach has not only achieved industrialized production and information-based management in pig farming but also steadily advanced towards intelligent upgrades.

2.2. Drivers of green technological innovation

2.2.1. External drivers

The external drivers of green technological innovation are as outlined below:

- (1) Pressure from policy regulations, as the global attention to environmental issues has been continuously rising, and China has also placed increasing importance on green development and environmental protection. Against this backdrop, the government has successively introduced a series of supportive policies aimed at promoting green technological innovation. Following the proposal of the national “dual carbon” goals, Muyuan has further reduced carbon emissions through measures such as promoting low-soybean-meal diets and constructing distributed photovoltaic power stations to meet policy requirements;
- (2) Market demand compels green technological innovation, where with the upgrading of the consumer market, consumer demand for pork products has shifted from basic supply to a high degree of concern for quality, safety, low carbon emissions, environmental protection, and sustainability. The market share of high-end organic meat products has expanded with significant premiums. At the same time, society's tolerance for

farming pollution has decreased, with environmental regulations and public oversight exerting dual pressures. To meet market demand for “zero-emission, odor-free, and low-carbon footprint” products and seize premium opportunities in the high-end market, Muyuan Group has had to engage in green technological innovation;

- (3) Increased market access thresholds in overseas markets such as Vietnam have stringent environmental protection standards for farming. To expand its international business through technology exports, Muyuan Group must comply with local environmental regulations. For example, the solutions provided by Muyuan to Vietnam’s BAF company for pig farm design, biosecurity, environmental protection, and other aspects all need to comply with international green standards, which compels the company to continuously improve its technological capabilities.

2.2.2. Internal drivers

The internal drivers of green technological innovation are as follows:

- (1) Strategic positioning, whereby Muyuan Group has elevated green and low-carbon practices to a long-term strategic priority for the enterprise, clearly setting the “five environmental protection steps” goal of “zero emissions, no hidden dangers, no odors, reduction of smog, and carbon reduction,” and establishing a full life-cycle carbon management system covering feed, breeding, and waste treatment;
- (2) The breeding industry faces cost pressures from multiple aspects, with feed costs being one of the primary sources. Feed accounts for as much as 60%–70% of the total breeding costs. In 2025, soybean meal prices increased by 28% year-on-year, and corn futures prices broke through the 3,000 Chinese Yuan/ton mark, significantly increasing breeding costs;
- (3) The costs of disease prevention and control cannot be overlooked. In recent years, frequent outbreaks of diseases have required breeding farms to increase investments in disinfection, isolation, and vaccines;
- (4) Small and medium-sized breeding farms may also experience higher incidence rates due to inadequate facilities and extensive management, further increasing treatment costs and breeding cycles;
- (5) Strict environmental protection policies have imposed additional expenses on the breeding industry, such as the transformation of manure treatment facilities. Failure to meet standards may result in fines or business suspensions for rectification.

Coupled with rental costs arising from land circulation and systemic costs caused by outdated supporting facilities and inadequate infrastructure, breeding costs remain high. Traditional breeding models face challenges such as high feed costs, significant losses from diseases, and high environmental governance expenses. Green technological innovation has become the key to overcoming cost dilemmas.

2.3. Current status of green technological innovation at Muyuan Group

Muyuan Laboratory has developed a soybean meal-free diet solution using the concept of green synthetic biology. Without compromising animal production performance, it utilizes crystalline amino acids to achieve soybean meal-free feeding, reducing the breeding industry’s reliance on soybeans and enhancing the stability of the supply chain.

In terms of breeding technology innovation, Muyuan Group has innovatively developed and applied equipment such as intelligent feeding systems, intelligent inspection robots, and intelligent environmental control systems. These systems can dynamically adjust feed formulations based on the age and weight of pigs, ensuring precise feeding. At the same time, they can monitor the breeding environment and pig vital signs in real time, precisely regulating parameters such as temperature and humidity. Regarding air pollution, Muyuan has implemented the application of air-filtered pigsty technology. The air intake end utilizes a four-layer filtration

system, achieving a virus interception rate of 99.3% and a sterilization and deodorization rate of 99.9%. This effectively prevents disease transmission and improves the surrounding environment of the breeding farms.

Muyuan Group has established an ecological model of crop-livestock integration, where pig manure and urine generated during the breeding process undergo solid-liquid separation and anaerobic fermentation. Biogas is reused as a clean energy source, while the liquid portion is converted into liquid fertilizer for surrounding farmland. Pig manure and biogas residue are made into organic fertilizers to meet the fertilization needs of cash crops. Muyuan Group operates over 1,100 breeding farms nationwide, and its established crop-livestock integration system processes 120 million tons of manure annually, serving 4.72 million acres of farmland and reducing chemical fertilizer usage by 154,600 tons. Additionally, the company has established an internal and external dual-cycle water resource utilization system, achieving 100% resource utilization of pig manure and urine, and cumulatively saving 179 million cubic meters of agricultural irrigation water. In terms of energy utilization, distributed photovoltaic power generation facilities have been constructed, promoting a “livestock-solar synergy” model with an annual power generation capacity exceeding 205 million kilowatt-hours and reducing carbon dioxide emissions by 108,400 tons.

The novel biodegradable material developed by the Muyuan Laboratory is recyclable, biodegradable, and has a relatively short degradation cycle. Its performance surpasses that of existing biobased materials on the market and has the potential to fully replace traditional petroleum-based materials in the future. The development of high-performance biobased degradable mulch film material has completed pilot-scale production and demonstration field mulching work.

3. Performance analysis of green technology innovation at Muyuan Group

3.1. Economic performance

It is clear from **Table 1** that the core of Muyuan’s economic performance is reflected in the significant expansion of production capacity. In 2020, the company’s hog slaughter volume stood at 18.115 million head, which had surged to 71.602 million head by 2024, marking a nearly fourfold increase. Particularly after 2021, the growth rate accelerated noticeably, indicating a rapid release of production capacity.

This growth was largely attributable to the widespread application of integrated livestock-crop farming technology. This technology recycles livestock and poultry manure for use as a substitute for traditional chemical fertilizers, helping to reduce costs in the planting sector while also boosting crop yields, thereby providing strong support for the expansion of production capacity.

In terms of cost control, economic performance also showed positive changes. The unit breeding cost gradually declined from a peak of 2,750 Chinese Yuan per head in 2020 to 1,537 Chinese Yuan per head. Soybean meal, a primary component of pig feed that provides the protein source necessary for pig growth, is costly. Muyuan has continuously increased its research and development efforts into low-soybean diets, investing 143 million Chinese Yuan to promote their application. This has reduced soybean meal usage, lowered breeding costs, and also decreased the supply of excess nitrogen, thereby reducing nitrogen and nitrous oxide emissions, achieving simultaneous enhancement of economic and ecological benefits.

However, in terms of changes in operating revenue, economic performance exhibited a certain degree of instability. The operating revenue growth rate peaked at 178.31% in 2020 but subsequently experienced a fluctuating decline, even registering a negative growth rate of -11.19% in 2023. This was primarily due to the persistent sluggishness in the hog market in 2023, with hog prices plummeting significantly. This highlights the significant impact of external market conditions on economic performance. In 2024, market conditions improved, with a rebound

in market demand and an increase in hog prices. Consumers’ willingness and ability to consume pork strengthened, enabling Muyuan to sell its hog products at better prices, thereby driving growth in operating revenue.

3.2. Environmental performance

Through technologies such as crop-livestock integration, amino acid substitution for soybean meal, non-heated pigsties, and air filtration, Muyuan has significantly reduced its carbon emissions. As shown in **Table 1**, the carbon emission intensity has been declining year by year since 2021. Even with a slight increase in 2024, the overall level remains stable. This indicates that green technological innovation has achieved remarkable results in reducing carbon emissions. Meanwhile, the energy consumption intensity has remained stable at around 0.2 over the past five years.

Muyuan has collaborated with local governments and research institutions to implement projects focused on soil improvement, terrestrial vegetation restoration, and biodiversity conservation. The area of improved saline-alkali land has increased from 130,000 mu in 2020 to 318,200 mu in 2024, showing a year-on-year increase. This reflects the positive role of the company’s green technological innovation in ecological governance, particularly in saline-alkali land improvement, and contributes to the improvement of the ecological environment.

3.3. Social performance

Employee training expenditures were 200 million Chinese Yuan in 2020, decreased in 2021, and then increased year by year from 2022 to 2024, reaching 720 million Chinese Yuan in 2024. This demonstrates the company’s growing emphasis on enhancing employee skills and development. By increasing training expenditures, the company supports employee growth and fulfills its social responsibilities. Despite fluctuations, the localization rate of employment has remained at a relatively high level overall, indicating the company’s commitment to providing local employment opportunities and promoting local economic development. The number of agricultural technical services provided has increased from 4,000 in 2020 to 9,293 in 2024, reflecting the company’s efforts to support agricultural technology promotion, industry development, and surrounding agricultural growth through the provision of agricultural technical services, thereby fulfilling its social service functions.

Table 1. Performance table of green technology innovation at Muyuan Group

Performances	2020	2021	2022	2023	2024
Economic performance					
Slaughter volume (10k heads)	1,811.5	4,026.3	6,120.1	6,381.6	7,160.2
Unit breeding cost (Chinese yuan/head)	2,750	2,185	1,798	1,723	1,537
Revenue growth rate	178.31%	40.18%	58.23%	-11.19%	24.43%
Environmental performance					
Carbon Emission Intensity	0.48	1.05	1.00	0.964	1.461
Energy consumption intensity (tce/ton product)	0.17	0.21	0.23	0.20	0.20
Improved saline-alkali land (10k mu)	13	18.52	22.44	22.95	31.82
Social performance					
Employee training expenditure (100 million)	2	1.28	5	7	7.2
Local employment rate	77.02%	74.90%	85.51%	75.98%	84.79%
Agricultural technical services (times)	4,000	8,334	9,680	9,759	9,293

4. Conclusion

The practices of Muyuan Group demonstrated that green technological innovation is not only a fulfillment of environmental responsibilities but also a core driver for enhancing corporate performance. By transforming low-carbon goals into quantifiable technical indicators, resource recycling into cost advantages, and social values into brand premiums, Muyuan has constructed a sustainable development model that integrates “technology-economy-society” triple benefits. This model provides a replicable path for the transformation of traditional agriculture towards a green and low-carbon future.

Disclosure statement

The authors declare no conflict of interest.

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Quantitative Risk Modeling and Portfolio Construction with ARMA-GARCH: An Empirical Study on the S&P 500

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Abstract: This study investigates the return dynamics, volatility structure, and risk characteristics of five representative S&P 500 stocks: Johnson & Johnson, Microsoft, NVIDIA, Coca-Cola, and Home Depot, using ARMA-GARCH models. Descriptive statistics and diagnostic tests confirm non-normality, negative skewness, fat tails, and volatility clustering, providing strong justification for conditional mean-variance modelling. Optimal model specifications are selected via the Bayesian Information Criterion, with EGARCH frameworks generally outperforming alternative GARCH variants in capturing asymmetric volatility responses. Rolling-window forecasts for 2024Q1 show that the models generate stable and reliable volatility predictions for low-volatility stocks (JNJ, KO), while performance is weaker for highly volatile stocks (NVDA), highlighting structural limitations under extreme market shifts. To evaluate risk management implications, one percent Value-at-Risk and expected shortfall were computed and backtested. Results indicated conservative tail-risk forecasts, with violation rates well within acceptable thresholds. Portfolio applications are further explored by constructing the Global Minimum Variance Portfolio (GMVP) and the Maximum Sharpe Ratio (Max SR) portfolio using rolling covariance estimates. Out-of-sample backtesting demonstrated that the GMVP delivered low volatility but modest returns, whereas the Max SR portfolio achieved significantly higher performance, consistent with the risk-return trade-off. Overall, the findings confirm that ARMA-GARCH models are effective tools for modelling conditional volatility and informing dynamic asset allocation. However, their limited adaptability to jump risk and nonlinear structural breaks underscores the need for more advanced modelling approaches in high-volatility environments.

Keywords: ARMA-GARCH; Expected shortfall; Portfolio optimization; S&P 500; Value-at-Risk; Volatility forecasting

Online publication: November 6, 2025

1. Data collection and description

1.1. Selection of stocks

As shown in **Table 1**, the five selected stocks constitute a representative portfolio encompassing growth, defensive,

and cyclical characteristics, consistent with the evidence of common risk factors highlighted by Fama and French ^[1].

Table 1. Selection of stocks

Stock name	Ticker	Sector	Selection rationale
Johnson & Johnson	JNJ	Health care	Low-volatility, defensive stock with stable cash flow and strong profitability, making it well-suited for portfolio inclusion
Microsoft Co.	MSFT	Information technology	A leading technology blue-chip with robust fundamentals and consistent profitability, serves as a representative long-term growth stock
NVIDIA Co.	NVDA	Artificial intelligence	A dominant player in the semiconductor industry, is characterized by high volatility and significant market influence
Coca-Cola Co.	KO	Consumer staples	A classic defensive consumer stock, offers stable earnings and plays a key role in conservative asset allocation strategies
Home Depot Inc.	HD	Consumer discretionary	A high-growth, high-profitability retail stock, is an essential candidate for portfolio construction in consumer-driven sectors

1.2. Descriptive statistics of log returns

Descriptive statistics further support this characterization. As shown in **Table 2**, NVDA has the highest mean return (0.00105) and volatility (SD = 0.03746), confirming its high-risk/high-return profile. JNJ and KO offer lower returns and volatility, reinforcing their defensive nature. All stocks exhibit negative skewness, suggesting susceptibility to extreme negative returns. High kurtosis values indicate fat-tailed distributions, highlighting elevated tail risk.

Table 2. Statistics test of log returns

Stock	Mean	SD	Skewness	Kurtosis
JNJ	0.00030	0.01216	-0.475	17.305
MSFT	0.00039	0.01925	-0.151	12.215
NVDA	0.00105	0.03746	-0.211	16.191
KO	0.00023	0.01307	-0.199	12.264
HD	0.00036	0.01931	-1.092	26.396

Price trends illustrate that HD and MSFT achieved the strongest long-term growth. NVDA, despite a lower starting price, surged post-2016, reflecting its high-growth trajectory. JNJ and KO maintained stable prices with low volatility, underscoring their role as hedging assets (**Figure 1**).

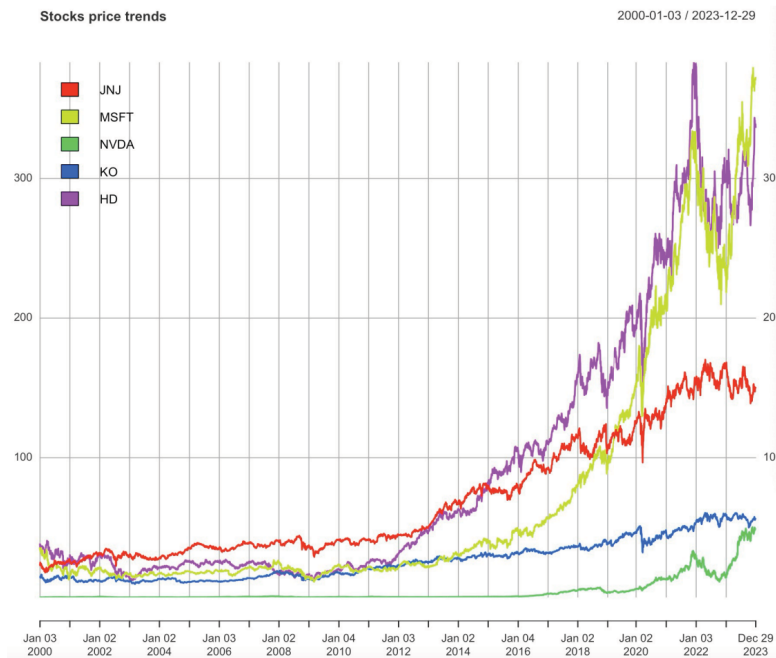


Figure 1. The price trends of varying stocks.

2. Properties of daily log returns

Statistical tests on the daily log returns of the five selected stocks reveal that mean returns are only weakly significant in some cases (e.g., NVDA: $P = 0.0300$; JNJ: $P = 0.0515$), suggesting limited predictive power based on mean alone (**Table 3**). All stocks showed significant skewness and kurtosis ($P = 0$), rejecting symmetry and normal tail assumptions, a result in line with the stylized facts of financial return distributions documented by Fama and French^[1]. This implies leptokurtic distributions, which is typical in financial return data.

The Jarque-Bera test confirms these findings, implying non-normal return distributions with fat tails and asymmetry. The Ljung-Box test identifies strong serial correlation in raw returns, validating the use of ARMA models for the conditional mean. Moreover, all stocks show significant autocorrelation in squared returns ($P = 0$), indicating volatility clustering and justifying the use of GARCH-type models.

Table 3. Statistical tests for log returns

Stock	Mean (P)	Skew (P)	Kurt (P)	JB (P)	LBQ (P)	LBQ (sq- P)
JNJ	0.0515	0	0	0	0.0000	0
MSFT	0.1173	0	0	0	0.0000	0
NVDA	0.0300	0	0	0	0.0001	0
KO	0.1662	0	0	0	0.0088	0
HD	0.1492	0	0	0	0.0000	0

In summary, the empirical tests provide robust evidence that:

- (1) The daily returns of all five stocks are non-normal, asymmetric, and fat-tailed;

- (2) There is strong evidence of both serial correlation and volatility clustering;
- (3) ARMA-GARCH models with appropriate distributional assumptions are well-suited for modeling the return dynamics of these stocks.

3. Modelling and forecasting variance and returns

3.1. Five firms optimal model selection

In the following part, ARMA-GARCH models were systematically constructed based on the daily log return series of the five selected companies. For each company, the optimal model was selected using the BIC to capture the dynamics of return and volatility.

During the mean equation modeling phase, I fit ARMA (p,q) models within the lag range (p,q) ∈ [0,2] to each company's return series:

$$r_t = \mu + \sum_{i=1}^p \phi_i r_{t-i} - i + \sum_{j=1}^q \theta_j \varepsilon_{t-j} - j + \varepsilon_t$$

Here, ϕ_i denotes the AR coefficients, θ_j the MA coefficients, and ε_t is the white noise error term.

$$BIC = -2 \ln (\hat{L}) + k \ln (n)$$

BIC was used as the model selection criterion to ensure a balance between model fit and complexity. Residual diagnostics are then conducted to examine the presence of heteroskedasticity.

As shown in **Table 4**, residuals generally exhibit negative skewness and leptokurtosis. The Jarque-Bera test rejects normality at the 1% significance level, while the Ljung-Box test indicates significant autocorrelation (P-values well below 0.05), justifying the use of GARCH-type models.

Table 4. Residuals diagnostics for ARMA models

Stock	Skewness	Kurtosis	JB-Test	LB-Test
JNJ	-0.5381	17.1535	0	8e-04
MSFT	-0.1695	12.0324	0	7e-04
NVDA	-0.2111	16.1913	0	1e-04
KO	-0.1989	12.2637	0	0.0088
HD	-1.0916	26.3962	0	0

In the volatility modeling phase, I consider SGARCH, GJR-GARCH, and EGARCH frameworks, estimated using the rugarch package in R ^[2]. Using BIC for model selection under the assumption of normal distribution. The optimal GARCH (p,q) structure is searched within (p,q) ∈ [1,2].

For example, in a first-order model:

(1) SGARCH (1,1):

$$r_t = \mu + \varepsilon_t, \varepsilon_t = \sigma_t \varepsilon_t$$

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2$$

(2) GJR-GARCH (1,1):

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \gamma \varepsilon_{t-1}^2 I(\varepsilon_{t-1} < 0) + \beta \sigma_{t-1}^2$$

(3) EGARCH (1,1):

$$\log(\sigma_t^2) = \omega + \beta \log(\sigma_{t-1}^2) + \gamma \frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \alpha \left(\left| \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right| - \sqrt{\frac{2}{\pi}} \right)$$

σ_t^2 represents conditional variance, α measures the immediate impact of return shocks on volatility, and β captures volatility persistence.

The final model selection results for the five companies are summarized in **Table 5**.

Table 5. Optimal ARMA-GARCH models for each stock

Stock	Best ARMA model (p,q)	BIC (ARMA)	Best conditional variance model	BIC (GARCH)
JNJ	ARMA(0,2)	-36097.63	EGARCH(1,1)	-6.3097
MSFT	ARMA(0,1)	-30569.52	EGARCH(2,1)	-5.3746
NVDA	ARMA(0,0)	-22504.64	EGARCH(1,2)	-4.0486
KO	ARMA(0,0)	-35217.35	EGARCH(1,1)	-6.1968
HD	ARMA(0,0)	-30506.04	EGARCH(1,1)	-5.4885

Overall, most stocks exhibit white noise characteristics in their return processes (typically ARMA (0,0) or similar), while their volatility processes show clear asymmetries and lagged shock effects. Among the models considered, EGARCH generally offers superior fitting performance compared to SGARCH and GJR-GARCH.

3.1.1. JNJ ARMA (0,2)-EGARCH (1,1)

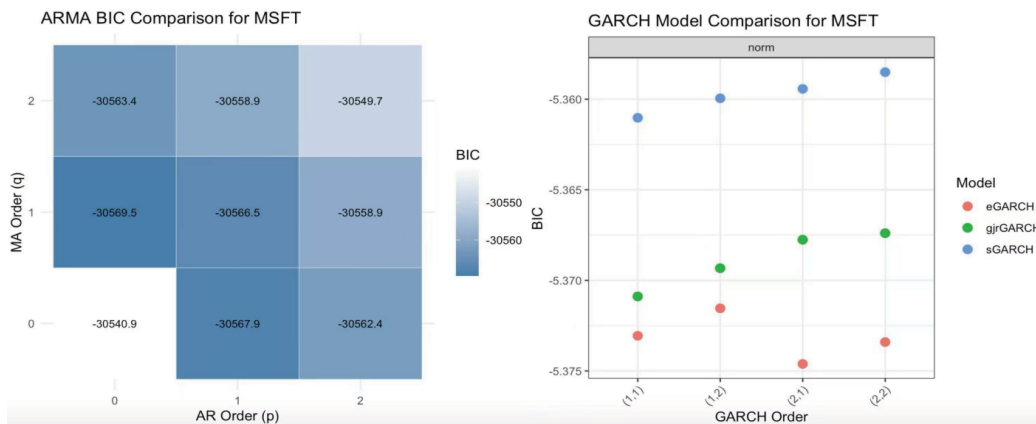


Figure 2. ARMA-GARCH model comparison for JNJ.

3.1.2. MSFT ARMA (0,1)-EGARCH (2,1)

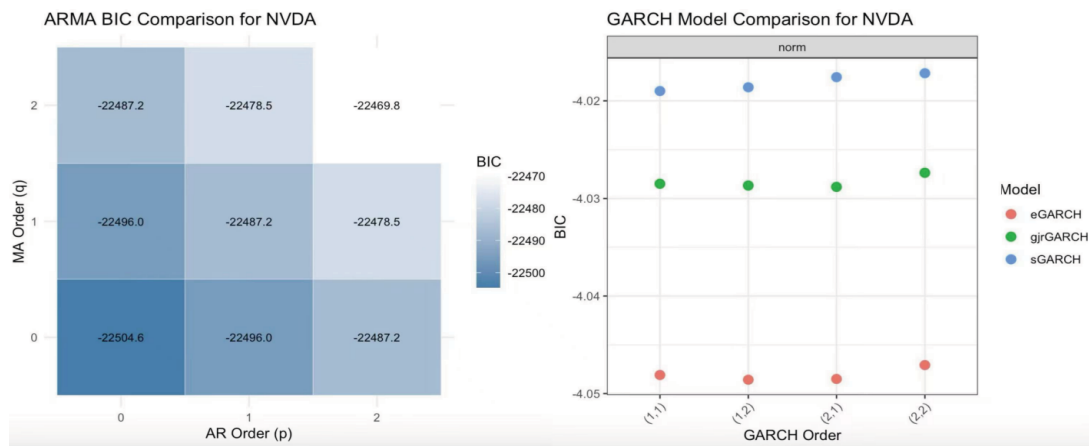


Figure 3. ARMA-GARCH model comparison for MSFT.

3.1.3. NVDA ARMA (0,0)-EGARCH (1,2)

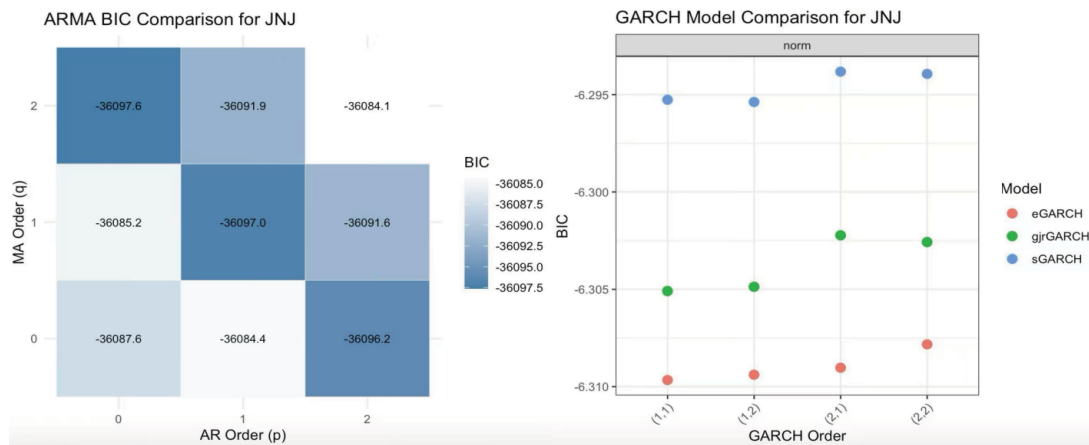


Figure 4. ARMA-GARCH model comparison for NVDA.

3.1.4. KO ARMA (0,0)-EGARCH (1,1)

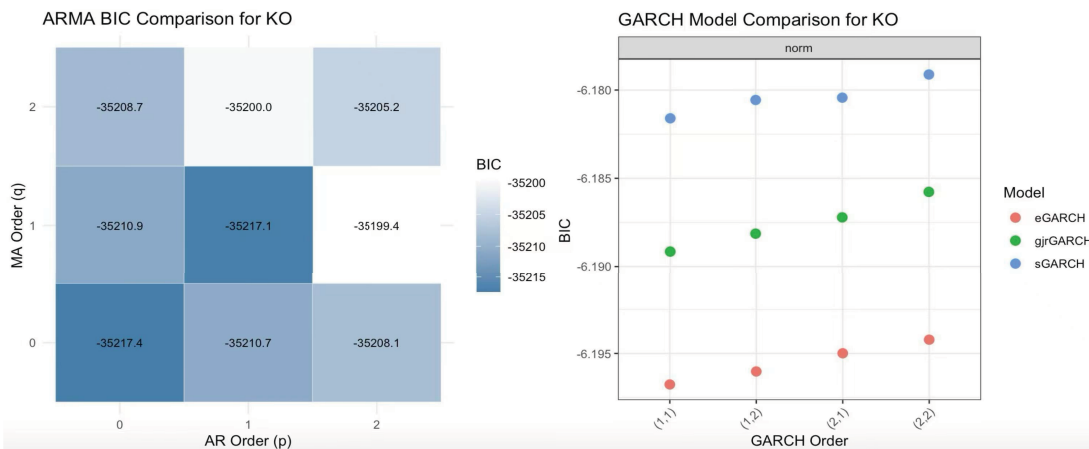


Figure 5. ARMA-GARCH model comparison for KO.

3.1.5. HD ARMA (0,0)-EGARCH (1,1)

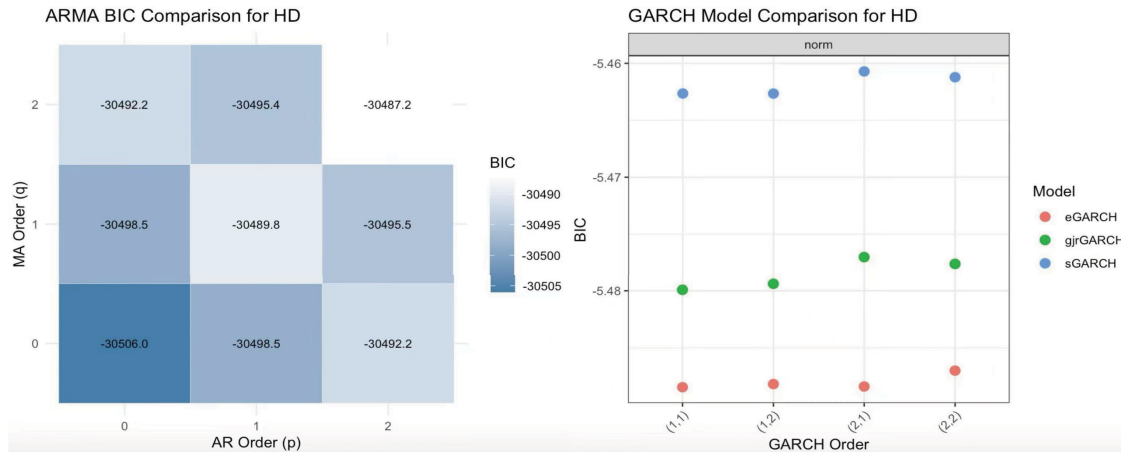


Figure 6. ARMA-GARCH model comparison for HD.

3.2. Forecast daily variance and return for each stock

A rolling window forecasting method was applied to model and predict the daily returns and volatilities of five stocks. To systematically assess the predictive accuracy of the ARMA-GARCH models, the predicted and actual values of return and volatility for 2024 Q1 were compared. The key observations are as follows:

3.2.1. JNJ

As shown in **Figure 7**, the forecasted volatility remains persistently high but generally aligns with actual trends, suggesting the model produces stable daily forecasts but cannot quickly adapt to sudden market shocks.

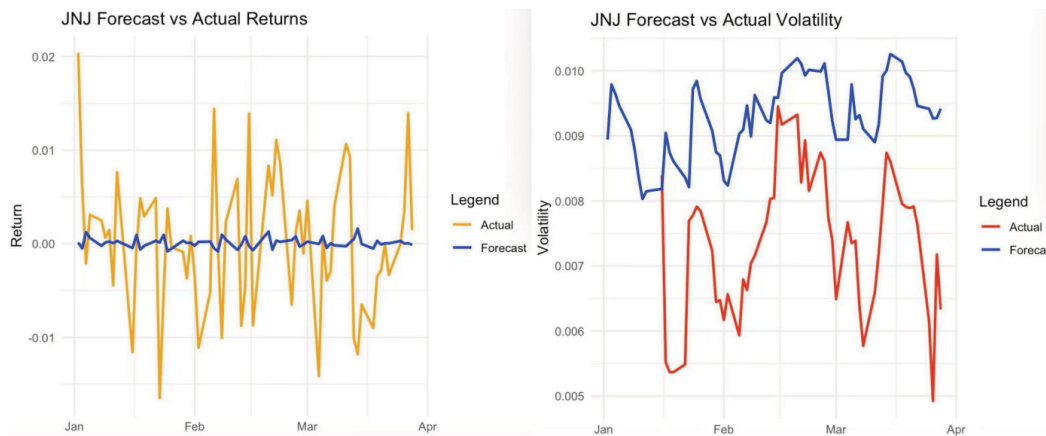


Figure 7. JNJ forecast vs actual returns (left) & volatility (right).

3.2.2. MSFT

Figure 8 indicates that volatility forecasts track the actual values relatively well.

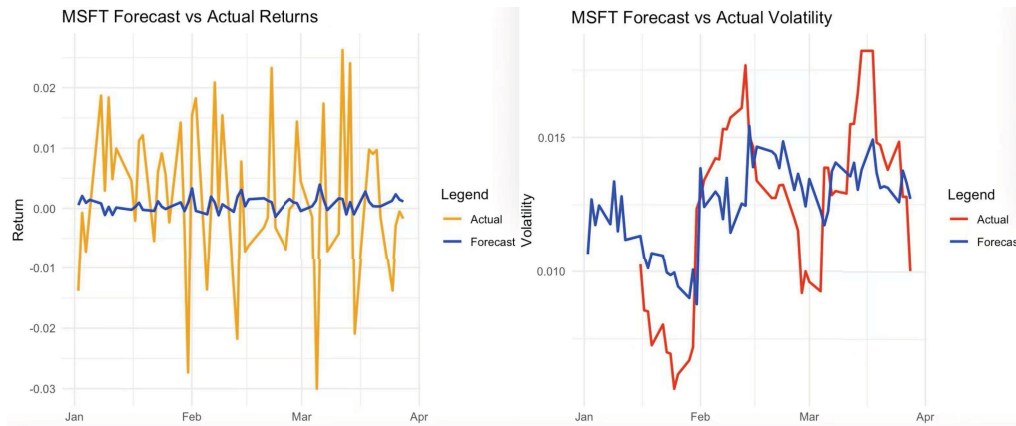


Figure 8. MSFT forecast vs actual returns (left) & volatility (right).

3.2.3. NVDA

As seen in **Figure 9**, actual returns are highly volatile, while forecasted returns show a monotonic upward trend. This indicates that the model struggles with capturing daily fluctuations.

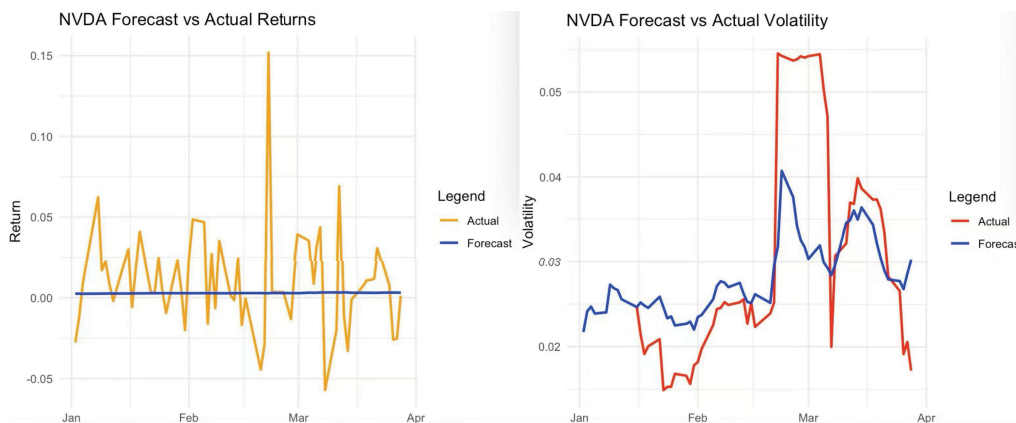


Figure 9. NVDA forecast vs actual returns (left) & volatility (right).

3.2.4. KO

As shown in **Figure 10**, the volatility forecast generally matches actual trends. However, peak timing mismatches suggest lagging adjustment to volatility shifts.

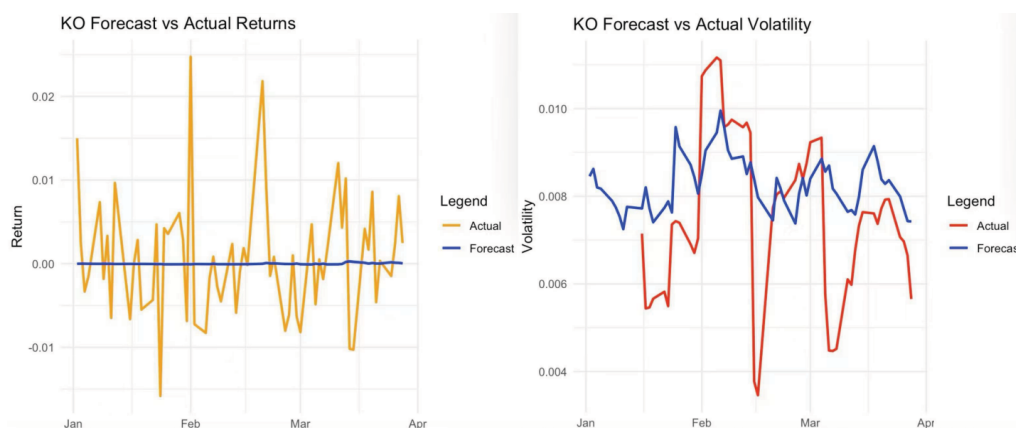


Figure 10. KO forecast vs actual returns (left) & volatility (right).

3.2.5. HD

Volatility forecasts match well in earlier periods, providing some early warning capacity. However, mismatches in later stages suggest lag in capturing real-time shifts (**Figure 11**).

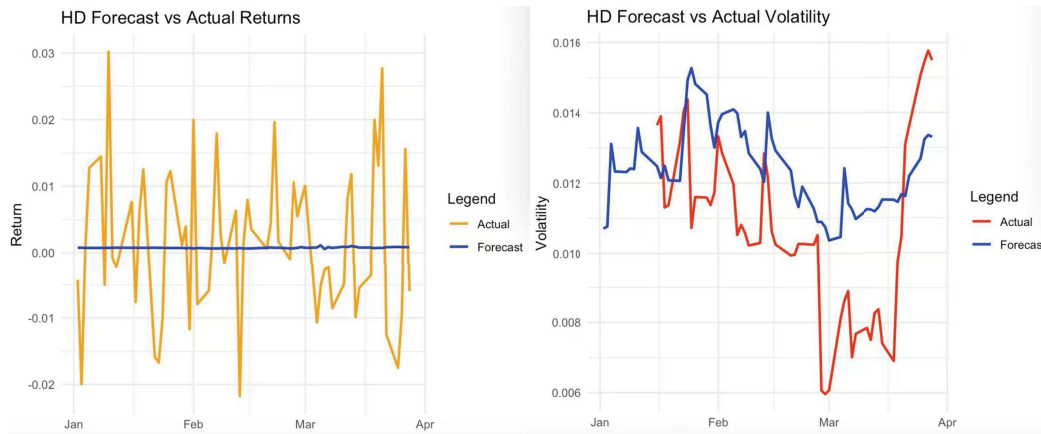


Figure 11. HD forecast vs actual returns (left) & volatility (right).

In summary, the selected ARMA-GARCH models demonstrate a certain degree of capability in identifying and fitting the daily volatility structure of the five stocks, especially in providing stable volatility forecasts. However, their ability to adapt to structural changes in actual returns is limited, indicating a need for more sophisticated models.

The performance evaluation metrics (RMSE and MAE) further confirm these findings:

- (1) Models for JNJ and KO are stable and well-fitted;
- (2) MSFT and HD perform reasonably with acceptable error levels;
- (3) NVDA, due to its high-growth and jump-prone characteristics, requires a more advanced modeling approach.

Table 6. Prediction performance evaluation

Stock	JNJ	MSFT	NVDA	KO	HD
RSME	0.007559139	0.012033189	0.031644395	0.007295385	0.011377432
MAE	0.005939529	0.009358054	0.021840805	0.005446621	0.009195828

4. Value-at-Risk (VaR) calculation

The risk measurement performance of the ARMA-GARCH models was assessed by computing and backtesting the 1% quantile VaR and ES for each stock. For each stock, the 1% VaR was calculated under the assumption of normality using the rolling forecasts of conditional mean and conditional volatility. The formula is:

$$VaR_{1\%} = \mu_t + \sigma_t \cdot z_{\alpha}$$

where μ_t is the forecasted return, σ_t is the forecasted volatility, and z_{α} is the 1% quantile of the standard normal distribution (approximately 2.326)

The following presents the VaR backtesting performance of five stocks during 2024 Q1:

Overall, the actual returns of all stocks, except MSFT, predominantly stayed above the VaR thresholds, indicating that the models were generally conservative and breaches were rare. Volatility levels varied significantly across sectors, with NVDA being the most volatile and KO the most stable.

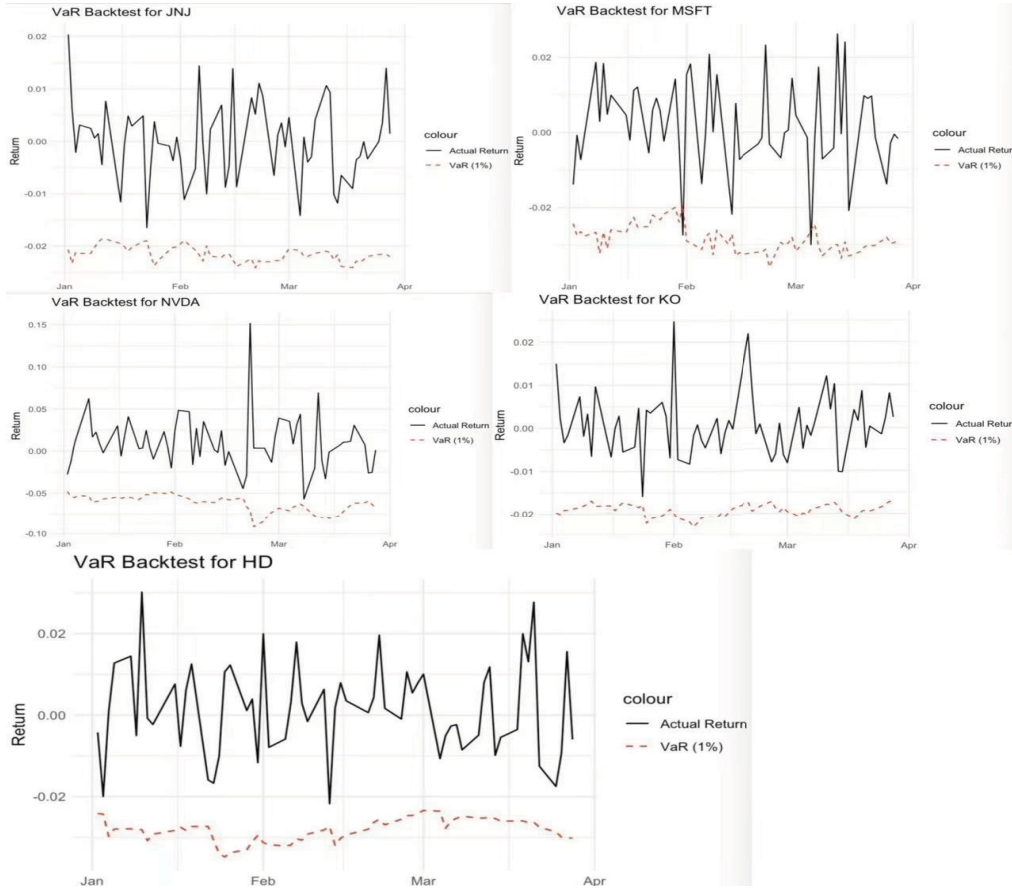


Figure 12. Five stocks 1% value-at-risk.

Following this, the corresponding ES is calculated as:

$$ES_1\% = \mu_t - \frac{\sigma_t \cdot \phi(z_\alpha)}{\alpha}$$

where $\phi(z_\alpha)$ is the standard normal density evaluated at z_α ($\alpha = 0.01$).

This provides a more accurate measure of tail risk.

To evaluate model accuracy and stability, the POF test is applied following Kupiec ^[3]. The results are as shown in **Table 7**, indicating that most models exhibit low violation rates and do not reject the null hypothesis, suggesting the ARMA-GARCH models effectively capture tail risk at the 1% level.

Table 7. VaR backtesting summary

Stock	Violation Rate	Kupiec (<i>P</i>)	ES (sum)
JNJ	0.0000	0.2682	-1.504830
MSFT	0.0328	0.1571	-1.986698
NVDA	0.0000	0.2682	-4.389194
KO	0.0000	0.2682	-1.345106
HD	0.0000	0.2682	-1.971365

Each stock's optimal ARMA-GARCH specification was used to perform rolling forecasts, yielding the following average 1% VaR estimates as shown in **Table 8**.

Table 8. 1% VaR estimate results

Stock	1% VaR estimate
JNJ	-2.15%
MSFT	-2.83%
NVDA	-6.24%
KO	-1.92%
HD	-2.81%

Based on the results, NVDA has a significantly higher 1% VaR than other stocks, indicating potential daily losses of 6.24% or more under extreme market conditions, reflecting higher volatility and greater tail risk. KO and JNJ show the lowest VaR, consistent with the stable nature of defensive stocks. MSFT and HD exhibit similar VaR levels, suggesting comparable risk profiles during the modeling period despite differing industries. These findings inform risk management, where high-VaR stocks may require tighter position control or hedging strategies, while low-VaR stocks can serve as risk buffers in a diversified portfolio.

5. Portfolio analysis

Subsequently, a rolling window estimation and out-of-sample backtesting method was applied to construct and evaluate two classic portfolio strategies (GMVP and Max SR) under the real market environment of 2024 Q1.

GMVP aims to minimize the overall portfolio volatility, the weight vector for the GMVP is calculated as:

$$\omega_{GMVP} = \frac{\Sigma^{-1} \mathbf{1}}{\mathbf{1}' \Sigma^{-1} \mathbf{1}}$$

where Σ^{-1} is the inverse of the covariance matrix and $\mathbf{1}$ is a column vector of ones.

While the Max SR portfolio seeks to maximize the excess return per unit of risk given a risk-free rate, its optimal weights can be represented as:

$$\omega_{MaxSR} = \arg \max_w \frac{\omega'(\mu - r_f)}{\sqrt{\omega' \Sigma \omega}}$$

where r_f denotes the risk-free rate.

Taking into account practical market conditions and optimal portfolio requirements, the following constraints were introduced for both strategies:

- (1) Non-negative weights(no short selling) with the total weight not exceeding 100%;
- (2) The risk-free rate is set at 2%, based on the U.S. Treasury yield hovering around this level in late 2023 and early 2024, ensuring both realism and the stability of the Sharpe ratio calculation;
- (3) A maximum allocation of 30% per single stock, to prevent over-concentration and reduce the impact of individual stock volatility on the overall portfolio.

For each out-of-sample date, to ensure stable and reliable estimation of expected returns (μ_t) and covariance matrices (Σ_t), 1000 trading days were rolled back, as this window length balances the trade-off between the need for sufficient historical information and the relevance to current market conditions, using maximum likelihood estimation:

$$\hat{\mu}_t = \frac{1}{M} \sum_{i=1}^M r_{t-i}$$

$$\hat{\Sigma}_t = \frac{1}{M} \sum_{i=1}^M (r_{t-i} - \hat{\mu}_t)(r_{t-i} - \hat{\mu}_t)'$$

where $M = 1000$, and r_{t-i} is the log return on day $t-i$.

Based on the estimation results, the portfolio weights were re-optimized, and rebalanced daily to form a complete sequence of out-of-sample portfolio returns. The backtest results are shown in **Table 9**.

Table 9. Assets allocation weight table

Stock	GMVP	Max SR
JNJ	30%	0%
MSFT	16.2%	30%
NVDA	0%	30%
KO	30%	20%
HD	23.8%	30%

As shown in **Table 10**, the GMVP portfolio concentrated its holdings in JNJ, KO, and HD, while completely avoiding NVDA. This allocation is consistent with the GMVP's objective of minimizing volatility, given that NVDA exhibited extremely high volatility, as identified in the VaR analysis.

In contrast, the Max SR portfolio, aiming to maximize the Sharpe ratio, preferred high-return assets despite higher volatility. MSFT, NVDA, and HD were each assigned the maximum allowed weight of 30%, with NVDA heavily overweighted to capitalize on its high expected returns.

Table 10. Return performance of the two portfolios

Portfolio	Total-Return ($E[R_p]$)	Annualized-Vol (σ_p)	Sharp ratio
GMVP	6.34%	9.3%	0.43
Max SR	27.86%	20.97%	0.82

The results further highlight the differences in performance: the GMVP achieved an annualized volatility of 9.3% and a relatively low Sharpe ratio of 0.43, with a total return of 6.34%, demonstrating its low-risk, low-return nature. In contrast, the Max SR portfolio exhibited a higher annualized volatility of 20.97%, but achieved a substantially higher total return of 27.86%.

Based on these figures, the theoretical annualized Sharpe ratio without adjustment would be:

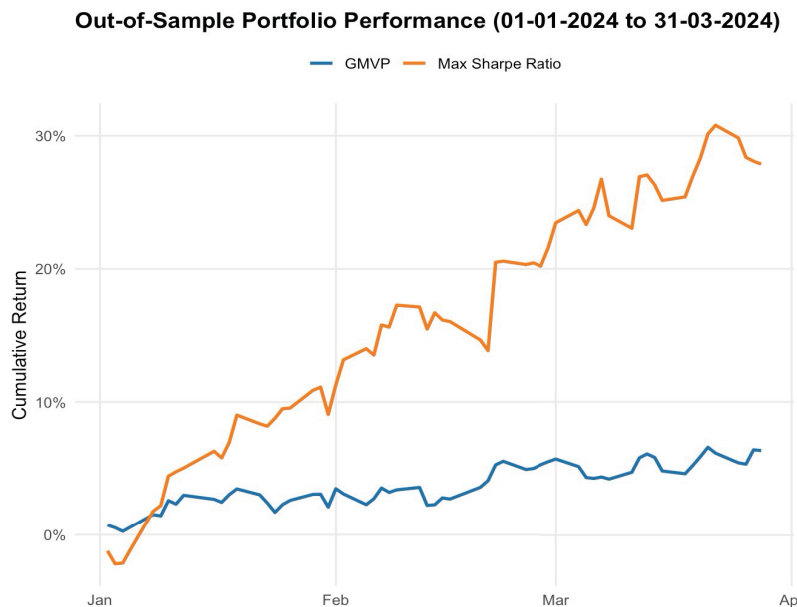
$$\text{Sharpe Ratio} = \frac{E[R_p] - R_f}{\sigma_p} = \frac{27.86\% - 2\%}{20.97\%} \approx 1.23$$

However, based on the R code, the Sharpe ratio is adjusted for the actual number of trading days in the out-of-sample period using the following scaling factor:

$$\text{Adjusted Sharpe Ratio} = \left(\frac{\bar{R}_p - R_f}{\sigma_p} \right) \times \sqrt{\frac{252}{(\text{Period Days}/21) \times 12}}$$

This adjustment corrects for the short evaluation window (three months) to avoid overstating performance. As a result, the final Sharpe ratio for the Max SR portfolio is 0.82. Although the Max SR portfolio assumed greater volatility, it significantly outperformed the GMVP on a risk-adjusted basis.

As illustrated in **Figure 13**, the Max SR portfolio displayed a consistently upward trajectory, with cumulative returns rising sharply and exceeding 30% within three months. Meanwhile, the GMVP portfolio maintained a much steadier and flatter trajectory, with cumulative returns around 5%.

**Figure 13.** Out-of-sample portfolio performance 2024 (Q1).

From an economic perspective, during Q1 2024, the Federal Reserve signaled a potential rate cut, and the AI and technology sectors experienced a strong rally. The Max SR portfolio, by overweighting high-expected-return assets such as MSFT and NVDA during optimization, captured the upward momentum in the market and significantly outperformed the GMVP ^[1].

Overall, the out-of-sample backtesting results validate the effectiveness of the two portfolio strategies. Each portfolio exhibited characteristics consistent with its intended risk-return trade-off, demonstrating robustness and economic plausibility under real-world market conditions.

6. Discussion and interpretation

6.1. The statistical properties of the selected stocks

In summary, the five selected stocks in this study constitute a representative portfolio encompassing growth, defensive, and cyclical characteristics. Based on empirical test results, all return series exhibit non-normality, negative skewness, and fat tails, indicating significant tail risks.

NVDA and MSFT show high market sensitivity and aggressive investment styles, while JNJ and KO demonstrate strong profitability and conservative investment behavior, making them suitable as risk-buffering assets in a portfolio. Moreover, the Ljung-Box test reveals significant autocorrelation and ARCH effects in both return and squared return series for all five stocks, providing a sound justification for the application of ARMA-GARCH models.

6.2. Effectiveness of ARMA-GARCH models

ARMA-GARCH models were selected for each stock based on the BIC, demonstrating strong performance in capturing return autocorrelation and conditional heteroskedasticity. In mean process modeling, most stocks approximate white noise, with low-order ARMA models being sufficient. In volatility modeling, EGARCH models significantly outperformed SGARCH and GJR-GARCH in capturing asymmetry and lagged shock effects.

The selected models fit well in-sample, with standardized residuals showing no significant autocorrelation or heteroskedasticity. Out-of-sample results confirm that the models provide stable volatility forecasts for low-volatility assets like KO and JNJ. However, the models are less effective at handling sudden jumps and nonlinear structural changes in high-volatility stocks like NVDA, suggesting a need for more complex or jump-diffusion models. Rolling forecast results show that predicted volatility generally aligns with actual trends. The 1%VaR estimates closely match actual losses, with the models generally producing conservative forecasts. While this enhances reliability in risk estimation, it may come at the cost of reduced capital efficiency and return potential.

6.3. Portfolio performance and management implications

Using the variance-covariance matrices derived from the ARMA-GARCH rolling forecasts, two classic portfolio strategies were constructed: the GMVP and the Max SR. Out-of-sample backtesting revealed distinct yet theoretically consistent performances. The GMVP exhibited low annualized volatility (9.3%) and a total return of 6.34%, reflecting a low-risk, low-return profile. In contrast, the Max-Sharpe portfolio favored high-return assets (e.g., NVDA, MSFT), achieving a higher total return of 27.86%, higher volatility (20.97%), and a superior Sharpe ratio of 0.82, indicating stronger risk-adjusted performance.

7. Conclusion

These results validate the classic risk-return trade-off: Max SR is better suited to risk-seeking investors, while GMVP aligns with risk-averse preferences and confirms the ability of the ARMA-GARCH model to dynamically describe the volatility and the co-movement relationship between assets in dynamic asset allocation. In practice, different macroeconomic cycles may warrant different portfolio strategies based on individual risk tolerance.

Disclosure statement

The authors declare no conflict of interest.

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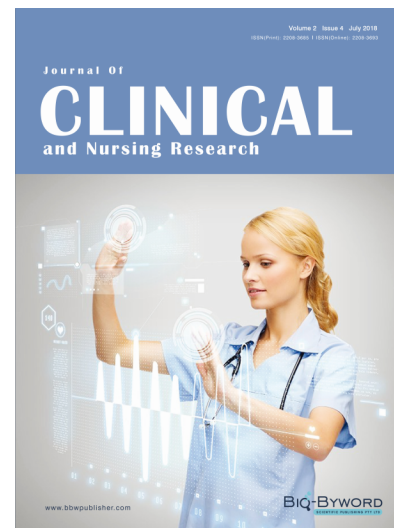
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