to curb fuel consumption in traditional internal combustion engine vehicles, promote energy conservation and emission reductions in passenger vehicles, and advance the production and widespread adoption of new energy vehicles. By employing a quantifiable credit-based system, it aims to balance the development trajectories of conventional and new energy vehicles. The policy mandates that automobile manufacturers comply with specific fuel efficiency standards and new energy vehicle production quotas, thereby exerting profound implications on both traditional and new energy vehicle producers [1]. Traditional automakers face substantial compliance challenges due to higher fuel consumption levels and insufficient credit accumulation. Conversely, while new energy vehicle manufacturers benefit from favorable credit standings, they continue to confront notable barriers in terms of market penetration and scaling up production capacity.

In 2017, the Chinese government introduced the "Dual Credit Policy for Passenger Vehicle Fuel Consumption and New Energy Vehicle Credits", commonly referred to as the "Dual Credit Policy". This regulatory framework comprises two core elements: Corporate Average Fuel Consumption Credits (CAFC) and New Energy Vehicle Credits (NEV) [2]. The CAFC is determined by the deviation between a manufacturer's actual fuel consumption of conventional internal combustion engine vehicles and the prescribed fuel efficiency standard; lower fuel consumption results in higher credit accumulation. The NEV credits are calculated based on the production volume, driving range, and technological classification (e.g., battery electric or plug-in hybrid electric vehicles) of new energy vehicles. If an automaker's average fuel consumption exceeds the regulatory threshold or its NEV credits fall below the mandated proportion, it will accumulate negative CAFC and/or NEV credits, which must be offset through the purchase or carryover of positive credits, including those acquired via inter-enterprise trading. Failure to comply may result in administrative penalties, such as suspension of new model approvals, restrictions on production capacity adjustments, and mandatory compliance rectification measures.

China's automotive manufacturing industry can be broadly categorized into three types: traditional fuel vehicle manufacturers (e.g., FAW Group, SAIC Motor, and GAC Group), new energy vehicle manufacturers (e.g., NIO, Li Auto, and XPeng), and hybrid manufacturers capable of producing both conventional fuel vehicles and new energy vehicles (e.g., BYD, Geely, and Chery). Among these, traditional fuel vehicle manufacturers are typically characterized by high sales volumes and elevated fuel consumption levels. Due to the absence of dedicated new energy vehicle production lines, they often accumulate substantial negative credits under the Dual Credit Policy. Consequently, these manufacturers are required to purchase positive credits directly from the credit market to offset their deficits, thereby incurring significant compliance costs. For example, according to a public announcement issued by the Ministry of Industry and Information Technology of China, the total negative credit balance of all FAW Group-affiliated automakers exceeded 1.7 million points. Based on the relatively conservative credit trading price of RMB 2,000–3,000 per point at that time, the estimated cost for credit compensation reached between RMB 4 to 5 billion yuan. Even after accounting for carried-over positive credits from 2019 within the group, increased NEV sales by FAW-Volkswagen in 2021, and potential bulk-purchase discounts, the total credit compensation still surpassed RMB 3 billion [1]. Where there are substantial losses from credit transactions, there are also notable beneficiaries. According to NIO's financial report, as of the first three quarters of 2021, revenue generated from the sale of 2020 new energy vehicle credits amounted to RMB 517 million, representing 5.27% of the company's total revenue during that period [3]. This contrast clearly underscores the pressing need for traditional automakers to develop strategic alternatives aimed at alleviating financial pressures and effectively meeting regulatory compliance requirements.

Therefore, this study investigates strategic collaborations between traditional automotive manufacturers and new energy vehicle producers within the framework of China's "Dual Credit Policy," with a specific emphasis on Original Design Manufacturing (ODM) strategies. The research seeks to elucidate how ODM partnerships can optimize credit management efficiency, strengthen market competitiveness, and accelerate the adoption of new energy vehicles. Through an in-depth analysis of the operational dynamics and strategic implications of such collaborations, this study aims to deliver actionable insights for policymakers and key industry stakeholders. It highlights both the potential advantages and limitations of ODM strategies in achieving regulatory compliance and facilitating market expansion. Ultimately, the study endeavors to demonstrate that well-structured ODM cooperation can serve as a mutually beneficial solution—enabling compliance with policy mandates while fostering sustainable and resilient growth across the automotive sector.

2. Model framework

Within the contemporary automotive supply chain, in addition to traditional fuel vehicle and new energy vehicle manufacturers, a diverse array of key participants and stakeholders play integral roles. These include component suppliers, dealerships and retail networks, infrastructure developers, recycling and remanufacturing enterprises, technology and digital service providers, logistics and transportation operators, research and development institutions, academic and vocational training centers, financial institutions, end consumers, as well as governmental bodies and industry associations. In recent years, as national subsidies for new energy vehicles have progressively declined, the "Dual Credit Policy" has emerged as a pivotal regulatory instrument driving industrial transformation and technological upgrading [4]. Under the oversight of carbon emission regulators, production planning for both conventional internal combustion engine vehicles and new energy vehicles remains highly sensitive to shifts in policy frameworks.

The central objective of the "Dual Credit" policy is to transition from fiscal subsidies to market-oriented regulatory instruments. On one hand, the policy employs CAFC credits to constrain enterprise-level fuel consumption, thereby compelling traditional automakers to advance fuel-efficient technologies. On the other hand, it progressively increases the mandatory NEV credit ratio to incentivize expanded production and supply of new energy vehicles. The ultimate goal is to simultaneously realize dual technological pathways: achieving energy conservation and emission reduction through improved internal combustion engine efficiency, while scaling up new energy vehicle output. This dual-track strategy aims to foster the development of a comprehensive electrified automotive industry chain and establish sustainable long-term competitive advantages.

However, after several years of implementation, the policy has revealed three critical structural deficiencies. First, persistent imbalances between credit supply and demand have resulted in substantial price volatility. In 2019, an oversupply caused transaction prices to plummet to 200–500 CNY per credit, effectively nullifying the intended economic incentives. Second, the policy's technical thresholds have disproportionately prioritized driving range while underemphasizing energy efficiency and safety standards, thereby incentivizing undesirable behaviors such as "range stacking" and oversized vehicle design. Third, inadequate investment in conventional energy-saving technologies has yielded minimal improvements in fuel efficiency—only a 1.6% reduction in average fuel consumption for internal combustion engine vehicles between 2018 and 2020. Small and medium-sized enterprises (SMEs) face particularly severe financial pressures due to simultaneous deficits in both CAFC and NEV compliance. Moreover, the frequent recalibration of regulatory targets complicates the formulation of medium- and long-term strategic plans, ultimately undermining the policy's intended effectiveness.

3. Interpretation of policy measures for the "Dual Credit" system

The calculation formula for Corporate Average Fuel Consumption credits is as follows: CAFC credits = (CAFC target value - CAFC actual value) * production volume or import volume of passenger vehicles.

Among them, the CAFC compliance target value is obtained by multiplying the enterprise's average fuel consumption target value by the upper limit of the ratio (such as 120%), representing the minimum compliance standard allowed by the policy; meanwhile, the actual CAFC value is calculated based on the weighted average of the actual fuel consumption of vehicle models, with different power types of vehicles adopting different weighting coefficients (for example, fuel vehicles are calculated based on the curb weight, and new energy vehicles are calculated based on zero fuel consumption).

That is, suppose a certain car manufacturer's target value is 6L/100km, the actual value is 7.5L/100km, and the production volume is 200,000 units. Then, the CAFC score = (6 * 120% - 7.5) * 200,000 = -60,000 points.

The formula for calculating NEV credits is as follows:

NEV Credits = Actual NEV Value − NEV Target Value.

Meanwhile, the actual value of NEV credits is determined by the actual production volume of new energy vehicles manufactured by automakers, including but not limited to battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). The specific credit value is calculated separately based on vehicle type classifications and further adjusted through sales volume-based weighting factors. Meanwhile, the NEV compliance threshold is derived by applying a regulatory ratio—such as 0.8 or the revised 0.4—to the total output of traditional internal combustion engine vehicles, thereby reflecting governmental policy support for the promotion of new energy vehicle development.

And the calculation of credits for each vehicle is based on the comprehensive records of previous years. For pure electric passenger vehicles, the credit calculation formula is 0.0056 * R + 0.4 (where R represents the driving range of the electric vehicle under the working condition method, measured in kilometers). When R is less than 100, the credit is 0; when $100 \leq R < 150$, the credit is 1; the upper limit of the credit is 3.4 points. For plug-in hybrid passenger vehicles, each vehicle is assigned a fixed credit value of 1.6. For fuel cell passenger vehicles, the credit calculation formula is 0.08 *P (where P represents the rated power of the fuel cell system, measured in kilowatts; the upper limit of the credit is 6 points).

When the NEV credits of an automaker are positive, these credits can be traded in the credit market, transferred among affiliated enterprises, or carried forward to subsequent years (with the carry-forward ratio decreasing year by year), and NEV credits can be used to offset the negative CAFC credits on an equal basis. Currently, there are mainly two credit compensation strategies in the market. One is to directly purchase NEV credits to offset negative CAFC credits. The other is to obtain NEV credits through the original equipment manufacturer (OEM) model of new energy vehicles, that is, traditional fuel vehicle manufacturers cooperate with new energy vehicle manufacturers, purchasing a certain number of new energy vehicles from new energy vehicle manufacturers at an agreed wholesale price, and then affix their own brand logos to these vehicles and sell them as their own products in the market [5]. In this context, traditional fuel vehicle manufacturers and new energy vehicle manufacturers face the same automotive market demand and compete with each other in the market in a Cournot competition model.

Looking ahead, the "Dual Credit" policy is expected to transition from a "quantity-driven stimulus" to a composite regulatory mechanism emphasizing both “quality enhancement and market stability.” Regulatory requirements will continue to intensify: the NEV credit ratio is projected to rise to 38% by 2025, while the average credit value per vehicle will decline by 40%. The CAFC target will be tightened to 4 L/100 km. Under these conditions, traditional automakers will struggle to meet compliance targets based solely on incremental improvements in fuel efficiency technologies.

The introduction of the credit pool system and the three-year carry-forward mechanism will be implemented concurrently, aiming to stabilize the market by anchoring transaction prices within the range of 2,000–3,500 CNY per credit, thereby mitigating enterprise risks associated with speculative price volatility.

Furthermore, the commercial vehicle segment is poised for inclusion in the policy framework, with hydrogen fuel-cell heavy-duty trucks and battery-swap logistics vehicles emerging as new growth areas. Plans are also underway to integrate carbon emissions from both production and end-of-life disposal stages into the assessment criteria, ultimately aligning with the national carbon market. This evolution will establish a dual regulatory constraint combining “credit obligations and carbon quotas.”

To remain competitive, automakers must adopt strategies centered on “high-efficiency technologies and full life-cycle emissions reduction.” Failure to do so will result in declining competitiveness due to widening credit deficits and rapidly escalating compliance costs.

4. Analysis of the Cournot game model

The foundational assumption of this study is the presence of a duopoly market structure comprising a single traditional fuel vehicle manufacturer and a single NEV manufacturer. From a product differentiation perspective, fuel vehicles and NEVs are considered substitutable goods, with consumers exhibiting substitution preferences between the two. With respect to decision-making, both firms simultaneously determine their respective production quantities. Furthermore, both firms operate under the regulatory framework of the “Dual Credit Policy,” which imposes compliance obligations; non-compliant firms incur credit-related costs. In terms of information structure, the model assumes complete information symmetry, whereby both parties have full knowledge of each other’s cost structures, policy parameters, and underlying market demand. **Table 1** shows the establishment and definition of notation symbols.

Table 1. Symbolic notation in the Cournot game model

Symbol	Implication	Symbol	Implication
q_f	output of fuel vehicle enterprises	q_e	output of new energy vehicle enterprises
p_f	market price of fuel vehicles	p_e	market price of new energy vehicles
c_f	unit production cost of fuel vehicles	c_e	unit production cost of new energy vehicles
π_f	profits of fuel vehicle enterprises	π_e	profits of new energy vehicle enterprises
p_z	market price of points (unit: CNY/point)	α	substitution coefficient between fuel vehicles and new energy vehicles ($0 < \alpha < 1$)

4.1. Demand function setting

Since fuel vehicles and new energy vehicles are substitutes for each other, a linear demand function is adopted here:

$p_f = a - b(q_f + \alpha q_e)$
$p_e = a - b(\alpha q_f + q_e)$

Here, a represents the potential market demand; b is the price sensitivity coefficient; and α indicates the degree of substitution of new energy vehicles for fuel vehicles (the larger the α, the stronger the substitutability).

4.2. Integral cost function

The cost of fuel vehicle enterprise credits is as follows: Fuel vehicle enterprises generate negative CAFC credits due to the production of fuel vehicles and need to offset them by purchasing NEV credits or manufacturing new energy vehicles. Therefore, the credit gap for them is set as:

$$Z_f = \beta q_f - \gamma q_e^{(self)}$$

Among them, β represents the negative credits generated by each unit of fuel vehicles; γ represents the positive credits generated by each unit of new energy vehicles; $q_e^{(self)}$ refers to the number of new energy vehicles produced by the fuel vehicle enterprise through ODM or self-production. If $Z_f > 0$, then the credits need to be purchased at the price of p_z and the cost of the credits is:

$$C_f = p_z * Z_f$$

While the revenue from NEV credits for new energy vehicle enterprises is as follows: New energy vehicle enterprises generate positive NEV credits solely due to their production of NEV, which can be sold for profit. Let the surplus of such credits be:

$$Z_e = \gamma q_e - \delta$$

Here, δ represents the required new energy vehicle credit standard set by policy. If $Z_e > 0$, the credit income is:

$$R_e = p_z * Z_e$$

4.3. Construction of the profit function

(1) Profits of fuel vehicle enterprises:

$$\pi_f = (p_f - c_f) q_f - C_f$$

(2) Substituting the cost of points yields:

$$\pi_f = (a - b(q_f + \alpha q_e) - cf) qf - p_z(\beta q_f - \gamma q_e^{(self)})$$

(3) Profits of new energy vehicle enterprises:

$\pi_e=(p_e-c_e)qe+R_e$

(4) Substituting the integral income, it can obtain:

$\pi_e=(a-b(\alpha q_f+q_e)-c_e)q_e+p_z(\gamma q_e-\delta)$

5. Derivation of Cournot equilibrium solutions

5.1. First-order conditions (FOC)

Take the partial derivatives of the profit function with respect to q_f and q_e, respectively, and set them to zero:

$$\partial\pi_f/\partial q_f=a-2bq_f-b\alpha q_e-c_f-p_z\beta=0$$
$$\partial\pi_e/\partial q_e=a-b\alpha q_f-2bq_e-c_e+p_z\gamma=0$$

By simultaneously solving the above system of equations, the Cournot equilibrium outputs q_f^* and q_e^* can be obtained.

Through comparative static analysis, any number in the "dual credit" policy can be directly mapped to the changes in the output, market share, and profit of enterprises, thus transforming the abstract policy provisions into measurable economic consequences. By using the explicit expressions of q_f^* and q_e^*, the critical points such as "at what level of ODM wholesale price w would traditional car manufacturers prefer to directly purchase credits" and "to what extent should the fuel consumption target be relaxed for the production of fuel vehicles to rebound" can be solved, providing quantitative basis for policy fine-tuning. In addition, by substituting q_f^* and q_e^* into the consumer surplus, enterprise profit, and social welfare functions, the net impact of different credit compensation strategies on the total social welfare and the penetration rate of new energy vehicles can be evaluated, avoiding "guesswork" policy recommendations [6]. In short, the Cournot equilibrium output is the hub that links the "policy parameters - enterprise behavior - market outcome" into a logical chain; without them, the micro-transmission mechanism of the dual credit policy would be impossible to discuss.

5.2. Integration of ODM production strategies

Under the "dual credit" policy, traditional fuel vehicle manufacturers are facing significant credit pressure. To reduce credit costs and quickly enter the new energy vehicle market, some traditional automakers are choosing to engage in ODM cooperation with new energy vehicle manufacturers [7]. It is obvious that the advantage of adopting the ODM strategy lies in that traditional automakers do not need to build new energy vehicle production lines in the short term, which can reduce the cost of transformation; new energy vehicle manufacturers can also obtain stable orders and profit sources. While achieving complementary resources, both sides can jointly enhance overall competitiveness.

Building upon the original Cournot game model, this study incorporates the ODM strategy. The newly added variable definitions are presented in **Table 2** as follows:

Table 2. New variables and definitions after the introduction of the ODM strategy

Symbol	Implication
$q_e^{(odm)}$	Number of new energy vehicles purchased by traditional automakers through the ODM model
w	ODM wholesale price (unit: CNY per vehicle)
p_{e1}	Retail price of ODM new energy vehicles sold by traditional automakers
p_{e2}	Retail price of NEVs sold by new energy vehicle manufacturers themselves

5.3. Market demand function adjustment

As there are two types of new energy vehicles in the market (ODM NEVs sold by traditional automakers and NEVs produced by new energy vehicle manufacturers), it is necessary to set up demand functions respectively:

$$p_{e1}=a-b(q_e^{(odm)}+\alpha q_{e2})$$
$$p_{e2}=a-b(\alpha q_e^{(odm)}+q_{e2})$$

5.4. Reconstruction of the enterprise profit function

The profit sources of the profit function of traditional fuel vehicle enterprises include: profits from selling fuel vehicles; profits from selling ODM new energy vehicles, and the cost (or income) of credits.

$$\pi_f=(p_f-c_f)q_f+(p_{e1}-w)q_e^{(odm)}-p_z(\beta q_f-\gamma q_e^{(odm)})$$

And the profit sources of the profit function of NEV enterprises include: profits from selling self-produced new energy vehicles; ODM wholesale profits and bonus income.

$$\pi_e=(p_{e2}-c_e)q_{e2}+(w-c_e)q_e^{(odm)}+p_z(\gamma q_{e2}+\gamma q_e^{(odm)}-\delta)$$

6. Solution of Cournot game equilibrium

Take the partial derivatives of the profit function with respect to q_f, $q_e^{(odm)}$, and $q_{e2,}$ respectively, and set them to zero (FOC):

$$\partial\pi_f/\partial q_f=a-2bq_f-b\alpha q_e^{(odm)}-c_f-p_z\beta=0$$
$$\partial\pi f/\partial q_e^{(odm)}=a-b\alpha q_f-2bq_e^{(odm)}-w-p_z\gamma=0$$
$$\partial\pi_e/\partial q_e=a-2bq_{e2}-b\alpha q_e^{(odm)}-c_e+p_z\gamma=0$$

By simultaneously solving the above system of equations, the Cournot equilibrium outputs q_f^*, $q_e^{(odm)*}$, and q_{e2}^* can be obtained. Assume that traditional automakers are now permitted to procure $q_e^{(odm)}$ units of new energy vehicles from new energy enterprises at a wholesale price of w=35 CNY per unit for private-label sales. The retail price of these vehicles remains identical to that of the models manufactured and sold directly by new energy enterprises, implying product homogeneity. Accordingly, the updated profit functions are formulated as follows.

(1) Traditional fuel vehicle enterprises:

$\pi_f=(100-q_f-q_e^{(odm)}-q_e^{(self)})q_f+(100-q_f-q_e^{(odm)}-q_e^{(self)}-35)q_e^{(odm)}-p_z(\beta q_f-\gamma q_e^{(odm)})$

(2) New energy vehicle enterprises:

$\pi_e=(100-q_f-q_e^{(odm)}-q_e^{(self)}-30)q_e^{(self)}+(35-30)q_e^{(odm)}+p_z(\gamma^*q_e^{(self)}+\gamma^*q_e^{(odm)}-\delta)$ (Assume that the benchmark for meeting the standard is 0)

Thus, the FOC is:

$$\partial\pi_f/\partial q_f=100-2q_f-q_e^{(odm)}-q_e^{(self)}-40-20=0$$
$$\partial\pi_f/\partial q_e^{(odm)}=100-q_f-2q_e^{(odm)}-q_e^{(self)}-35-30=0$$
$$\partial\pi_e/\partial q_e^{(self)}=100-q_f-q_e^{(odm)}-2q_e^{(self)}-30+30=0$$

Solve the system to obtain the new equilibrium solution: $q_f=7.5, q_e^{(odm)}=7.5, q_e^{(self)}=12.5$, as shown in **Table 3** below.

Table 3. The benefits of both sides under the new equilibrium solution

Indicator	No ODM	ODM	Variation
Production of fuel-powered vehicles	10	7.5	↓25%
Production of fuel-powered vehicles	20	20	keep balance
The credit gap of traditional automakers	20 points	2*7.5−3*7.5=−7.5 points	Turn from negative to positive
The credit gap of traditional automakers	100	156.25	↑56%
Profits of new energy vehicle manufacturers	400	443.75	↑11%

As can be seen from the above, embedding the ODM production strategy into the Cournot game framework is equivalent to endogenizing policy constraints (credits) into the output decisions of enterprises, thereby for the first time explaining the three forces of "compliance costs - cooperative benefits - output competition" within the same mathematical language. First, it can quantitatively answer at what level of wholesale price *w* cooperation will break down; second, it explains why raising the credit price p_z through policy, which seemingly "subsidizes new energy", actually accelerates the ODM demand of traditional automakers; finally, it provides a testable proposition that when *w* is within a certain reasonable range, the profits of both parties will be higher than the "no ODM" benchmark, that is, there exists a cooperation range.

This means that raising the price of new energy credits, the credit value per vehicle, and the credit ratio requirements can simultaneously exert pressure from both the demand and supply sides. On the one hand, traditional fuel vehicle manufacturers, in order to reduce the high compliance costs, will be forced to cut fuel vehicle production and produce a large number of new energy vehicles through OEM methods to obtain positive credits. On the other hand, new energy vehicle manufacturers will also expand production capacity due to the credit premium [8]. The combined force of these two aspects will jointly promote the expansion of the new energy vehicle industry and curb the production of traditional fuel vehicles.

Conversely, if the fuel consumption target is relaxed, the production expectations of traditional fuel vehicle manufacturers will rise, and the resulting negative CAFC credits will also increase simultaneously. To make up for the shortfall, the orders for new energy vehicles from their OEMs will further expand. Although this alleviates the credit pressure on traditional automakers, it leads to a sudden increase in supply and intensified competition in the new energy vehicle market, ultimately squeezing the production volume and profit margins of new energy vehicle manufacturers.

7. Case study

Since its implementation, the “dual credit” policy has become an important policy tool for promoting the green transformation of China’s automotive industry. In the actual implementation process, different enterprises have adopted diverse response strategies, forming rich case study materials [9].

7.1. Typical enterprise cases analysis

As a leading enterprise in the new energy vehicle sector, BYD has achieved significant innovation and autonomous control over core technologies—including batteries, motors, and electronic control systems—through vertical integration of its industrial chain. Under the framework of the “Dual Credit” policy, BYD has accumulated substantial positive credits due to its large-scale production of new energy vehicles. These credits not only fulfill its internal compliance requirements but also generate additional revenue through credit trading. Furthermore, BYD is proactively exploring strategic collaborations with traditional fuel vehicle manufacturers, thereby expanding its market presence through technology transfer and brand partnerships.

NIO specializes in the high-end segment of the new energy vehicle market and has strengthened its brand competitiveness through innovative service models, including battery swapping solutions and user community engagement. Under the framework of the “Dual Credit” policy, NIO has accumulated significant positive credits by producing new energy vehicles with extended driving ranges. Furthermore, NIO has established strategic partnerships with traditional automakers such as Jianghuai Automobile, leveraging their production qualifications and manufacturing capabilities to accelerate product launches and expand its market presence.

Li Auto employs range-extended hybrid technology, effectively mitigating consumer concerns regarding driving range. Under the framework of the “Dual Credit” policy, the company has accumulated substantial positive credits through the manufacturing of range-extended electric vehicles. Moreover, Li Auto is proactively advancing its portfolio of battery electric vehicles to align with anticipated regulatory requirements concerning the proportion of new energy vehicles in the market.

Great Wall Motor has established a comprehensive market presence across both traditional fuel vehicle and new energy vehicle segments through its diversified brand portfolio, including Haval, WEY, and Ora. Faced with the regulatory pressures of the “Dual Credit” policy, the company has significantly enhanced its R&D investment in new energy vehicle technologies, resulting in the launch of multiple plug-in hybrid and battery electric models. Concurrently, Great Wall Motor has implemented technological innovations to improve the fuel efficiency of conventional internal combustion engine vehicles, thereby minimizing the accumulation of CAFC negative credits.

7.2. Cases of corporate cooperation and strategic alliances

As a traditional fuel vehicle manufacturer, Jianghuai Automobile has engaged in contract manufacturing of new energy vehicles through its strategic collaboration with NIO. This collaborative model has not only allowed

Jianghuai Automobile to utilize its excess production capacity but also provided the company with valuable production experience and financial benefits derived from new energy vehicle credits.

BYD and Toyota have initiated a strategic partnership in the new energy vehicle sector, jointly developing battery electric vehicle models. Through this technological collaboration, BYD has further strengthened its innovation capabilities, while Toyota has expedited its new energy vehicle deployment by integrating BYD's advanced battery technology.

8. Policy impact and changes in corporate behavior

The "Dual Credit" policy has exerted a significant influence on corporate behavior within the automotive industry. On one hand, companies have substantially increased their R&D investments in new energy vehicles, thereby driving technological innovation and facilitating industrial upgrading. On the other hand, inter-firm collaborations and strategic alliances have proliferated, enabling enterprises to collectively address regulatory pressures through resource integration and complementary competitive advantages.

Obviously, under the original design manufacturing (ODM) strategy, both traditional fuel vehicle manufacturers and new energy vehicle manufacturers can realize enhanced profitability. As national average fuel consumption (CAFC) targets become progressively stricter, compliance costs for traditional automakers are expected to rise regardless of whether they opt to directly purchase new energy credits or implement the ODM strategy. Nevertheless, the adoption of ODM may potentially lead to increased profits rather than declines. Meanwhile, the mandated proportion of new energy credits and the per-unit credit value are determined by regulatory frameworks and technical specifications, independent of the market price of credits. Furthermore, new energy vehicle manufacturers benefit from increased credit demand, with profits rising as a result of ODM implementation. Should any of the key indicators—such as new energy credit price, credit proportion requirements, or per-unit credit value—increase, the profitability of new energy enterprises would be further enhanced. This analysis aligns with the "2023 Annual Dual Credit Calculation Table" released by the Ministry of Industry and Information Technology in 2024. Among the 141 passenger vehicle manufacturers surveyed, traditional automakers employing the "direct purchase of credits" strategy incurred an average compliance cost of approximately 3,300 CNY per vehicle, whereas those adopting the "ODM branding" strategy experienced a reduction in average compliance costs to the range of 2,100–2,600 CNY per vehicle, thereby substantiating the hypothesis that the ODM strategy effectively reduces credit expenditure [10]. These findings suggest a stronger preference for the ODM strategy over direct purchases in the new energy credit market.

9. Conclusion

In conclusion, this study demonstrates that within the framework of the "Dual Credit" policy, the credit compensation strategies of traditional fuel vehicle manufacturers and new energy vehicle manufacturers do not constitute a binary choice between competition and cooperation, but rather reflect a dynamic equilibrium characterized by both. By integrating the ODM (Original Design Manufacturer) branding strategy into the Cournot output competition model, we reveal that traditional automakers can expand their sales volumes in both fuel-powered and new energy vehicles without investing in dedicated new energy production facilities, thereby achieving minimized compliance costs. Meanwhile, new energy vehicle manufacturers benefit from increased wholesale orders, enabling rapid scale-up of production. Collectively, these strategic interactions contribute to a significant increase in the overall volume of new energy passenger vehicles. Although the adoption of ODM intensifies market and inter-firm competition, its net impact on the penetration rate of new energy vehicles remains positive. Consequently, from a policy perspective, this mechanism serves as an effective instrument for promoting industry transformation through strategic collaboration.

The effectiveness boundary of the ODM strategy exhibits a pronounced dynamic convergence trend—as regulatory pressures intensify and technological advancements accelerate, the cooperation threshold range progressively narrows over time. Enterprises are advised to establish a comprehensive three-dimensional monitoring framework encompassing "policy, technology, and market" dynamics. When the credit price falls below the dynamically calculated unit cost and the collaborating partner is capable of offering a minimum threshold of technology premium compensation, traditional automakers may adopt the ODM strategy to simultaneously enhance new energy market penetration and achieve profit maximization. However, in scenarios where the credit price reaches the upper threshold and the technology premium falls below a critical level, firms should promptly revert to a hybrid defensive strategy combining "credit procurement and incremental, controllable in-house technology development." This evolutionary trajectory is expected to catalyze the emergence of a novel industrial organization model—"policy-driven technology alliances." Concurrently, this dynamic equilibrium is fostering the development of a new competitive-cooperative paradigm in the automotive industry, characterized by the principle of "technology for market."

Disclosure statement

The author declares no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

An Empirical Study on the Impact of China's Virtual Economy on the Relationship between Money Supply and Inflation

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Abstract: This study examines the mechanisms through which China's virtual economy impacts the relationship between money supply and inflation. The study constructs a VAR model and conducts Granger causality tests using data collected from 2010 to 2025. The analysis comparatively investigates the differential effects of money supply changes on key virtual economy sectors, that specifically equity markets and real estate markets. This study reveals a bidirectional causal relationship between China's stock market and M1 money supply, exerting a significant influence on monetary structure. The real estate market demonstrates a pronounced diverting effect on M2, which indirectly impacts the CPI. Virtual economy attenuates the positive correlation between money supply and inflation established by the Fisher Effect, forming a complex mechanism characterized by asymmetric responses under specific conditions.

Keywords: Virtual economy; VAR; Monetary policy transmission

Online publication: September 11, 2025

1. Introduction

Virtual economy represents a major trend in the new era of economic development, having significantly outpaced the growth of physical economy in recent years. Despite China's sustained M2 growth rate exceeding GDP growth for an extended period, consumer price index (CPI) increases have remained consistently moderate, even transitioning through phases of low inflation. Traditional monetary theory primarily focuses on currency circulation and transaction behaviors within the real economy. The emergence of virtual economy has fundamentally altered the liquidity patterns and transactional mechanisms of money. Price fluctuations and trading volume changes in virtual assets influence both money supply and demand, ultimately impacting inflation levels.

The underlying mechanism likely involves monetary funds flowing into virtual economic sectors like stocks and real estate through financial innovation. While this elevates asset prices, the effect isn't fully transmitted to tangible goods prices. Consequently, it leads to monetary deceleration and a phenomenon of virtual-real decoupling, manifesting as a distinctive "Virtue-Reality Divergence" in China's economic operations. This study integrates stock markets and real estate markets within a unified analytical framework. By constructing a Vector Autoregression (VAR) model and conducting Granger causality tests, it systematically reveals how virtual economy differentially influence inflation transmission mechanisms through monetary structure adjustments. The analysis specifically examines variations in how distinct virtual economy sectors mediate the relationship between money supply and inflation.

2. Current status and characteristics of China's virtual economy

The virtual economy typically refers to an economic domain distinct from the physical economy, primarily supported by financial systems. Stock markets and real estate markets are critical subsectors within this framework. The development status of these sectors significantly impacts the overall stability of the virtual economy.

2.1. China's stock market

China's stock market capitalization has demonstrated sustained growth since 2010, expanding from ¥26.54 trillion to ¥85.47 trillion by 2024 as shown in **Figure 1**. This trajectory reflects significant market scale expansion, notwithstanding a modest contraction in recent years that still maintains historically elevated levels. Concurrently, the number of listed companies has exhibited persistent growth, with accelerated expansion in earlier years moderating recently while remaining substantial. These trends collectively indicate historically heightened market transaction activity.

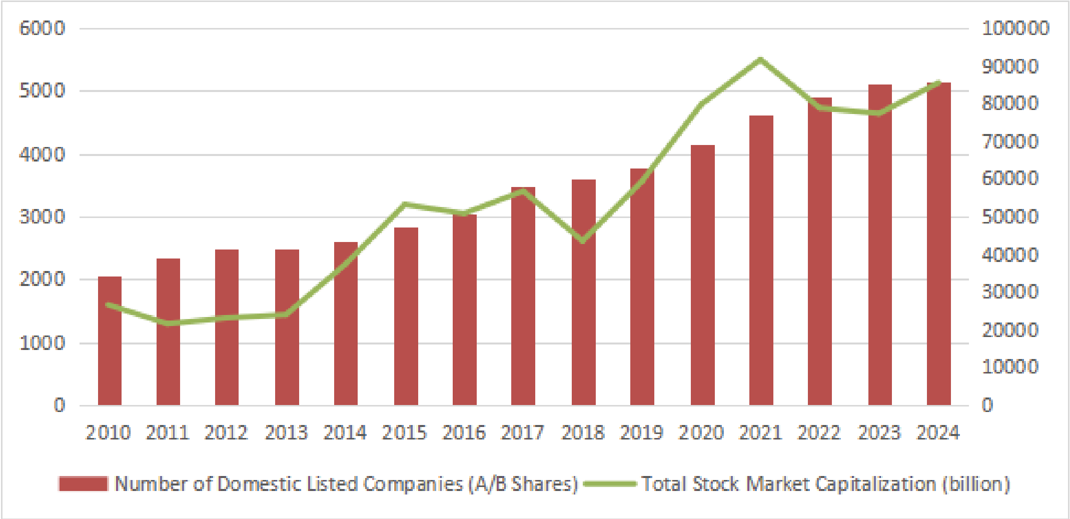

Figure 1. Stock market capitalization and number of listed companies (Source: The National Bureau of Statistics of China).

China's stock market exhibits high trading activity, with the average daily trading volume maintaining over ¥1.2 trillion in 2024. Significant volatility is observed, particularly on the ChiNext Board where the daily turnover ratio reaches 5.36%, that surpassing both the Main Boards (Shanghai/Shenzhen) and the STAR Market. Market fluctuations demonstrate pronounced sensitivity to policy shifts and economic cycles, where favorable policies or economic recovery signals can rapidly boost market and investor confidence.

2.2. China's real estate market

The real estate industry encompasses numerous sectors and has a relatively long industrial chain, exerting significant positive influence on China's overall economic development. As shown in **Figure 2**, after reaching historical peaks during 2016–2017, the sales area and revenue of Chinese residential properties entered an adjustment period; however, housing prices did not experience a noticeable decline during this time. This could be attributed to the continued presence of both improvement-driven demand and investment-driven demand, which supported housing prices. Additionally, regulatory policies in the real estate market helped stabilize housing prices to some extent.

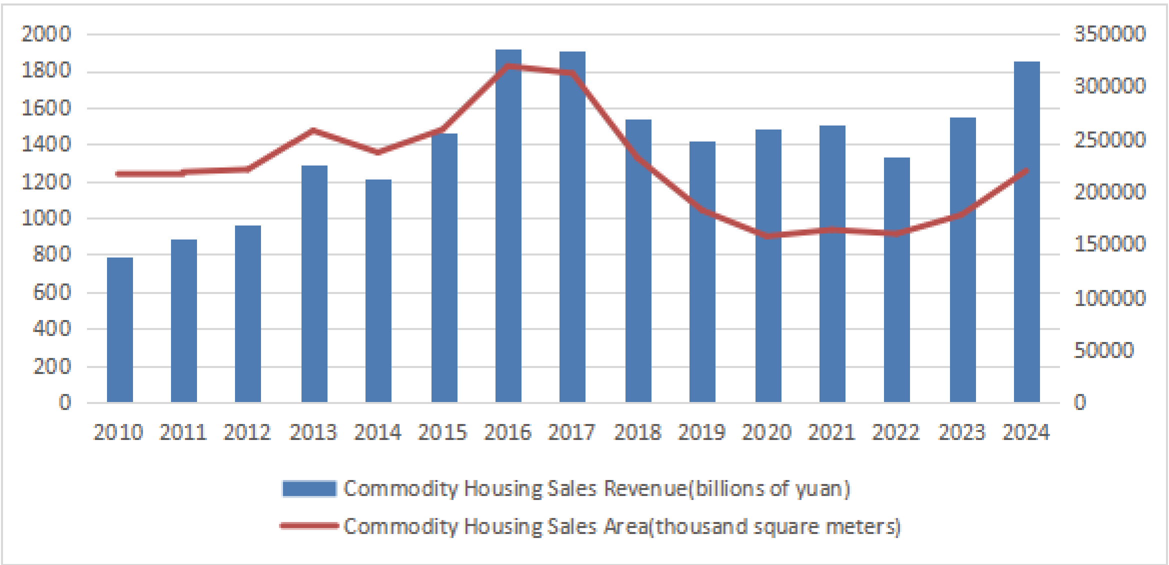

Figure 2. Sales Revenue and Sales Area of Real Estate Market in China (Source: The National Bureau of Statistics of China).

Currently, China's real estate market is undergoing in-depth adjustments, with distinct regional disparities. In first-tier cities and well-known second-tier cities, that characterized by high economic development levels, rational industrial structures, and strong population attraction, where housing demand remains relatively stable. Policy adjustments have swiftly influenced the recovery process of these cities' real estate markets. In contrast, most third and fourth tier cities face weaker industrial foundations, insufficient economic growth momentum, and population outflow issues, resulting in significant housing inventory pressure.

3. Characteristics of the relationship between money supply and inflation in China

During the early stages of monetization in China, there was no strong correlation between money growth and inflation. Subsequently, as the economy continued to expand, the country's money supply has persistently increased, yet the inflation rate has remained relatively stable, fluctuating within a narrow range. No significant inflation has emerged, leading to a prolonged scenario of low inflation coexisting with high asset prices in China.

As shown in **Figure 3**, quasi-money M2 surged from 62 trillion in early 2010 to 320 trillion in February 2025 (projected), marking a fivefold increase. During the same period, however, the CPI rose by only 35%. This phenomenon challenges the quantity theory of money, as the expansion in money supply did not fully translate into inflationary pressures, nor did it exhibit a strictly positive correlation. The reasons for this outcome can be explained through multiple mechanisms in economic theories.

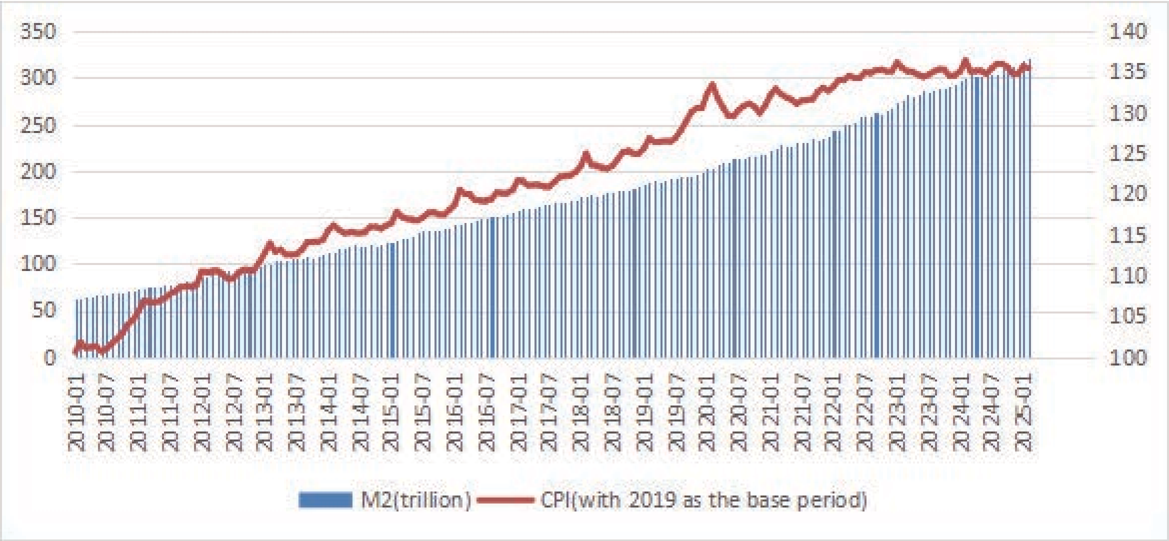

Figure 3. M2 and CPI (Source: The National Bureau of Statistics of China).

3.1. The effect of the stock market on money supply

During a bull market in the stock market, relatively higher investment returns draw substantial capital inflows from alternative avenues such as savings and bonds into equities. The impact of stock prices on money demand primarily operates through two channels: First, by affecting economic entities, stock price fluctuations influence the opportunity cost of holding money, thereby altering the willingness to hold monetary assets. This subsequently affects the speculative demand for money. Second, stock prices indirectly impact money demand through their effect on aggregate supply and demand, as well as financial asset prices. These changes influence domestic income levels and the volume of financial asset transactions, which in turn affect both the transactions demand and precautionary demand for money, ultimately shaping overall money demand.

3.2. Impact of the real estate market on money supply

Due to the high-leverage nature of the real estate sector, it is intrinsically linked with bank credit expansion. Real estate and infrastructure have become the primary engines of credit creation, which makes the credit expansion in the real estate market directly drive the rapid expansion of bank credit, thus increasing money supply. Home purchasing behavior also influences money supply: when housing prices rise, the nominal wealth held by the public increases, relaxing individual budget constraints and boosting the demand for money within the economy, ultimately leading to an expansion of money supply. As housing prices continue to climb, the scale of residential mortgage loans has also grown substantially. The issuance of large volumes of housing loans enables the banking system to create more money.

3.3. The impact of the stock market on inflation

During a stock market boom, rising share prices generate a wealth effect, which increases the value of investors' assets and boosts consumer confidence and spending. Investors may engage in substantial purchases of high-end consumer goods and real estate, driving up the prices of related goods and services and exerting upward pressure on inflation. The appreciation of stock prices also enhances the market value of enterprises, making it easier for them to raise capital through equity financing and expand production capacity. However, if the growth rate of market demand fails to keep pace with the expansion of corporate capacity, it may lead to oversupply, thereby curbing price increases. Conversely, during a stock market downturn, the erosion of investor wealth reduces their willingness to consume and invest, which may lead to price declines and trigger deflationary pressures.

3.3.1. The effect of the real estate market on inflation

Rising housing prices drive up residential consumption costs, which carry significant weight in the Consumer Price Index (CPI) and consequently impact inflation levels. Housing price increases also elevate product prices across the real estate-related industrial chain, thereby triggering inflation. The wealth effect from property appreciation boosts homeowners' consumption expenditure, further driving up prices of other goods and services. However, an overheated real estate market may attract excessive capital inflows, crowding out investment in the real economy. This could lead to a decline in production efficiency, ultimately causing cost-push inflation.

4. Empirical analysis of the impact of virtual economy on money supply and inflation

4.1 Data sources and VAR model specification

The variables selected in this study include: the growth rates of M1 (narrow money supply) and M2 (broad money supply), the month-on-month growth rate of CPI (Consumer Price Index), the return rate of the Shanghai Stock Exchange Composite Index (STK_SH), housing price appreciation (FDC). The time span covers data from June 2010 to February 2025 (as shown in **Table 1**).

Table 1. Descriptive statistics of variables

	CPI	FDC	M1	M2	STK_SH
Mean	0.165706	0.350831	0.264856	0.386502	0.101273
Median	0.1	0.28	0.336592	0.362354	-0.061338
Maximum	1.56	2.83	2.117517	1.593245	10.70827
Minimum	-1.23	-0.92	-3.078937	-0.554221	-15.74994
Std. Dev.	0.498868	0.61559	1.01413	0.411535	3.593767
Skewness	0.17225	1.168624	-0.775488	0.344367	-0.321832
Observations	177	177	177	177	177

This study establishes both a baseline VAR model and an extended VAR model. The baseline model examines the impulse response of CPI to M2. In the extended model, factors from the virtual economy such as the stock market and housing prices are incorporated to analyze and compare changes in the dynamic transmission process relative to the baseline model.

The baseline VAR model is specified as follows:

$$CPI_t = a_{10} + A_{11}CPI_{t-1} + A_{12}CPI_{t-2} + B_{11}M2_{t-1} + B_{12}M2_{t-2} + e_{t1}$$

$$M2_t = a_{20} + A_{21}CPI_{t-1} + A_{22}CPI_{t-2} + B_{21}M2_{t-1} + B_{22}M2_{t-2} + e_{t2}$$

where e_{t1}, e_{t2} are n × 1 error vectors.

The extended VAR model examines the impulse responses of the stock market, housing prices, M1, and M2 to CPI:

$$CPI_t = a_{10} + \sum_{i=1}^{p} A_{11i}\, CPI_{t-i} + \sum_{i=1}^{p} A_{12i}\, \mathrm{STK\_SH}_{t-i} + \sum_{i=1}^{p} A_{13i}\, \mathrm{FDC}_{t-i} + \sum_{i=1}^{p} A_{14i}\, \mathrm{M1}_{t-i} \sum_{i=1}^{p} A_{15i}\, \mathrm{M2}_{t-i} + e_{t1}$$

$$\mathrm{STK\_SH}_t = a_{20} + \sum_{i=1}^{p} A_{21i}\, CPI_{t-i} + \sum_{i=1}^{p} A_{22i}\, \mathrm{STK\_SH}_{t-i} + \sum_{i=1}^{p} A_{23i}\, \mathrm{FDC}_{t-i} + \sum_{i=1}^{p} A_{24i}\, \mathrm{M1}_{t-i} \sum_{i=1}^{p} A_{25i}\, \mathrm{M2}_{t-i} + e_{t2}$$

$$FDC_t = a_{30} + \sum_{i=1}^{p} A_{31i}\, CPI_{t-i} + \sum_{i=1}^{p} A_{32i}\, STK\_SH_{t-i} + \sum_{i=1}^{p} A_{33i}\, FDC_{t-i} + \sum_{i=1}^{p} A_{34i}\, M1_{t-i} \sum_{i=1}^{p} A_{35i}\, M2_{t-i} + e_{t3}$$

$$M1_t = a_{40} + \sum_{i=1}^{p} A_{41i}\, CPI_{t-i} + \sum_{i=1}^{p} A_{42i}\, STK\_SH_{t-i} + \sum_{i=1}^{p} A_{43i}\, FDC_{t-i} + \sum_{i=1}^{p} A_{44i}\, M1_{t-i} \sum_{i=1}^{p} A_{45i}\, M2_{t-i} + e_{t4}$$

$$M2_t = a_{50} + \sum_{i=1}^{p} A_{51i}\, CPI_{t-i} + \sum_{i=1}^{p} A_{52i}\, STK\_SH_{t-i} + \sum_{i=1}^{p} A_{53i}\, FDC_{t-i} + \sum_{i=1}^{p} A_{54i}\, M1_{t-i} \sum_{i=1}^{p} A_{55i}\, M2_{t-i} + e_{t5}$$

where e_{t1}, e_{t2}, e_{t3}, e_{t4}, e_{t5} are n × 1error vectors.

4.2. Granger causality test

The following **Table 2** presented the Granger causality test results. The test outcomes reveal some significant granger causal relationships identified in this study. **Figure 4** illustrated these causal relationships among these variables based on these findings.

Table 2. Granger causality test

Null Hypothesis	Obs	F-Statistic	Prob (*p*-value)
M2 does not Granger Cause STK_SH	175	0.27833	0.7574
STK_SH does not Granger Cause M2	175	0.76122	0.4687
M1 does not Granger Cause STK_SH	175	3.36209	0.037
STK_SH does not Granger Cause M1	175	4.04359	0.0192
CPI does not Granger Cause STK_SH	175	2.77419	0.0652
STK_SH does not Granger Cause CPI	175	4.21185	0.0164
M1 does not Granger Cause M2	175	1.6616	0.1929
M2 does not Granger Cause M1	175	9.8389	9.E - 05
FDC does not Granger Cause M2	175	1.2144	0.2995
M2 does not Granger Cause FDC	175	0.89993	0.4085
CPI does not Granger Cause M2	175	3.33353	0.038
M2 does not Granger Cause CPI	175	9.18601	0.0002
FDC does not Granger Cause M1	175	4.04485	0.0192
M1 does not Granger Cause FDC	175	0.50664	0.6034
CPI does not Granger Cause M1	175	1.31024	0.2725
M1 does not Granger Cause CPI	175	21.8326	4.E - 09
CPI does not Granger Cause FDC	175	0.38638	0.6801
FDC does not Granger Cause CPI	175	2.07418	0.1288

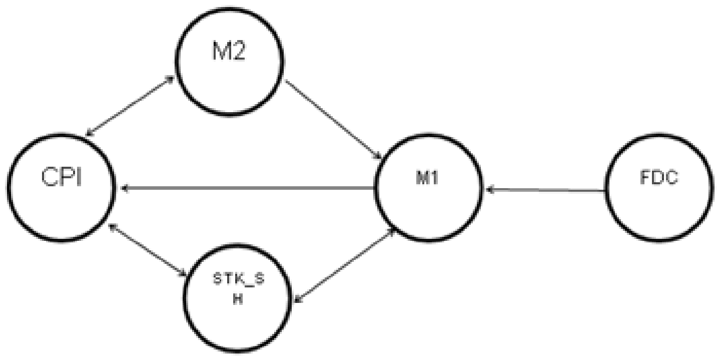

Figure 4. Causal relationships among these variables.

4.3. Impulse response analysis

Here is the impulse response data table for the baseline VAR model. It was observed that the data initially exhibits a positive pulse, which begins to decline into a negative pulse starting in period 2. It then gradually stabilizes and maintains a state close to zero (as shown in **Table 3**).

Table 3. Impulse response data for the baseline model of CPI and M2

Period	CPI	M2
1	0.466385	0.0000
2	0.11686	0.1311
3	-0.04622	-0.048855
4	-0.03507	-0.024013
5	-0.006727	0.004792
6	0.004775	0.002598

The following **Table 4** presents the impulse response results from an extended VAR model incorporating FDC and STK_SH.

Table 4. Impulse response data for the extended model

Period	CPI	M1	M2	FDC	STK_SH
1	0.431030	0.000000	0.00000	0.000000	0.00000
2	0.091449	0.190711	0.040709	0.039210	-0.05638
3	-0.039003	0.085503	-0.104269	-0.003619	0.032695
4	-0.028555	-0.048006	-0.042854	0.019247	0.020614
5	-0.025993	-0.011554	0.007074	0.015456	-0.015456
6	-0.007753	0.003995	0.008019	0.004469	

In the impulse response data of stock prices to CPI, we observe an initial decline forming a negative pulse, followed by an increase resulting in a positive pulse, and then gradual fluctuations before stabilizing. For M1's impulse response to CPI, there is initially a positive pulse that reaches its peak before rapidly declining into a negative pulse. In the case of M2's impulse response to CPI, the data shows an initial small-range increase forming a positive pulse, followed by a decline resulting in a negative pulse. Compared to the baseline model's impulse response data, the positive pulse effect of M2 on CPI weakens while the negative pulse effect intensifies. For housing prices' impulse response to CPI, the data initially experiences a brief rise and consistently maintains a positive pulse.

5. Conclusion

This study analyzes and compares the different effects of changes in money supply on stock markets and real estate markets, which are considered virtual economic sectors. By establishing a baseline model and an extended model, it offers rational explanations for these differing impacts.

In the extended model, we find that the response of CPI to an M1 shock is more pronounced, indicating that the immediate liquidity effect of M1 on price levels is quite rapid. After incorporating stock market variables, it appears that some funds are channeled into the stock market and absorbed by capital markets, thereby weakening the impact of M2 on the real economy sectors. The stock market enhances the short-term driving role of M1 on CPI by altering the structure of money supply, while diminishing the direct transmission effect of M2 on CPI. This effect suggests that fluctuations in the stock market will influence the monetary liquidity structure during monetary policy adjustments, particularly highlighting the signaling role of changes in M1 for short-term price stability.

We also find that after incorporating real estate variables, the impact of M2 on CPI diminishes, while the influence of M1 on CPI continues to show a persistent upward trend. The development and sales of real estate have driven price increases in related industrial chains, which may exert some positive pressure on CPI. If housing prices continue to rise, consumers may curtail other expenditures to accommodate housing costs, thereby suppressing overall consumption demand. Stable housing prices help unlock residents' consumption potential. These dynamic shifts in consumer behavior significantly affect CPI trends. The real estate market alters the transmission mechanism of M2 by absorbing monetary funds, while also influencing M1 through transaction activities, which in turn affects CPI via M1.

Disclosure statement

The author declares no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on the Impact of Artificial Intelligence (AI) on Corporate Finance and Financial Professionals

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Abstract: The development of artificial intelligence has brought tremendous changes to enterprises and also pose higher demands on financial professionals. Through literature research, this paper explores the viewpoints of domestic and foreign scholars and industry experts on the impact of Artificial Intelligence (AI) on corporate financial management and the role transformation of financial professionals. It analyzes the current application status of AI technology in finance. The results indicate that AI will replace some repetitive and highly procedural tasks, such as simple data entry and bookkeeping. AI can improve the processing speed and accuracy of corporate financial data. With its learning capabilities, AI can assist financial professionals in addressing knowledge gaps. However, AI cannot completely replace human thinking, judgment, and decision-making, especially in areas like emotional communication and aesthetic experience. This requires financial professionals to continuously improve their overall qualities, leverage their strengths, and achieve complementary advantages with machines, jointly promoting innovative financial development in the era of artificial intelligence.

Keywords: Artificial intelligence; Corporate finance; Financial professionals

Online publication: September 11, 2025

1. Introduction

In July 2017, the State Council issued the "Development Plan for a New Generation of Artificial Intelligence", clearly stating the need to "promote the industrialization of artificial intelligence technology." In August 2018, the Ministry of Industry and Information Technology released the "Three-Year Action Plan for Promoting the Development of a New Generation of Artificial Intelligence Industry (2018-2020)", calling for pilot demonstrations in key industries such as healthcare, transportation, and education, vigorously promoting smart manufacturing, and building a self-controllable information technology system. Therefore, it is necessary to re-examine financial work, and financial professionals should transition from traditional bookkeeping roles to strategic management roles. The traditional financial management model has become inadequate to meet the demands of rapid modern economic development. How to effectively address this issue using new technologies has become a topic of common concern in both academia and practice [1]. On one hand, enterprises are actively exploring AI-based financial management models; on the other hand, the state has introduced relevant policies to guide and regulate the development of AI. For example, the "13th Five-Year Plan for National Economic and Social Development of the People's Republic of China" proposes implementing smart transformation projects in manufacturing, agriculture, energy, and other sectors. The "13th Five-Year National Informatization Plan" emphasizes promoting the construction of smart cities and the application of emerging technologies such as the Internet of Things, cloud computing, big data, and spatial geographic information integration in areas like government services and city management [2]. The "Guiding Opinions on Accelerating the Establishment of a Government Purchase of Public Services System" proposes advancing structural reforms on the supply side of public services and exploring the use of government purchases to provide public goods and services [3]. The "13th Five-Year National Science and Technology Innovation Plan" proposes accelerating breakthroughs in key generic technologies such as human-computer interaction, natural language understanding, machine learning, and deep learning. These policies not only promote the popularization and application of AI technology but also place higher demands on corporate financial management. Artificial Intelligence (AI) refers to the ability of computer systems to simulate human intelligence, including learning, reasoning, perception, decision-making, and more [4]. Zhang Xinmin points out that financial work is an indispensable part of enterprise operations, mainly including financial accounting, financial analysis, budget management, fund management, tax planning, and other content [5]. Financial work is highly rule-based, repetitive, and data-dependent, making it an ideal field for the application of AI technology. Zhang Guiqiao, Chen Zhibin, and others have pointed out that AI can process large amounts of structured data through automation and intelligent methods, and make predictions and decisions based on algorithmic models, thereby significantly improving the efficiency and accuracy of financial work [6]. In recent years, the application of AI technology in the financial field has gradually deepened. For example, Robotic Process Automation (RPA) is widely used in repetitive tasks such as invoice processing and report generation; machine learning algorithms are used for complex analyses such as financial risk prediction and credit evaluation; and Natural Language Processing (NLP) technology is used for intelligent customer service and contract review [7]. However, the degree of AI application in the financial field varies depending on the industry and region. In highly digitized industries such as finance and technology, the application of AI is more mature [8]; whereas in traditional manufacturing and service industries, the penetration rate of AI is relatively low [9]. Furthermore, there are also gaps in AI application between domestic and foreign countries. Developed countries represented by the United States and the United Kingdom are leading in the research and development and application of AI technology, while developing countries such as China and India are accelerating their pursuit [10]. This article aims to explore the impact of AI on corporate finance and financial professionals, and analyze the current status of AI technology application in the financial field.

2. Current status of AI technology application in finance

Since Turing proposed the concept of Artificial Intelligence (AI) in 1956, AI has developed for more than 60 years. However, China started late in the research and application of AI. It was only in the 1980s that China began to explore the relevant theories and practices of AI.

2.1. Automation of financial processes

In the study of financial process automation, RPA (Robotic Process Automation) and OCR (Optical Character

Recognition) technologies have become important forces driving the digital transformation of finance. These technologies not only focus on the automation of routine processes such as account processing, report generation, and expense reimbursement, but also gradually extend to more complex financial activities, such as automatic reconciliation and budget control [11]. Researchers have delved into how these technologies can standardize and normalize financial processes by simulating manual operations, and how to continuously optimize process efficiency through learning mechanisms. Li Weihong's research not only revealed that RPA has significantly reduced processing time by 70% in accounts receivable management, but also further analyzed how this efficiency improvement can be translated into improved cash flow and enhanced credit management capabilities for enterprises [12]. The study pointed out that the application of RPA reduces human error, improves customer satisfaction, and saves a lot of human resources for the enterprise. Zhao Yan's research on OCR technology in invoice recognition and entry not only achieved an accuracy rate of over 95% but also emphasized the importance of this technology in improving the flexibility and response speed of financial processes [13]. Through OCR, enterprises can quickly process large amounts of paper or electronic invoices, greatly reduce the financial cycle and provide management with more timely and accurate financial information.

2.2. Intelligent financial analysis and decision support

With the advent of the big data era, AI technologies such as machine learning and deep learning are increasingly applied in financial data analysis, risk prediction, investment decision-making, and other related fields. Researchers not only focus on the construction and optimization of algorithmic models, but also actively explore how to combine AI technology with the actual business needs of enterprises to achieve intelligent and personalized financial analysis. For instance, Cheng Ping and other researchers have constructed an enterprise financial risk warning model, which not only achieves a prediction accuracy rate of 85% but also automatically adapts to market changes and identifies potential risks ahead of time. This provides a valuable time window for enterprises to formulate response strategies [14]. Furthermore, research has demonstrated how this model can assist enterprises in optimizing their capital structure and reducing financing costs. Min Tong's analysis of stock market data using deep learning techniques not only provides a scientific basis for investment decisions but also reveals the impact of factors such as market sentiment and policy changes on stock prices [15]. This study highlights the significant potential of AI technology in improving investment decision efficiency and reducing investment risks.

2.3. Intelligent tax management

In the field of intelligent tax management, the application of AI technology is not limited to the automation of tax declarations but also covers various aspects such as tax planning and tax risk control. Through big data analysis, machine learning, and other technical means, researchers deeply explore the value hidden in tax data, providing enterprises with more precise and efficient tax management solutions. Zhang Shaofei has developed an AI-based intelligent tax declaration system that not only improves declaration efficiency and accuracy but also helps enterprises discover potential tax optimization points through intelligent analysis, achieving refined tax management [16]. The system can also automatically update declaration rules based on the latest tax law changes, ensuring tax compliance. Xu Wenwen's research on tax risk identification and evaluation using big data and AI technology not only helps enterprises avoid tax risks but also achieves tax burden minimization through data-driven tax planning [17]. The study points out that AI technology can monitor enterprises' tax status in real time, discover and alert potential tax risk points, providing strong support for enterprises' tax management.

3. The impact of AI technology on financial professionals

3.1. The changing role of financial professionals

With the rapid development of AI technology, the role of financial professionals is shifting from the traditional "accountant" to a "strategic decision support" role. Research mainly focuses on how AI technology is changing the functional positioning of financial professionals and how they can adapt to this transformation. The application of AI technology is replacing basic and repetitive tasks of financial professionals, such as data entry and report generation, enabling them to devote more energy to high-value strategic work. For example, Peng Yan proposes that future financial professionals need to possess capabilities such as data analysis, business insight, communication, and collaboration to better support corporate decision-making [18]. Research indicates that financial professionals need to extract business value from data to support corporate strategy development. Liu Ziqi explores how financial professionals can utilize AI technology to enhance their own value and become drivers of corporate digital transformation. The study finds that financial professionals can optimize financial processes and improve overall corporate operational efficiency by mastering AI tools [19]. This role transformation requires financial professionals to not only possess traditional financial knowledge but also develop cross-domain comprehensive abilities, such as business analysis, technology application, and strategic thinking.

3.2. Changing skill requirements for financial professionals

In the context of AI technology application, significant changes have occurred in the skill requirements for financial professionals. Research primarily focuses on what new skills financial professionals need to master to adapt to the demands of the AI era. The application of AI technology has raised higher requirements for the skills of financial professionals. They need to master skills such as data analysis, programming, and AI tool application to cope with the increasingly complex financial environment. For instance, Fu Yuanlue constructs a capability framework for financial professionals in the AI era, including data analysis ability, business analysis ability, and technology application ability [20]. Research shows that financial professionals need to have data processing and interpretation capabilities, able to extract valuable information from massive amounts of data. Zhang Yaning explores how universities can reform the curriculum system of financial management majors to cultivate financial talents who meet the needs of the AI era [21]. The study finds that future financial education needs to strengthen the curriculum settings of data analysis, programming languages such as Python and R, and other AI tool applications. Additionally, financial professionals need to have strong learning abilities and adaptability to cope with the rapidly changing technological environment [22]. The popularity of AI technology makes it necessary for financial professionals not only to master financial expertise but also to understand the basic principles and application scenarios of technology, enabling better collaboration with technical personnel and promoting the digital transformation of corporate finance.

The application of AI technology is profoundly changing the role and skill requirements of financial professionals. Financial personnel need to shift from traditional accounting roles to strategic roles, while mastering new skills such as data analysis and technology application. This transformation not only places higher demands on financial personnel but also provides new opportunities for their career development.

4. Summary

Artificial intelligence and finance are two different fields, but there is a certain connection between them. Overall, the application of artificial intelligence (AI) in corporate finance will have a significant impact on its development, but it also brings opportunities and challenges to corporate financial personnel. Therefore, enterprises should actively take measures to promote the integration of artificial intelligence (AI) and corporate finance, thereby improving the management level and work efficiency of corporate finance. In the future development, artificial intelligence will become an important productive force and have a profound impact on the financial management of enterprises.

Disclosure statement

The author declares no conflict of interest.

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Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on the Responsibility Traceability Mechanism Based on AI and the Application Boundary of Algorithmic Ethics in Medical Decision Making

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Abstract: With the rapid advancement of medical artificial intelligence (AI) technology, particularly the widespread adoption of AI diagnostic systems, ethical challenges in medical decision-making have garnered increasing attention. This paper analyzes the limitations of algorithmic ethics in medical decision-making and explores accountability mechanisms, aiming to provide theoretical support for ethically informed medical practices. The study highlights how the opacity of AI algorithms complicates the definition of decision-making responsibility, undermines doctor-patient trust, and affects informed consent. By thoroughly investigating issues such as the algorithmic "black box" problem and data privacy protection, we develop accountability assessment models to address ethical concerns related to medical resource allocation. Furthermore, this research examines the effective implementation of AI diagnostic systems through case studies of both successful and unsuccessful applications, extracting lessons on accountability mechanisms and response strategies. Finally, we emphasize that establishing a transparent accountability framework is crucial for enhancing the ethical standards of medical AI systems and protecting patients' rights and interests.

Keywords: Algorithmic ethics; Medical decision-making; Liability tracing; Medical AI; Patient rights protection

Online publication: September 11, 2025

1. Introduction

1.1. Research background and significance

The rapid advancement of artificial intelligence (AI) technology in medicine has led to significant developments in areas such as medical image analysis, treatment planning, and algorithmic decision-making in clinical diagnosis. These technologies are now widely applied, offering powerful tools to support medical professionals. However, their widespread use has also raised increasing ethical concerns, particularly regarding the decision-making process in clinical settings. As AI becomes more integrated into medical practice, ethical and moral considerations must be weighed alongside technical and professional criteria to ensure that patients' rights, autonomy, and dignity are fully respected and protected [1].

The medical decision-making process is basically a complicated ethical decision-making process. At present, the medical decision-making model in our country is still dominated by family medical decisions, especially in the treatment options for serious diseases such as cancer. This decision-making model has created a number of ethical issues [2]. In the context of the intervention of artificial intelligence algorithms in medical decision-making, how to balance algorithmic technology with the subjectivity of doctors, how to ensure that the basic rights of patients are respected, and how to regulate the development of technology for good have become key issues that need to be addressed urgently [3].

Medical ethics includes several important subjects such as human trials and patient rights, which are not only related to academic talks and research, but also deeply affect the development and application of medical and nursing practices. Ethical decision confidence refers to the degree of confidence that decision-makers have in their ethical judgments and moral judgments. In clinical practice, having a high level of ethical decision confidence is critical for medical staff to make good ethical decisions, which helps to better protect patients' rights and interests, provide high-quality care, and ensure that care practices comply with ethical principles [4].

The purpose of this study is to investigate the application boundaries of medical decision-making algorithm ethics. Constructing AI diagnostic system-based responsibility mechanism, and give theoretical support and practical direction. In the field of medicine, for the purpose of making ethical analyze the ethical conundrums of medical decision. In this study, we witnessed that the doctor's professional judgment is divided algorithmic advice in an AI-assisted decision-making environment and how to make sure the decision-making the procedure adheres to moral precepts and how to explain responsibility when things happen to them. This is significant to enhance the ethics of medical decision-making and protecting patients' rights and interests, further promoting the development and progress of medicine and nursing [5].

1.2. Research objectives and methods

By creating a traceable accountability procedure, the main goal of this research is to investigate the ethical limitations of algorithmic decision-making in medical AI systems and to accomplish efficient regulation and evaluation of medical AI systems. This research attempted to solve important problems, such as ambiguous responsibility definitions and algorithmic black boxes, by conducting a thorough examination of the decision-making process in medical AI systems [6]. To create a responsibility traceability assessment model, the research approach integrated empirical research with theoretical analysis.

The time component, risk coefficient, and corresponding weight coefficients were indicated by the following symbols, which stand for the decision factor and the time dimension. Through qualitative analysis, this study addressed the ethical problems faced by medical AI systems in actual applications, including the lack of algorithmic transparency and the problem of trust between doctors and patients. Combined with case study methods, typical medical AI events were studied, key influencing factors were removed, and an evaluation index system was built. In the process of data collection, the principle of multi-source validation was adopted to assure the reliability and universality of the research conclusions.

The purpose of this study was to build a methodological model for analyzing the choice of the AI system quantitatively, as well as by combined fieldwork, expert interviews, and field research in order to build an entire system of responsibility. In addition to efficiently locating possible risks in the process of making decisions, this method also gives the foundation of a theory that is needed to construct a trustworthy medical artificial intelligence system [7].

2. An overview of algorithmic ethics

2.1. Definition and framework of algorithmic ethics

In the context of digital technology, algorithmic ethics are the bottom-line standards for guaranteeing the scientific and reasonable application of medical artificial intelligence systems. It would be possible to comprehend the two main components of this concept: functionality and normality. In terms of normative thinking, algorithmic ethics is the moral standards and value standards that must be adhered to in the design, development, and application of artificial intelligence systems. It attempts to guarantee the upkeep and promotion of human well-being in algorithmic decision-making processes, particularly to ensure that patients' rights are not violated in medical settings from a functional standpoint. In the context of digital technology, algorithmic ethics are the bottom-line standards for guaranteeing the scientific and reasonable application of medical artificial intelligence systems. It is possible to comprehend the two main components of this concept: functionality and normality. In terms of normative thinking, algorithmic ethics is the moral standards and value standards that must be adhered to in the design, development, and application of artificial intelligence systems. It attempts to guarantee the upkeep and promotion of human well-being in algorithmic decision-making processes, particularly to ensure that patients' rights are not violated in medical settings from a functional standpoint.

In the discipline of medical artificial intelligence, the core of algorithm the methodology was balanced in the relationship between technical progress and medical ethical values. This balance could be represented by the algorithmic ethics valuation function. In this case, the algorithm's ethical score was shown, which is the first ethical principle's weight, and the algorithm performs on that principle with the following performance score: the algorithm is in charge of the first. This mathematical model makes the abstract ethical concepts quantifiable by allowing us to measure the ethical evaluation of algorithms.

There are basically four basic pillars that make up the medical algorithm ethics model: responsibility; privacy protection; and transparency. In order to make the process of making an algorithm transparent and understandable; it is necessary to allow patients and staff of the medical system to be able to understand how the AI system approaches particular diagnostic judgments. Fairness places the idea of using algorithms to keep the system from being discriminated against particular populations, make sure that diagnosis outcomes are not affected by variables such as a patient's socioeconomic level; privacy protection concentrates on the security of patients' medical information during collection, storage, and use; liability tracing, however, attempts to identify the responsible party and the course of accountability when problems arise in algorithm-assisted decision-making.

One of the main tenets of artificial intelligence algorithms, with the use of algorithms to make decisions and the replacement of physician decision-making and option rights in medical practice, and the ability to present more automated decision-making features and is becoming increasingly weak. This characteristic is at odds with the fundamental characteristics of conventional medical practice, which gives rise to ethical concerns. According to some academics, the concept of Isaac Asimov ought to be incorporated into machine behavior mechanisms after being processed in a computer that is "computable" and should be incorporated in the process of behavior, and that the concept should be taken into account in order to direct machine behavior through moral principles and ethical norms a computer [8].

2.2. Categories of ethical issues

Ethical issues in the area of medical artificial intelligence are various and might be classified into several main categories based on their scope and type of influence. Data privacy and security problems are the most important ethical problems in medical AI applications, involving the collection, storage, and use of patient sensitive information. The current legal system in China has not yet clearly defined the data rights that extend from patients' privacy. How to protect patients' privacy rights during the application of AI technology has become a big issue that needs to be immediately addressed in the ethical governance of the medical AI industry [9].

Second major ethical dilemma is the question of whether or not fairness and algorithmic transparency are important. Because of the complicated models and huge numbers of parameters of AI algorithms, it is frequently difficult to comprehend and analyze how to make decisions, which is referred to as an "algorithmic black box." This opacity also limited patients from having the right to informed consent and autonomy, which also weakens their confidence and acceptance of decisions. Artificial intelligence technology is directly related to patient rights and medical equity, which are two common ethical issues that arise from algorithmic discrimination, the rationality of algorithmic decision-making, and the problem of transparency.

Third, there is the third moral issue with the definition and allocation of responsibility. Currently, the relevant laws and rules of the law still lack specific guidance, which not only undermines the basis of social morality and legal responsibility, limits the ability to assign responsibility and control decisions, but also gives lawbreakers more opportunity, which further exacerbates public concerns about medical AI technology. Ethical risks such the opacity of the decision-making process, the effect on the role of doctors, and the possible erosion of patients' rights are also new problems because of the application of AI algorithms in healthcare, which has great potential in improving diagnosis and treatment efficiency and optimizing medical services.

The problem of public cognition and attitude is the fourth category of ethical challenge that cannot be ignored. As the end users of medical AI technology, the public's view and attitude directly affect the early development of the product and its practical application in the middle and later stages. The classification of these ethical difficulties helps us obtain a more systematic knowledge of the ethical problems of AI application in the medical field and lays the basis for developing an effective accountability mechanism.

3. Overview of AI diagnostic systems

3.1. Technological developments in AI diagnostic systems

3.1.1. Applications of AI technology in medical care

The medical industry is gradually adopting the use of artificial intelligence technology, especially as it is becoming more and more common in the field of medical imaging diagnosis. With the use of artificial intelligence to perform denoising, image segmentation, and quantitative analysis, AI systems have successfully increased the accuracy of disease diagnosis, efficacy assessment, and prediction of the prognosis [10]. AI technology has been widely used in particular application areas to the diagnosis of diseases such as lung cancer, gastric cancer, thyroid nodules, and diabetic retinopathy. Besides than detecting colonic polyps and adenomas, researchers have created computer-aided detection systems that can evaluate the quality of a colonoscopy. The medical industry is gradually adopting the use of artificial intelligence technology, especially as it is becoming more and more common in the field of medical imaging diagnosis. Using artificial intelligence to perform denoising, image segmentation, and quantitative analysis, AI systems have successfully increased the accuracy of disease diagnosis, efficacy assessment, and prediction of the prognosis [11]. AI technology has been widely used in particular application areas to the diagnosis of diseases such as lung cancer, gastric cancer, thyroid nodules, and diabetic retinopathy. In addition to detecting colonic polyps and adenomas, researchers have created computer-aided detection systems that can evaluate the quality of a colonoscopy.

AI-assisted technologies have been used in the measurement of myocardial strain in the fields of cardiology. With the help of this technology, patients can receive more precise diagnoses and treatment regimens and can increase the accuracy of diagnosis by reducing the amount of labor they need [12] . Artificial intelligence is very likely to be used in the diagnosis of colorectal cancer by medical imaging as deep learning technology has advanced. AI algorithms can assist doctors in identifying possible lesions early by learning and analyzing vast volumes of imaging data.

Despite the advantages of AI technologies in the medical field, its use also has ethical and safety problems. The algorithms of medical AI are described by complicated models and a huge number of parameters, making their decision-making processes sometimes difficult to understand and interpret, creating what is termed a "black box" problem [13]. This opacity not only prevents patients from exercising their right to informed consent and autonomy, but may also undermine patients' trust and acceptance of AI's diagnostic judgments.

As physicians' main authority uses algorithms to improve their ability to make decisions and to uphold the fundamental rights of patients, more and more voices in the development of medical AI are advocating for a return to the subjective position with doctors as the primary body. The best course of action for medical AI applications in the future might be this human-machine collaboration model, which would give patients and the trust of their patients the advantages and dependability of medical decision-making, while also fully utilizing the benefits of AI technology.

3.1.2. Key technologies and their advantages

The creation of medical artificial intelligence diagnostic systems was based on the assistance and application of various important technologies, which were the basis of medical AI as a whole and give clinical diagnosis strong support. Medical artificial intelligence systems mostly use technologies like deep learning, natural language processing, computer vision, and other technologies in terms of their own advantages and are important to the medical field in terms of practical application.

Deep learning technologies have shown to have a substantial advantage in the medical imaging diagnosis. AI-assisted diagnostic systems are capable of denoising, lesion segmentation, and quantitative analysis on medical images, effectively increasing the accuracy of disease diagnosis, as well as the evaluation of prognosis. For instance, in the diagnosis of pulmonary nodules, multiple AI-assisted diagnosis has been used extensively throughout the nation with diagnostic accuracy equal to that of experienced medical [14]. The second Xiangya developed the "Rui Fu System" Hospital of Central University had done very well within the field of skin disease diagnosis. The system can assist in the process of identifying skin conditions including a topic and psoriasis militias with an accuracy rate of up to 95.80% [15].

The significant application of artificial intelligence (AI) in the treatment of patients is the clinical decision support system, or CDSS. these kinds of systems might help clinicians make decisions on a variety of clinical possibilities as well as more precise and efficient ones in the diagnosis, course of the patient, therapy, and so on of a patient [16]. Using AI (the National Clinical Research Center for Kidney Disease) to predict the long-term prognosis risk of IgA nephropathy and can provide decision support to nephrologists in a number of top-tier hospitals in the nation. An additional study was designed to diagnose pediatric pneumonia using both natural language processing and deep learning techniques with an accuracy rate that was similar to that of experienced pediatricians, which was based on a large volume of pediatric patient referral data. An additional study was designed to diagnose pediatric pneumonia using both natural language processing and deep learning techniques with an accuracy rate that was similar to that of experienced pediatricians, which was based on a large volume of pediatric patient referral data. An additional study was designed to diagnose pediatric pneumonia using both natural language processing and deep learning techniques with an accuracy rate that was similar to that of experienced pediatricians, which was based on a large volume of pediatric patient referral data. An additional study was designed to diagnose pediatric pneumonia using both natural language processing and deep learning techniques with an accuracy rate that was similar to that of experienced pediatricians, which was based on a large volume of pediatric patient referral data. An additional study was designed to diagnose pediatric pneumonia using both natural language processing and deep learning techniques with an accuracy rate that was similar to that of experienced pediatricians, which was based on a large volume of pediatric patient referral data.

Medical theories and medical technologies show great potential; however, there are ethical difficulties with the ability of the decision-making process; the effect of algorithming; the harm of physicians; and the deterioration of patient rights as well. The emergence of medical artificial intelligence will need to maintain a people-oriented value orientation in order to keep that decision, which will guarantee that algorithmic decisions always satisfy the requirements of human health, to keep the technological layer from becoming more and more complicated, and to continuously improve the situation of changing medical situations.

4. Future direction

With the continuous development of artificial intelligence technology, the application prospects of AI diagnostic systems in the medical field are getting more and more broad. Medical AI systems are moving towards higher precision, greater interpretability and a wider variety of application situations. These developments will bring new changes to medical practice, along with new ethical difficulties.

The technical development of artificial intelligence diagnostic systems will focus more on algorithmic transparency and explainability. “The black box” nature of the current AI decision-making process makes it difficult for doctors and patients to understand the reasons for their recommendations, which not only affects trust between doctors and patients, but also weakens patients’ compliance with medical treatment plans [17]. Future artificial intelligence systems will make the medical decision-making process clearer by increasing technological transparency and explainability, helping patients exercise their right to informed consent and autonomy, and increasing trust in AI-assisted decision-making. This tendency is not only a requirement for technological advancement, but also an unavoidable choice to address ethical problems.

Medical AI systems will pay more attention to value orientation and ethical standards. In the face of the possible threat of AI algorithm decision-making to patients’ basic rights, future developments will adhere to a people-oriented value orientation, improve the knowledge boundaries and value benchmarks of AI algorithms, and further define patients’ rights such as data autonomy, privacy, right to know, and right to use. By clarifying the scope of patient rights, the “domestication” of algorithmic technology will enable medical AI algorithms to be morally just, therefore increasing diagnosis and treatment efficiency and optimizing medical services while effectively avoiding ethical risks.

Interdisciplinary integration will be a major trend in the development of medical AI. Future medical AI technologies will be more closely integrated with medicine ethics, law, sociology and other disciplines to create a fuller ethical governance structure. This integration is not only shown in the technical part, but also in institutional design, responsibility distribution and the construction of social consensus. Through interdisciplinary collaboration to jointly address ethical problems that arise in the application of medical AI, such as algorithmic puzzles, data security issues, accountability problems, and social equity issues, it provides a good foundation for the sustainable development of AI technology in the medical field.

4.1. The current status of artificial intelligence diagnostic system applications

4.1.1. Data privacy and security issues

The use of medical artificial intelligence systems has becoming more common as a means of gathering, storing, and processing data because they are unable to perform without the need for large amounts of medical data and the security protection of patient privacy data. Patients' medical records, genetic information, diagnosis results and so on, are the examples of sensitive information that is included in clinical data. When AI is diagnosed, these data might be at danger of being made public or not accessible.

Medical data protection mainly depends on three levels. In the data collection process, patients' small information may be leaked if they are not controlled by medical staff or intentionally leaked by insiders. Technical issues such as system weakness and hacking might result in the theft of database data during the data storage phase. When processing data in the training of artificial intelligence models in the data application phase, there may be privacy leakage [18].

In order to deal with these security issues, a reliable data protection system must be developed. Clinical data should be desensitized and the informed consent of patients should always be strictly enforced when collecting data. To guarantee data security, strict encryption approaches and access control procedures should be used during data transmission and storage. Privacy computing techniques are useful tools for using data to secure patients' privacy in the training of AI models.

4.1.2. Ethical compliance assessment

The process of guaranteeing that medical AI is applied rationally is known as ethics compliance evaluation, which is an important first step in the process of making sure the system is used reasonably. Ethical governance in the field of medical AI focuses on factors such as fairness, algorithm openness, and the protection of patient privacy. The four guiding principles of medical ethics should be the foundation of the ethical compliance assessment system; this is why the AI should be expanded to create an assessment matrix that can be used to express the weights of each dimension as follows

In this section, the total number of evaluation dimensions, which stand for the weight of the ethical dimension, and the score of that dimension are shown.

Algorithmic black box problems are particularly significant throughout the evaluation process. The decision-making procedure of medical AI systems is generally difficult to understand and interpret, which not only limits patients from exercising their right to informed consent and autonomy, but also undermines patients' trust and acceptability of decisions. Therefore, developing explainable AI algorithms that increase their legitimacy and enable healthcare practitioners to grasp and accept their results has become one of the key indicators in ethical compliance assessment [19].

Another important component of evaluation is patient data protection. A lot of patient data is being used in the process of creating and validating AI models, which increases the possibility of losing patient privacy by raising the sensitivity and specificity of the models, all of which are highly sought after by the enormous amount of patient data. Ethical disputes have also increased as medical institutions use patient data on a large scale for AI model training without getting patient informed permission [20].

Besides that, an assessment on ethics compliance should also focus on the issue of identification of responsibility. In case of the AI intervention there are some medical controversies about using artificial intelligence which is the need to deal with the problem of medical injury traceability and liability division by the new legislation and regulations, so that the responsibilities of each party can be clearly seen in the medical decision-making process, the evaluation system should include the assessment of the effectiveness of accountability mechanism in this regard, so as to ensure that the roles of every party can be seen clearly in the process of medical decision-making.

4.1.3. Collaboration between healthcare personnel and AI

Healthcare workers and the use of artificial intelligence systems are changing the way they work together. The widespread use of AI in the healthcare industry means that medical practitioners must modify their approaches to fit the needs of human-machine cooperation and consider the use of these technologies to be an effective means of auxiliary assistance. Physicians may more precisely identify lesions by using AI-assisted image analysis, such as CT and MRI, which occasionally goes beyond the diagnostic capabilities of human specialists [21].

Although there has been improvement in medicine efficiency due to the introduction of artificial intelligence, there are also new needs for medical practitioners. Professionals in medicine are not only required by law to be able to collaborate with AI systems but also to know how to work with them. One of the biggest problems for primary care workers is the absence of expertise and abilities to run complicated artificial intelligence systems; this is because they need ongoing training and support for education [22]. The primary cause of the diagnosis and treatment outcome is the degree of collaboration between physicians and artificial intelligence.

The best equilibrium, where E is the outcome, H is the expert judgment of the human physician, M is the auxiliary decision-making of the AI model, and α and β are its weight coefficients, respectively.

Physicians' subjective responses are having difficulty, which is being made worse by the extensive application of artificial intelligence [23]. The conventional "medical staff decision-making" model is progressively changing to the "AI decision-making-doctor verification review" model with the advent of autonomous AI. When there is medical harm, this change complicates the definition of medical liability and makes the responsible party a complex issue, a balance in which technological advancements are made and ethical standards are broken in order to build efficient human-machine collaboration [24]. Medical AI systems ought to always give patients the top priority and adhere to the principle of no harm.

It makes reference to an intelligent organization with the ability to make judgments and make decisions in the most autonomous way possible, which has a certain degree of autonomous decision-making ability.

5. The requirement of procurance connection

5.1. The idea and significance of liability retroactive

5.1.1. Legal liability and the ecological obligation

Legal and ethical liability in the decision-making process of medical AI algorithms constitutes a dual dimension of the liability traceability mechanism. Legal liability emphasizes responsibility in accordance with the law and is mandatory and obvious. Ethical responsibility, on the other hand, focuses on moral appraisal, which is reflected in the value orientation and humanistic care of medical services. These two duties interweave with each other in the AI diagnostic system and together create a complete responsibility traceability system.

At the level of legal liability, medical artificial intelligence algorithm decision-making includes many parties, including algorithm developers, medical institutions and individual doctors. When an AI system makes a diagnostic error, the determination of liability needs to take into account aspects such as the transparency of the algorithm the extent of the doctor's intervention, and patient information consent. To defend the patient's rights in various circumstances, the legal system must clearly define the limits of responsibility for each party. In order to protect the patient's right, the FDA's Action Plan on AI/Machine Learning-based Medical Device Software, published in 2021, places a strong emphasis on regulation and an assessment of the whole life cycle of medical AI software, increases product transparency, and offers a significant reference for assessing legal liability.

Medical artificial intelligence algorithmic decision-making in the field of ethical responsibility needs to adhere to the five AI ethical principles of "accountability, fairness, traceability, reliability, and controllability". Patients' autonomy and the ability to know and exercise autonomy are hampered by algorithmic black box issues, which also jeopardize patient trust in decision-making. Positive value-oriented human intervention is required in the process of algorithmic programming in order to address this problem, and a "top-down" governance paradigm is created to direct and control machine behavior through universal medical ethics guidelines.

Reimbursing the subjective position to the doctors as the main body and algorithmic technology as an auxiliary, strengthening the decision-making capacity of doctors and respecting the basic rights of patients; Encouraging algorithmic optimization and discipline technology for good; the coordinated construction of legal and ethical responsibilities is necessary. The creation of this dual responsibility framework will guarantee the robust development of medical AI systems. Reimbursing the subjective position to the doctors as the main body and algorithmic technology as an auxiliary, strengthening the decision-making capacity of doctors and respecting the basic rights of patients; Encouraging algorithmic optimization and discipline technology for good; the coordinated construction of legal and ethical responsibilities is necessary. The creation of this dual responsibility framework will guarantee the robust development of medical AI systems.

5.1.2. Influencing factors of accountability traceability

The accountability of medical AI algorithmic decisions is determined by many things, which together constitute a complicated network of accountability determination. In the medical situation, the degree of responsibility for algorithmic judgments can be described as the following relationship.

Where is the data quality factor; is the algorithm transparency is the degree of human intervention; and is the weight coefficients of each factor, which is the compliance level, the level of human interaction and represents the degree of human interference. The efficacy of accountability is directly impacted by algorithmic decisions that are transparent and interpretable. To guarantee the transparency of information, including the algorithm model's structure, training data, input or output and more, medical institutions must be able to assess the algorithm's applicability and dependability [25].

The level of information protection and data security are two things that must be fully realized in the storage and application of medical data, which is a key factor influencing accountability. In the process of medical institutions to prevent the theft of data and to abuse it, they must use dependable data encryption, which is necessary to prevent security and access control systems from being used. Another prerequisite that must be taken into account in the digital age of policy-making and enforcement is the variety of features that are considered, such as "digital bureaucracy", and "digital discretion", which have an impact on the process of being responsible [26].

A physician-patient trust relationship can also be developed with the help of the construction of accountability processes, which are also important. By providing doctors with the right training, which will raise patients' awareness of the diagnosis results as well as their understanding of technology and the degree of patient awareness regarding the results of the diagnostic process, it may be possible to increase the acceptance and trust of medical artificial intelligence. Meanwhile, in order to guarantee that AI technology is being used fairly and in accordance with compliance, ethical rules and monitoring systems established by relevant organizations and enterprises are also required [27].

5.1.3. Accountability and trust building

The building and development of accountability mechanisms are of great significance for maintaining the doctor-patient trust relationship. In the application cases of medical artificial intelligence, the doctor-patient relationship has changed from the traditional two-party relationship to a complicated relationship among doctors, patients and artificial intelligence [28]. Accountability strategies have been developed to positively increase patients' trust in health care services, and to further promote the healthy development of medical AI.

In medicine practice, the establishment of accountability systems might increase the openness and legitimacy of doctor-patient communication. Medical AI applications might help increase patients' trust in doctors by influencing doctor-patient contact, knowledge reserves, and environmental circumstances. Appropriate training of doctors to increase their understanding of the technology and patients' awareness of the diagnosis results might increase the acceptance and trust of medical AI by both doctors and patients.

It's worthwhile to keep in mind that using Artificial Intelligence could enhance the likelihood of a proficiency decrease. To avoid this the duty of the responsibility system to defend drugs, a staff members need to be more flexible and think critically to be the main in the processes. At the same time, it is necessary to adjust the application of technology in connection. To humanistic treatment as well as the requirement to avoid using artificial in intelligence and the interpersonal relationship so fpat and Pat patients who neglect the exchange of information and communication. When it comes to developing patient trust, medical services are essential comfort because they use different kinds of resources and materials, such as humanistic treatment and sympathy, which constitute the basis of both ecology-based and humanistic treatment of medical staff members.

Through the standardized building of accountability procedures, the application of medical artificial intelligence will better reflect the people-oriented concept of medical services, improve the quality of medical service sand, and thereby improve and promote patients' confidentiality with doctors. The construction of such a mechanism requires multi-party collaboration, including joint efforts in improving relevant laws and policies, formulating ethical guidelines and norms and strengthening quality monitoring and use evaluation.

5.2. Design and implementation of the traceability mechanism

5.2.1. Key elements of the traceability mechanism

Medical artificial intelligence algorithms are based on the idea of "meaningful human control" as part of the retroactive mechanism for making decisions about medical artificial intelligence; each subject in the system has a different set of moral standards that are clearly defined. The retroactive method is concerned with the division of moral thresholds among many levels of accountable entities, including legislators, programmers, and system designers, in addition to direct operators [29].

Medical artificial intelligence systems must use three main components to track the process of traceability: data rights, accountability allocation, and algorithmic transparency. Because of the complicated models and a lot of parameters that not only have an impact on the reasonableness of patient assessment decisions, the decision-making process of the system is frequently difficult to understand and interpret when it comes to algorithmic but also limits patientives of their right to autonomy and consenting a certain way. In order to deal with this issue, in order to protect the algorithm's main technologies as it runs and to build an explanatory decision-making mechanism while making an accountable decision route recording system, the traceability mechanism must be established. The doctors, the AI systems and hospitals need to clarify the allocation of responsibility so that doctors always use the main authority in medical practice; and the AI technology is positioned as a tool for auxiliary decision-making; so as to ensure that doctors always use the primary authority in medical practice.

Data rights protection is a significant aspect of the retrospective process, involving several aspects such as patients' privacy rights, data autonomy, and the right to know. Under the current legal system, data rights that extend from patient privacy have not been clearly defined, making data protection an urgent problem to be addressed in the field of medical AI. The traceability mechanism needs to build a full chain of data usage records to ensure that every link in the data flow can be tracked and audited, whereas establishing a sound data security protection mechanism to prevent privacy leakage and data abuse. Data rights protection is a significant aspect of the retrospective process, involving several aspects such as patients' privacy rights, data autonomy, and the right to know. Under the current legal system, data rights that extend from patient privacy have not been clearly defined, making data protection an urgent problem to be addressed in the field of medical AI. The traceability mechanism needs to build a full chain of data usage records to ensure that every link in the data flow can be tracked and audited, whereas establishing a sound data security protection mechanism to prevent privacy leakage and data abuse.

5.2.2. Application of technical means in traceability

In order for medical AI algorithms to be accountable for the decisions, multiple technical means are needed to ensure that the results are transparent and traceable throughout the process. The use of technology is very important for protecting the rights of patients and the trustworthiness of medical decisions, especially in the context of the increasing algorithmic black box phenomenon.

Through the distributed ledger characteristic of medical decision-making and can guarantee that the data is both immutable and intact. The use of smart contracts, which also provide a clear path for the tracing of responsibility, enables the automatic definition of all parties' sentences and obligations in medical decision-making, which is also a means of achieving the goal of the tracing process of responsibility. The combination of these technologies supports the development of reliable medical AI systems [30].

In the use of liability traceability technology, there are four basic process which are the data acquisition, storage verification, analytic and processing, result output, and so on. The technology makes use of different encryption techniques so as to check the security of data by monitoring the real-time operation status of artificial intelligence algorithm, keeping the key data nodes in the decision process, and using several encryption techniques. At the same time, the technology has developed a robust log auditing system which can easily identify and solve the problems that may occur, which will ensure the reliability and traceability of medical decisions, and the system has developed a good log auditing mechanism with the ability to quickly identify and address the problems which may occur.

5.2.3. Clear responsibilities in doctor-patient communication

In doctor-patient communication, the definition of rights and responsibilities among the AI diagnostic system, where the doctors and patients can ease the explanation of roles in it is a part of the process. Because the "black box" nature of AI diagnostic systems makes their decision-making process difficult to comprehend and explain, which presents a new obstacle for doctor-patient communication. When the diagnostic recommendations of AI systems are different from those of doctors, there is a difference in the clinical experience of these systems, so it is necessary to have clear accountability mechanisms to control how to explain and communicate to patients and who is ultimately responsible for decision-making.

By constructing a three-tier attribution model in practice, clear responsibility might be realized. Create the attribution function, in which the person in charge of medical judgments is represented, and assign responsibility as follows.

The quantifiable indicators of different kinds of responsibility are represented by the variables in this category, which also show the weights of various kinds of accountability. The limits of liability for each party at the legal and ethical levels are made easier by this quantification technique. To control the interpretation process of AI diagnostic reports and guarantee that patients fully comprehend the shortcomings of the AI system and its supporting function throughout the diagnosis and treatment process, medical institutions must create comprehensive communication rules.

During the process of making informed consent, physicians ought to give a clear explanation of the AI system's application and possible dangers, as well as to document the patient-led consent process. In the case of a medical dispute, these records will be a key source of liability trending. Conflicts between doctors and patients as a result of information asymmetry can be successfully decreased by creating uniform communication processes and documentation systems [31]. This system of accountability not only safeguards the rights and interests of physicians and patients, but also offers critical feedback for the AI diagnostic system to be continuously optimized.

6. Case analysis

6.1. Cases of AI diagnostic systems domestically and abroad

6.1.1. Analysis of successful cases

It has been very helpful to use clinical practice with the use of medical AI diagnostic equipment. When it comes to protecting patient safety by putting a strong system of responsibility, medical institutions have been able to combine AI technology with medical practice with an efficient combination of the latter. these success reports show the ability of AI to improve medical efficiency; although they guarantee ethical safety [32].

In the study of accountability procedures, some healthcare institutions have created explainable AI algorithms that increase the credibility of AI diagnostic results, enabling healthcare personnel to understand and accept their judgments. This approach effectively decreases the barriers of trust between doctors and patients and develops a good doctor-patient relationship. By building a sense of community between doctors and patients, doctors and people have reached a new consensus of trust in AI-assisted diagnosis and treatment. This approach not only protects patients' rights, but also lays the basis for the continual development of medical AI.

In terms of data protection and privacy protection, successful cases have generally adopted strict hierarchical authorization mechanisms and data desensitization approaches. The application of these technologies has helped medical institutions to effectively use medical data to optimize AI models while completely protecting patients' privacy. At the same time, by establishing a good risk feedback mechanism and response measures, medical institutions can quickly find and solve possible problems in the application of AI, ensuring the security and reliability of medical AI algorithms.

6.1.2. Lessons from failure cases

The diagnostic system used by the artist system has had several medical problems, and there are many of them in the medical field, which gives us helpful information. Patients find it difficult to decide whether or not they are reasonable because many of the major problems with an artificial intelligence system are the absence of algorithms and the difficulty of describing the decision-making process. At the same time, because of this lack of opacity, patients are less likely to be granted permission and autonomy as a way to obtain informed consent. As a result, the latter also weakens their acceptance of AI diagnostic tools and their degree of trust.

In actuality, some medical facilities overly depend on the diagnostic performance of AI systems, controlling the dominant position and professional judgment of doctors. This practice goes against the basic tenet of "doctors as the main body and algorithmic technology as the wings", resulting to a rift in the doctor-patient relationship. While data is generally de-identified in medical AI projects, there is still a risk of re-identifying persons through cross-reference of data, and this privacy breach seriously damages the rights of patients [33].

To solve these problems, some medical institutions have begun to use the practices of companies like Google and build tight ethical frameworks when developing medical AI systems. These frameworks require that the training data and decision results of the algorithms must meet principles such as fairness, and the performance of the systems is evaluated by particular algorithmic ethics testing platforms. This approach assists to increase the interpretability and legitimacy of AI systems, permitting medical practitioners to better understand and accept their results [19].

6.1.3. Legal and ethical reflections

Medical AI was concerned with the legal and ethical aspects of a number of issues and calls for a well-developed legal and moral framework to deal with them. An examination of the current cases shown in actual practice, medical AI systems deal with important problems such as inadequate algorithmic transparency and data privacy protection as well as the division of decision-making duties. Under these circumstances, the establishment of an efficient ethical review system is especially crucial because it involves the participation of specialists from all relevant fields, which is necessary to guarantee the protection of the legitimate rights and interests of both the medical practitioner and the patients [34].

Several challenges may arise in addressing algorithmic transparency and ethical issues in medical AI. These include the difficulty of explaining black-box algorithmic decisions, the need to develop explainable AI systems, concerns over data privacy and the responsible use of patient data, the establishment of clear accountability and auditing processes, and insufficient interdisciplinary cooperation in ethical assessments. To effectively address these challenges, both legal and ethical frameworks must be strengthened simultaneously. Legally, patients' rights to reputation and data privacy should be clearly defined, with robust auditing and tracking mechanisms implemented to prevent data misuse. Ethically, the role of doctors should be reinforced, positioning AI systems as auxiliary decision-making tools that respect patients' rights to informed consent and autonomy.

In the long term, the healthy development of medical AI required the building of a complete regulatory structure that includes legal requirements, ethical guidelines and their enforcement procedures. This system should focus on encouraging trust between doctors and patients, and encourage the good development of AI technology in the medical field through algorithm optimization and risk control. Relevant institutions also need to conduct routine ethical effect evaluations to guarantee that AI applications always meet ethical and moral requirements and give better medical services to patients [35].

6.2. Practice of accountability mechanisms

6.2.1. Examples of the application of the mechanism

The responsibility mechanism of AI diagnostic systems has produced positive results in actual operation, which is why research on the use of these systems in our nation's major medical institutions has been done.

The use of medical artificial intelligence has been well known for being a physician, and they have also been supported by algorithms. The main body of this concept, which puts doctors as the main body and algorithmic technology as the wings, has been effectively used to guard against ethical hazards emerging from the use of algorithmic decision-making in the field of medical artificial intelligence.

Google's healthcare artificial intelligence system is based on the ethical framework practice, which gives us a key reference. In order to satisfy criteria including fairness, the system created a transparent ethical framework that calls for the training of the algorithm as well as the results of decisions. The system is able to produce simulated data for various social situations through a dedicated algorithm ethics testing platform, which also evaluates the ethical compliance of algorithmic judgments and gives suggestions for optimization based on the evaluation results [36].

In terms of algorithm transparentness and explainability, healthcare practitioners can evaluate the reliability and applicability of AI algorithms by making public information such as the model structure, training data, input/output, and performance evaluation of AI algorithms.

At the same time, to preserve patient privacy, healthcare institutions use security measures such as data encryption and access control to avoid data loss and leakage. these precautions not only assure the quality of medical services, but also lay the basis for establishing a doctor-patient trust relationship.

6.2.2. The impact of mechanisms on medical decisions

Significantly altering the application model of medical artificial intelligence, the accountability mechanism has a significant effect on the medical decision-making process. Physicians are the primary authority in the traditional medical decision-making system to diagnose and treat patients, but the use of artificial intelligence has complicated the process. Medical institutions can rationally assign the decision-making weights of doctors and AI systems while safeguarding the rights and interests of patients by establishing a reliable traceability mechanism.

Intelligent technology is being made more transparent thanks to the application of accountability methods. When making judgments, medical AI systems must give the reasoning and decision-making process a clear foundation, which aids physicians in comprehending and assessing the rationale of AI suggestions. At the same time, patients can have a greater understanding of the exercise and diagnosis process to be aware of and independent. The trusting relationship between physicians and patients is effectively strengthened by this increase in transparency.

The traceability mechanism gives significant evidence in the early clinical evaluation of medical artificial intelligence systems in terms of safety assessment. Medical facilities may quickly determine possible safety hazards and develop corresponding preventive actions by routinely recording and evaluating every facet of AI decision-making. The harmful effects that AI applications might cause are effectively decreased by this preventive method of risk management.

In addition to encouraging the value orientation of medical artificial intelligence systems, the use of the traceability mechanism is another way that the latter are carried out. System crews can include ethical principles in the algorithm design phase by clearly defining the rights of patients and the extent of privacy protection. When giving decision support, AI systems can always show respect and care for people because of this "technology for good" orientation.

6.2.3. Feedback and adjustment from medical institutions

Medical institutions continuously compile and analyze real-world data to evaluate and improve the effectiveness of responsibility mechanisms applied to AI diagnostic systems. Feedback from multiple institutions indicates that the transparency and explainability of medical AI systems have significantly improved as a direct result of implementing these mechanisms. However, many institutions emphasize that regulatory and institutional frameworks for AI tools still require further development. To address this, several organizations have started integrating ethical principles into algorithm development and increasing ethical training for medical staff to raise awareness of AI-related issues. Additionally, medical institutions actively collaborate with companies and research bodies to optimize accountability mechanisms, tackling critical challenges such as medical injury traceability and responsibility allocation.

In line with medical practice, institutions recommend positioning physicians as patient-centered leaders, with algorithmic technologies serving as supportive tools. This approach prioritizes the protection of patients' fundamental rights and aims to enhance trust between doctors and patients by continuously optimizing AI algorithms. Such adjustments not only safeguard the professional judgment of physicians but also clearly establish ethical standards for AI systems.

7. Discussion and suggestions

7.1. Discussion of research results

This paper emphasizes the principal ethical issues surrounding the use of medical artificial intelligence (AI), focusing particularly on the challenges posed by algorithmic opacity. It systematically examines the ethical and regulatory practices involved in AI-driven medical decision-making. According to recent reports, AI algorithms in medicine hold great promise for enhancing diagnostic accuracy, treatment effectiveness, and optimizing medical services. However, these benefits are accompanied by significant moral hazards, including the potential substitution of doctors' decision-making authority, erosion of patients' fundamental rights and interests, and a growing crisis of trust between physicians and patients. The literature closely aligns with these concerns, highlighting issues such as algorithmic opacity, fairness, and responsibility.

In studying the traceability of accountability mechanisms, this paper identifies the "algorithmic black box" phenomenon as a major barrier to responsibility attribution. When medical decisions rely on complex deep learning models, the lack of transparency in the decision-making process obscures accountability boundaries. As emphasized by the four principles of medical ethics, this opacity compromises patients' rights to informed consent and autonomy, while also undermining trust in clinical decision-making.

The value of accountability mechanisms can be expressed in terms of transparency, which reflects legal compliance; in instances where transparency exists, appropriate weighting coefficients can be assigned to measure compliance levels.

Further analysis reveals that effective accountability requires multi-stakeholder cooperation. Building a sense of community between doctors and patients and fostering shared values are essential to resolving trust issues. Simultaneously, the regulation and governance of AI algorithms must clarify their complementary role in medical decision-making, not a substitute for human judgment. Medical AI systems should serve as tools to assist clinicians, with final decision-making authority remaining firmly with medical professionals who bear ethical responsibility.

At the legal level, this study finds that existing laws in our country lack clear definitions regarding patients' data rights and privacy protections. There is an urgent need to establish a comprehensive legal framework to safeguard patient privacy. Drawing on China's rich tradition of medical ethics, emphasizing benevolence and compassion. Integrating modern technical ethics can provide robust support for addressing challenges posed by medical AI.

7.2. Suggestions for future research

With the rapid advancement of medical artificial intelligence (AI) and ongoing research, it is crucial to deeply integrate accountability and algorithmic ethics in clinical applications. To ensure that AI decision-making fully respects patients' rights to informed consent and autonomy, medical AI systems must establish a comprehensive ethical framework bridging medicine and technology. Developers should incorporate principles of justice, data acquisition, and decision outcomes into ethical frameworks, drawing on practical examples such as Google's healthcare AI system.

Future research should focus on creating dedicated algorithm ethics testing platforms that simulate diverse social contexts to evaluate whether AI decisions meet ethical standards across scenarios, providing optimization feedback based on deviations. Privacy protection and fairness principles must be prioritized as foundational elements for building trusted medical AI systems. Additionally, research should emphasize human-centered values, aiming to enhance health and well-being while ensuring that the autonomy of healthcare providers and patients remains paramount, without being supplanted by technology.

Addressing algorithmic challenges requires applying medical ethics regulations to guide machine behavior, supported by a "top-down" governance approach. Future studies could explore how moral principles might be translated into "computable" ethical rules programmed into AI behavior, akin to Asimov's three laws of robotics. Given the current lack of clear legal definitions regarding patients' data rights in our country, protecting patient privacy must become a central focus of ethical governance in medical AI.

Ultimately, medical AI should reaffirm the primacy of doctors as decision-makers, with algorithms serving as supportive tools, thereby enhancing clinical judgment and safeguarding patient rights. Emphasis should also be placed on continuous algorithm optimization, ethical regulation of technology, risk management, and strengthening trust between doctors and patients. Through these multifaceted efforts, the ethical and accountability systems of medical AI can be significantly improved.

8. Conclusion

There were previously unheard-of medical changes and problems as a result of the rapid development of artificial intelligence in the medical profession, particularly with regard to the extensive use of AI diagnostic systems. In this study, the main topics of this study are the creation and enhancement of accountability mechanisms for AI diagnostic systems, which highlight the main problems and solutions in the current ethical governance of medical AI, by looking into the application boundaries of algorithmic ethics in medical decision-making.

The research shows that the "black box" nature of artificial intelligence algorithms seriously affects the trust relationship between doctors and patients and the transparency of decision-making, while making the definition of responsibility attribution ambiguous. Under the classic medical model, the positions of medical institutions and doctors as service responsibility subjects were obvious, but the introduction of AI technology has brought about fundamental changes in the doctor-patient relationship, making the issue of responsibility determination increasingly complex [37]. The lack of current rules and regulations further worsens this situation, not only breaking the basis of social morality and legal responsibility, but also sowing the seeds of possible dangers, which explain the duties and obligations of those concerned in the system life cycle [38]. In addition, it is important for the government, enterprises, medical institutions and patients to work together to strengthen relevant laws and regulations, strengthen ethical supervision and establish a data security management system to solve ethical and legal issues in the application of AI in medical care [39].

The main goals of future study are to address the main problems that are related to patient privacy protection, the innovation of medical AI, and the privacy of patients, which in turn promotes the organic integration of algorithmic ethics and medical practice, as well as the healthy and sustainable development of AI diagnostic systems in the medical field. The benefits of artificial intelligence (AI) in enhancing medical efficiency and accuracy can only be used to the fullest extent possible, and the balanced development of patient rights and medical ethics can be guaranteed.

Disclosure statement

The authors declare no conflict of interest.

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Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on the Model and Pathways for Border Tourism Development and Poverty Alleviation in Ethnic Regions — A Case Study of the Northwest Yunnan Region

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Abstract: Against the backdrop of globalization and regional economic integration, border tourism, as a unique form of tourism, is increasingly emerging as a significant driving force for promoting economic development in border regions, fostering cultural exchange, and strengthening international cooperation. The northwestern Yunnan region, located in China's Southwestern frontier, is a key area bordering Southeast and South Asian countries, endowed with abundant border tourism resources. This article delves into the border tourism models and pathways for border development and prosperity in ethnic regions, using a case study of the Northwest Yunnan region to analyze the mechanisms and influencing factors of border tourism in promoting local economic development, social progress, and cultural heritage. This provides empirical evidence for further understanding the development patterns of border tourism and also contributes to strengthening ethnic unity and maintaining harmony and stability in border regions. This study addresses the current research gap in exploring the development models and pathways of border tourism in specific regions, offering valuable references and insights for future related research.

Keywords: Border tourism; Border prosperity and people's well-being, ethnic regions; Models and pathways

Online publication: September 10, 2025

1. Introduction

Luo *et al.* conducted a study based on panel data from 2009 to 2021 on border counties in Guangxi and Yunnan provinces. They found that the "Prospering the Border and Enriching the People" initiative has achieved significant results in border counties, and the development of tourism has a positive impact on the initiative, with a nonlinear relationship between the two [1]. The tourism industry primarily drives the prosperity of border regions through economic benefits and market scale, with regional heterogeneity. Guangxi exhibits a nonlinear effect, while Yunnan demonstrates a linear promotional effect. Zhao and Zhang conducted a visualization analysis of relevant literature, pointing out that China's border tourism research achievements are abundant, focusing on themes such as the spatial structure of border tourism and cross-border tourism [2]. Wen argues that border regions, as the frontline of national sovereignty, possess unique geographical locations that make them natural tourist attractions. Border tourism not only promotes common prosperity among ethnic groups in border areas, reduces regional development gaps, and mitigates perceptions of "marginalization," but also facilitates cross-border ethnic exchanges and interactions between inland and border ethnic groups, fostering an emotional connection of "the Chinese nation as one [3]. "Jiang Lujuan *et al*. propose that border tourism serves as an open window and a "grassroots bridge" for cross-border cooperation, facilitating border trade and cultural exchange [4].

2. Current status of border tourism development in Northwest Yunnan

The Northwest Yunnan Region is located in the Northwestern part of Yunnan Province, China, at the southeastern edge of the Qinghai-Tibet Plateau, serving as an important gateway to China's Southwestern frontier. Its unique geographical location borders the Tibet Autonomous Region to the north and shares a border with Myanmar to the west. It is a region inhabited by multiple ethnic groups, with a rich and diverse ethnic composition, including the Naxi, Bai, Tibetan, Lisu, Nu, and Dulong ethnic groups.

2.1. Development of tourism resources

The development of natural landscape tourism resources in Northwest Yunnan has achieved certain results, with numerous famous attractions drawing large numbers of visitors [5]. For example, the "Three Parallel Rivers" region, a UNESCO World Natural Heritage Site, attracts many adventure enthusiasts and natural ecology researchers with its unique geological landforms and rich biodiversity. Yulong Snow Mountain, with its magnificent snow-capped peaks and unique alpine ecosystem, has become a popular tourist destination in Northwest Yunnan, with the number of visitors continuing to grow each year. Lugu Lake is renowned for its picturesque lake and mountain scenery and unique Mosuo culture. Tourism development allows visitors to fully appreciate the charm of highland lakes and ethnic minority customs. In terms of ethnic cultural tourism resource development, Lijiang Ancient Town, as an outstanding representative of Naxi culture, has preserved the architectural style and traditional cultural customs of the Ming and Qing dynasties. Dali Ancient Town showcases the architectural art, religious beliefs, and folk customs of the Bai people. Visitors can tour the Chongsheng Temple Three Pagodas to experience the Buddhist culture of the Bai people and participate in their traditional festivals to immerse themselves in the unique ethnic customs.

2.2 Development of tourism infrastructure

The Northwest Yunnan region has made remarkable progress in the construction of transportation infrastructure [6]. Highway construction has been continuously improved, and a highway network connecting major scenic spots and cities has basically taken shape. For instance, the expressways from Dali to Lijiang and from Lijiang to Shangri-La have been put into operation one after another, which has greatly shortened the travel time between cities and enhanced the travel convenience for tourists. There have also been new breakthroughs in railway construction. The opening and operation of the Lijiang-Shangri-La Railway has integrated Shangri-La into the railway network, further improving the transportation network in Northwest Yunnan. This not only facilitates the travel of local residents but also provides a more convenient transportation option for tourists. In terms of aviation, the Northwest Yunnan region is home to multiple airports, such as Lijiang Sanyi International Airport, Dali Huangcaoba Airport, and Diqing Shangri-La Airport. The number of air routes has been increasing, and direct flights to major domestic cities and some international cities have been realized, offering convenience for tourists to enter and exit the region. Regarding accommodation facilities, the number of tourist hotels has been on the rise, covering high, medium, and low grades. These hotels are capable of meeting the needs of different types of tourists.

2.3. Development status of the tourism market

In recent years, the number of tourists visiting the northwest Yunnan region and tourism revenue have shown a growing trend. With the development of tourism resources and the improvement of infrastructure, an increasing number of tourists are choosing to travel to the northwest Yunnan region. The tourism market is developing in a diversified manner. In addition to traditional sightseeing tourism, forms of tourism such as leisure and resort tourism, ecological tourism, and cultural experiences are gradually gaining popularity among tourists. However, the development of the tourism market in Northwest Yunnan also faces some challenges. Marketing methods are relatively limited, with some tourism enterprises primarily relying on traditional advertising and cooperation with travel agencies, while insufficiently utilizing emerging marketing methods such as new media marketing and online marketing. The tourist market is narrow, with the current tourist base in Northwest Yunnan primarily concentrated in the eastern developed regions of China and neighboring provinces, while international market development remains insufficient. The region’s appeal to international tourists is relatively weak, primarily due to factors such as low internationalization of tourism products, inadequate internationalization of tourism services, and limited international marketing channels.

3. Border tourism development model for prosperity in the Northwest Yunnan region

3.1. “Scenic Area + Community” collaborative model

The “Scenic Area + Community” collaborative model is one of the key development models for border tourism in the Northwest Yunnan Region, with the integrated development of Lijiang Ancient Town and surrounding rural areas serving as a typical example of this model [7]. As a UNESCO World Heritage Site, Lijiang Ancient Town boasts rich historical and cultural resources and unique ethnic customs, making it one of the core attractions of tourism in Northwest Yunnan. Surrounding villages such as Baisha Ancient Town and Yuhu Village are located in close proximity to Lijiang Ancient Town, complementing it in terms of natural landscapes and cultural characteristics, and thus possess a solid foundation for collaborative development. Lijiang Ancient Town, leveraging its high profile and substantial tourist traffic, has brought a significant influx of visitors to the surrounding villages.

Under the “scenic area + community” linkage model, residents in surrounding communities have gained more employment opportunities and income channels. On one hand, residents can directly participate in tourism operations, such as running farmhouse restaurants, homestays, and selling specialty agricultural products and handicrafts, achieving a transition from traditional agriculture to tourism. On the other hand, the development of tourist attractions has also driven improvements in surrounding infrastructure and public service levels, creating better living conditions for villagers. This collaborative model has also promoted cultural heritage and protection.

With the development of tourism, rural culture has received more attention and importance, and villagers' sense of identity and pride in their own culture has continued to grow, leading them to participate more actively in cultural heritage and protection efforts.

3.2. "Tourism + Industry Integration" model

Taking the tourism industry as the core driving force, this model deeply integrates the rich ethnic culture, specialty agriculture, handicrafts, and ecological resources of the Dianxi Northwest region. Through the penetration, overlap, and restructuring of industries, it forms a regionally distinctive composite tourism product and industry system. This model breaks through the limitations of traditional single-industry development, using the "Tourism +" approach to achieve industrial synergy and upgrading. It not only enriches the supply of tourism products to meet the diverse needs of tourists but also drives the development of related industries, promoting regional economic growth and increased income for residents. It is an important pathway to achieving prosperity and development in border areas. Through the integration of tourism and the cultural industry, the ethnic culture of Northwest Yunnan has been better preserved and innovated. Industrial integration has also driven regional infrastructure construction and improvements in public services, improving the living environment of local residents, promoting the overall development of the northwestern Yunnan region, and laying a solid foundation for the realization of the goal of enriching the border areas and improving the livelihoods of the people.

4. Optimizing the pathway for border tourism development and prosperity in Northwest Yunnan

4.1. Strengthening infrastructure construction and improving tourism service quality

Increasing investment in transportation infrastructure for border tourism in Northwest Yunnan is a key measure to improve transportation conditions [8]. The government should actively promote the coordinated development of various transportation modes, including highways, railways, and aviation, to enhance the coverage and accessibility of the transportation network. In terms of accommodation and catering facilities, efforts should be made to improve quality and diversify types. Encourage tourism enterprises to increase investment in accommodation facilities, and construct a batch of high-end, high-quality resort hotels to meet the diverse accommodation needs of tourists. Improving public service facilities is a crucial guarantee for enhancing tourists' travel experiences [9]. Increase efforts to build and renovate public service facilities such as parking lots, restrooms, and tourist service centers in border tourism scenic areas. In addition, the signage system within the scenic area should be improved by installing clear and accurate tourist signs to provide clear guidance to visitors.

4.2. Precisely target the tourism market and innovate tourism product development

Deeply exploring the cultural essence of the various ethnic groups in the Dianxi region is the foundation for developing distinctive tourism products [10]. By researching and organizing ethnic cultural elements, these elements can be integrated into tourism products to create tourism products with unique ethnic characteristics. In addition to traditional sightseeing tourism products, efforts should be made to develop a variety of tourism products, including leisure and resort tourism, ecological tourism, cultural experience tourism, educational tourism, and health and wellness tourism. In the development of leisure and resort tourism products, leverage the natural landscapes and ethnic cultural resources of Northwest Yunnan to build a series of leisure and resort tourism destinations, such as resort hotels around Erhai Lake and leisure fishing villages around Lugu Lake, providing visitors with onestop services for leisure, resort stays, and entertainment. In terms of ecological tourism product development, strengthen the protection and development of nature reserves and ecological scenic areas, and launch ecological tourism projects such as ecological sightseeing, hiking adventures, and bird watching, allowing tourists to enhance their ecological conservation awareness while enjoying natural scenery. In terms of cultural experience tourism product development, deeply explore the essence of ethnic culture and develop more interactive and experiential cultural experience projects, such as ethnic traditional festival experiences and folk life experiences, allowing tourists to personally feel the charm of ethnic culture. In terms of educational tourism product development, combine the historical and cultural, natural science, and other resources of the Dianxi Northwest region to develop a series of educational tourism bases and courses.

5. Conclusion

This article conducts an in-depth exploration of the border tourism model and pathways for border development and prosperity in the Northwestern Yunnan region. In terms of effectiveness, border tourism has played a significant role in promoting border development and prosperity in the Northwestern Yunnan region. In terms of economic growth, it has driven the development of related industries such as catering, accommodation, and transportation, thereby increasing local economic income; in terms of job creation, it has provided numerous employment opportunities for local residents, effectively alleviating employment pressure; In terms of cultural heritage and exchange, it has promoted the dissemination and display of ethnic cultures and strengthened cultural exchanges with neighboring countries and regions; in terms of ethnic unity and social stability, it has enhanced exchanges and cooperation among ethnic groups, maintained social stability, and strengthened the cohesion of border regions.

In the future, border tourism in the Dianxi Northwest region is expected to develop in a more diversified, internationalized, and intelligent direction. As people's tourism needs continue to evolve, emerging tourism forms such as leisure and resort tourism, cultural experience tourism, and health and wellness tourism will develop more rapidly. The Dianxi Northwest region should fully leverage its abundant tourism resources and intensify efforts to develop these emerging tourism products to meet the increasingly diverse needs of tourists.

Disclosure statement

The authors declare no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Application of Multiple Correlations Analysis in Portfolio Selection

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Abstract: Portfolio selection based on the global minimum variance (GMV) model remains a significant focus in financial research. The covariance matrix, central to the GMV model, determines portfolio weights, and its accurate estimation is key to effective strategies. Based on the decomposition form of the covariance matrix. This paper introduces semi-variance for improved financial asymmetric risk measurement; addresses asymmetry in financial asset correlations using distance, asymmetric, and Chatterjee correlations to refine covariance matrices; and proposes three new covariance matrix models to enhance risk assessment and portfolio selection strategies. Testing with data from 30 stocks across various sectors of the Chinese market confirms the strong performance of the proposed strategies.

Keywords: Portfolio selection; GMV model; Semi-variance; Asymmetric correlation; Chatterjee correlation

Online publication: September 10, 2025

1. Introduction

The GMV model is a portfolio selection framework designed to achieve the lowest variance through optimized asset allocation. Unlike the classical mean-variance model, GMV focuses solely on minimizing risk rather than prioritizing future profitability [1]. This makes it widely applicable to portfolio selection problems, as seen in studies by many researchers [2, 3]. In the GMV model, the optimal portfolio weights depend exclusively on the covariance matrix of risky assets. The covariance matrix can be decomposed into variance and correlation, represented as the product of a diagonal variance matrix and a correlation coefficient matrix. Variance quantifies the risk of individual assets, while the correlation coefficient captures relationships between assets, facilitating effective risk diversification. Nonetheless, both variance and correlation coefficients have limitations in portfolio selection [4].

In assessing portfolio risk, researchers have found that semi-variance offers a more accurate measure of asymmetric risk. According to Mao, traditional methods treat positive and negative deviations equally, which does not align with actual investor psychology [5]. To address this, Artzner *et al.* emphasized the importance of focusing on adverse changes in returns, termed downside risk [6]. Wu *et al.* investigated dynamic mean-downside risk portfolio optimization under random interest rate changes in a continuous-time framework [7]. Rutkowska-Ziarko and Kliber used semi-variance to quantify downside risk, capturing investors' risk preferences more accurately [8]. Their findings revealed that investors exhibit decreasing risk aversion when ranking assets, showing a readiness to accept higher risks for greater rewards.

Asymmetric correlation plays a crucial role in portfolio selection, garnering significant attention in asset correlation analysis [9]. Longin and Solnik revealed that extreme market conditions increase correlations across international stock markets [10]. Ang and Chen found that correlations between assets intensify during market downturns, highlighting essential risk characteristics of investment portfolios [11]. Hong *et al.* introduced a model-free testing approach for analyzing asymmetric correlations in size and momentum portfolios, offering empirical support [12]. Meanwhile, Chuang *et al.* developed a nonparametric method to explore asymmetric co-movement in financial markets, finding significant evidence of such behavior in stocks and market indices [13]. These studies provide valuable theoretical insights, enabling investors to better understand and manage portfolio risk.

As researchers delve deeper into asset correlations, they have identified non-linear characteristics among financial assets. Distance correlation, introduced by Székely *et al.*, effectively captures these non-linear relationships, outperforming traditional Pearson correlation in risk characterization [14]. Extensions like Zhou's auto-distance correlation function (ADCF) and Székely *et al.* high-dimensional independence testing have enhanced its applicability [15, 16]. Meanwhile, Dueck *et al.* studied the problem of computing the distance correlation coefficient between Lancaster distribution class random vectors and derived a general series representation of the distance covariance of these distributions, enriching the theoretical foundation of distance correlation [17]. Applications in portfolio risk-return measurement further demonstrate its versatility and theoretical significance [18].

In this paper, three portfolio selection strategies within the GMV model is proposed, based on the variance-correlation decomposition of the covariance matrix while addressing asymmetry in both time and individual dimensions of financial risk assets. The key steps include: (i) replacing variance with semi-variance to account for investors' focus on downside risk; (ii) measuring correlations using distance, asymmetric, and Chatterjee correlations to capture time and individual asymmetries; (iii) constructing three novel covariance matrices and corresponding portfolio selection strategies to enhance effectiveness.

2. Preliminary works

In this section, some of the key preparatory works will be discussed in five aspects: the global minimum variance model, semi-variance, asymmetric correlation, distance correlation, and Chatterjee correlation.

2.1. Global minimum variance model

Given p risky assets, let $R_t = (r_{1t}, r_{2t}, ..., r_{pt})$ denote the p×1 vector of asset returns at time t where $t(t=1,2,...,n)$ denotes time, n is the sample size, and (·)T indicates the transpose operation. The traditional GMV model is expressed as,

$$min_{\omega}\ \omega^{\top}\Sigma\omega, \quad s.t. \quad \omega^{\top}1 = 1 \tag{1}$$

where ω is a p×1 weight vector, $\sum = Cov(R_t)$ is a p×p covariance matrix, and 1 is a p×1 vector of ones. The optimal portfolio weight for Equation (1) can be obtained as follows:

$$\omega^{\min}\left(\Sigma^{-1}\right)=\frac{\Sigma^{-1}\mathbf{1}}{\mathbf{1}^{\top}\Sigma^{-1}\mathbf{1}}.$$

But the true covariance matrix Σ is unknown, and the sample covariance matrix $\widehat{\Sigma}$ is used to replace Σ , that is

$$\widehat{\omega}^{min}(\widehat{\Sigma}^{-1})=\frac{\widehat{\Sigma}^{-1}1}{1^{T}\widehat{\Sigma}^{-1}1} \quad (2)$$

Where $\widehat{\Sigma}=\frac{1}{n}\Sigma_{t=1}^{n}\left(R_t-\widehat{\mu}\right)\left(R_t-\widehat{\mu}\right)^{\top}$ and $\widehat{\mu}=\frac{1}{n}\Sigma_{t=1}^{n}R_t$. .

The covariance matrix can be decomposed into a variance-correlation form, which is the product of the diagonal matrix of variance and the correlation coefficients matrix. Variance measures risk and correlation coefficients measures the correlation of different financial assets. However, there are some shortcomings in using the traditional GMV model to deal with portfolio selection problems:

(1) Variance is a traditional risk measurement method. Although it has been widely used in many portfolio selection problems, it also has some practical limitations, such as considering any value above the mean as asset risk. Then semi-variance is presented to measure variance of portfolio reasonably.

(2) The eigenvalues of the sample covariance matrix do not match the eigenvalues of the true covariance matrix. The estimation error in the sample covariance matrix remains unresolved, and this error can lead to ineffective decisions in portfolio optimization and risk management. In the following sections, semi-variance, asymmetric correlation, distance correlation, and Chaterjee's correlation will be introducedone by one.

2.2. Semi-variance

Semi-variance does have significant value as a tool for assessing a portfolio's potential downside risk. Markovitz proposed and extended the application of semi-variance, respectively [1]. In recent years, many scholars have further studied and applied semi-variance. Huang assumes that ζ is a fuzzy variable with a finite expected value e, then the semi-variance S(ζ) of ζ is defined as follows [19]:

$$S[\zeta]=\ E\{[(\zeta-e)^{-}]^{2}\},$$

Where

$$(\zeta-e)^{-}=\begin{cases}\zeta-e & if\ \ \zeta\le e,\\ 0 & if\ \ \zeta>e.\end{cases}$$

Considering the above definition of semi-variance, the sample semi-variance can be further defined as:

$$\widehat{SVAR}_i=\frac{1}{n}\sum_{t=1}^{n}\left\{\left[\min\left(0,r_{it}-B\right)\right]^2\right\}$$

where $\widehat{SVAR}_i$ is the *i*-th value in the sample data set, r_{it} is the return value, *B* is the expected value of the sample data set, *n* is the number of non-zero terms.

2.3. Asymmetric correlation

By considering asymmetric correlation, investors, risk managers, and policymakers can better assess and manage market risks, develop more effective investment strategies, and create regulatory policies that contribute to greater stability and security across various market environments.

Suppose the two risky assets of return in period t are $\{r_{1t},r_{2t}\}$. Consider the extreme case of the two variables exceeding the correlation (i.e. exceeding a certain critical value of c standard deviations). The correlation exceeds the level is defined as the correlation between the two variables when they exceed standard deviations of their means, respectively:

$$\rho^{+}(c) = corr(r_{1t}, r_{2t} | r_{1t} > c, r_{2t} > c),$$
$$\rho^{-}(c) = corr(r_{1t}, r_{2t} | r_{1t} <- c, r_{2t} <- c),$$

where $c \geq 0$ is a given level, $\rho^{+}(c)$ measures the correlation between two returns above a certain exceeding level c, $\rho^{-}(c)$ measures the correlation between two returns below a certain exceeding level .

2.4. Distance correlation

Distance correlation is a statistic that measures the dependence between two random variables or data sets. It does not require the assumption of a linear relationship or distribution form between the variables. Unlike the traditional Pearson correlation coefficient, distance correlation can capture nonlinear relationships and is insensitive to changes in marginal distributions. Székely and Rizzo defined the distance-dependent statistic as follows [16].

Given an observed random sample $(\mathrm{U},\mathrm{V}) = \{(\mathrm{U_i},\mathrm{V_i}): \mathrm{i} = 1, \ldots, \mathrm{n}\}$ from the joint distribution of random vectors $\mathrm{U} \in \mathrm{R^p}$ and $\mathrm{V} \in \mathrm{R^q}$, the following is redefined:

$$c_{ij} = |U_i - U_j|_p, \quad \bar{c}_{i\cdot} = \frac{1}{n}\sum_{j=1}^{n} c_{ij}, \quad \bar{c}_{\cdot j} = \frac{1}{n}\sum_{i=1}^{n} c_{ij}, \quad \bar{c}_{\cdot\cdot} = \frac{1}{n^2}\sum_{i,j=1}^{n} c_{ij}$$
$$C_{ij} = c_{ij} - \bar{c}_{i\cdot} - \bar{c}_{\cdot j} + \bar{c}_{\cdot\cdot},$$

where $i,j = 1,\ldots,n$. Similarly, it is define:

$$d_{ij} = |V_i - V_j|_q, \text{ , then } D_{ij} = d_{ij} - \bar{d}_{i\cdot} - \bar{d}_{\cdot j} + \bar{d}_{\cdot\cdot},$$

for $i,j = 1,\ldots,n$. The empirical distance covariance $V_n(U,V)$ is the nonnegative number defined by:

$$\mathcal{V}_n^2(U,V) = \frac{1}{n^2}\sum_{i,j=1}^{n} C_{ij}D_{ij}.$$

Similarly, $V_n(U)$ is the nonnegative number defined by:

$$\mathcal{V}_n^2(U) = \mathcal{V}_n^2(U,U) = \frac{1}{n^2}\sum_{i,j=1}^{n} C_{ij}^2.$$

The empirical distance correlation $R_n(U,V)$ is the square root of

$$\mathcal{R}_n^2(U,V) = \begin{cases} \dfrac{\mathcal{V}_n^2(U,V)}{\sqrt{\mathcal{V}_n^2(U)\mathcal{V}_n^2(V)}}, & \mathcal{V}_n^2(U)\mathcal{V}_n^2(V) > 0; \\ 0, & \mathcal{V}_n^2(U)\mathcal{V}_n^2(V) = 0. \end{cases}$$

2.5. Chatterjee correlation

The Chatterjee correlation can better measure the individual asymmetry of correlation between financial risk assets. In recent years, Chatterjee introduced a new correlation coefficient calculation method, which mainly studies the correlation between individual assets [20]. Let (X,Y) be a pair of random variables where Y is not a constant. Let $(X_1,Y_2),\ldots,(X_n,Y_n)$ be iid pairs with the same law as (X,Y), where $n \geq 2$. Assume that X_i and Y_i have no relationship, and rearrange the data. Since X_i has no relationship, there is a unique way of doing this. Let τ_i be the rank of Y_i, that is, the number of j such that $Y_j \leq Y_i$. The new correlation coefficient is defined as

$$\xi_n(X,Y) := 1 - \frac{3\sum_{i=1}^{n-1} |Ti+1-Ti|}{n^2-1} \tag{3}$$

in the constrained case, ξn is defined as follows. If there are relationship among the Xi , then the incremental rearrangement as described above is chosen by breaking the relationship uniformly at random. Let τ_i be the same as before, and additionally define l_i to be the number of j such that $Y_j \geq Y_i$. Then define

$$\xi_n(X,Y) := 1 - \frac{n\sum_{i=1}^{n-1} |Ti+1-Ti|}{2\sum_{i=1}^{n-1} li(n-li)} \tag{4}$$

when there is no relationship among Y_i, $l_1, \ldots, l_n$, is just a permutation of 1,...,n, so the denominator in the above expression is just $n(n^2-1)/3$, which simplifies this definition to the Equation (3). Subsequently, several authors, through theoretical derivations and numerical simulations, demonstrated the advantages of Chatterjee's correlation coefficient over other commonly used measures of correlation, such as the Pearson correlation coefficient, under various statistical models [21]. This evidence shows that Chatterjee's correlation coefficient not only possesses theoretical optimality but also enhances performance in practical applications, particularly in high-dimensional data or settings involving complex dependencies.

3. New strategy for portfolio selection

Considering that the correlation between financial risk assets exhibits asym- metry in both time and individual dimensions, this section introduces new for- mulations to constructing the covariance matrix, which is then applied to derive more effective portfolio selection strategies. Three novel strategies is proposed using different combinations of correlation measurement tools:

(1) Shrinking the inverse covariance matrix to the product of inverse asymmetric correlation and inverse Chatterjee correlation (STICV-TVI).

(2) shrinking the inverse covariance matrix by combining the inverse asymmetric correlation with the inverse Chatterjee correlation (STICV(TV∪I)).

(3) Shrinking the inverse covariance matrix to a combination of the product of inverse asymmetric and Chatterjee correlations, plus the inverse covariance matrices of asymmetric and Chatterjee correlations (STICV(TV∪I∪TVI)).

3.1. Constructing the STICV-TVI

3.1.1. Step1: Construct covariance matrix

It is well established that the covariance matrix can be expressed in its variance correlation decomposition form, such that $\hat{\Sigma}_{\mathrm{d}} = \hat{\Lambda}_{\mathrm{semi}}\hat{\mathrm{R}}_{\mathrm{dis}}\hat{\Lambda}_{\mathrm{semi}}$, where $\hat{\Lambda}_{\mathrm{semi}}$ represents the semi-variance matrix, specifically $\mathrm{diag}(\widehat{\mathrm{SVAR}}_1, \ldots, \widehat{\mathrm{SVAR}}_{\mathrm{p}})$ and $\hat{\mathrm{R}}_{\mathrm{dis}}$ signifies the distance correlation matrix, specifically $\mathrm{V}^2 = [\mathrm{V}_{\mathrm{ij}}^2]$, where $\mathrm{V}_{\mathrm{ij}}^2$ is the distance correlation between r_{it} and r_{jt}.

By leveraging the advantages of semi-variance and asymmetric correlation, replace the traditional variance and Pearson correlation matrix with the semi-variance matrix and the asymmetric correlation matrix, respectively. Consequently, the covariance matrix is expressed as $\hat{\Sigma}_{\mathrm{asi}} = \hat{\Lambda}_{\mathrm{semi}}\hat{\mathrm{R}}_{\mathrm{asi}}\hat{\Lambda}_{\mathrm{semi}}$, where $\hat{R}_{asy}$ represents the asymmetric correlation matrix, specifically $Z = [Z_{ij}]$, where $Z_{ij} = Z_{ji}$ and is computed based on this symmetric correlation. (iii) The individual correlation matrix is used as a replacement for the Pearson correlation matrix. Therefore, the covariance matrix can be defined as $\hat{\Sigma}_{ast} = \hat{\Lambda}_{semi}\hat{R}_{asy}\hat{\Lambda}_{semi}$, where $\hat{R}_{asi}$ represents the individual correlation matrix, specifically $C = [c_{ij}]$, where $c_{ij} \neq c_{ji}$, each element C_{ij} is defined based on the dependency relationship between the corresponding variables according to Chatterjee, and the matrix is asymmetric.

For the convenience of parameter selection, an unknown parameter α needs to be introduced, so the following inverse sample covariance matrix can be built.

$$\hat{S}_{\text{TVI}}^{-1}1 = a\hat{\Sigma}_d^{-1} + (1-a)\hat{\Sigma}_{asi}^{-1}\hat{\Sigma}_{asi}^{-1} \tag{5}$$

3.1.2. Step 2: Calculation of portfolio weights

Next, solve for the weights of the model using the equation below:

$$\hat{\omega}(\hat{S}_{\text{TVI}}^{-1}) = \frac{\left(a\hat{\Sigma}_d^{-1} + (1-a)\hat{\Sigma}_{asi}^{-1}\hat{\Sigma}_{asi}^{-1}\right)1}{1^T\hat{S}_{\text{TVI}}^{-1}1} \tag{6a}$$

Let us reintroduce an unknown coefficient β and let $\beta = \frac{a1^T\hat{\Sigma}_d^{-1}1}{c}$. Through Equation (2) the equation below is obtained.

$$\hat{\omega}(\hat{S}_{\text{TVI}}^{-1}) = \beta\hat{\omega}\left(\hat{\Sigma}_d^{-1}\right) + (1-\beta)\hat{\omega}\left(\hat{\Sigma}_{asi}^{-1}\hat{\Sigma}_{asi}^{-1}\right) \tag{6}$$

From Equation (6), it is known that, to determine the optimal portfolio weights, calculate the coefficient.

3.1.3. Step 3: Selection of the shrinkage coefficients.

Using the variance minimization method to select the shrinkage coefficient β, the objective function can be derived as $\varphi_2\,\hat{\omega}\left(\hat{\Sigma}_{ast}^{-1}\right)^\top R_t + (1-\varphi_1-\varphi_2)\,\hat{\omega}\left(\hat{\Sigma}_{asi}^{-1}\right)^\top R_t)$

$$var(\hat{\omega}^{min}\left(\hat{S}_{\text{TVI}}^{-1}\right)^T \mathrm{R}_t) = \mathrm{var}(\beta\hat{\omega}\left(\hat{\Sigma}_d^{-1}\right)^T R_t + (1-\beta)\hat{\omega}\left(\hat{\Sigma}_{asi}^{-1}\hat{\Sigma}_{asi}^{-1}\right)^T Rt \tag{7}$$

Simplify Equation (7), take its derivative with respect to and set it equal to 0, and then, find the solution as shown in Equation (8).

$$\beta = \frac{\mathrm{cov}(\hat{\omega}\left(\hat{\Sigma}_d^{-1}\right)^T R_t, \hat{\omega}\left(\hat{\Sigma}_{asi}^{-1}\hat{\Sigma}_{asi}^{-1}\right)^T R_t - var(\hat{\omega}\left(\hat{\Sigma}_{asi}^{-1}\hat{\Sigma}_{asi}^{-1}\right)^T Rt)}{var(\hat{\omega}\left(\hat{\Sigma}_d^{-1}\right)^T R_t - \hat{\omega}\left(\hat{\Sigma}_{asi}^{-1}\hat{\Sigma}_{asi}^{-1}\right)^T R_t} \tag{8}$$

3.2. Constructing the STICV(TV ∪ I)

The new model is constructed according to the following steps.

(1) Step 1: Construct the covariance matrix

Similar to step 1 in Section 3.1, for the convenience of parameter selection, introduce two unknown parameters , so the following model can be built

$$\hat{S}_{\text{TV}\cup\text{I}}^{-1} = \gamma_1\,\hat{\Sigma}_d^{-1} + \gamma_2\,\hat{\Sigma}_{ast}^{-1} + (1-\gamma_1-\gamma_2)\hat{\Sigma}_{asi}^{-1} \tag{9}$$

(2) Step 2: Calculation of portfolio weights

Next, solve for the weights of the model, to get:

$$\hat{\omega}(\hat{S}_{\text{TV}\cup\text{I}}^{-1}) = \frac{(\gamma_1\,\hat{\Sigma}_d^{-1} + \gamma_2\,\hat{\Sigma}_{ast}^{-1} + (1-\gamma_1-\gamma_2)\hat{\Sigma}_{asi}^{-1})1}{1^T\hat{S}_{\text{TV}\cup\text{I}}^{-1}\,1} \tag{9a}$$

Let us reintroduce two unknown parameters φ 1, φ2 and let $\varphi_1 = \frac{\gamma_1 1\,\hat{\Sigma}_d^{-1} 1}{c}$, $\varphi_2 = \frac{\gamma_2 1\,\hat{\Sigma}_{ast}^{-1} 1}{c}$. So, $1 - \varphi_1 - \varphi_2 = \frac{(1-\gamma_1-\gamma_2) 1^T \hat{\Sigma}_{asi}^{-1} 1}{c}$. Through Equation (2), the below is obtained:

$$\widehat{\omega}(\hat{S}_{\mathrm{TV}\cup\mathrm{I}}^{-1}) = \varphi_1 \widehat{\omega}(\hat{\Sigma}_d^{-1}) + \varphi_2 \widehat{\omega}(\hat{\Sigma}_{ast}^{-1}) + (1 - \varphi_1 - \varphi_2) \widehat{\omega}(\hat{\Sigma}_{asi}^{-1}) \tag{10}$$

From Equation (10), it is know that it needs to find the generalized inverse weights of the three conditional covariances separately, namely $\widehat{\omega}(\hat{\Sigma}_d^{-1})$, $\widehat{\omega}(\hat{\Sigma}_{ast}^{-1})$ and $\widehat{\omega}(\hat{\Sigma}_{asi}^{-1})$.

(3) Step 3: Selection of the shrinkage coefficients

Similarly to 3.1, use minimum variance method to select the shrinkage coefficients, and the objective function is as follows:

$$var\left(\widehat{\omega}^{\min}\left(\widehat{S}_{\mathrm{TV}\cup\mathrm{I}}^{-1}\right)^{\top} R_t\right) = var\left(\varphi_1 \widehat{\omega}\left(\widehat{\Sigma}_d^{-1}\right)^{\top} R_t + \varphi_2 \widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\right)^{\top} R_t + (1-\varphi_1-\varphi_2)\widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right). \tag{11}$$

Simplify (11) first, then take the derivative of φ 1 and φ2 and set it equal to 0, and the result is as follow

$$\varphi = M^{-1} b, \tag{12}$$

Where φ = (φ1 φ2)T ,

φ = (φ1 φ2)T ,

$$M = \begin{bmatrix} A & B \\ B & C \end{bmatrix},$$

$$b = \begin{bmatrix} 2var\left(\widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}_d^{-1}\right)^{\top} R_t, \widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) \\ 2var\left(\widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\right)^{\top} R_t, \widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) \end{bmatrix},$$

where A,B,C are defined as follows

$$A = 2\mathrm{var}\left(\widehat{\omega}\left(\widehat{\Sigma}_d^{-1}\right)^{\top} R_t - \widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right), \quad C = 2\mathrm{var}\left(\widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\right)^{\top} R_t - \widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right),$$
$$B = 2\mathrm{cov}\left(\widehat{\omega}\left(\widehat{\Sigma}_d^{-1}\right)^{\top} R_t, \widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\right)^{\top} R_t\right) - 2\mathrm{cov}\left(\widehat{\omega}\left(\widehat{\Sigma}_d^{-1}\right)^{\top} R_t, \widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) -$$
$$2\mathrm{cov}\left(\widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\right)^{\top} R_t, \widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) + 2\mathrm{var}\left(\widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right).$$

$R_t)$

3.3. Constructing the STICV(TV ∪ I ∪ TVI)

3.3.1. Step 1: Construct covariance matrix

Similar to step 1 in section 3.1., for the convenience of parameter selection, three unknown parameters α1, α2, α3 needs to be introduced, so the following model can be built:

$$\widehat{S}_{\mathrm{TV}\cup\mathrm{I}\cup\mathrm{TVI}}^{-1} = \alpha_1 \widehat{\Sigma}_d^{-1} + \alpha_2 \widehat{\Sigma}_{ast}^{-1} + \alpha_3 \widehat{\Sigma}_{asi}^{-1} + (1 - \alpha_1 - \alpha_2 - \alpha_3)\, \widehat{\Sigma}_{ast}^{-1} \widehat{\Sigma}_{asi}^{-1} \tag{13}$$

3.3.2. Step 2: Calculation of portfolio weights

Next, solve for the weights of the model, to get:

$$\widehat{\omega}(\widehat{S}_{\mathrm{TV}\cup\mathrm{I}\cup\mathrm{TVI}}^{-1}) = \frac{\left(\alpha_1 \widehat{\Sigma}_d^{-1} + \alpha_2 \widehat{\Sigma}_{ast}^{-1} + \alpha_3 \widehat{\Sigma}_{asi}^{-1} + (1 - \alpha_1 - \alpha_2 - \alpha_3)\, \widehat{\Sigma}_{ast}^{-1} \widehat{\Sigma}_{asi}^{-1}\right) \mathbf{1}}{\mathbf{1}^{\top} \widehat{S}_{\mathrm{TV}\cup\mathrm{I}\cup\mathrm{TVI}}^{-1} \mathbf{1}}.$$

Reintroduce three unknown parameters β_1, β_2, β_3 and let $\beta_1 = \frac{\alpha_1 1^\top \hat{\Sigma}_d^{-1} 1}{c}$, $\beta_2 = \frac{\alpha_2 1^\top \hat{\Sigma}_{asi}^{-1} 1}{c}$, $\beta_3 = \frac{\alpha_3 1^\top \hat{\Sigma}_{ast}^{-1} 1}{c}$. So $1 - \beta_1 - \beta_2 - \beta_3 = \frac{(1-\alpha_1-\alpha_2-\alpha_3) 1^\top \hat{\Sigma}_{ast}^{-1} \hat{\Sigma}_{asi}^{-1} 1}{c}$. Next, simplify to get

$$\widehat{\omega}\left(\widehat{S}^{-1}_{\mathrm{TV}\cup\mathrm{I}\cup\mathrm{TVI}}\right) = \beta_1 \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{d}\right) + \beta_2 \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\right) + \beta_3 \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{asi}\right) + (1-\beta_1-\beta_2-\beta_3)\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right). \tag{14}$$

From Equation (14), it is known that it needs to find the generalized inverse weights of the three conditional covariances separately, namely $\widehat{\omega}(\widehat{\Sigma}_d^{-1})$, $\widehat{\omega}(\widehat{\Sigma}_{ast}^{-1})$ and $\widehat{\omega}(\widehat{\Sigma}_{asi}^{-1})$.

3.3.3. Step 3: Selection of the shrinkage coefficients

Similar to step 3 in section 3.1, the objective function is as follows:

$$\min var\left(\widehat{\omega}\left(\widehat{S}^{-1}_{\mathrm{TV}\cup\mathrm{I}\cup\mathrm{TVI}}\right)^\top R_t\right) = var\Big(\beta_1 \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{d}\right)^\top R_t + (1-\beta_1-\beta_2-\beta_3)\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t + \beta_3 \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t + \beta_2 \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\right)^\top R_t\Big). \tag{15}$$

Simplify Equation 15, first, then take the derivative of β1, β2, and β3 and set it equal to 0, and the result is as

β = Q-1m,

where

β = (β1 , β2 , β3)T ,

$$Q = \begin{bmatrix} \mathcal{A} & \mathcal{B} & \mathcal{C} \\ \mathcal{B} & \mathcal{D} & \mathcal{E} \\ \mathcal{C} & \mathcal{E} & \mathcal{F} \end{bmatrix},$$

$$m = \begin{bmatrix} 2var\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{d}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) \\ 2var\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) \\ 2var\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) \end{bmatrix},$$

where $\mathcal{A}, \mathcal{B}, \mathcal{C}, \mathcal{D}, \mathcal{E}, \mathcal{F}$ are defined as follows

$$\mathcal{A} = 2var\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{d}\right)^\top R_t - \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right), \quad \mathcal{D} = 2var\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\right)^\top R_t - \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right),$$

$$\mathcal{B} = 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{d}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\right)^\top R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{d}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) + 2var\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right),$$

$$\mathcal{C} = 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{d}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{d}\right)^\top R_t, \widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right) + 2var\left(\widehat{\omega}\left(\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}\right)^\top R_t\right),$$

$$\mathcal{E} = 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\right)^{\top} R_t, \widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) - 2cov\left(\widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\right)^{\top} R_t, \widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) -$$

$$2cov\left(\widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t, \widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right) + 2var\left(\widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right),$$

$$\mathcal{F} = 2var\left(\widehat{\omega}\left(\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t - \widehat{\omega}\left(\widehat{\Sigma}_{ast}^{-1}\widehat{\Sigma}_{asi}^{-1}\right)^{\top} R_t\right).$$

4. Data and methodology

4.1. Data

In the empirical analysis, the stock data employed comes from the Chinese stock market, to calculate its logarithmic return based on its closing price. For stock details, please see the **Table 1**.

Table 1. The data for 30 stocks are from the Chinese stock market from October 1, 2018 to March 18, 2020

Code	Code	Code	Code	Code
000568.SZ	002493.SZ	600276.SH	601012.SH	601933.SH
000651.SZ	300750.SZ	600346.SH	601288.SH	601939.SH
000708.SZ	300760.SZ	600438.SH	601318.SH	603259.SH
002024.SZ	600019.SH	600519.SH	601601.SH	603816.SH
000858.SZ	600028.SH	600690.SH	601628.SH	603833.SH
002304.SZ	600036.SH	600809.SH	601857.SH	603899.SH

4.1.1. Verify the asymmetry of correlation between individual stock returns

Section 2.3 mentioned the importance of asymmetric correlation in financial markets. To test the asymmetric correlation of the Chinese stock market dataset, the model-free test approach is used, formalizing the null hypothesis (H0: ρ+ (c) = ρ - (c) for all c ≥ 0) and alternative hypothesis (HA: ρ+ (c) ≠ ρ - (c) for some c ≥ 0) of Hong *et al.* [12]. The significance level of the hypothesis test is 0.05, and c is a given level (c = 0 in this paper). So the statistic for testing the null hypothesis is defined as follows:

$$J_p = T(\hat{\rho}^+ - \hat{\rho}^-)^{\top}\hat{O}^{-1}(\hat{\rho}^+ - \hat{\rho}^-),$$

Where

$$\hat{O} = \sum_{l=1-T}^{T-1} k(l/p)\hat{\Upsilon}_l, \quad k(\cdot) = (1-|z|)I(|z|<1), \quad \hat{\Upsilon}_l(c_i, c_j) = \frac{1}{T}\sum_{t=|l+1|}^{T} \hat{\chi}_t(c_i)\hat{\chi}_{t-|l|}(c_j),$$

$$\hat{\chi}_t(c) = \frac{T}{T_c^+}\left[\hat{X}_{1t}^+(c)\hat{X}_{2t}^+(c) - \hat{\rho}^+(c)\right] I(r_{1t} > c, r_{2t} > c) -$$

$$\frac{T}{T_c^-}\left[\hat{X}_{1t}^-(c)\hat{X}_{2t}^-(c) - \hat{\rho}^-(c)\right] I(r_{1t} < -c, r_{2t} < -c),$$

where T is the size of sample, and I is the indicator function, Υ_l is a matrix with (i, j)-th element, and $k(\cdot)$ is a kernel function that assigns a suitable weight to each lag of order *l*, *p* is the smoothing parameter or lag truncation order. In this paper, the Bartlett kernel is used.

Table 2. The partial *P*-value of stock pair

Stock pair	*P*-value	Stock pair	*P*-value
(000858.SZ, 002493.SZ)	5.20E-03	(002304.SZ, 002493.SZ)	1.34E-04
(600438.SH, 600519.SH)	4.15E-02	(601939.SH, 603259.SH)	5.06E-04
(603259.SH, 000568.SZ)	9.40E-03	(601857.SH, 603259.SH)	6.20E-04
(002493.SZ, 601012.SH)	3.21E-02	(002493.SZ, 002024.SZ)	7.66E-05
(601012.SH, 603259.SH)	1.40E-03	(603259.SH, 601318.SH)	3.86E-04

Table 2 presents the partial *P*-values of the stock pairs under analysis. Setting the significance level for the hypothesis test at 0.05, the analysis of the data in **Table 2** reveals that the calculated *P*-values are significance lower than the set threshold. This finding provides robust evidence to support the rejection of the null hypothesis, thus favoring the acceptance of the alternative hypothesis. Consequently, it can be inferred that there is sufficient evidence to demonstrate the existence of asymmetric correlation between pairs of stocks.

4.1.2. Verify the Chatterjee correlation between individual stock returns

The returns of eight stocks (**Table 3**) is used to verify the Chatterjee correlation. **Table 4** presents the partial of the stock pairs under analysis. Due to Moutai's market leadership and brand in influence in the alcohol industry, take Kweichow Moutai's stock code (600519.SH) as an example of the leading stocks compared to Shanxi Fenjiu (600809.SH). It is found that within the same industry, 600519.SH's in influence on 600809.SH is greater than 600809. SH's in influence on 600519.SH, and the situation is similar in other industries, such as Sinopec Corp. (600028.SH) and Hengli Petrochemical (600346.SH). There exists asymmetry of correlation between stocks, and that Chatterjee correlation can effectively measure the asymmetry of correlation between stocks individuals.

Table 3. Select eight of these stocks to verify Chatterjee Correlation

Code	English abbreviation
600809.SZ 600519.SH 600346.SH 600028.SH	Shanxi Xinghuacun Fen Wine Factry Co Ltd Kweichow Moutai Co. Ltd Hengli Petrochemical Co Ltd China Petroleum Chemical Corp (Sinopec Corp.)

Table 4. The partial ξn (X, Y) of stock pair

Code	600809.SH	600519.SH	Code	600028.SH	600346.SH
600809.SH	0.9925	0.0482	600028.SH	0.9925	0.0437
600519.SH	0.1124	0.9925	600346.SH	-0.0214	0.9925

4.2. Portfolio selection strategies

Analyze the proposed portfolio strategy by comparing it with several established strategies documented in the literature (**Table 5**). The strategies LW(id) and LW(lf) are derived from the research of Ledoit, Wolf [22, 23]. The ICVARI, ICVARF, and ICVARIF strategies are based on the work of Kourtis *et al*. [24].

Table 5. List of portfolio selection strategies

Abbreviation	Expression
Panel A: The benchmark optimization model for this portfolio selection	
ICVARF ICVARIF ICVARI LW(lf) LW(id) AST·ASI ASI NAIVE GMV	$\widehat{S}^{-1}_{ARF}=\alpha\widehat{\Sigma}^{-1}_{ast}+(1-\alpha)\widehat{\Sigma}_{F}$ $\widehat{S}^{-1}_{ARIF}=\alpha_1\widehat{\Sigma}^{-1}_{ast}+\alpha_2\widehat{\Sigma}_{I}+(1-\alpha_1-\alpha_2)\widehat{\Sigma}_{F}$ $\widehat{S}^{-1}_{ARI}=\alpha\widehat{\Sigma}^{-1}_{ast}+(1-\alpha)\widehat{\Sigma}_{I}$ $\widehat{S}_{lf}=\alpha\widehat{\Sigma}_{ast}+(1-\alpha)\widehat{\Sigma}_{F}$ $\widehat{S}_{id}=\alpha\widehat{\Sigma}_{ast}+(1-\alpha)\widehat{\Sigma}_{I}$ $\widehat{S}^{-1}_{TI}=\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}$ $\widehat{S}^{-1}_{ASI}=\widehat{\Sigma}^{-1}_{asi}$ $\widehat{S}^{-1}_{NA}=(1/p)I$ $\widehat{S}^{-1}_{GMV}=\widehat{\Sigma}^{-1}$-1
Panel B: The new optimization model	
STICV-TVI STICV(TV ∪ I) STICV(TV ∪ I ∪ TVI)	$\widehat{S}^{-1}_{TVI}=\alpha\widehat{\Sigma}^{-1}_{d}+(1-\alpha)\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}$ $\widehat{S}^{-1}_{\text{TV}\cup\text{I}}=\gamma_1\widehat{\Sigma}^{-1}_{d}+\gamma_2\widehat{\Sigma}^{-1}_{ast}+(1-\gamma_1-\gamma_2)\widehat{\Sigma}^{-1}_{asi}$ $\widehat{S}^{-1}_{\text{TV}\cup\text{I}\cup\text{TVI}}=\alpha_1\widehat{\Sigma}^{-1}_{d}+\alpha_2\widehat{\Sigma}^{-1}_{ast}+\alpha_3\widehat{\Sigma}^{-1}_{asi}$ $+(1-\alpha_1-\alpha_2-\alpha_3)\widehat{\Sigma}^{-1}_{ast}\widehat{\Sigma}^{-1}_{asi}$

4.3. Performance evaluation metric

To evaluate out-of-sample portfolio performance, the rolling window technique is employed. Specifically, the portfolio weight ω_t^k for each strategy *k* was estimated using the daily returns from *t-h* to *t*-1, where *h* represents the window length. Subsequently, the corresponding out-of-sample portfolio returns at time *t*+1 were calculated as $R_{t+1}^k=(\omega_t^k)^\top\cdot R_{t+1}$, producing a time series of excess returns for each portfolio strategy. Here, R_{t+1} denotes the asset returns at time *t*+1. The sample mean $\hat{\mu}^k$ and standard deviation $\hat{\sigma}^k$ of the excess returns were then computed, followed by the calculation of the out-of-sample performance metrics as outlined in **Table 6**.

Table 6. Partial results for out-of-sample Mean

Name	Expression
Mean	$\hat{\mu}^k=\frac{1}{n-h}\sum_{t=h}^{n-1}(\omega_t^k)^\top R_{t+1}$
Sharpe ratio	Sharpe ratio $\widehat{SR}^k=\frac{\hat{\mu}^k}{\hat{\sigma}^k}$, with $\hat{\sigma}^k=\sqrt{\frac{1}{n-h-1}\sum_{t=h}^{n-1}\left((\omega_t^k)^\top R_{t+1}-\hat{\mu}^k\right)^2}$

5. Empirical results

In this study, 30 stocks from the Chinese stock market is examined. To create datasets of varying dimensions, 5, 10, 15, and 20 stocks is randomly selected from the original 30. For each subset, calculate the returns. The subsequent analysis focuses on two key aspects: Average Return and Sharpe Ratio (SR).

5.1. Results for out-of-sample mean

Table 7 presents the results for the average excess partial returns for each portfolio strategy examined (The data results in the table are also enlarged 1000 times). From the experimental data, the following conclusions can be drawn. Comparing with other indicators, it is found that STICV-TVI, STICV(TVUI), and STICV(TVUIUTVI) out-of-sample mean is generally better than the other indicators; there is a higher out-of-sample mean, which means that asymmetric correlation, individual structure, and time-varying structure are useful, especially when combined with the distance correlation matrix. The results indicate that the combination of multiple correlation coefficients has a positive effect on increasing the out-of-sample mean of the portfolio.

Table 7. Partial results for out-of-sample Mean

h	Method	5IP	10IP	15IP	20IP
20	ICVARF	0.5525	1.0941	0.2929	1.0084
	ICVARIF	0.2329	0.5486	0.8669	0.8371
	ICVARI	1.1062	1.4118	1.6999	1.1942
	LW(lf)	0.3055	0.3999	0.8072	0.2750
	LW(id)	0.6875	1.2797	1.0306	1.0051
	AST·ASI	1.2186	4.8612	-2.9773	1.9278
	ASI	0.4567	0.7216	0.7562	0.5812
	NAIVE	0.5990	1.0360	1.0835	0.7189
	GMV	0.2256	0.5149	0.9616	-0.0058
	STICV(TVUI)	-7.9213	1.6049	-3.5750	8.8302
	STICV(TVUIUTVI)	2.5275	0.9527	2.2463	0.6912
	STICV-TVI	1.6241	-0.3569	8.2101	0.5884

5.2. Results for out-of-sample Sharpe ratio

Table 8 shows the partial results for reports. The average SR of the excess returns for each portfolio strategy considered and the data results in the table are also enlarged 1000 times. From the experimental data, the following conclusions can be drawn.

Regardless of the length of the window width and the dimension of the portfolio, STICV (TVUIUTVI) outperforms other indicators in terms of Sharpe ratio performance. This shows that the shrinkage method and asymmetry used in the model effectively reduce the estimation error and improve the effectiveness of risk management. At the same time, adding individual structure and time-varying structure factors to the model more accurately captures the correlation and volatility of assets. The combination of these methods also enables the portfolio to better balance risk and return. If the results of STICV-TVI, STICV(TVUI), and STICV (TVUIUTVI) is compared, it is found that STICV (TVUIUTVI) is better than STICV-TVI and STICV(TVUI).

Table 8. Partial results for out-of-sample SR

h	Method	5IP	10IP	15IP	20IP
	ICVARF	14.7382	34.3888	0.9208	3.5457
	ICVARIF	6.1908	16.5571	2.7435	2.9913
	ICVARI	60.3090	97.7646	35.5108	26.4221
	LW(lf)	18.0527	17.4015	37.6193	9.9798
	LW(id)	34.3661	59.3272	54.3114	41.7454
	AST·ASI	38.3274	45.9780	-6.6462	40.3556
	ASI	25.7129	46.7267	43.8700	36.2112
20	NAIVE	29.4312	66.6518	22.2036	15.5550
	GMV	12.3570	25.4235	46.9831	-0.2464
	STICV(TVUI)	-42.1990	26.0394	-39.8212	41.8262
	STICV(TVUIUTVI)	80.2958	50.8548	71.4911	29.6349
	STICV-TVI	77.6193	-17.6901	54.2835	19.6410

6. Conclusion

This paper investigates the application of asymmetric correlation and its extensions to portfolio selection problems. By incorporating both time and individual dimensions of asymmetric correlation, a robust and effective asymmetric influence matrix is developed. This matrix is applied within the compressed inverse covariance matrix portfolio selection framework to optimize corresponding parameters. The results demonstrate that these innovations enhance portfolio performance under the GMV model, offering practical insights for investors.

The proposed portfolio selection strategy is applied to empirical data. Empirical analysis reveals that: (1) applying only the time or individual dimension with the standard correlation coefficient matrix is insufficient for optimal performance; (2) after adopting the new strategy STICV (TVUIUTVI), achieves a higher out-of-sample mean and outperforms traditional approaches in terms of the Sharpe ratio. However, this study also highlights challenges. While shrinking the inverse covariance matrix significantly improves portfolio performance, limited research exists on shrinking the inverse of asymmetric correlation matrices. This paper uses the generalized inverse to address this, but recognizes the need for further exploration into simplifying parameter calculations within this framework. Future research should aim to refine covariance matrix shrinking techniques under asymmetric influence conditions.

Funding

National Natural Science Foundation of China (Project No.: 12201579)

Disclosure statement

The authors declare no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Construction and Empirical Research on the Value Dimension of Tourists' Experience in Urban Heritage Parks

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Abstract: With the simultaneous growth of cultural heritage activation and urban renewal needs, urban heritage parks are increasingly becoming important carriers for the integrated development of historical heritage protection and public space utilization. This article focuses on the construction of measurement dimensions of tourist experience value in urban heritage parks. Based on the theoretical frameworks of flow theory and experience value theory, combined with literature analysis and UGC text mining, it initially constructs an emotional, cultural, and functional three-dimensional index system. Through text analysis of 970 online reviews of Chongqing Kaifa Heritage Park, social value is identified as a potential new dimension. Subsequently, this article adopts exploratory and confirmatory factor analysis methods to verify the structural validity and reliability of the evaluation model with four dimensions and eighteen indicators, confirming that tourist experience value consists of four dimensions: emotional, cultural, functional, and social. The research not only fills the empirical research gap on social interaction value in cultural heritage tourism spaces, but also provides a quantifiable evaluation tool and evidence-based basis for the operation, management, and experience optimization of heritage parks, which has certain theoretical innovation significance and practical guidance value.

Keywords: Urban Heritage Parks; Tourists' experience; Evaluation index system; Cultural heritage activation

Online publication: September 8, 2025

1. Introduction

A heritage park is a planning model that combines site protection with park functions, and has become an important practical direction for the protective development of historical and cultural heritage at home and abroad. As an innovative model for the revitalization and utilization of cultural heritage, urban heritage parks combine the functions of site protection and public space. They are not only important platforms for the protection and display of heritage sites, but also effective ways to improve the management system of large heritage sites and realize their social value. Historical architectural relics, as an important component of urban cultural capital, have dual value dimensions in their protection and revitalization: on the one hand, as physical carriers of collective memory, they maintain the continuity of the city's cultural context; on the other hand, as cultural consumption spaces, they promote regional economic development through the creation of tourism experience value. This dual attribute requires a paradigm shift in heritage protection from physical restoration to value transmission. The urban heritage park model integrates site protection with functions such as public education and leisure recreation through spatial narrative reconstruction, providing a practical path to solve the governance dilemma of "protective destruction" and "developmental idleness."

With the advent of the experience economy era, tourist demand has shifted from basic sightseeing to immersive experiences. The experience demands of tourists in cultural heritage sites have evolved from superficial functional needs (accessibility, facility completeness) to intermediate cultural cognitive needs (historical information acquisition, place spirit perception), and deep emotional resonance needs (cultural identity, self-actualization). This evolution in demand structure poses new challenges to the experience value supply system of heritage parks.

Based on the flow theory and experiential value theory, this study initially constructs a tourist experience evaluation system that includes three dimensions: emotional, cultural, and functional. Through topic mining of online review texts for Chongqing Kaifa Site Park, a potential value dimension of social value is identified. Subsequently, based on the identified dimensions and observation indicators, a structured questionnaire is designed, and a tourist survey is conducted. Exploratory factor analysis is used to empirically test the data, and finally, a tourist experience evaluation model for city heritage parks is constructed and validated, including four dimensions: emotional, cultural, functional, and social interaction.

2. Literature review

2.1. Urban heritage parks

In the 1970s, Japan took the lead in developing the city heritage park model to address the destruction of precious historical relics during urbanization. While protecting heritage, typical cases of appropriately restoring the ancient human living environment have satisfied the public's strong desire to return to nature. The success of Hiroshima Peace Memorial Park and Nara Heritage Park has promoted the development of heritage parks globally. In 1983, the planning and construction of China's Yuanmingyuan Heritage Park marked the formal integration of the "heritage park" concept with cultural heritage management [1]. The emergence of city heritage parks coincided with the expansion and improvement of the heritage museum concept. Peng Li defines city heritage parks in his research as urban parks established on the basis of heritage sites within the current or planned construction areas of the city [2]. Yao Lang et al. verified the mechanism of cultural implantation to enhance tourism value through the case of Xi'an Daming Palace, while Li Yue constructed a spatial narrative theoretical model based on Jinyang Ancient City, elucidating the synergistic effect of field continuity design on cultural dissemination [3, 4]. The Qujiang Heritage Park and Ming Palace project explored collaborative paths for protection and development from the perspectives of economic balance and micro-renewal strategies, respectively [5, 6]. Contemporary research further reveals that as a "cultural-ecological-social" three-dimensional complex, it undertakes multiple functions such as heritage protection, public education, and leisure recreation, becoming a medium for transforming the social value of large heritage site management.

2.2. Tourists' experience

In the field of research on measuring dimensions of experience value, the five-dimensional framework proposed by Sheth and others is widely regarded as a classic, including five dimensions: functional, social, emotional, epistemic, and situational [7]. Zhang *et al.* further validated the rationality and scientific nature of Sheth's research by dividing customer experience value into five dimensions: functional, situational, emotional, epistemic, and social [8]. Additionally, Pine and Gilmore classified people's experiences into four dimensions: entertainment, education, esthetics, and escapism, constructing the famous "4E" experience theory model, which provides another important perspective for the study of experience value [9].

As the main body of tourism, visitors have a crucial impact on the development of the tourism industry. Visitor experience not only has the characteristics of participation, interaction, and comprehensiveness, but also carries a strong personal color. Through multidimensional theoretical exploration and practical verification, the study of visitor experience value has gradually formed a systematic cognitive framework. At the level of value attributes, the academic community has revealed the multiple connotations of experience value from perspectives such as basic services, interactive learning, composite characteristics, and cultural dissemination, highlighting its dual characteristics of functional practicality and cultural constructiveness [10–13]. Dimensional deconstruction research presents methodological innovations. The four-dimensional model proposed by Yang and the three-dimensional framework of Ma *et al.* expand analytical perspectives from value types and experience levels, respectively, while Ross's subject-object dichotomy provides a theoretical tool for cross-contextual comparison [14–16]. In the field of practical application, scholars have verified the field dependence and dynamic complexity of visitor experience value evaluation through the 28-factor model of museum scenes and the emotional-cognitive pathway research of performing arts scenes [17, 18].

Despite significant progress in research, there are still certain limitations in existing achievements: Firstly, specific research on the experience value of city site parks has not formed an independent system; secondly, it is difficult for static questionnaire-led evaluation methods to capture real-time experience feedback implicit in online comment data. This paper constructs a four-dimensional evaluation model specific to city site parks by integrating theoretical deduction and text mining, and conducts empirical testing to provide a new paradigm for the sustainable challenge of "protection-utilization-inheritance" of city site parks, as well as a new analytical framework and practical path for the study of experience value in cultural heritage sites.

3. Construction of indicator system

3.1. Initial establishment of theoretically guided indicators

Compared to other forms of tourism, urban heritage parks not only satisfy visitors' entertainment needs but also serve important functions such as architectural heritage protection, science popularization education, and cultural inheritance. Through a systematic review and analysis of relevant literature, this study primarily draws on the basis for dividing the structural dimensions of tourism experience and indicator selection methods from scholars such as Pi *et al.*, Fan, Na, Li, Bai, Li, Li, Liu, and Bai [19–25]. Taking into account the unique attributes of urban heritage parks, targeted adjustments were made to the indicators. On this foundation, an evaluation system model for visitor experience value in urban heritage parks was initially constructed, covering three main dimensions: emotional value, cultural value, and functional value.

3.2. Optimization of UGC text data evaluation index system

3.2.1. Data collection and processing

As a typical representative of modern China's inland trading ports, Chongqing Port Opening Memorial Park relies on the historical site of Liddell & Co. as its foundation and is a representative relic of Chongqing's port opening history. The park integrates three functional sections: a museum, a park, and a casual street, making it an important place for urban leisure. As a city heritage park, it not only undertakes cultural tourism functions but also serves as a city park for daily leisure activities for local residents, targeting not only foreign tourists but also local residents. Therefore, this study chose text data from Dianping platform as the source. As a local life service platform, Dianping provides a comprehensive service including ratings and reviews for businesses, with core businesses such as check-in and recommendation functions. Tampermonkey plugin was used to manage Greasemonkey scripts, converting text data from tourist reviews on Dianping since the park opened in batches. Finally, 970 original review texts since the park opened (as of January 2025) were obtained, and 839 valid data were retained after deduplication and cleaning.

3.2.2. Experience value identification

Through the extraction and coding of review indicators from the review texts of Chongqing Open Port Heritage Park, the initially constructed evaluation index system for the park was optimized and improved. Four new observation indicators were identified for the functional value measurement dimension, including transportation convenience, leisure and entertainment facilities, service quality, and historical and cultural facilities. Additionally, a new measurement dimension of social value and its two observation indicators were identified, specifically, photo-taking and check-in, and social experience. Finally, an evaluation index system for tourist experience value in Chongqing Open Port Heritage Park was formed, as shown in **Table 1**:

Table 1. Evaluation index system for tourist experience in city heritage parks

Dimension	Code	Indicator	Explanation
A. Emotional value	A1	Pleasurable experience	Tourists' positive emotional experiences and satisfaction gained in the park
	A2	Attractiveness	The park's appeal to tourists, including visual and emotional attraction
	A3	Engagement	The degree of tourists' active participation in park activities and resulting immersion
	A4	Distinctive perception	Tourists' awareness and recognition of the park's unique cultural experiences
B. Cultural value	B1	Knowledge acquisition	Tourists' evaluation of educational experiences and new knowledge gained
	B2	Behavioral identity	Tourists' sense of identification with the park as a cultural landmark and willingness to recommend
	B3	Heritage revitalization	Tourists' perception of innovative conservation and adaptive reuse of historical buildings
	B4	Cultural confidence	Tourists' sense of pride in Chongqing's unique cultural charm during visits
C. Functional value	C1	Food & accommodation	Tourists' evaluation of dining and hotel service quality
	C2	Cultural creative products	Assessment of product diversity and quality (e.g., "Kaiwu" brand)
	C3	Performance activities	Attractiveness of cultural events and performances
	C4	Environmental landscape	Integration effect of natural scenery and historic architecture
	C5	Transportation accessibility	Perceived convenience of park access
	C6	Recreational facilities	Comprehensive evaluation of entertainment facilities' fun and recreational value
	C7	Service quality	Perception of staff attitude, service level and infrastructure
	C8	Historical facilities	Evaluation of cultural display effectiveness and historical facilities
D. Social value	D1	Photo sharing	Tourists' photo-taking and social media sharing behavior
	D2	Social interaction	Quality of social experiences with companions in the park

4. Empirical analysis

4.1. Questionnaire design and data collection

Based on the evaluation system constructed in the previous section, and after two rounds of expert reviews and pre-surveys (with a total of 50 questionnaires and 37 valid questionnaires), this study formed a complete questionnaire consisting of 5 basic information questions, 6 questions about tourist behavior characteristics, 18 scale questions, and 1 open-ended question.

Through a combination of online and offline methods, online data was collected through the Questionnaire Star website, while offline data was collected during different time periods on weekdays and holidays. A total of 259 questionnaires were collected, with 237 valid questionnaires. Among the surveyed population, 40.1% were male respondents and 59.90% were female respondents. In terms of age, the majority of respondents were between 26 and 35 years old (38.4%). Regarding education level, the majority of respondents had a bachelor's degree (43.5%). In terms of occupation, the majority were students (22.4%) and corporate employees (38.0%).

4.2. Exploratory factor analysis

This study chose exploratory factor analysis. Before applying the factor model analysis, a factor model suitability analysis was first conducted on the scale data. The analysis results showed that the KMO value was 0.912 > 0.6, and it passed the Bartlett's test of sphericity with a significance level of 0.05 ($P = 0.000 < 0.05$), indicating that the data set met the conditions for factor analysis. Factor analysis was performed on the data set, and the factor loading values for each item were obtained using the varimax orthogonal rotation method, as shown in **Table 2**. From the rotated factor loading matrix table, it can be seen that the 18 items of the scale only had loadings higher than 0.6 on one dimension, indicating good structural validity of the scale items and initially verifying the reliability of the evaluation index system for tourist experience value in city heritage parks.

Table 2. Rotated component matrix

Item No.	Item description	Component			
		Functional value	Emotional value	Cultural value	Social value
C7	Service quality	0.782			
C3	Performance activities	0.771			
C5	Transportation accessibility	0.768			
C8	Historical facilities	0.761			
C2	Cultural creative products	0.747			
C6	Recreational facilities	0.732			
C1	Food & accommodation	0.724			
C4	Environmental landscape	0.683			
A1	Pleasurable experience		0.820		
A4	Distinctive perception		0.810		
A2	Attractiveness		0.775		
A3	Engagement		0.775		
B3	Heritage revitalization			0.800	
B4	Cultural confidence			0.795	
B2	Behavioral identity			0.779	
B1	Knowledge acquisition			0.741	
D1	Photo sharing				0.871
D2	Social interaction				0.829

Analysis Method: Principal Component Analysis

Rotation Method: Kaiser Normalization with Varimax Rotation. A rotation converged after 5 iterations.

4.3. Confirmatory factor analysis

Based on exploratory factor analysis, confirmatory factor analysis was used to further validate the evaluation model. The research results showed that the factor loadings on all items of the evaluation model, including 18 observation indicators and 4 measurement dimensions, were greater than 0.40 (**Figure 1**), indicating that the scale items were reasonably set. According to the analysis results of the model fitting indicators: χ^2/df=1.161 < 3, GFI=0.936, CFI=0.990, both exceeding 0.9, RMSEA=0.026 < 0.05, SRMR=0.033 < 0.05, indicating that the overall performance of the model was good and the fitting accuracy of the data was high. As can be seen from Table 3, the square root of AVE of each measurement dimension is greater than the absolute value of the correlation coefficient between factors, which means that it has good discriminant validity. The discriminant validity of the evaluation model of tourist experience value in city site parks is ideal.

In addition, the Cronbach's Alpha values of the emotional value, cultural value, functional value, and social value scales ranged from 0.858 to 0.909, greater than 0.8, and the composite reliability (CR) values ranged from 0.810 to 0.90, all higher than 0.7, indicating good reliability of the evaluation model (**Table 3**). In summary, the evaluation model of tourist experience value in city site parks has passed the reliability and validity tests.

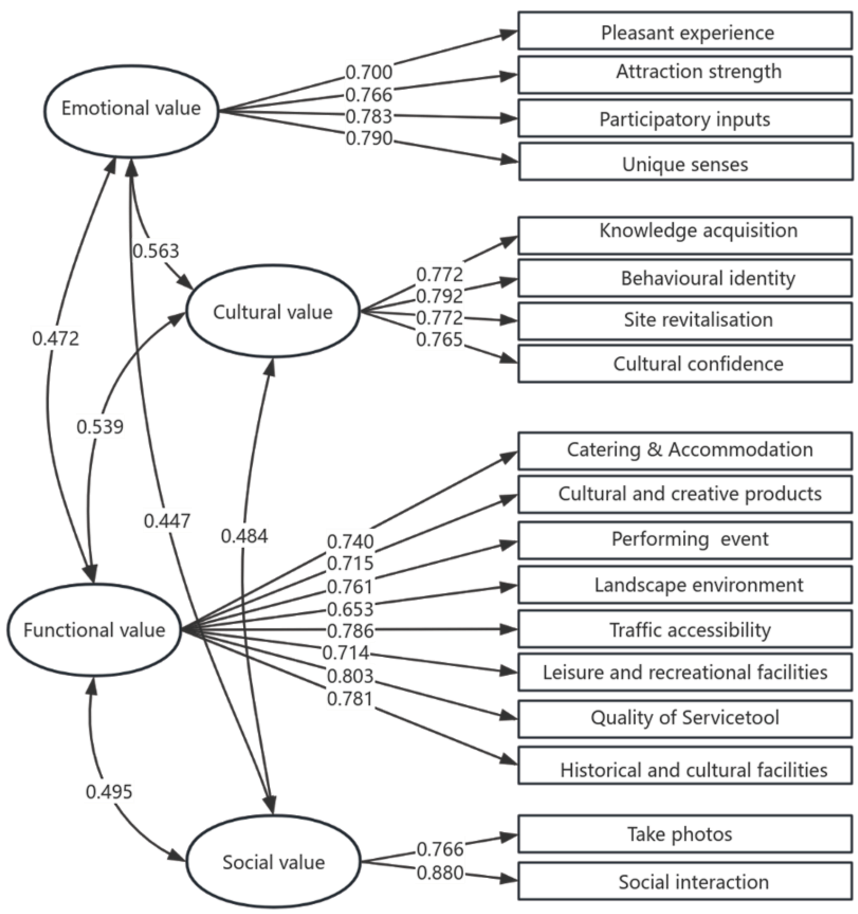

Figure 1. Confirmatory factor analysis model of Urban Heritage Park

Table 3. Pearson Correlation and AVE square root values

	Emotional value	Cultural value	Functional value	Social value
Emotional value	0.782			
Cultural value	0.485	0.775		
Functional value	0.421	0.472	0.746	
Social value	0.377	0.412	0.417	0.825

Note: The bold numbers on the diagonal are the square root values of AVE.

5. Management suggestions

Based on the four-dimensional evaluation model of tourist experience value in city heritage parks constructed and validated in this study, the Chongqing Open Port Heritage Park demonstrates certain advantages in emotional, cultural, functional, and social dimensions, but there is still room for improvement. To better unleash the dual value of cultural dissemination and public service in city heritage parks, the following management suggestions are proposed:

(1) Optimize the cultural narrative system and strengthen the transmission of cultural value. It is necessary to deepen the historical interpretation of the heritage site itself, combining the background of the city's opening and regional culture to construct a coherent spatial narrative chain. Strengthen cultural exhibitions and interactive education links, so that tourists can "understand, remember, and be willing to share".

(2) Enhance spatial functional configuration and enrich functional experience content. It is recommended to improve the traffic guidance system, optimize route design, and enhance tourists' participation and satisfaction in the entire chain of "seeing, playing, and shopping".

(3) Focus on emotional awakening mechanisms and deepen the creation of emotional value. Introduce multi-sensory experience elements (sound, scent, touch), set up immersive experience devices, create an emotionally evocative visiting path, promote emotional connections between tourists and the place, and enhance overall satisfaction and word-of-mouth dissemination.

(4) Establish a closed-loop experience feedback system and promote dynamic management mechanisms. Based on the experience value evaluation scale proposed in this study, build an online and offline integrated tourist feedback system to achieve precise matching and continuous optimization between tourist needs and park management.

6. Conclusion

While preserving historical heritage, urban heritage parks also provide places for the public to get close to nature and understand history. In the research perspective of urban heritage parks, issues such as the protection and development of urban heritage, tourism product design, heritage and urban development occupy a dominant position, and there is relatively little research on the subject experience of tourists after long-term operation. As the most direct experiencers and evaluators, the needs and feedback of tourists deserve more attention and importance. Therefore, based on the theoretical framework of tourist experience and flow theory, this study collected 970 online reviews of Chongqing Kaiport Heritage Park. Through text mining combined with exploratory and confirmatory factor analysis, a four-dimensional evaluation system for tourist experience value in urban heritage parks was constructed and validated. The study found that:

Emotional value, cultural value, functional value, and social value constitute the core dimensions of experience value. Among them, cultural value, as the core characteristic of heritage parks, strengthens tourists' cultural identity and enhances cultural confidence through the path of "historical knowledge acquisition - perception of heritage activation - behavioral identity". The newly identified dimension of social value reveals the impact of digital imaging social networking (photo-taking and checking in) and interactive experiences on the tourism experience in the digital age.

The study further identified four key observation indicators of functional value: transportation convenience and service quality constitute the basic experience guarantee; entertainment facilities and historical and cultural facilities are superimposed through interesting and educational functions, realizing the upgrading of the "integration of tourism and education" experience, and improving the depth of the experience.

Based on this, an 18-item scale for tourist experience value has been developed, providing urban ruins park operators with technical tools for dynamically monitoring tourist experiences and decision-making basis for optimizing resource allocation. At the same time, it can quantitatively evaluate the effectiveness of cultural activation, thus providing methodological support for the sustainable development of urban ruins parks.

Funding

Research on Evaluation and Improvement Strategies of Tourist Experience Value in Chongqing Kaifa Site Park from the Perspective of Cultural Confidence (Project No.: YKJCX2420807)

Disclosure statement

The authors declare no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on the Impact of the Digital Economy on Enterprises' ESG Performance

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Abstract: The digital economy has significant positive externalities in promoting the sustainable development of enterprises, providing an important opportunity for enterprises to improve their ESG performance. Through analysis, it is found that the digital economy has a huge impact on enterprise performance, mainly through three mechanisms: promoting environmental performance, strengthening social responsibility, and optimizing the governance structure. The research results of this paper help to expand the understanding of the dividend effect of the digital economy and deepen the theoretical understanding of the sustainable development of enterprises in the context of the digital economy.

Keywords: Digital economy; Enterprise ESG; Mechanism of action

Online publication: September 10, 2025

1. Introduction

The "Overall Layout Plan for Digital China Construction" clearly points out that the digital economy is an important driving force for promoting Chinese-style modernization. According to the data in "The Research Report on the Development of China's Digital Economy (2023)", in 2022, the total volume of China's digital economy exceeded 50.2 trillion yuan, accounting for 41.5% of GDP. The rapid development of the digital economy not only promotes high-quality economic growth but also provides strong impetus for digital economy construction. With the advancement of industrial digitalization, the digital economy has brought significant dividends to real-economy enterprises. It alleviates the financing difficulties of enterprises by changing the traditional financial ecology, promotes the application of digital technologies, improves enterprise efficiency, and drives management transformation. These changes have a profound impact on the sustainable development of enterprises. Environment, Social, and Governance (ESG), as the core criteria for measuring the sustainable development capabilities of enterprises, have received increasing attention from all parties [1]. The performance of enterprises in environmental responsibility, social responsibility, and corporate governance reflects their comprehensive management level. Therefore, it has become an important task at present to encourage enterprises to fulfill more

ESG responsibilities, especially in the context of the digital economy [2].

2. Overview of the digital economy

2.1. The connotation of the digital economy

The digital economy refers to the sum of various economic activities driven by digital technologies, with data as the key production factor and modern information networks as the foundation. Its core lies in deeply optimizing and reconstructing resource allocation, production processes, and service models through technical means, thereby improving the efficiency and quality of economic operation [3].

2.2. The characteristics of the digital economy

(1) Relying on cutting-edge technologies such as big data and artificial intelligence, it significantly improves the operating efficiency of enterprises, making the decision-making process more scientific and intelligent.

(2) The development of the platform economy and blockchain technology has broken the traditional centralized model, promoting the open flow and collaborative sharing of resource elements.

(3) The digitalization and visualization of information enhance the transparency of the transaction process, improving the controllability and compliance of enterprise management.

3. The impact mechanism of the digital economy on enterprises' ESG performance

3.1. The promoting effect on environmental performance

3.1.1 Improving resource utilization efficiency

Through technical means such as intelligent manufacturing, the industrial Internet, and the Internet of Things, the digital economy enables enterprises to conduct real-time monitoring and dynamic optimization management of energy, water resources, raw materials, etc. For example, intelligent sensors can collect energy consumption data, and with the help of AI algorithms, identify energy-efficiency bottlenecks and put forward improvement suggestions. The industrial Internet platform can achieve remote equipment management and predictive maintenance, reducing energy consumption and emissions and improving the overall resource allocation efficiency, helping enterprises build a green production system [4–6].

3.1.2. Promoting green innovation

Digital technologies also provide solid support for green technology research and development. A big-data-based carbon-emission monitoring system can accurately assess the carbon footprint of enterprises, providing a scientific basis for setting carbon-emission reduction targets and performance appraisals. At the same time, enterprises can use cloud computing and artificial intelligence to accelerate the design and testing of green products, promoting the industrialization of technological achievements such as new energy, degradable materials, and green packaging, and forming a sustainable green-innovation ability [7].

3.1.3. Realizing the transparency of environmental information

With its characteristics of "non-tampering" and "full-process traceability", blockchain technology provides a new solution for the recording and disclosure of enterprise environmental information. At the same time, enterprises can use the blockchain system to record energy use, emission data, and green investment, building an open and trustworthy environmental-information disclosure platform. This not only enhances the transparency and credibility of environmental protection data but also facilitates the supervision of enterprises' responsibility-fulfilling behaviors by the government, investors, and the public, further promoting enterprises to assume environmental responsibilities.

3.2. The strengthening effect on social responsibility

3.2.1. Promoting the intelligent management of employee welfare and labor protection

The health and safety of employees are related to their well-being and should be taken seriously. With the help of digital human-resources management systems, enterprises can monitor the health, safety, and satisfaction of employees in real-time. Through big-data analysis of career preferences and performance trends, personalized career-development paths and welfare policies can be customized for employees. For example, some enterprises have provided health-consultation services for employees through remote-medical platforms, enhancing employees' well-being and sense of belonging and reflecting their attention to employees' rights and interests [8].

3.2.2. Expanding public welfare and social influence

Digital platforms (such as WeChat official accounts, public-welfare APPs, and crowdfunding platforms) provide convenient and efficient channels for enterprises to participate in public-welfare activities. Enterprises can expand their public-welfare influence through live-streaming, short videos, online donations, etc., enhancing social recognition. For example, some enterprises use digital tools to carry out targeted poverty alleviation, connecting the specific needs of poverty-stricken areas to achieve efficient resource allocation, thereby enhancing the enterprise's social reputation and public trust [9].

3.2.3. Ensuring the fairness and compliance of the supply chain

Digital supply-chain management tools (such as ERP systems and blockchain traceability platforms) enable enterprises to monitor all links of the supply chain in real-time, ensuring that the sources of raw materials are legal and that suppliers have no issues such as child labor, forced labor, or environmental violations. The system can also automatically identify risk nodes and provide early-warning prompts, strengthening supply-chain responsibility governance, effectively reducing legal and reputational risks, and improving the overall performance of enterprises in social responsibility [10].

3.3. The optimizing effect on corporate governance

3.3.1. Improving governance transparency and data visualization capabilities

Enterprises can use business intelligence (BI) tools, data dashboards, and financial-analysis systems to keep track of key business data in real-time, improving governance transparency. Intelligent audit systems (such as RPA combined with AI technology) can automatically identify financial anomalies, strengthening internal control and reducing the risk of fraud. Data visualization transforms complex operational data into intuitive charts, providing accurate decision-making support for management and optimizing governance effectiveness [11].

3.3.2. Strengthening external supervision and investor communication

Digital technologies promote the standardized and real-time disclosure of enterprise ESG information. Through sustainable-development report platforms and ESG rating websites, enterprises can actively release key information such as environmental emissions, social-responsibility fulfillment, and governance structures, improving information transparency and investor confidence. At the same time, enterprises can also use online investor-relations management systems to interact with the market in real-time, meeting the high requirements of the capital market for sustainable governance [12].

3.3.3. Supporting the optimization of the governance structure

Digital tools provide the board of directors and management with real-time operation and external-environment data, enhancing their sensitivity to the operating status of the enterprise and their ability to respond. For example, an AI-driven strategic-management platform can dynamically assess external risks and internal performance of the enterprise, assisting in formulating and adjusting development strategies. In addition, intelligent systems can support the board of directors in achieving refined management in risk control, performance appraisal, and incentive-mechanism design, promoting the evolution of corporate governance towards transparency and professionalism [13].

4. Typical case analysis

In the context of the rapid development of the digital economy, Alibaba Group, relying on its powerful digital-technology capabilities, actively promotes the comprehensive improvement of enterprises in environmental protection, social responsibility, and corporate governance (ESG), becoming a model for Chinese enterprises to achieve sustainable development through digital means.

4.1. Environmental performance: Building a green supply chain and carbon-management system

Cainiao Network, a subsidiary of Alibaba, uses the Internet of Things and big-data technology to create an intelligent logistics system, optimizing the transportation routes of packages and significantly reducing carbon emissions. In 2021, Cainiao launched the “Green Package” initiative, promoting the use of degradable environmental-protection packaging materials and driving the use of recyclable express boxes nationwide. Cumulatively, it has reduced plastic use by more than 30,000 tons. In addition, Alibaba Cloud’s “Carbon-Neutral Computing Platform”, which combines cloud computing and blockchain technology, provides carbon-emission monitoring, accounting, and reporting services for enterprise customers, effectively helping upstream and downstream enterprises carry out green transformation [14].

4.2. Social responsibility: Digital platform empowering public-welfare practices and inclusive development

In terms of social responsibility, Alibaba advocates that users reduce their carbon footprint through the Ant Forest project. For every certain amount of “green energy” accumulated by users, the platform plants trees on their behalf. As of 2023, this project has planted more than 400 million trees in western China, significantly improving the ecological environment in desertified areas. At the same time, Alibaba uses its e-commerce platform and big-data capabilities to implement the “Digital Village” plan, helping agricultural products enter the market and driving millions of small and medium-sized farmers to increase their incomes, demonstrating its important role in promoting inclusive social development.

4.3. Corporate governance: Digital governance system improving transparency and decision-making efficiency

In terms of corporate governance, Alibaba has built a complete digital governance framework. Through the enterprise middle-platform, it integrates the operation data of various business units in real-time, providing scientific decision-making support for the board of directors. Its compliance management department uses AI algorithms for public-opinion monitoring and risk identification, improving compliance early-warning capabilities and effectively preventing enterprise risks. In terms of ESG information disclosure, Alibaba introduced the SASB and TCFD framework standards in its annual reports released on the Hong Kong and New York Stock Exchanges, establishing a systematic ESG disclosure mechanism and continuously enhancing investor relations management and social supervision transparency.

5. Policy recommendations and enterprise countermeasures

Driven by the digital-economy wave, it has become a key path for enterprises to achieve high-quality sustainable development by using digital technologies to improve their Environmental, Social, and Governance (ESG) performance. To further unleash the potential of the digital economy in empowering enterprises to improve their ESG performance, this paper puts forward the following recommendations from the two levels of policy-making and enterprise practice [15]:

5.1. Policy recommendations

5.1.1. Improve the policy framework for digital ESG governance

The state should accelerate the establishment of an ESG evaluation and supervision system supported by digital technologies, promote the formulation of unified and authoritative digital information-disclosure standards for ESG, improve the comparability, transparency, and standardization of ESG data, and build an efficient and collaborative governance system.

5.1.2. Increase policy support for green digital technologies

The government should set up special funds and tax-incentive mechanisms to encourage enterprises to carry out green-technology innovation and digital transformation, and promote the in-depth application of technologies such as the industrial Internet, artificial intelligence, and big data in fields such as green manufacturing, energy conservation and emission reduction, and environmental monitoring.

5.1.3. Promote the construction of a data-sharing mechanism between the government and enterprises

It is recommended to build a data-collaboration platform between the government and enterprises, promote the interconnection and sharing of data in key ESG areas such as carbon emissions, labor protection, and work safety, and improve the regulatory efficiency and the authenticity and integrity of enterprise ESG data.

5.1.4. Strengthen digital empowerment support for small and medium-sized enterprises

In view of the shortcomings of small and medium-sized enterprises in digitalization and ESG construction, the government can provide customized technical consultations, talent training, and financial support to help them reduce the transformation threshold and enhance their sustainable development capabilities.

5.2. Enterprise countermeasures

5.2.1. Develop a digital-driven ESG strategic plan

Enterprises should combine their industry characteristics and development stages, clarify the path to achieve ESG goals through digital means, and develop a digital-transformation strategy covering environmental, social, and governance dimensions, realizing the coordinated promotion of sustainable development and technological innovation.

5.2.2. Build an enterprise-level ESG data platform

Promote the construction of an internal data-governance system, integrate multi-dimensional data resources such as finance, operation, supply chain, environmental protection, and human resources, and establish a unified and efficient ESG information-management platform to provide strong support for internal management and external disclosure.

5.2.3. Strengthen the construction of green-innovation capabilities

Actively apply advanced technologies such as artificial intelligence, the Internet of Things, and blockchain to promote green product design, green manufacturing, and green logistics, improve the ability to apply for green patents and transform technologies, and build the core competitive advantage of enterprise sustainable development.

5.2.4. Promote the transformation of corporate culture and governance mechanisms

Pay attention to the integrated cultivation of digital literacy and sustainable development concepts, and build a composite management team with both technical and ESG awareness. Strengthen the supervision responsibility of the board of directors in ESG affairs, guide management to pay attention to long-term value creation, and achieve a transformation from a “compliance-oriented” governance model to a “value-oriented” one.

5.2.5. Strengthen the interaction mechanism with stakeholders

Rely on digital tools to build a communication platform for enterprises with investors, employees, customers, communities, and other parties, improve information transparency and response efficiency, and build an ESG ecosystem in which enterprises and stakeholders have positive interactions and share the benefits.

6. Conclusion

Under the combined influence of policy support and market demand, digital inclusive finance and corporate green finance are showing a trend of deep integration. Digital technology has made the popularization of green finance possible, while green concepts have infused inclusive finance with the connotation of sustainable development. In the future, as relevant policies are further implemented and technology continues to advance, the two will play a greater role in serving the real economy, promoting social equity, and achieving carbon neutrality goals

Finding

Exploration of the Impact of Financial Reforms in the Hainan Free Trade Port on Enterprises, General Project (Project No.: HKKY2024-13)

Disclosure statement

The authors declare no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Opportunities, Challenges, and Strategies of China's Sporting Goods Export under the Background of RCEP

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Abstract: China has long been recognized as a major producer and exporter of sporting goods, with its share of global sporting goods exports continuing to rise steadily. The implementation of the RCEP agreement presents both opportunities and challenges for China's sporting goods export trade. To achieve sustained growth, enterprises must enhance their innovation capacity, improve product quality, strengthen brand influence, and refine marketing strategies. At the same time, they must proactively manage risks related to exchange rate fluctuations and rising international logistics costs.

Keywords: RCEP; Sporting goods; Exports; Challenges; Opportunities

Online publication: September 10, 2025

1. Introduction

China's sporting goods industry as a national strategic emerging industry, its foreign export trade is of great significance to promote industrial upgrading, increase employment, and promote economic growth. The signing of the Regional Comprehensive Economic Partnership (RCEP) has provided new opportunities and challenges for trade exchanges among member countries. As one of the important members of RCEP, China's export trade of sporting goods will face a new development environment under the background of the RCEP.

2. The current situation of China's export trade of sporting goods

2.1. Export scale and product structure

According to the General Administration of Sport, China's total exports of sporting goods and equipment reached $17.669 billion in 2022, surpassing the $15.812 billion in 2020, showing the industry's resilience [1]. However, China's exports of sporting goods and equipment in 2022 decreased by $511.4037 million compared with the same period in 2021, down 22.3 percent year on year. In the first quarter of 2023, the export value of sporting goods and equipment was 4.074 billion US dollars, an increase of 4.22% from the previous quarter, indicating the recovery trend of foreign trade in the sporting goods industry [2]. This change may be affected by a variety of factors, including changes in international market demand, the impact of the trade environment, and changes in the economic situation at home and abroad [3].

The product structure of China's sporting goods exports can be seen in **Table 1**.

Table 1. Structure of export products of China's sporting goods

Product classification	Product categories
Apparel	Clothing accessories; Gloves, mittens, leather or synthetic leather, with padding, specially designed for sporting use
	Sportswear, ski and swimwear (knitted or crocheted)
	Athletic wear, swimwear, and other clothing (not knitted or crocheted)
Footwear	Sneakers; Rubber or plastic outsole and upper
	Sneakers; Made of rubber, plastic, leather or synthetic leather
	Sneakers; Tennis shoes, basketball shoes, sneakers, training shoes, etc
Equipment	Yachts and other boats; And recreational or sports, rowboats and canoes
	Articles and equipment not listed in this chapter for general sports activities, gymnastics, competitive and other sports (including table tennis), or outdoor games
	Fishing rods, fishing hooks and other fishing supplies; Shoeing "birds" and similar hunting supplies

For a long time in the past, the export of China's sporting goods mainly concentrated on low-end products, such as sports shoes, sportswear, and so on. These products usually have price advantages, but relatively low technical content and added value. However, the product structure of China's sporting goods exports is gradually shifting to high-end products, as the country's sporting goods manufacturing industry is making technological progress and strengthening brand building. For example, high-end sports equipment includes professional sports shoes, sports apparel, sports equipment, etc. These products usually use high-performance materials and technologies to meet the needs of professional athletes and high-end consumers. China's sporting goods manufacturing industry is also actively responding to changes in demand in the international market by launching high-end products that meet market demand, boosting the competitiveness and market share of China's sporting goods in the international market [4].

In addition, the Chinese government is also actively promoting the upgrading and transformation of the sporting goods manufacturing industry. Through policy support and financial investment, enterprises are encouraged to increase investment in research and development, enhance technological innovation capabilities, and promote the development of sporting goods manufacturing to a high-end and intelligent direction. Chinese sporting goods companies are also actively exploring overseas markets and further expanding their export scale by establishing overseas branches and participating in international exhibitions [5].

2.2. Distribution of export markets

According to the quarterly research report of China Sporting Goods Industry Federation in 2023, the geographical distribution of China's sporting goods export market is shown in **Table 2** [6]. From the perspective of export share in the past ten years, the export situation of China's sporting goods in major markets shows a diversified and growing trend, among which ASEAN and East Asia markets are important destinations for China's sporting goods exports, the status of the CIS market is gradually declining, and South Asia, West Asia, Central and Eastern Europe and Central Asia markets, although relatively small, but still have potential (**Table 3**).

Table 2. Geographical distribution of China's sporting goods export market

Regions	Nation
ASEAN	Vietnam, Laos, Myanmar, Cambodia, Timor-Leste, Malaysia, Indonesia, Thailand, Philippines, Singapore, Brunei
East Asia	Mongolia, North Korea, South Korea, Japan
CIS	Russia, Moldova, Ukraine, Belarus, Georgia, Azerbaijan, Armenia
South Asia	Nepal, Bhutan, Bangladesh, Maldives, India, Pakistan, Sri Lanka, Afghanistan, Iraq, Iran, Syria, Jordan, Lebanon, Israel
West Asia	Palestine, Saudi Arabia, Bahrain, Qatar, Kuwait, Oman, Yemen, Egypt, Turkey, United Arab Emirates
Central and Eastern Europe	Poland, Lithuania, Estonia, Latvia, Czechoslovakia, Hungary, Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Albania, Romania, Bulgaria, Macedonia
Central Asia	Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan

Table 3. Export status of China's major sporting goods markets

Year	ASEAN		East Asia		CIS		South Asia	
	Export value	Percentage	Value of exports	Percentage	Value of exports	Percentage	Value of exports	Take up a proportion of
2009	3.61	2.55%	4.11	2.90%	4.14	2.93%	0.43	0.31%
2010	3.91	2.42%	4.70	2.91%	4.81	2.98%	0.68	0.42%
2011	4.97	2.77%	5.47	3.05%	5.71	3.19%	0.80	0.45%
2012	6.87	3.72%	5.66	3.07%	5.97	3.24%	1.01	0.55%
2013	8.96	4.62%	6.13	3.16%	7.44	3.83%	0.96	0.49%
2014	9.29	4.46%	6.98	3.35%	7.82	3.75%	1.18	0.57%
2015	9.02	4.47%	7.18	3.56%	4.82	2.39%	1.32	0.66%
2016	8.11	4.45%	5.44	2.99%	4.66	2.56%	0.83	0.46%
2017	8.01	4.29%	5.71	3.06%	4.08	2.18%	0.86	0.46%
2018	8.82	4.42%	6.01	3.01%	4.28	2.15%	0.81	0.41%
2019	12.63	5.90%	6.80	3.17%	4.77	2.23%	0.96	0.45%
2020	18.28	7.39%	8.07	3.26%	5.04	2.04%	0.90	0.36%
2021	14.59	6.69%	6.41	3.22%	5.40	2.81%	0.93	0.48%
2022	17.45	7.66%	7.84	4.01%	6.94	2.97%	1.14	0.54%
2023	21.17	8.45%	9.05	4.38%	6.68	3.05%	1.38	0.60%

Year	West Asia		Central and Eastern Europe		Central Asia	
	Value of exports	Percentage	Value of exports	Percentage	Value of exports	Percentage
2009	6.61	4.67%	2.01	1.42%	1.20	0.85%
2010	7.31	4.53%	2.09	1.29%	0.85	0.53%
2011	7.98	4.45%	2.87	1.60%	0.97	0.54%
2012	8.94	4.85%	3.01	1.63%	0.98	0.53%

Table 3 (Continued)

Year	West Asia		Central and Eastern Europe		Central Asia	
	Value of exports	Percentage	Value of exports	Percentage	Value of exports	Percentage
2013	9.94	5.12%	2.99	1.54%	1.87	0.96%
2014	11.81	5.67%	3.63	1.74%	2.70	1.29%
2015	10.42	5.16%	3.39	1.68%	1.05	0.52%
2016	8.56	4.70%	3.15	1.73%	1.18	0.65%
2017	7.83	4.19%	3.54	1.90%	1.49	0.80%
2018	6.98	3.50%	4.20	2.11%	1.58	0.79%
2019	9.33	4.36%	4.57	2.13%	1.70	0.79%
2020	10.58	4.27%	5.45	2.20%	1.43	0.58%
2021	9.17	4.71%	3.61	1.80%	1.50	0.77%
2022	9.87	5.12%	5.28	2.27%	2.24	0.94%
2023	10.89	5.78%	6.02	2.48%	2.46	1.18%

Source: United Nations Commodity Trade Statistics Database [8]

The export data of China's sporting goods industry in 2023 shows that the United States is still the largest destination of China's sporting goods exports, accounting for more than one-third of the share. This shows that the US market has a strong consumption power for Chinese sporting goods. In addition, India, the United Kingdom, Germany, Spain, Russia, and other countries are also the main markets of China's sporting goods exports, and have long been among the top ten export countries [7].

2.3. Export patterns and trade channels

At present, China's sports goods export trade patterns are mainly divided into two kinds: the first is OEM (Original Equipment Manufacturer) mode, that is, the original equipment manufacturing mode. In this mode, our country's sporting goods enterprises produce according to the requirements of foreign brands, and the products are finally sold in the name of foreign brands. The advantage of this model is that enterprises can use their own production advantages to reduce production costs while avoiding the risks of brand building and market promotion. However, the profit under this model is relatively low, and the company's control over the market is weak [9]. The second model is the self-owned brand export model. In this model, China's sporting goods enterprises through independent research and development, design, production, and their own brand to promote and sell in the international market. The advantage of this model is that enterprises can obtain higher profits, while enhancing brand influence and market competitiveness. However, this model requires companies to have strong research and development capabilities, brand promotion capabilities, and market operation capabilities [10].

At present, China's sporting goods export trade channels mainly include the following: the first is a foreign trade company. As a professional trade intermediary, foreign trade companies can help sporting goods enterprises to find overseas customers, conduct trade negotiations, handle export procedures, etc. The second kind is the exhibition. Exhibition is an important platform for sporting goods enterprises to display products, find customers, and expand the market. By participating in well-known sporting goods exhibitions at home and abroad, enterprises can directly contact overseas buyers, understand the market demand, and find cooperation opportunities. The third is an e-commerce platform. With the rapid development of the Internet, e-commerce platform has become a new channel for sporting goods enterprises to expand the international market. Through internationally renowned e-commerce platforms such as Alibaba and Amazon, companies can quickly enter overseas markets, reduce trade costs, and improve trade efficiency. The fourth type is overseas agents. Sporting goods companies can quickly enter the local market and increase product sales by looking for overseas agents and using the resources and services of agents [11].

3. Opportunities and challenges of RCEP for China's sporting goods export trade

3.1. Opportunities brought by RCEP for China's export trade of sporting goods

3.1.1. Tariff reduction and remission

The implementation of the RCEP agreement will significantly reduce tariffs among member countries, which is a huge opportunity for China's foreign export trade of sporting goods. The tariff reduction will directly reduce the export costs of Chinese sporting goods companies and improve the price competitiveness of their products. Against the backdrop of lower tariffs, the prices of Chinese sporting goods in RCEP member countries' markets will be more attractive, especially in price-sensitive markets, which will help boost the market share of Chinese products. The tariff reduction will also help promote trade facilitation, simplify customs clearance procedures, and speed up the flow of goods, thereby improving trade efficiency. This will help Chinese sporting goods companies better seize market opportunities and expand into the international market [12].

3.1.2. Investment facilitation

The investment facilitation measures in the RCEP agreement provide new development opportunities for Chinese sporting goods enterprises. The investment facilitation will help Chinese sporting goods companies better "go global" and make direct investments in overseas markets. By establishing local production bases or sales networks, companies can more directly understand and meet the needs of the local market, while also circumventing some trade barriers and localizing production. This will help improve the competitiveness of Chinese sporting goods in the international market and push enterprises to achieve a global layout. Investment facilitation will also help promote international exchanges of technology and management experience, and enhance the innovation ability and management level of Chinese sporting goods enterprises.

3.1.3. Expand market access

The expansion of market access means that Chinese sporting goods will face more potential customers and a larger market space, which will help enterprises achieve economies of scale, reduce unit costs, and improve overall benefits. The RCEP agreement will enable Chinese sporting goods companies to access the markets of other member countries more conveniently. The expanded market access will also help promote brand building and market promotion of Chinese sporting goods enterprises, and enhance the visibility and influence of Chinese sporting goods in the international market. In the context of expanding market access, Chinese sporting goods enterprises should actively adjust their strategies, seize opportunities, expand the international market, and enhance global competitiveness [13].

3.2. Challenges brought by RCEP for China's sporting goods export trade

3.2.1. Intensified competition

With the implementation of the RCEP agreement, trade barriers between member states will be gradually reduced, which will lead to more intense market competition for China's sports goods export trade. Chinese sporting goods companies will face competition from companies in other member countries, which may have lower production costs, more advanced technology, or stronger brand influence. The implementation of the RCEP agreement will attract more foreign companies to the Chinese market, which will intensify competition in the domestic market. Under such circumstances, Chinese sporting goods companies need to improve their competitiveness and cope with the competitive pressure by improving product quality, strengthening brand building, and enhancing innovation capabilities.

3.2.2. Increased trade frictions

The implementation of the RCEP agreement may bring some trade frictions, which is a challenge for China's sports goods export trade. The increase in trade between the member countries will lead to some trade disputes and frictions, such as anti-dumping and anti-subsidy. These trade frictions may have a certain impact on the export of Chinese sporting goods enterprises [14].

The implementation of the RCEP agreement may cause some member countries to have doubts about China's trade policy, fearing that a large number of Chinese products may have an impact on their own industries. Under such circumstances, Chinese sporting goods companies need to strengthen communication and coordination with other member countries and actively deal with possible trade frictions.

3.2.3. Heightened technical barriers

The implementation of the RCEP agreement may bring about an increase in some technical barriers, which is a challenge for China's sports goods export trade. On the one hand, with the increase in trade between member states, there may be some technical barriers to trade, such as technical standards and certification requirements. These technical barriers may have a certain impact on the export of Chinese sporting goods enterprises. On the other hand, the implementation of the RCEP agreement may cause some member countries to have doubts about China's technology policy, fearing that a large number of Chinese products may have an impact on their own industries. Under such circumstances, Chinese sporting goods companies need to strengthen their research and development capabilities and upgrade the technical content of their products to cope with possible technical barriers [15].

4. Suggestions on China's sporting goods export under the background of RCEP

4.1. Optimize market competition strategies and innovate marketing methods

Optimizing market competition strategy is the key to the development of China's sporting goods export trade. Enterprises need to formulate differentiated market positioning and competitive strategies according to their own characteristics and the needs of target markets. For example, companies can stand out in the market by researching and developing products with unique features and designs that meet the needs of specific consumer groups. In addition, companies can improve customer loyalty and market share by providing quality products and services, building a good brand image, and reputation. To better implement these strategies, companies can make use of market research and data analysis tools to gain an in-depth understanding of the demand and competition conditions of their target markets and formulate corresponding market entry and expansion plans.

With the development of digitalization and networking, enterprises can also make use of modern technological means, such as social media and e-commerce platforms, for precision marketing and brand promotion. In addition, enterprises can also carry out online sales and cross-border e-commerce through e-commerce platforms to expand sales channels and market coverage. To better implement these innovative marketing means, enterprises need to cultivate talents with digital marketing capabilities and innovative thinking, while strengthening cooperation with other enterprises and industries to share resources and market information for mutual benefit and win-win results.

4.2. Strengthen trade facilitation and deepen international cooperation and exchanges

Strengthening the construction of trade facilitation is the key to the development of China's sporting goods export trade. Trade facilitation includes simplifying import and export procedures, improving customs clearance efficiency, and reducing trade costs. By strengthening the construction of trade facilitation, trade barriers can be reduced, and the competitiveness of Chinese sporting goods in the international market can be improved. The government can further simplify the procedure of export tax refund, improve the efficiency of tax refund, and reduce the burden on enterprises. On the other hand, cooperation with other RCEP member states can also be strengthened to promote intra-regional trade facilitation measures, such as establishing a unified electronic customs clearance system and simplifying requirements for certificates of origin, so as to reduce intra-regional trade costs and boost exports of Chinese sporting goods.

4.3. Improve the innovation capacity of enterprises and build their brand image

Enterprises should attach importance to product innovation to meet the changing market demand. Enterprises can invest more resources in the research and development of high-tech sporting goods with independent intellectual property rights, such as smart wearable devices and sports equipment made of environmentally friendly materials. At the same time, companies can also introduce fashion elements to enhance product appearance and user experience by cooperating with internationally renowned design teams. For example, Anta Sports launched a running shoe with the latest cushioned technology in 2023, which received a warm response from the market. In addition, companies can use big data and artificial intelligence technology to analyze consumer demand, achieve personalized customization of products, and increase the added value of products.

5. Conclusion

Under RCEP, China's sporting goods exports gain opportunities, tariff cuts lower costs, investment facilitation supports overseas layout, and expanded market access opens up broader space, while facing challenges like intensified intra-regional competition, more trade frictions, and heightened technical barriers.

This study systematically sorts out the industry's export status, including scale, structure, markets, and clarifies RCEP's impact paths, offering practical strategies for enterprises and enriching research on regional trade agreements and specific industries.

However, the study has limitations: discussions on opportunities and challenges are mostly qualitative (e.g., only noting tariff cuts reduce costs without quantifying export scale growth). Future research can use quantitative methods (e.g., econometric models, competition indexes) to measure RCEP's specific impact on export volume or competition intensity, providing more precise support for industry development.

Funding

Jilin International Studies University 2025 Batch National College Students' Innovation Training Program Project, Opportunities, Challenges, and Strategies of China's Sporting Goods Export under the Background of RCEP (Project No.: 202510964038)

Disclosure statement

The authors declare no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Database of Clause Depth of China's Regional Trade Agreement and Its Characteristics

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Abstract: This paper analyzes the text of 3261 clauses of 20 RTAs signed by China, classifies them into 52 policy areas according to the international mainstream HMS method, and assigns them through coding. The clause depth of China's RTAs is measured across three-dimensional systems (policy areas, clauses, and core clauses) and two generations of trade policy areas (WTO+, WTO-X, and all policy areas). It is observed that China's RTAs exhibit greater depth in Industrial Products, Agricultural Products, TBT, Antidumping, Countervailing, and Investment, while showing comparatively less depth in Fiscal Policy, Innovation Policies, and related areas.

Keywords: Regional trade agreement; Clause depth; Database construction; Agreement text

Online publication: September 10, 2025

1. Introduction

In the 21st century, trade has become more complex, and the demand for more complex international trade rules has also emerged. Due to the lack of flexibility in multilateral coordination of the WTO, the gap in rules has been filled by regional coordination. The number of bilateral and regional trade agreements (RTA) has increased explosively. By the first half of 2022, the cumulative number of effective RTA notified to the WTO has reached 580 (**Figure 1**). With the increasingly close relationship between trade and a country's finance, technology, culture, and other fields, the content of RTA has gradually developed to a wider and deeper level. This kind of coordination through deep regional trade agreements is also called 21st-century regionalism by scholars [1].

In the context of new regionalism, scholars have begun a preliminary discussion on the depth of RTA [2–5]. They use RTA clauses to construct indicators to measure the depth, and gradually increase from index construction to database construction [3–5]. Provide data support for RTA from quantitative research (using traditional trade openness indicators such as the percentage of tariff reduction and dummy variables of whether to sign a trade agreement) to in-depth research on the content of complex clauses, bringing the research on trade openness into a new stage [6–8].

Foreign research attaches great importance to database construction, but there is no systematic RTA in-depth database of China. President Xi Jinping emphasized during his visit to Renmin University on April 25 this year

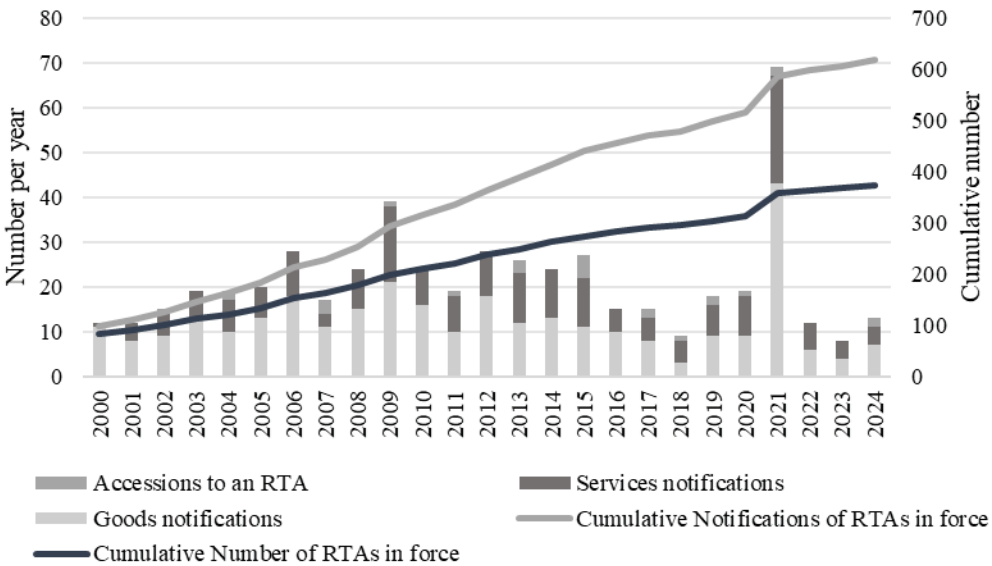

Figure 1. RTAs currently in force, 2000–2024

that China should be taken as a reflection, take the reality as a reflection, solve China's problems based on China's reality. The construction of China's RTA database should also conform to this purpose, scientifically measure, and effectively solve China's practical problems in economic and trade development. In the past, domestic research basically used foreign databases to carry out empirical analysis, but the three existing databases are difficult to match with Chinese research.

First, in response to the objective requirements of the new trend of Global trade system reform, China's active participation in regional economic cooperation and governance and accelerating the construction of high-level RTA are the inevitable choice to build a new system of higher-level open economy, and also an important path to actively integrate into high-standard international economic and trade rules and build a trading power [9]. Although the development of China's RTA started relatively late, and it was only signed after entering the 21st century, it has made great progress in a short period of time. However, these important RTAs signed by China in recent years are not within the statistical period of the above databases, which makes the current research on the depth of China's RTA lack of data support. It is necessary to build acore depth measurement index for China's RTA.

Second, with the signing of more and more high-level trade agreements, it can be found that the clauses of each chapter in the agreement are becoming more and more detailed. Existing databases and cutting-edge research on this issue by domestic scholars often only assign 1/0 based on whether the agreement involves a certain topic area, lack of a more detailed indicator system to measure, and cannot highlight the importance of the specific content involved in a certain clause in a trade agreement [10–13]. In order to break through this limitation, correspond to the 52 policy areas, and use text analysis to build the RTA depth's core indicator system, which can be used for subsequent extended research and can also be used to test the robustness of the analysis conclusions.

Third, as a developing country, some core clauses in the RTA signed by China will play an important role and cannot be mixed with the core clauses valued by developed countries. The index system in the above databases cannot be fully applicable to China's problems. It is necessary to scientifically build composite indicators of core clauses focusing on the key areas of RTA signed by China, so as to achieve a multidimensional measurement of the depth of RTA.

Therefore, under the background of high-quality trade development, it is urgent to fill the gap in the in-depth data of China's signing of RTA clauses, innovatively build China's RTA in-depth three-dimensional database that fully meets the research needs, and provide data support for the classification and refinement of the impact of RTA depth on improving the quality of China's economic and trade development in the new era. Based on the agreement text, this paper will focus on the content and depth of the RTA itself signed by China so far, and build a three-dimensional index system reflecting the depth of RTA, so as to build a systematic database of China's RTA clauses.

2. Literature review

As a "lubricant" for bilateral or regional countries to trade in goods, economic exchanges and international services, the contents of the terms covered by the trade agreement are further deepened, from the initial level of "border measures" such as tariff and non-tariff barrier reduction to the level of "post border measures" covering intellectual property protection, service trade, competition policy, e-commerce, etc. It has become an irreversible trend for countries to pursue a higher level of trade openness by signing deep RTA [14–16].

2.1. Meaning of RTA depth

The concept of "RTA Depth" was first proposed by Lawrence (1996) [17]. He believed that there was a difference between deep RTAs and shallow RTAs, and some scholars later call it the heterogeneity of trade agreements, pointing out that the dummy variables of RTA or simple tariff elimination could not evaluate RTA well [18]. Most of the leading-edge literature titles are "deep regional trade agreements" or "RTA depth". In short, the meaning of RTA depth is not just to see how many RTAs have been signed, but to download and reorganize the text of each signed agreement, and measure the depth of the signed RTA through an in-depth analysis of the clauses.

2.2. Research progress of RTA clause depth

Previous studies have mainly analyzed the impact of whether to sign a certain agreement, but Kohl *et al.*, pointed out that due to the heterogeneity of trade agreements, the traditional method of dummy variables is misleading [4]. Not all types of clauses in trade agreements have trade-promoting effects and should be studied by category. That is, this traditional method cannot reflect the influence of the heterogeneity of the RTA depth terms. In order to solve this problem, Horn *et al.* earlier deepened the research perspective into the specific clauses of RTAs, and proposed the HMS method, which uses "Agreement Coverage Rate" and "Legal Commitment Rate" to measure the RTA clause depth [2]. After studying the 28 effective RTA clauses signed by the United States and the European Union, they divided the 52 issues involved in these agreements into two categories: "WTO+" and "WTO-X". The former is known as "first-generation" trade policy, referring to issues that exist within the WTO system. The latter is known as "second-generation" trade policy, referring to new issues that have evolved over time (**Table 1**).

This classification method is cited by WTO (2011), making the classification methods of "WTO+" and "WTO-X" more authoritative. In the HMS method, "agreement coverage rate" refers to the ratio of the number of articles involving WTO+ or WTO-X in the agreement to the total number of clauses. And "legal commitment rate" refers to the ratio of the number of substantive legally binding clauses involving WTO+ or WTO-X in the agreement to the total number of clauses covered. The HMS method has since been widely adopted by research in this field [4, 5, 10–12, 19–25].

Table 1. Category of RTA clauses by HMS

WTO+ field	WTO-X field		
FTA Industrial Goods	Competition Policy	Environmental Laws	Investment
FTA Agricultural Goods	Labour Market Regulation	Movement of Capital	Consumer Protection
Customs Administration	Data Protection	Agriculture	Approximation of Legislation
Export Taxes	Audio Visual	Civil Protection	Innovation Policies
Sanitary and Phytosanitary Measures	Cultural Cooperation	Economic Policy Dialogue	Education and Training
State Trading Enterprises	Energy	Financial Assistance	Human Rights
Technical Barriers to Trade	Illegal Immigration	Illicit Drugs	Industrial Cooperation
Countervailing Measures	Information Society	Mining	Money Laundering
Antidumping	Nuclear Safety	Political Dialogue	Public Administration
State Aid	Regional Cooperation	Research and Technology	Small and Medium Enterprise
Public Procurement	Social Matters	Statistics	Taxation
Trade-related Investment Measures	Terrorism	Visa and Asylum	Health
Trade in Services Agreement	Anti-Corruption	Intellectual Property Protection	
Trade-related Intellectual Property Rights			

2.3. Three existing RTA clause depth databases

While conducting in-depth research on RTA terms, scholars have gradually shifted from index measurement to database construction. There are currently three major databases in this field.

2.3.1. DESTA

Dür *et al.* conducted a text analysis of 587 RTAs signed between 1945–2009, involving a total of 3310 initial memberships, covering 10 broad sectors of cooperation, encompassing market access, services, investments, intellectual propoerty rights, competition, public procurement, standards, trade remedies, non-trade issues, and dispute settlement [3]. Through text analysis, for each of these fields, Dür *et al.* performed assignment coding and added them to obtain the RTA depth index, and constructed the DESTA database. The DESTA project team regularly updates the extended database, which has currently coded over 710 agreements (as of October 2020).

When the DESTA database was released in 2014, 8 Chinese RTAs were coded. With the continuous updating of the database, the number has risen to 14, but it is still far from being fully covered, and it has not counted RCEP, the world's largest RTA. In addition, the policy areas selected by Dür are not in the same system as the HMS method. They did not use the mainstream 52-category issue classification method, but selected areas that they considered to be widely involved and assigned subjective scores to build the database. The results of studies using this database are not comparable to those of studies using the HMS.

2.3.2. GPTAD

Kohl *et al.* used the HMS method to conduct a textual analysis of 296 RTAs signed between 1948–2011, including the clause coverage and legal commitment of 13 WTO+ fields (agriculture, anti-dumping & countervailing measures, customs administration, export restrictions, import restrictions, intellectual property rights, investment, public procurement, sanitary and phytosanitary measures, services, state aid, state trading enterprises, technical barriers to trade) and 4 WTO-X fields (capital mobility, competition, environment, labor) [4]. In addition, Kohl also established 9 RTA institutional quality indicators (consultations, definition, dispute settlement, duration & termination, evolutionary clause, institutional framework, objectives, plan & schedule, transparency) to examine the heterogeneity of RTA in program design and enforceability. Based on these metrics, Kohl *et al.* constructed the GPTAD database [4].

The GPTAD database is a database constructed based on the mainstream HMS classification method, which facilitates research on different RTAs within a unified framework. It covers 17 policy areas, and is more comprehensive in terms of the breadth of policy areas compared to DESTA. It can support researchers to search a large number of agreement texts by keywords, and compare similar clauses in different agreements. It also adds institutional quality indicators to deal with the heterogeneity of institutional design and legal enforceability, and to apply these differences to international trade. The database was used by Inmaculada & Walid to investigate whether a comprehensive RTA can help reduce air pollution [26]. In addition, the database's RTA sample also includes non-WTO member trade agreements, which helps scholars study the possible heterogeneity or consistency between the nature and quantity of clauses contained in non-WTO member's RTAs.

The GPTAD database covered 7 China's RTAs when it was released, but it has not been updated since then. If it is used to study China's RTAs, it will face a serious problem of missing samples, and the topics covered by the database are not comprehensive enough, which brings many limitations to frontier research, especially only four WTO-X issues are included, making it impossible for scholars to conduct second-generation trade policy-related research based on this database. In addition, in terms of presentation form, the database has no ready-made data for direct use. Therefore, if scholars want to use this database to conduct research, they need to integrate it themselves, which is inconvenient.

2.3.3. CDTA

Hofmann *et al.* collected the texts of 279 RTAs covering 189 countries around the world from 1958 to 2015 [5]. Based on the HMS method, they studied all 52 categories of WTO+ and WTO-X, and systematically sorted out the specific clauses and legal enforceable information of these RTAs. They further divided the 52 issues into four sub-categories: "WTO+ AC", "WTO+ LE", "WTO-X AC", and "WTO-X LE", where AC is the area coverage and LE is the legal enforceability. The database provides detailed data on the content and depth of RTAs. It can be used to compare the number of trade agreements signed by different countries and the number of areas covered and legal commitments. It can also illustrate the dynamics of the number of agreements signed, the number of clauses covered, and the number of legal commitments between 1958 and 2015.

The database only contains the RTA that has come into force and notified the WTO, making the sample of the database less than the samples of the above two databases. Based on this database, Hofmann found that the 14 policy areas of WTO+ and 4 core policy areas of WTO-X (competition policy, investment, movement of capital, and intellectual property) are important characteristics of deep RTA. In order to explore the reasons behind it, Hofmann systematized the information extracted from the agreement text and further constructed three composite indexes to measure the depth of RTA: total depth index, core depth index, and PCA depth index (obtained by principal component analysis). Through this database, it is intuitively found that RTA is deepening, especially in the fields already covered by WTO+ and the core fields in WTO-X.

It can be said that the CDTA database covers the widest range of policy areas among the three databases, including 52 issues under the HMS method, and is widely used by scholars to study the impact of the agreement depth of global RTA [11, 23, 27–30]. Some Chinese scholars also apply it to the research of Chinese RTA, but because the Chinese RTA samples contained in the database are limited, the sample period they use is only until 2015 [16, 31].

The CDTA database covered 11 RTA signed by China when it was released in 2017, and has been updated to 13 now. However, compared with the 22 agreements signed by China at present, it is far from complete coverage. Although the policy area is comprehensive, it doesn't refer to core and detailed clause indicators.

2.4. Summary

In conclusion, among the three major databases, DESTA database contains the most RTA samples, covering 14 China's RTAs. However, it is not under the mainstream HMS research method system, but uses the 0-7 scoring method. GPTAD database uses HMS method for reference, but it covers only 7 China's RTAs and involves few policy areas. Moreover, the database is presented in the form of text content, which requires further integration by researchers. CDTA database has the most comprehensive policy areas and the most convenient data use among the three databases. But it is more suitable for the study of global RTA. The sample size of China's RTA is only 13. The three databases lack the detailed and essential clause analysis for China's key policy areas, which is not conducive to the in-depth study of China's RTA.

It is worth noting that the current research on RTA is getting more and more in-depth, and scholars are gradually focusing on a single RTA clause. Among them, the research on the origin clause, intellectual property clause, environmental clause, service clause, investment clause, and competition clause is relatively mature. For example, studying the relationship between rules of origin and enterprise productivity and trade costs [32, 33]; studying the impact of RTA with IPR clauses on the import and export of IPR-intensive products [34, 35]; studying the export-inhibitory effect of environmental protection clauses [36–38]; studying the reversal effect of technological innovation [39, 40]; studying the relationship between service clauses and firm productivity and trade liberalization [41–43]; studying the investment clauses on FDI [44, 45]; and studying the impact of competition policy clauses on innovation and investment [46, 47].

It can be seen that the research on a single clause has been gradually carried out, while the existing database is still at the overall depth. It is not refined to the specific clause level indicators of the number of clauses, area coverage, and implementation efficiency of each policy area. It may bring misjudgments to empirical research and policy recommendations. At the same time, there is also a lack of core clause synthesis indicators for robustness testing. The synthetic clauses are highly subjective and lack scientific basis under the same database system, and it is impossible to carry out comparative research on the impact of main clauses under the same system.

Therefore, the research on China's RTA needs to rise from the quantitative level to the depth level, and the existing research lacks a systematic measurement of the depth of China's RTA. It is urgent to build a multi-level database of China's RTA depth that meets the needs of comprehensive

3. Construction and measurement of China's RTA core clause depth

Scholars have given different definitions of core terms or core areas [5, 23, 48]. Summarizing these standards, it is believed that the characteristics of the core clauses are: wide coverage (frequently appearing in different agreement texts), and promoting the trade and investment of the contracting parties. Two composite indicators of China's RTA core clauses can be constructed based on the key clauses concerned by current Chinese scholars' literature and the important fields that repeatedly appear in China's RTA:

3.1. Measurement based on literature

The Chinese literature on the research of RTA clauses can be summarized in the above, and regarded the six widely studied clauses (origin clause, intellectual property clause, environmental clause, service clause, investment clause, and competition clause) as the core clauses of China's RTA to construct the indicator.

$$Coredepth_{C1} = \sum_1^6 clausecoverage_{ab} \Big/ 6 \quad (7)$$

where $Coredepth_{C1}$ is the core clauses index, $clausecoverage_{ab}$ is the specific clause coverage rate, *a* is RTA, *b* is clause.

$$Coredepth_{L1} = \sum_1^6 LCR_{ab}/6 \quad (8)$$

3.2. Measurement based on the agreement text

After sorting out the original texts of China's RTAs, areas with high coverage rate were covered to construct the core clause index. The coverage rate of 52 clauses was sorted, selected the clauses with more than 60% coverage rate, and finally got 19 clauses. According to the characteristics of China's RTA, "industrial product concessions" and "agricultural product concessions" is combined nto "product concessions", and finally used 18 clauses to construct the core clauses index. These include 9 WTO+ areas—product concessions, TBT, GATS, customs administration, anti-dumping, countervailing, SPS, TRIM, TRIP, and 9 WTO-X areas—regional cooperation, investment, economic policy dialogue, competition policy, data protection, research and technology, taxation, environmental laws, and industrial cooperation. The calculation formula is the same as the above method. Using the corresponding data, China's core clause indexes and under measurement 2 can be obtained.

4. Analysis of database results and basic characteristics

From the perspective of economic effectiveness, some clauses may be more important economically than others. Therefore, two sets of Chinese RTA core clauses is built in combination with the clauses widely concerned in the current Chinese scholars' literature and the important fields in the actual text collation process to calculate the composite core clause indicators, respectively. The results are shown in **Table 2**.

Table 2. The core indicators of China's RTA

	(1)	(2)	(3)	(4)	(5)	(6)
	Depth$_C$	***Depth$_L$***	***Coredepth***	***Coredepth***	***Coredepth***	***Coredepth***
APTA	0.91%	0.43%	0.83%	0.42%	2.08%	0.97%
China - ASEAN	3.49%	2.16%	14.58%	6.25%	7.29%	4.86%
China - ASEAN (Upgraded)	3.12%	1.79%	8.05%	3.45%	7.66%	4.79%
China - Chile	1.07%	0.54%	3.86%	1.79%	2.48%	1.19%
China – Chile (Upgraded)	1.61%	0.25%	9.69%	4.46%	3.75%	0.65%
China-Pakistan	1.06%	0.49%	5.02%	1.00%	3.01%	1.07%
China - New Zealand	1.36%	0.40%	6.39%	1.40%	3.38%	0.78%
China - New Zealand (Upgraded)	1.40%	0.39%	6.69%	1.36%	3.35	0.87
China - Singapore	1.59%	0.65%	5.36%	1.88%	4.35%	1.64%
China – Singapore (Upgraded)	1.48%	0.89%	3.15%	4.17%	4.08%	2.44%
China - Peru	1.51%	0.46%	6.22%	3.07%	3.62%	1.11%
China - Costa Rica	1.07%	0.33%	5.65%	3.17%	2.45%	0.76%
China - Iceland	1.13%	0.46%	7.75%	5.17%	2.84%	1.21%
China - Switzerland	1.50%	0.87%	7.85%	5.56%	3.80%	2.08%
China - Korea	1.58%	0.66%	8.52%	3.37%	4.11%	1.65%
China - Australia	1.32%	0.39%	9.76%	1.88%	3.43%	0.98%
China - Georgia	1.98%	0.46%	9.42%	2.48%	4.63%	1.09%
China - Mauritius	1.65%	1.11%	10.91%	5.07%	4.22%	2.88%
China - Cambodia	1.58%	0.40%	4.94%	1.38%	3.71%	0.81%
RCEP	1.63%	0.43%	9.05%	2.17%	3.76%	0.97%

The two columns (1) (2) in the table are the average values of specific clause coverage and legal commitment rate$_{(2)}$ of 52 issues. Column (3) and Column (4) are the core clause indicators calculated according to the six topics widely concerned by Chinese scholars in the literature. Column (5) and Column (6) are the core clause indicators based on the 18 areas (9 WTO+, 9 WTO-X) that appear frequently in the text of the agreement signed by China.

First, comparing (1) (3), it is found that except for the APTA, the average coverage rate of the other 18 RTAs according to the selected 6 areas is higher than that of all 52 areas, and from the perspective of stricter legal coverage, this feature is also found in comparison with (2) (4). The reason is that the APTA belongs to the economic integration of preferential trade arrangements, and its goal is to promote intra-regional trade in goods and reduce tariff barriers. In addition to the rules of origin and trade in services, the other four provisions, IPR, environment, investment, and competition policy, have no direct relationship with traditional trade. The APTA has little mention of these four areas, and the rate of specific clause legal commitments is 0. In particular, the RTA signed with ASEAN has the highest index of core clauses, which may be related to the relatively simple content of the agreement and the small number of articles, only 16. Among them, there are 8 articles involving the six core clauses.

From a multi-dimensional analysis, China's core clauses index does not show a clear trend of steady rise or fall over time, and the differences in the economic development levels of the contracting states have not had a regular impact on the index. This may be due to the limited number of agreements China has signed. The contracting is based on the actual economic and trade exchanges with various countries, and the selection of the six core clauses is only based on the focus of academic attention, not from the agreement itself, so it may lack certain representativeness. But in terms of these 6 clauses, rules of origin contribute the most to the index, and its commitment rate ranks first among the 6 clauses, followed by the trade in services and investment rules, while the total commitment rate of IPR, environment, and competition provisions is only two-fifths of the rules of origin. Most of the parties to the agreement with a certain commitment rate in these clauses are developed countries. For example, the commitment rate of IPR clauses in RTA signed with Switzerland reached 10.34%, while the average was only 1.25%. As important post border measures, these three provisions deserve more attention in China's future agreement negotiation and signing process.

Second, comparing (1) (5) and (2) (6) respectively, the average of the specific clause coverage and legal commitment rates of the 18 areas selected are higher than the total average of all 52 areas, and have similar trends, indicating that the selected areas are representative. From the perspective of the RTA type, it is found that the average core clause index of plurilateral trade agreements is higher than that of bilateral agreements. This may be because plurilateral agreements involve multiple countries, and the specific needs of each country for integration need to be integrated in the agreement, and the areas involved are expanded compared to bilateral agreements. In addition, when many countries sign an agreement, more accurate and enforceable clauses need to be negotiated to facilitate the implementation of RTA's preferential policies in the later region, so as to reduce the cost of implementation and coordination among many countries.

Although the method is different, the DESTA database also calculates the core depth (value range is 0–7), so it is compared with the results of the database in **Figure 2**.

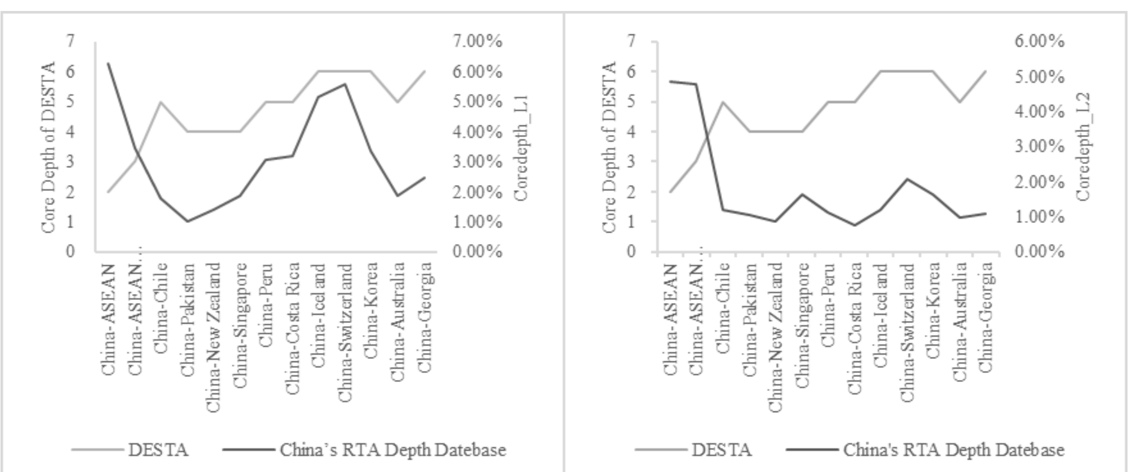

Figure 2. Comparison of two core depths of DESTA and China RTA depth database

Among the 14 RTAs DESTA contains, China-Switzerland, China-Korea, China-Iceland, and China-Georgia have the deepest depths of 6, while China-ASEAN has the shallowest depths of only 2. Based on the core clauses, the first set of core clause index ranked in the top 4 in depth is China-ASEAN, China-Switzerland, China-Iceland, and China-ASEAN (upgraded) is selected; while the second set of core clause index ranked in the top 4 in depth

China-ASEAN, China-ASEAN (upgraded), China-Switzerland, China-South Korea. It can be seen that the ranking of the core depth of China-ASEAN in the two databases is diametrically opposite. This is due to the different core clauses selected on the one hand, and the basic data used for calculation on the other hand. Our core clause index is calculated using secondary data, and the ratio is high due to the small number of articles in China-ASEAN. The China-ASEAN and its upgraded version have a much higher than average commitment rate in product concessions and customs administration, making its core clause index higher than other RTA. China and ASEAN are highly complementary in trade, close in geographical distance and low in logistics cost. Providing convenience in the trade of goods can further create and share trade dividends. Therefore, there are more in-depth provisions on the relevant provisions of trade in goods in the trade agreement. The fact that ASEAN and China became the largest trading partner of goods also confirms the effectiveness of this decision. Using other databases can not accurately reflect this feature, which will also mislead the follow-up empirical research.

5. In-depth analysis of indicator for clauses on digital trade

Digital trade rules do not belong to the 52 areas of the RTA identified by the WTO (2011), but are an emerging area. In addition, China has developed rapidly in this field. At present, there are few literatures on digital trade rules. The calculation of the depth of digital trade rules in the existing literature is mainly based on the TAPED database [49]. On the basis of previous research, this paper defines digital trade clause as including the following: e-commerce, data flow, digital intellectual property, and also includes the following three aspects: digital trade facilitation (including paperless trade, electronic signatures and authentication, digital tariffs), data security and network security (including location of computing facilities, cross-border data flow, personal privacy protection), promotion of digital participation of SMEs and the public (including online consumer protection, SME cooperation).

As can be seen from **Table 3**, among the RTAs signed by China so far, first of all, from the perspective of the four RTAs with upgrading agreements, namely the China-ASEAN Agreement (Upgraded), the China-Singapore Agreement (Upgraded), the China-New Zealand Agreement (Upgraded) and the China-Chile Agreement (Upgraded) have significantly improved the coverage of digital trade clauses compared with the old agreements, reaching 13.80%, 6.63%, 9.29% and 12.79% respectively. It shows that the formulation of digital trade rules has been given high attention in the process of agreement upgrading, among which the China-Chile upgrade agreement has the highest coverage of digital trade among all 20 RTAs.

Table 3. The index data of digital trade

	Clause Coverage Number II	**Legal Commitment Number II**	**Clause Coverage Rate II**	**Legal Commitment Rate$_{(1)}$ II**	**Legal Commitment Rate$_{(2)}$ II**
APTA	0	0	0.00%	0.00%	0.00%
China - ASEAN	1	0	6.25%	0.00%	0.00%
China - ASEAN (Upgraded)	4	0	13.79%	0.00%	0.00%
China - Chile	9	2	7.44%	22.22%	1.65%
China – Chile (Upgraded)	11	3	12.79%	27.27%	3.49%

Table 1 (Continued)

	Clause Coverage Number II	Legal Commitment Number II	Clause Coverage Rate II	Legal Commitment Rate $_{(1)}$ II	Legal Commitment Rate $_{(2)}$ II
China-Pakistan	2	2	2.41%	100.00%	2.41%
China - New Zealand	8	4	3.74%	50.00%	1.87%
China - New Zealand (Upgraded)	25	6	9.29%	24.00%	2.23%
China - Singapore	3	2	2.61%	66.67%	1.74%
China – Singapore (Upgraded)	13	2	6.63%	15.38%	1.02%
China - Peru	13	2	6.47%	15.38%	1.00%
China - Costa Rica	8	3	4.76%	37.50%	1.79%
China - Iceland	7	1	5.43%	14.29%	0.78%
China - Switzerland	4	1	2.30%	25.00%	0.57%
China - Korea	37	6	12.05%	16.21%	1.95%
China - Australia	14	2	6.31%	14.29%	0.90%
China - Georgia	7	0	4.17%	0.00%	0.00%
China - Mauritius	12	3	5.53%	25.00%	1.38%
China - Cambodia	17	4	11.72%	23.53%	2.76%
RCEP	27	8	7.48%	29.63%	2.22%

Secondly, RCEP includes a special "e-commerce" chapter. Other chapters, such as rules of origin, customs administration and trade facilitation, trade in services, IPR, investment, and SME all involve digital trade-related content. Digital trade has become a new trend in the development of global economy and trade. Finally, the RTAs established by China and developed countries, such as the China-South Korea and China-Australia agreements, have high coverage of digital trade clauses, but they do not clearly reflect the differences between developed and developing countries, like IPR clauses. In fact, the agreements signed by China and developing countries also have a high coverage of digital trade clauses, such as the China-Cambodia and China-Mauritius agreements, which also reflect its high attention to digital trade rules.

In terms of legal commitment rate, the digital trade rules clauses in the RTA signed in the early stage lacked legal commitment. Such clauses began to be given legal commitment after the China-Chile agreement, and the number of digital trade clauses in its upgraded agreement accounted for the highest legal commitment rate of all agreements. Although the digital trade clauses in the China-ASEAN upgrade agreement have the highest coverage, they are put forward in the form of initiatives and do not have legal commitments. Although the coverage of the clauses in the China-Pakistan agreement is low, each of them has legal commitment. Among them, more than 50% of the digital trade clauses signed with Pakistan, Singapore, and New Zealand have legal commitments, while RCEP, which has the largest number of articles in this area (27), also has a legal commitment rate of about 30%.

6. Conclusion

Regional trade arrangements have increasingly become a new driving force for the growth of Global trade, and their effects have also become a hot topic of academic attention. However, subject to factors such as incomplete data samples of China's RTA, incomplete policy areas, inconsistent standards, and incomplete indicators, compared with the research on RTAs in the United States and Europe, our research is relatively shallow, and there are certain obstacles in the research.

Many studies are currently trying to construct an index of RTA core clauses to study the depth of RTA. Therefore, the three-level index constructed can provide a good reference for subsequent scholars to study China's RTA core clauses index and conduct robustness tests. The indicators in this paper and basic data can be used to carry out a series of empirical research. Scholars can study and compare the depth of provisions in the areas of WTO+ and WTO-X in a more specific way, and excavate more data value from the comparative study of traditional rules and the new generation rules. It is also possible to compare the data of specific policy areas between RTAs, which is of great significance for the specific analysis of the country factors of RTA signing.

Funding

General Project of Beijing Social Science Foundation, "Research on the Internal and External Strategic Alignment of Regional Trade Agreements and the High-Quality Construction of China (Beijing) Pilot Free Trade Zone" (Project No.: 21GLB021)

Disclosure statement

The authors declare no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

An Empirical Study on the Impact of Bank Credit on Real Estate Price Fluctuations in China——A Case Study of 35 Large and Medium-sized Cities

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Abstract: Fluctuations in real estate prices are closely linked to the macro-economy, exerting a profound influence on social investment and consumption levels. As a key source of funding for the real estate market, bank credit significantly affects housing price changes in major Chinese cities. This paper explores the transmission mechanisms and pathways of bank credit on real estate prices through theoretical analysis and empirical research. It constructs a panel regression model to empirically analyze the relationship between bank credit scale and housing prices in 35 large and medium-sized Chinese cities from 2012 to 2022, assess the impact of credit on housing price fluctuations, and compare differences between first-tier and second-tier cities. Based on these findings, the paper proposes suggestions for regulating housing prices by controlling credit scale, aiming to deepen the understanding of the relationship between bank credit and housing prices and support the stable development of China's macro-economy and real estate market.

Keywords: Bank credit scale; Credit structure; Real estate prices

Online publication: September 10, 2025

1. Introduction

With the continuous development of China's market economy, the real estate market has become increasingly dependent on bank credit, and its violent fluctuations have a significant impact on the domestic and foreign economy. Therefore, it is crucial to deeply study the interactive relationship between bank credit scale and real estate prices. This helps to comprehensively understand the development direction of the real estate market and financial policy support, clarify the ways, mechanisms, and extent of bank credit's impact on housing prices, to guide banks to adjust the scale and direction of credit, and ultimately promote the healthy and sustainable development of the real estate market. Studying the impact of bank credit on real estate prices has far-reaching theoretical and practical significance.

2. Analysis of the impact mechanism and path of bank credit on real estate price fluctuations

2.1. Impact mechanism of bank credit on real estate price fluctuations

First, in terms of the liquidity effect mechanism, the expansion of bank credit will release liquidity, expand the investment scale of the real estate market, and thus promote the rise of asset prices. When the economy is ascending, individuals, enterprises, and financial institutions are optimistic about economic growth, prompting a simultaneous increase in enterprise investment, personal consumption, bank lending willingness, and credit scale. On the one hand, the growth of commercial bank credit solves the loan problems of investors, improves asset and market liquidity, and promotes the rise of real estate prices; on the other hand, real estate prices are significantly affected by consumers' expenditure budgets and preferences. Credit expansion reduces the financial pressure on homebuyers and stimulates the demand in the real estate market. However, due to the long development cycle of real estate, the supply elasticity is small in the short term, so the joint effect of expanding demand and slow supply growth will lead to the rise of housing prices.

Second, in terms of the expectation effect mechanism, expectations reflect investors' confidence in macroeconomic development. For real estate development enterprises, the growth of bank credit improves the business environment, and real estate investors expect the economy to continue to develop upward, maintain positive development expectations, enhance the industry's ability to absorb social investment, and urge enterprises to expand their scale to enhance market competitiveness. For individual homebuyers, the increase in bank credit releases more capital flows and stimulates housing purchase demand. The rise in real estate prices enhances investors' confidence. Expectations make real estate investment demand interact with the real economy, and the performance of the real economy in turn acts on real estate prices.

2.2. Impact path of bank credit on real estate price fluctuations

In terms of real estate development loans, real estate enterprises are highly dependent on the credit support from financial institutions. Bank credit runs through the entire process of real estate development, construction, and sales. Credit expansion alleviates the financial pressure and increases the liquidity of more development enterprises, which affects the supply level of the real estate market and thus influences prices. In terms of personal housing loans, they affect housing prices by changing the demand and expectations of homebuyers. The financial characteristics of real estate stimulate investment demand, further strengthening the connection between personal housing loans and housing prices. In terms of loan interest rates, changes in loan interest rates have a significant impact on real estate prices, as investment is a negative function of interest rates. An increase in interest rates raises the costs of real estate investment, financing, and development, increases the repayment pressure on homebuyers, and reduces housing purchase demand. Therefore, financial policies such as loans have a significant impact on real estate prices. When the real estate market is sluggish, measures such as lowering interest rates and reducing the down payment ratio are adopted to stimulate housing purchase demand. In the second half of 2020, in order to establish a long-term mechanism, financial regulatory authorities introduced the mortgage loan concentration management system and the "Three Red Lines" system to limit the growth of real estate loans, standardize the financing behavior of development enterprises, guide market expectations, and stabilize real estate prices. The domestic loans of development enterprises were gradually reduced, and the real estate market entered a period of in-depth adjustment.

3. Empirical analysis of the impact of bank credit scale on real estate price fluctuations

3.1. Sample selection and data source

This paper selects the annual statistical data of 35 large and medium-sized cities across the country from 2012 to 2022 (**Table 1**). The data sources are as follows: the sales prices of commercial housing, urban GDP, and permanent population in each city are from the National Bureau of Statistics, the China Economic and Social Big Data Research Platform, and urban statistical yearbooks; the bank loans and personal housing loans of real estate development enterprises are from the China Real Estate Statistical Yearbook and the China Economic Network Statistical Database.

Table 1. Classification table of 35 major and medium-sized cities in the country

Classification	Cities
First-tier cities	Beijing, Shanghai, Guangzhou, Shenzhen
Second-tier cities	Shijiazhuang, Harbin, Xining, Urumqi, Fuzhou, Changsha, Chengdu, Tianjin, Jinan, Chongqing, Xiamen, Ningbo, Guiyang, Dalian, Yinchuan, Haikou, Changchun, Nanning, Shenyang, Wuhan, Hangzhou, Xi'an, Hefei, Kunming, Qingdao, Hohhot, Taiyuan, Lanzhou, Nanchang, Zhengzhou, Nanjing

3.2. Index description and model setting

To study the impact degree of the total real estate loans in each region on housing prices, the following model is constructed in this paper:

$$Yit = \mathrm{A} + \mathrm{B}Xit + \mathrm{C}Zit + \varepsilon it \quad (1)$$

Among them, i represents 35 cities, and t represents the year; Yit is the explained variable, that is, the commercial housing price (P); A represents the intercept term; B and C are coefficients; εit is the disturbance vector; Xit is the explanatory variable, the total real estate Loan, where Loan = Loan1 + Loan2; Zit are control variables, namely urban GDP and urban permanent population (POP). There are many factors affecting real estate prices, among which the economic development level of each region is very important. This paper selects the urban GDP to measure the economic development level, and the population is also selected as one of the control variables. In terms of data processing, this paper eliminates the impact of inflation through the consumer price index, and adopts logarithmic processing of data to eliminate the problem of heteroscedasticity, making the data more smooth.

3.3. Stationarity test

In order to avoid the problem of spurious regression, this paper first detects the stability of the variables. The original hypothesis (H0): It is assumed that the data of each variable sequence is not stationary. The LLC test method is used to carry out the stationarity test on the data of the two types of cities, respectively (the results are shown in **Table 2**).

It can be seen from the results that the P-values of all variables are less than 0.1, indicating that the results are significant, that is, the original hypothesis that the variable sequence data is not stationary is rejected. Therefore, after the LLC test, the variable data of first-tier cities and second-tier cities are both stationary.

Table 2. LLC test results of variables

City	Variable	Adjusted t-statistic	*P*-value	Result
First-tier cities	LNP	-1.5362	0.0622	Stationary
	LNLoan	-3.9386	0.0142	Stationary
	LNLoan1	-5.4214	0.0050	Stationary
	LNLoan2	-2.8595	0.0021	Stationary
	LNGDP	-4.2158	0.0000	Stationary
	LNPOP	-3.4082	0.0002	Stationary
Second-tier cities	LNP	-9.1125	0.0005	Stationary
	LNLoan	-7.9764	0.0356	Stationary
	LNLoan1	-9.5863	0.0017	Stationary
	LNLoan2	-7.8752	0.0002	Stationary
	LNGDP	-8.6367	0.0000	Stationary
	LNPOP	-6.9929	0.0427	Stationary

3.4. Correlation analysis

Table 3 shows the correlation between variables. Housing price (LNP) is positively correlated with total bank credit (LNLOAN) (coefficient 0.132, significant at the 5% level). GDP (LNGDP) is positively correlated with housing price (0.682, significant at the 1% level). Permanent population (LNPOP) is positively correlated with housing price (0.389, significant at the 1% level).

Table 3. Results of correlation analysis

	LNP	LNLoan	LNLoan1	LNLoan2	LNGDP	LNPOP
LNP	1					
LNLoan	0.136**	1				
LNLoan1	0.242***	0.761***	1			
LNLoan2	0.185***	0.733***	0.648***	1		
LNGDP	0.681***	-0.288***	-0.335***	-0.323***	1	
LNPOP	0.387***	0.411***	-0.421***	0.433***	0.783***	1

Notes: *** and ** indicate significance at the 1% and 5% levels, respectively.

3.5. Regression result analysis

The regression estimation results show (**Table 3**) that the coefficients of LNLoan in first-tier cities and second-tier cities are 0.1907 and 0.1218, respectively, indicating that bank credit has a positive impact on housing prices in both places, and the impact in first-tier cities is stronger. Because the housing prices in first-tier cities are high, the demand for residential mortgages is large, and real estate loans and personal housing loans account for a high proportion in the total bank credit, the impact of credit in large cities on housing prices is greater than that in medium-sized cities, providing a theoretical basis for implementing policies tailored to different cities.

The coefficients of LNGDP show that it is 1.3377 in first-tier cities and 0.7668 in second-tier cities, indicating that GDP has a significant positive impact on housing prices in both types of cities, indicating that the economic development level has a significant impact on housing prices. The coefficients of LNPOP show that the permanent population in both types of cities also has a significant positive impact on housing prices.

Table 3. Classification panel regression results for first and second-tier cities

	First-tier cities	**Second-tier cities**
LNLoan	0.190*** (4.050)	0.122** (0.748)
LNLoan1	0.058** (2.642)	0.02** (1.251)
LNLoan2	0.142*** (3.556)	0.077*** (3.681)
LNGDP	1.337*** (21.159)	0.767*** (14.210)
LNPOP	0.0721** (0.087)	0.550** (0.083)
Adjusted R-squared	0.9691	0.9023
F-statistic	173.4638	79.6058
Prob.	0.0000	0.0000

Notes: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

4. Policy recommendations

4.1. Adjust the scale and structure of banks' real estate credit

The development of China's real estate industry is closely related to the scale of bank loans, and the capital demand of the real estate industry has also promoted the rapid development of bank credit business in reverse. Therefore, commercial banks should timely adjust the credit scale and structure according to the real estate market conditions to prevent loan risks. In loan approval, banks should strengthen loan review and identify potential risks in advance; reasonably adjust the proportion of development loans and personal housing loans to avoid excessive concentrated investment. Bank credit should play a core role in promoting the structural improvement of the real estate market.

4.2. Implement policies tailored to different cities and increase the effective supply of housing in hotspots

As a regional market, the characteristics of the real estate market determine that there is a significant regional imbalance in China's urban real estate market, and the policy of "implementing policies tailored to different cities" should be effectively implemented. Under the premise of "housing is for living in, not for speculation", ensure the housing supply in large cities and urban agglomerations from the supply side to meet the housing demand brought by urban development. The supply of real estate in hot cities and regional urban agglomerations can be appropriately increased, land resources can be scientifically and reasonably allocated, and the supply of residential land in first-tier and second-tier hot cities and urban agglomerations can be increased according to the trend and law of population flow. For cities with a serious surplus of real estate supply, the newly added construction land should be strictly controlled, focusing on the transformation of old residential areas and improving the quality of housing, so as to avoid the impact of cliff-like decline in housing prices on the local economy and people's livelihood stability.

4.3. Gradually cancel administrative real estate control measures

The empirical study in this paper shows that the impact of bank credit on real estate prices in first-tier cities is greater than that in second-tier cities, and the real estate prices in small and medium-sized cities are less affected by bank credit control and are mainly affected by the relationship between supply and demand. Excessive administrative restrictions may affect the normal development of the real estate industry in small and medium-sized cities. Before the implementation of the real estate loan concentration management policy, in order to achieve the goal of "stabilizing land prices, housing prices, and expectations", hot cities adopted administrative control measures such as purchase restrictions, loan restrictions, and sales restrictions to suppress market demand; for real estate development enterprises, policies such as the "three red lines" were implemented to prevent development enterprises from excessive leverage and debt expansion risks. These measures were necessary before establishing a long-term real estate regulation mechanism, but after the implementation of the real estate loan concentration system, trial orderly cancellation of administrative control measures can be carried out to release reasonable improved consumption demand and investment demand and prevent the risk of "hard landing" in the real estate market.

5. Conclusion

Establishing and improving a long-term mechanism, continuously implementing the management of real estate loan concentration, guiding the steady development of the real estate industry and the stable operation of the real estate market, and thus promoting the healthy development of the economy should become the focus of long-term work.

Funding

"Public Management" Project; Guangdong Provincial Characteristic Key Discipline (Project No.: 2017STSZD01)

Disclosure statement

The authors declare no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Analysis of Risk Control Strategy of Enterprise Self-Funded Investment Management

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Abstract: With intensifying market competition and growing financial complexity, strengthening risk control in corporate capital investment management has become imperative. This paper examines the critical role of risk management in ensuring financial stability, optimizing resource allocation, and achieving strategic objectives. It identifies key risk categories including market volatility, liquidity challenges, operational risks, and strategic misalignment, while proposing targeted strategies such as dynamic monitoring, strategic planning, decision-making optimization, and focused risk management.

Keywords: Enterprise; Self-owned capital; Investment management; Risk control

Online publication: September 11, 2025

1. Introduction

Amidst accelerating economic shifts and heightened financial market volatility, enterprises are increasingly leveraging their own capital for investments [1]. In this context, effective risk management directly determines the safety and profitability of corporate investments. Potential risks including market uncertainties, liquidity constraints, operational errors, and strategic misalignments, if not properly identified and controlled, could jeopardize financial stability and sustainable growth. Therefore, developing tailored risk control strategies that address the unique characteristics of self-owned capital investment holds significant practical value. Such strategies enable companies to enhance value creation and achieve strategic objectives while ensuring capital security.

1.1. The significance of risk control in the investment management of enterprise own capital

1.1.1. Promoting the optimization of enterprise resources

During the investment project evaluation phase, enterprises can conduct precise analysis of return-to-risk ratios through risk control systems. By accurately assessing each project's risk level and ensuring risk exposure aligns with corporate strategic positioning, companies can achieve targeted resource allocation. For low-risk projects with sustainable returns, management may moderately expand capital injections to maintain competitive leadership. When dealing with high-risk investments offering substantial profit potential, phased capital distribution should be implemented through risk management frameworks, coupled with appropriate control measures. This approach enables enterprises to effectively avoid excessive capital concentration while pursuing high returns, thereby achieving efficient capital turnover and promoting coordinated development of profit margins and resource conversion efficiency [2].

1.1.2. Supporting the achievement of enterprise strategy

Corporate investment projects typically revolve around strategic objectives, ranging from vertical integration and diversified operations to global expansion. Optimizing investment portfolios serves as a driving force for these initiatives. Strengthening risk control mechanisms enables enterprises to promptly identify and mitigate risks in strategic development. When implementing multi-sector expansion strategies or entering new industries, inadequate risk management may lead to operational difficulties due to insufficient understanding of legal constraints and market structures. Prior to entering new sectors, companies should conduct thorough risk identification and assessment, develop contingency plans, and ensure the safety of internal funds as a prerequisite. This approach facilitates stable diversification efforts while guaranteeing that strategic implementation achieves anticipated outcomes [3].

2. Risks of investment management of enterprise's own capital

2.1. Market risks involve technological progress and demand changes

In sectors with high technical barriers, the critical challenge lies in dynamically adapting technology roadmap decisions to evolving market demands. Cutting-edge innovation typically manifests through coexisting multi-technological paradigms. The delayed unification of technical standards diminishes the early-mover advantage of initial investments, while interrelated technological alternatives accelerate the depreciation of existing corporate capital. The non-linear nature of standardization processes further complicates decision-making.

Product iteration cycles are compressed by shifting consumer habits and upgraded application scenarios. Manufacturers must establish demand forecasting systems. Any misjudgment regarding technological innovation directions or consumer acceptance risks becoming technologically constrained. This risk is particularly pronounced in frontier fields like semiconductors and new energy technologies, where existing investments struggle to keep pace with emerging demands. Their value diminishes continuously, resulting in capital appreciation efficiency far below market expectations. When technology iteration frequency fails to align with asset depreciation schedules, systemic impairment risks may emerge [4].

2.2. Liquidity risk is faced by asset characteristics and market conversion

Given the capital-intensive nature of heavy asset investments, capital lock-in periods are inherently prolonged. Specialized equipment typically requires 3–5 years from planning to full production capacity realization. The mismatch between asset depreciation cycles and technological upgrade rates forces existing assets to undergo technical upgrades before profitability takes hold. When supply chains shift, this characteristic becomes increasingly pronounced: component shortages can immediately disrupt production systems. The limited functionality of specialized equipment makes it difficult to realize value through secondary circulation. Combined with liquidity constraints and valuation barriers for non-standard assets, the uncertainty of technological substitution strips residual value assessments of reference benchmarks, putting pressure on secondary market transactions. Insufficient corporate subscriptions lead to hidden cost losses. In sectors like energy storage equipment and specialized processing machinery, the "investment-as-solidification" phenomenon continuously deteriorates balance sheets, ultimately triggering cash flow depletion [5].

2.3. Operational risks exist in the decision-making process and execution system

Inadequate institutional frameworks in investment decision-making create a cycle of risk accumulation. When relying solely on subjective judgment without data-driven analysis, emerging sectors like the metaverse often suffer from evaluation biases that undermine risk assessment frameworks and hinder cross-departmental collaboration. This slows decision-making processes, particularly in time-sensitive fields such as AI-powered healthcare and autonomous driving, where market timelines are typically estimated monthly. Inefficient administrative procedures directly impede the identification of investment opportunities. Modern digital management systems face a critical mismatch between security protocols and innovative technology platforms, particularly evident in scenarios like remote work solutions and cloud computing platforms. This contradiction manifests through dual risks: potential data breaches due to security vulnerabilities, coupled with trade-offs between enhanced protection measures and decision-making efficiency, creating a zero-sum game where increased security measures often come at the expense of business opportunities [6].

2.4. Strategic risk is manifested as the contradiction between resource allocation and enterprise ability

When enterprises blindly chase market trends, they risk disrupting strategic resource allocation. Overinvesting in non-core sectors during diversification efforts weakens core business support and erodes technological advantages. Incoherent strategic investments often lead to operational disruptions, increased complexity, and coordination costs. Structural imbalances in innovation investments create systemic risks: projects prioritizing quick returns may divert resources from core R&D, weakening corporate technological leadership. Innovation gaps in biotechnology and advanced manufacturing could undermine industry dominance. Rash strategic realignments may trap companies in a "growth trap", that experiencing revenue growth while sacrificing core competencies, resulting in low-quality expansion [7].

3. Risk control strategy of enterprise self-owned capital investment management

3.1. Establish and improve the dynamic monitoring and rapid response mechanism

To address the reality of rapid industry competition, this study established a 24/7 multi-domain risk identification platform. This involves designing technical data collection processes through patent database searches, academic literature tracking, and industry exhibition monitoring to map technological breakthrough pathways. By applying NLP methods for semantic mining of technical data, this study pinpointed potential industry innovation hotspots. A market environment change early-warning system should be established by aggregating customer demand signals, marketing channel insights, and industry benchmarking materials. Data-driven approaches will predict demand fluctuation nodes and create demand fluctuation early-warning monitoring models. From a decision implementation perspective, this study adopted responsive investment management strategies: breaking long-term investments into multiple rounds of trials, with phased verification benchmarks for technical maturity and market adaptability. Operational stages include creative testing, solution validation, and pilot production. Multi-dimensional decision-making teams should conduct challenger simulation assessments to regularly evaluate the risk resilience of technical implementation plans and business logic. For strategic-level key investments, this study applied risk-hedging R&D frameworks while advancing both primary and alternative solutions. Through redundant planning of technical approaches, this study mitigated path dependence risks. From resource integration perspectives, flexible investment units should be established [8].

In line with the technology lifecycle, this study should strategically allocate capital investments: During initial innovation phases, prioritize data collection and pilot projects; when scaling up production, ramp up manufacturing investments; after maturation, secure competitive advantages through mergers and acquisitions while establishing real-time risk monitoring systems. Incorporate critical metrics like technology obsolescence risks and market coverage into investment calculations. When key variables exceed predefined thresholds, proactively activate contingency plans that include technology integration, asset restructuring, and transformation strategies. By implementing closed-loop management, this approach enables a paradigm shift from passive risk response to proactive value creation [9].

3.2. Carry out scientific investment layout

When implementing internal capital investment management, enterprises can effectively control risks through portfolio allocation. By diversifying disposable funds across different asset classes, companies can mitigate significant losses caused by underperforming individual assets and maintain overall portfolio stability. Given the high interdependence of global economies and the strategic importance of regional diversity, distinct economic cycles, political landscapes, and monetary policies across countries lead to markedly different market dynamics. Adopting a geographical diversification strategy allows enterprises to strategically allocate investments while recognizing that emerging economies may still maintain robust growth momentum even as domestic markets contract [10].

Implementing geographically diversified investment portfolios effectively controls exposure risks from regional concentration, enhancing portfolio resilience and safety margins. In portfolio management, enterprises should adopt an industry-wide deployment approach as the fundamental principle. Major industries exhibit differentiated growth drivers with varying potential and risk levels. Technological breakthroughs and R&D expenditures form the cornerstone of the tech sector, whose performance correlates positively with consumer disposable income and consumption propensity. When enterprises invest with self-raised funds, they should control the concentration of investments in a single industry by adopting a diversified investment strategy across sectors. This approach reduces the constraining effect of risks in specific industries on portfolio performance. Implementing investment categorization by enterprise scale enables effective risk management. Large enterprises typically demonstrate stable operations and strong risk resilience, though their revenue growth tends to be relatively slow.

Small enterprises, however, face inherent risks. Their long-term value-added potential is evident. During the investment planning phase, strategically allocating investments according to enterprise size levels allows the portfolio to better respond dynamically to market changes and economic conditions, thereby achieving risk diversification objectives [11].

Optimize strategic decision-making and collaborative execution. In the decision-making framework, this study implemented a data-driven collective evaluation process by establishing a comprehensive assessment matrix that evaluates technical feasibility, market potential, and financial returns. Technologically, we utilize patent landscape analysis and technology maturity curves. Commercially, this study integrates consumer profiling data and competitor monitoring through Monte Carlo simulations to predict financial risks and returns. An empowerment evaluation system quantifies qualitative factors, reducing subjective biases in decision-making. Practically, this study established an intelligent decision hub to ensure seamless data integration across departments, enabling real-time synchronization of investment, risk control, and execution data [12]. By implementing RPA technology for approval processes, we transform sequential approvals into parallel workflows. Intelligent matching algorithms optimize approval routes, shorten critical investment timelines, resolve decision conflicts, and automatically initiate external expert reviews for contentious projects, preventing missed deadlines due to prolonged disputes. For security protection, this study adopted a zero-trust architecture. The established security framework replaces traditional perimeter defenses with dynamic identity authentication mechanisms. By leveraging real-time identity verification and behavioral pattern analysis, it effectively prevents data security breaches. Through micro-segmentation of core decision-making systems with minimal access controls, the system maintains operational integrity even when individual components are compromised.

Concurrently, the development of a security acceleration engine enhances hardware-based encryption computation and compliance review modules, significantly reducing verification time while ensuring data security and achieving sub-second-level system response capabilities [13].

3.3. Strengthening strategic focus and resource integration capacity

From a holistic strategic perspective, this study developed an R&D investment evaluation matrix structured in three dimensions: technological barriers, market synergy potential, and resource alignment. This framework enables dynamic adjustments to core competency scopes, utilizing Porter's Five Forces model for industry analysis to identify key competitive factors. Resources are strategically allocated to areas that build long-term competitive advantages, such as IC design companies exploring cutting-edge processes and automakers developing core battery control systems [14].

This study established clear boundaries for resource allocation: when marginal business investments exceed 15%, the system automatically triggers strategic review to prevent resource fragmentation caused by reckless expansion. To meet risk diversification requirements, we upgraded capital operation models through industrial merger funds and technology incubation platforms, effectively separating risks between core operations and hot sectors. This dual approach balances strategic synergy with financial returns, enabling small-scale equity participation in frontier fields like quantum computing and metaverse development while maintaining technological tracking and expenditure control. Establishing a reverse feedback channel for innovation outcomes will create a technical and data integration bridge between external capital investment and core business operations, enabling the reverse transmission of innovative achievements.

For innovation management, this study developed tracking metrics including the proportion of basic research funding, patent coverage extent, and pre-research project cycles, incorporating these quantitative indicators into executive performance contracts. A CTO-directed cutting-edge technology pre-research team will be established to manage mid-term (3–5 years) technological resource development. Implementing a real-time technical reserve alert system, we will activate investment enhancement mechanisms when industry upgrade probability exceeds 60%, execute periodic optimization plans, conduct quarterly strategic resource reviews, and utilize heat maps to visually display resource distribution density. This ensures synchronized advancement of technological reserves and industry rankings [15].

4. Conclusion

Risk management in corporate capital investment is crucial for ensuring fund safety and stable growth. By implementing strategies including dynamic monitoring, strategic investment planning, optimized decision-making execution, and focused strategic positioning, enterprises can effectively navigate complex market conditions and control risks. Companies must stay attuned to evolving market trends and updated risk management philosophies. Through continuous evaluation and refinement of their risk control systems, businesses can address emerging challenges and ensure sustained, healthy development outcomes.

Disclosure statement

The authors declare no conflict of interest.

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Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Quantitative Research on Environmental Risk Factors in Green Bond Pricing

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Abstract: Amid the global shift toward climate governance and low-carbon transformation, accurately quantifying environmental risk factors within green bond pricing mechanisms has emerged as a critical issue. Drawing on data from China's green bond market between 2018 and 2023, this study develops a multifactor pricing model that integrates environmental risk premiums. Through regression analysis, it empirically investigates the effects of environmental reputation, transparency of information disclosure, and third-party certification on bond risk premiums. The results indicate that green-labeled bonds carry, on average, a 42.6 basis point lower risk premium compared to non-green bonds, while third-party certification further reduces this premium by an additional 54.1 basis points. Moreover, a one standard deviation improvement in the quality of environmental information disclosure leads to a reduction in bond financing costs by approximately 18 to 25 basis points. Issuers operating in high-energy-consuming industries bear significantly higher environmental risk premiums relative to those in low-energy-consuming sectors. By integrating an ESG scoring framework into bond pricing, this study reveals the transmission channels of environmental risks into market pricing and provides a theoretical foundation for enhancing pricing benchmarks in the green bond market.

Keywords: Green bonds; Environmental risk factors; Pricing model; ESG scoring

Online publication: September 8, 2025

1. Introduction

With the accelerated implementation of the Paris Agreement, green finance has become a pivotal driver of low-carbon economic transition. By February 2023, China's cumulative issuance of green bonds reached RMB 3.72 trillion, accounting for 25% of the global market share. However, challenges persist, including imperfect "green premium" mechanisms and distorted environmental risk pricing. Existing research predominantly focuses on credit ratings or macroeconomic policy impacts, lacking micro-level quantitative analysis of environmental risk factors, particularly the pricing effects of non-financial elements such as environmental reputation and disclosure transparency. Current literature exhibits three major limitations. (1) Absence of unified environmental risk quantification tools, with internationally prevalent frameworks like NGFS facing adaptability gaps in domestic practice; (2) Overreliance on static cross-sectional data, failing to capture dynamic influences of environmental risk factors; (3) Descriptive rather than causal inference in studies on third-party certification's pricing effects.

This study addresses these gaps by constructing a dynamic panel data model and innovatively integrating the Postal Savings Bank of China's ESG risk scoring system with bond pricing. It specifically investigates the nonlinear impact of environmental risk factors on bond risk premiums.

2. Identification and classification of environmental risk factors

2.1. Multidimensional definition of environmental risk factors

The multi-dimensional definition of environmental risk factors requires breaking through the framework of a single physical indicator and forming a three-dimensional analysis system covering explicit risks, implicit risks and dynamic risks. Explicit risk factors focus on the direct quantification of environmental elements, with greenhouse gas emission intensity as the core indicator, which can be calculated as the ratio of a company's total carbon emissions to its main business income, reflecting the environmental cost per unit of economic output. Water resource consumption density is measured by the deviation of water consumption per unit of output from the industry benchmark value, reflecting water resource utilization efficiency. The compliance rate of pollutant emissions should be combined with regulations such as the "Comprehensive Emission Standard of Air Pollutants" to construct a composite compliance index including key pollutants such as sulfur dioxide, nitrogen oxides, and chemical oxygen demand [1].

Implicit risk factors emphasize the quantification of institutional elements. The completeness of the environmental risk management system can be measured by secondary indicators such as the coverage rate of ISO 14001 certification and the rate of formulation of special environmental risk plans [2]. The effectiveness of environmental emergency plans needs to establish a three-level assessment model including emergency response time, disposal success rate and control rate of secondary disasters. The transparency of environmental information disclosure should be calculated by weighting the completeness rate of disclosed items in the Bloomberg ESG database and the coverage rate of third-party audit reports, with the disclosure rate of key environmental indicators (KPI) needing to reach over 80% to be considered effective disclosure [3].

Dynamic risk factors need to capture the time-varying characteristics of the policy environment. The coverage of the carbon pricing mechanism can be measured by dual indicators such as the proportion of industry output included in the national carbon market and the trading activity level of regional pilot markets. The trading activity level is calculated as the ratio of annual transaction volume to circulation volume [4]. The intensity of environmental tax collection is reflected by the elasticity coefficient of the actual environmental tax paid by enterprises to the amount of taxable pollutants emitted, with a coefficient greater than 1 indicating that the tax policy has a significant constraint on pollution emissions. The incentive intensity of green finance policies needs to construct a composite policy index including preferential re-lending rates, adjustments to risk weights and tax credit ratios, with the tax credit ratio needing to be dynamically adjusted according to the "Notice on Improving Financial Support Policies for Green and Low-Carbon Transformation" [5].

2.2. Quantification methodologies

2.2.1. Physical risks

Lifecycle assessment (LCA)coupled with input-output analysis. For instance, photovoltaic projects attribute >

60% of emissions to silicon production [6].

2.2.2. Transition risks

Policy Uncertainty Index (PUI) derived from textual analysis of policy documents (e.g., China's 2030 Carbon Peak Plan) and entropy weighting [7].

2.2.3. Reputation risks

ESG rating differentials (e.g., MSCI AAA vs. CCC) reveal marginal financing cost impacts. Composite risk indices (ERI) employ AHP-entropy hybrid weighting, with physical risks initially weighted at 0.4–0.5. Cronbach's $\alpha \geq 0.7$ ensures reliability [8].

3. Transmission mechanisms of environmental risk factors in green bond pricing

Market perception heterogeneity leads to significant regional differences in institutional investors' environmental preferences. Analysis of green bond custody data from 2020 to 2025 shows that European institutional investors hold 67% of their portfolios in renewable energy projects, while Asian-Pacific institutional investors prefer green transportation projects (52%). Such preference differences result in pricing differentiations of similar bonds in different markets. For instance, the issuance rate of a wind power project bond in the Luxembourg market is 42 basis points lower than that in the Singapore market [9]. Retail investors' cognitive biases have behavioral finance characteristics. By simulating the decision-making process of individual investors through experimental economics methods, it was found that when green bond promotional materials highlight environmental benefits, the required yield by investors is 38 basis points lower than when only financial information is disclosed.

However, such cognitive biases have a threshold effect. When environmental benefit quantification data is missing or questionable, investors shift towards higher risk compensation. Tracking the sales data of a commercial bank's green financial products shows that products providing third-party environmental certification reports have sales 2.7 times higher than those without such reports, and the customer repurchase rate increases by 41%. The evolution of international investors' pricing power shows structural characteristics. The formation mechanism of green premiums in offshore markets is fundamentally different from that in onshore markets [10]. Analysis of the Dim Sum Bond market data from 2018 to 2025 indicates that for every 10-percentage-point increase in the proportion of international investors, the average bond issuance rate decreases by 29 basis points. However, such pricing advantages reverse in specific industries. For example, in the nuclear power sector, due to the inclusion of nuclear energy in the EU's Sustainable Finance Taxonomy, European investors' pricing power over domestic nuclear power bonds has significantly increased, resulting in related bond yields being 15–20 basis points lower than those of similar photovoltaic bonds [11].

4. Empirical design

4.1. Sample selection and data sources

The research samples covered labeled green bonds and comparable ordinary bonds issued from January 1,2018 to June 30, 2025. After excluding special varieties such as perpetual bonds and subordinated bonds, a total of 2,876 valid samples were finally obtained, including 1,642 green bonds and 1,234 ordinary bonds. The data sources adopt a multi-source cross-validation approach. The basic information of bonds comes from the Wind database.

The valuation data of China Bond is used to construct the interest rate term structure. The certification data of the Climate Bonds Initiative (CBI) is used to identify internationally certified bonds [12]. The public documents of the Ministry of Ecology and Environment are used to extract environmental penalty information. Outlier handling employs the Winsorize method to truncate extreme values at the 11% percentile, with a focus on key variables such as the issuance rate, issuance scale, and environmental risk index. Standardize the continuous variables to eliminate the dimensional influence. Among them, the comprehensive Environmental Risk Index (ERI) is standardized by Z-score by industry groups to ensure the validity of cross-industry comparisons, and dummy variables are set for categorical variables [13]. Third-party certifications can be classified into three categories: international certifications (such as CBI, CICERO, etc.), domestic certifications (such as China Chengxin, Lianhe Credit Rating, etc.), and uncertified ones [14].

4.2. Variable setting and model construction

The explained variable is selected as the Spread between the bond issuance rate and the yield of Treasury bonds of the same term. This indicator can effectively eliminate the impact of risk-free interest rate changes. To capture the characteristics of the interest rate term structure, the Nelson-Siegel model is adopted to fit the Treasury bond yield curve to ensure the accuracy of matching with the same term. For floating-rate bonds, the difference between their coupon rate and the Shibor rate of the same period is used as a substitute indicator. The core explanatory variables consist of three dimensions. The Comprehensive Environmental Risk Index (ERI), as a continuous variable, reflects the overall environmental risk level of the issuer. The third-party Certification dummy variable (Certification) distinguishes international certification (with a value of 1) from non-international certification (with a value of 0). The Policy Incentive Intensity Index (Policy) adopts a standardized weighted value of the proportion of fiscal subsidies and the amount of tax preferences, where the weight of the proportion of fiscal subsidies is set at 0.6 and the weight of the amount of tax preferences is set at 0.4 [15]. The control variables cover traditional pricing factors. The bond item adopts the rating results of China Bond Rating, which are converted into numerical variables ranging from 1 to 10. The logarithm of the issuance Size is taken for processing to alleviate the right-skewed distribution. Market Liquidity is measured by the average daily turnover rate of bonds with the same rating at the time of issuance. The Maturity of bonds is set as a dummy variable and is classified into three categories:1–3 years, 3–5 years, and more than 5 years. Macroeconomic variables (GDP-growth, CPI) are based on the actual values of the quarter prior to issuance [16].

4.3. Empirical test and result analysis

The benchmark regression results show that the coefficient of the Environmental Risk Composite Index (ERI) is 0.18 and is significant at the 1% level, indicating that for every 1 standard deviation increase in environmental risk, the bond spread rises by an average of 18 basis points. The coefficient of the ERI square term is -0.05, indicating that the relationship between environmental risk and the spread has an inverted U-shaped feature [17]. When the ERI exceeds 2.8 (industry average + 1.5 standard deviation), the growth rate of the risk premium slows down. The coefficient of the dummy variable for third-party certification is -0.12, indicating that international certification can reduce the spread by 12 basis points [18]. This effect is more significant in the renewable energy industry (coefficient = -0.19). The coefficient of the policy incentive intensity index is -0.07, indicating that for every 1 standard deviation increase in policy incentives, the spread decreases by 7 basis points. However, this effect weakens to 3 basis points when the proportion of fiscal subsidies exceeds 15% [19].

5. Applications

5.1. Dynamic environmental risk margin mechanism for optimizing green bond issuance pricing

The design of the environmental risk margin mechanism for pricing optimization at the issuance end needs to establish a dynamic adjustment model. taking a certain photovoltaic enterprise as an example. Its historical default data shows that when the environmental risk index (ERI) exceeds 1.2 times the industry average, the default probability rises to 3.7%, which is 2.1 times the industry average. Based on this, the linear relationship between the margin ratio and ERI can be set. The margin ratio = 0.5% + 0.3%* (ERI-industry average) industry standard deviation. When ERI reaches the threshold, the margin ratio increases to 1.1%. This mechanism can reduce the yield demanded by investors by 18 to 22 basis points while keeping the increase in the issuer's financing costs below 8 basis points [20].

5.2. Revising IRR to incorporate environmental risk and benefit adjustments in investment decision-making

The traditional IRR indicator needs to be revised for the calculation of the return rate after adjusting for environmental risks in the investment end decision support. The traditional IRR of a certain sewage treatment project was 6.8%, but after considering the cost of environmental externalities (calculated based on the social cost carbon price of 68 yuan per ton), the revised IRR dropped to 5.9%. Further introduction of environmental benefit cash flow (calculated based on a subsidy of 0.5 yuan per ton of COD reduction), the revised IRR rebounded to 7.2%, which was 0.4 percentage points higher than the traditional IRR. This model has increased investors' preference for environmentally friendly projects by 31% and the proportion of green projects in investment portfolios has risen from 28% to 45%.

5.3. Enhancing environmental information disclosure and risk monitoring through industry-specific standards and intelligent regulation

The upgrading of environmental information disclosure standards at the regulatory end requires the formulation of industry-specific guidelines. For the steel industry,12 core indicators such as the proportion of long-process technology, the progress of ultra-low emission transformation and the carbon emission intensity per ton of steel are required to be disclosed. For the photovoltaic industry,8 indicators such as the power consumption for silicon material production, the conversion efficiency of solar cells and the recovery rate of modules are mandatory to be disclosed. In the first year of implementation, the standard deviation of the ERI index for steel industry bonds decreased by 0.21 the degree of information asymmetry dropped by 19% and the liquidity premium of related bonds narrowed by 14 basis points. The construction of a risk early warning mechanism requires the adoption of machine learning algorithms. Based on the XGBoost model,23 characteristic variables such as environmental penalty records ERI index and public opinion data were integrated to conduct risk scoring for 200 high energy-consuming enterprises in a certain province. The AUC value of the model on the test set reached 0.87 and it could identify 83% of the enterprises that subsequently defaulted on the environment 6 to 12 months in advance. The regulatory authorities conducted on-site inspections of 12 enterprises based on model warnings and found that 9 of them had undisclosed environmental risks. They promptly took measures such as restricting bond issuance to prevent potential losses of approximately 2.3 billion yuan.

6. Conclusion

This study demonstrates that environmental risk factors critically influence green bond pricing through transparency and certification effects, with sectoral heterogeneity shaping risk transmission. Policymakers should standardize disclosures and enhance certification credibility, while issuers must improve environmental management to reduce long-term costs. Future research could explore cross-border pricing under divergent environmental standards.

Disclosure statement

The author declares no conflict of interest.

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Proceedings of Business and Economic Studies, 2025, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Research on the Impact Mechanism of Green Finance on the Optimization and Upgrading of Regional Industrial Structure

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Abstract: Under the background of this era, green finance and the upgrading and optimization of industrial structure have become a hot research topic. The article focuses on Jiangsu Province, carefully explores the impact of green financial development on the upgrading and optimization of industrial structure and the real effect, collates and summarizes the theories of green finance and industrial structure at home and abroad, and carefully analyzes the development of green finance in Jiangsu Province, such as the gradual expansion of green credit scale, the characteristics of industrial structure, the change of the proportion of three industries, the development situation of emerging industries and so on. By means of econometrics, an empirical model covering Green Financial Development Indicators and industrial structure optimization indicators is established to do multiple linear regression analysis and stability test. The empirical results show that the development of green finance in Jiangsu plays an obvious positive role in the optimization and upgrading of industrial structure. Green finance is environmental protection, new energy and other green industries are given important financial support, which drives their scale expansion and technological innovation, and makes the industrial structure develop towards a higher level and a more reasonable direction. From this point of view, corresponding proposals are put forward to improve the policy incentive system, add green financial products, and strengthen the construction of green financial market. The purpose is to give better play to the advantages of green finance, accelerate the optimization and upgrading of industrial structure in Jiangsu, and provide theoretical basis and practical guidance for achieving green economic transformation and sustainable development.

Keywords: Green finance; Optimization and upgrading of industrial structure; Entropy weight method; Multiple linear regression model

Online publication: September 11, 2025

1. Introduction

The idea of green finance originated in the 1970s. With the vigorous development of the industrial revolution, capitalism blindly pursued economic benefits, resulting in waste of resources and environmental pollution. Yes, environmental issues have gradually attracted people's attention, and some international organizations and financial institutions have begun to realize the role of Finance in environmental protection and advocate the ecological concept of harmony and unity between man and nature. But this idea did not have a global impact until the 1980s and 1990s, when the bank for International Settlements (BIS) issued the Basel Accord, which for the first time linked capital adequacy to bank risk, including environmental risk considerations, prompting banks to pay more attention to environmental factors in their business. After entering the 21st century, with the increasing attention of the international community to climate change, China's green finance has ushered in development opportunities. In 2007, the State Environmental Protection Administration and other departments issued policies such as green credit, green insurance and green securities to guide financial resources to invest in green industries. Financial institutions responded positively and continuously developed many green financial products. The scale of green credit gradually expanded, green insurance products gradually increased, and the green securities market began to rise, which shows that China's green financial system has initially taken shape.

To sum up, Jiangsu Province, as a major economic province in China, has been in the forefront of the country for a long time, but the traditional industries with high energy consumption and high emissions account for a large proportion, facing the dual pressure of resource constraints and environmental pollution. Therefore, in the current context, green finance is not only the key grasp to achieve environmental governance, but also the core driving force to promote the transformation of industrial structure from high carbon to low carbon. Therefore, this paper takes the development of green finance in Jiangsu Province in the past ten years as the research object, adopts the research method of correlation between theoretical elaboration and empirical analysis, and analyzes its mechanism of action on the improvement process of industrial structure in detail, so as to give policy suggestions with application value and give reference to the sustainable development of green finance in Jiangsu Province.

From the perspective of financial theory, we can expand the application of green finance in regional economic development, fill in the theoretical details of the relationship between green finance and industrial structure in Jiangsu, improve the analytical framework of Green Finance on the transmission mechanism of industrial structure adjustment, provide theoretical support for the transformation of traditional industries in Jiangsu to green direction and the emergence of emerging green industries within the scope of industrial economy theory, and explain how green financial resources are effectively allocated to various industries to promote the development of industrial structure towards upgrading and rationalization, and help establish a regional industrial economy theoretical system in line with the concept of sustainable development.

2. Literature review

2.1. Research on green finance

In terms of the research on the temporal and spatial characteristics of green finance, many scholars have deeply explored the temporal and spatial evolution of the development level of green finance. By measuring the development level of green finance in China's four major regions, Zhou and Tang have studied the regional heterogeneity of its development, revealing the phenomenon of club integration of green finance, that is, regions with similar development levels tend to gather [1]. In addition, some scholars focus on the spatial impact effect of green finance, and use spatial econometrics model to deeply analyze the spatial correlation and spillover effect of green finance. For example, Huang *et al*. showed that there was a positive spatial autocorrelation in green