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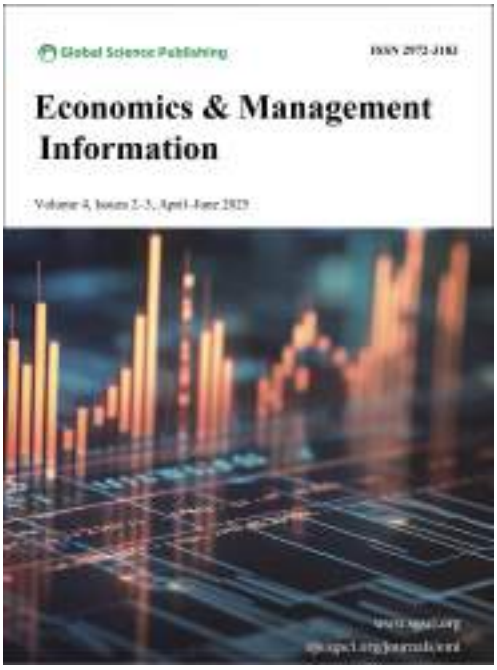

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Contents

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Article

Research on the Impact of Low-Carbon Pilot Policies on the Upgrading of China's Urban Industrial Structure

Jieqin Zhou

School of Economics and Management, Qingdao University of Science and Technology, Qingdao 266101, China

Abstract: The construction of low-carbon cities in China represents a profound socio-economic transformation. This study investigates whether the implementation of low-carbon city pilot projects facilitates industrial structure adjustment. Utilizing panel data from 297 prefecture-level cities spanning 2001 to 2020, this research treats the low-carbon city pilots as a quasi-natural experiment to examine their impact on industrial structure upgrading and the underlying mechanisms. The findings indicate that low-carbon city initiatives positively contribute to the optimization of the industrial structure but have a limited effect on its rationalization. Mechanism analysis reveals that green technological innovation driven by pilot projects plays a crucial role in promoting industrial structure upgrading. Regional heterogeneity analysis shows that the impact of low-carbon city pilots is more pronounced in central and western regions compared to the eastern region, with no significant effect observed across all three regions collectively. This study offers valuable insights for integrating low-carbon city development with industrial structure upgrading.

Keywords: low-carbon pilot; industrial structure upgrading; industrial structure rationalization; differentially differential method; green technology innovation

1. Introduction

China's reform and opening-up has brought elements of a market economy, attracted domestic and foreign investment, and promoted industrial upgrading and the rise of export-oriented manufacturing. The period saw rapid development in light industry, electronics and information technology, but the extensive industrial development model also led to environmental problems such as climate change. Since the beginning of the 21st century, in the context of the global response to climate change, China, as a major carbon emitter, has gradually adjusted and upgraded its industrial structure, focusing on the development of high-tech industries such as electronics, semiconductors and biotechnology, service industries such as finance, e-commerce and the Internet, and cultural and creative industries. In order to achieve the goal of "achieving carbon peak before 2030 and carbon neutrality before 2060" (referred to as "double carbon"), the National Development and Reform Commission launched the pilot work of low-carbon provinces and cities in 2010, and further expanded the scope of the pilot in 2012 and 2017.

Environmental policies play an important role in solving environmental problems and promoting industrial restructuring. China has entered the stage of high-quality development, and after the rapid industrialization process, the rapid rise of high-carbon industries and become the leading economic development, so there is an

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Corresponding: Jieqin Zhou (jieqinzhou@163.com)

urgent need to adjust the industrial structure and promote industrial transformation and upgrading. Undoubtedly, the low-carbon pilot policy proposed by China will impose constraints on urban economic growth, industrial structure and population development mode. Is the low-carbon pilot policy, an important means in environmental improvement policies, capable of facilitating the upgrading of industrial structure and realizing the integrated development where low-carbon cities and industrial structure upgrading go hand in hand? On the one hand, the public is worried that the "dual carbon" goal will have a negative effect on urban economic growth, restrict the realization of corporate profit goals, and thus delay industrial transformation and upgrading. On the other hand, according to Porter's hypothesis, appropriate environmental regulation can stimulate the impetus of innovation of enterprises and promote their research and development of green technologies, processes and products. In order to cover the cost of environmental compliance either to some degree or entirely, so as to increase the technological innovation potential and competitiveness of enterprises [1]. From this perspective, low-carbon pilot policies will promote the upgrading of industrial structure. In addition, under the constraints of environmental regulations, enterprises' pollution management strategies will reduce investment in high-energy-consuming and high-polluting production, which will lead to the transfer of production resources from high-polluting and high-energy-consuming areas to low-polluting and low-energy-consuming areas [2].

There exist two principal challenges in evaluating the influence of environmental regulation on the upgrading of industrial structure. First, there are endogenous problems in environmental regulation and industrial structure upgrading. On the one hand, the implementation of regional environmental policies may be affected by the level of industrial structure and have mutual influence. On the other hand, unobservable individual heterogeneity and macroeconomic trends may also have an impact on economic performance. These unaccounted factors can lead to model estimation errors [3]. Secondly, most of the existing studies use proxy indicators, like the release of pollutants, discharge cost, environmental pollution expenditure, etc. These indicators are not only related to the intensity of environmental supervision, but also affected by many factors such as enterprises' pollution behavior and local environmental supervision. It is often challenging, therefore, to link the changes in these indicators to the adjustment of environmental regulations.

To solve the above problems, Hering L and Poncet S, Greenstone M and Hanna R., Guo X and Zhang P and other scholars used natural experiment methods to build a differentially based model [4–6]. In addition, the intermediary effect model under the framework of causal inference is one of the most popular methods for analyzing policy mechanisms. Zhou and other scholars expanded the relationship between multiple influencing mechanisms on the basis of the traditional intermediary effect and solved the problem of biased estimation caused by missing variables [7]. In this paper, the above two methods will be adopted to evaluate the effects of environmental policies and analyze the mechanism of policy action.

In this research, the implementation of the low-carbon city pilot program in China is treated as a quasi-natural experiment. The difference-in-differences (DID) approach is employed to assess how this pilot initiative affects the upgrading of China's industrial structure. This article selects 297 prefecture-level cities nationwide as samples. Among them, 116 cities were granted permission to construct low-carbon cities prior to 2012, offering us an eminently appropriate quasi-natural experimental object. Within these samples, these 116 low-carbon pilot cities constitute the experimental group, while the remaining 181 prefecture-level cities naturally form the control group. On one hand, applying the DID method can rule out the impacts of non-time-varying unobservable regional factors (such as the economic foundation and natural conditions). on the other hand, a series of annual macroeconomic indicators of cities before and after the pilot can be controlled through detailed geographic location information to further reduce the estimation error caused by missing variables. The second part is the construction of the econometric model, the third part is the empirical analysis, including benchmark regression, parallel trend test, robustness test, heterogeneity analysis and mechanism analysis, and the last part is the research conclusions and suggestions.

2. Econometric Model

2.1. Data Sources

From 2001 to 2020, data of 297 Chinese cities is used in this paper to investigate the impact of low-carbon pilot cities. The list of 116 low-carbon cities comes from the "Notice on carrying out the pilot work of low-carbon provinces and regions and low-carbon cities" document and the second and third batch of notification documents of pilot cities in this category released later. The economic data of prefecture-level cities are derived from the China City Statistical Yearbook, including per capita GDP, informatization level, human capital level, urbanization degree, openness degree, etc. The economic data of prefecture-level cities are derived from the "China Urban Statistical Yearbook" and the statistical yearbooks of various provinces. After obtaining the initial data, the prefecture-level cities with severely lacking data were eliminated, and some missing data were completed through the interpolation method.

2.2. Model Construction

The difference-in-differences (DID) methodology, widely utilized in recent years for evaluating policy impacts, is particularly suitable for the research topic addressed in this paper. This approach effectively addresses variations at two key levels: inter-city differences and year-to-year disparities. By controlling for these dual dimensions of variation, it can accurately assess changes in industrial structure within China's pilot and non-pilot cities before and after the introduction of the low-carbon city pilot policy. The low-carbon city pilot policy was implemented in 2010 and 2012, with an additional implementation in 2017. However, due to the significant time gap between 2017 and the earlier implementations, only the data from 2010 and 2012 were selected to ensure accuracy. To operationalize this, we created a binary variable, "treat", indicating whether a city was affected by the pilot policy in 2010 or 2012. Cities designated as pilots were assigned a value of 1, while those that were not were assigned a value of 0, forming the control group. This resulted in a sample of 116 cities in the experimental group and 181 cities in the control group. Additionally, we introduced a binary variable, "period", based on the timing of policy implementation. If the observation occurred during or after the policy year, it was coded as 1; otherwise, it was coded as 0. Consequently, a two-way fixed effects model was employed to estimate the policy impact. The DID model is structured as follows:

$$Upgrading_{i,t} = \alpha_0 + \alpha_1 treat_i + period_t + \gamma X_{i,t} + \mu_t + \phi_i + \varepsilon_{i,t} \quad (1)$$

In Equation (1), $Upgrading_{i,t}$ serves to represent the upgrading level of the urban industrial structure in the *i* city during the *t* year, measured by the two dimensions of industrial structure upgrading AIS and industrial structure rationalization TL. $treat_i = 1$ indicates that city *i* in *t* year is a low-carbon city. $treat_i = 0$ means city *i* is not a low carbon city in t years. $period_t = 0$ indicates before the implementation of the project, and $period_t = 1$ indicates during or after the implementation of the project. $X_{i,t}$ represents a set of control variables at the annual city-level. These variables incorporate the economic development level, informatization level, human capital level, urbanization degree, openness degree, and so on. ϕ_i Represents the fixed effect of the city, controlling factors such as geographical location that do not change over time. μ_t Represents fixed effects in time, controlling for features that do not vary with region, such as changes in macroeconomic conditions. In the aforementioned formula, if the estimated value $\alpha_1 > 0$, it demonstrates that the pilot policy is beneficial for the upgrading of the industrial structure in Chinese cities. If the estimated value $\alpha_1 < 0$, it implies that the pilot policy has an inhibitory effect on the industrial structure.

2.3. Description of Variables

2.3.1. Explained Variables

In this paper, the variable to be explained is industrial structure upgrading, which can be broken down into two aspects: the advancement of the industrial structure and the rationalization of the industrial structure. The rationalization of the industrial structure is a dynamic progression where the coordination capabilities within industries are increasingly strengthened. It reflects the degree of coupling between the allocation of factor inputs

and output distribution [8]. The degree of industrial structure rationalization is measured by some scholars using the degree of structural deviation [9]. Yet, this technique fails to consider the relative importance of the industry and puts the absolute value into the calculation process.

By surmounting the deficiency of structural bias, the TL index can maintain its theoretical basis and economic significance [10]. The TL index, therefore, is picked by this paper to be a proxy index for the rationalization of the industrial structure in prefecture-level cities. The equation is expressed as:

$$TL = \sum_{m=1}^{3} y_{i,m,t} \ln(y_{i,m,t}/l_{i,m,t}), m = 1, 2, 3 \quad (2)$$

In Equation (2), $y_{i,m,t}$ represents the proportion of m industry in region i in year t. $l_{i,m,t}$ Represents the proportion of employees in m industry in region i in year t. The industrial structure index of these regions mirrors the production and employment structures of China's three main industries. When the value of this index is 0, it implies that the industrial structure has reached an equilibrium state. Conversely, if the value is non-zero, it suggests that the industrial structure is departing from equilibrium, meaning that the industrial structure is irrational. Industrial structure upgrading is the process through which the industrial structure, in accordance with the historical and logical order of economic development, evolves step-by-step from a lower-tier state to a higher-tier state [11]. Usually, following Clark's Law, the upgrading of industrial structure is defined as the growth in the share of non-agricultural industries. It can be measured using indicators like the coefficient of industrial structure level, the Mole structure variation index, and the percentage of high-tech industries [12]. Using the industrial structure level coefficient, the evolution process of the three industries is quantitatively described from the relative change of the proportion. The equation is as follows:

$$AS_{i,t} = \sum_{m=1}^{3} y_{i,m,t} \times m, m = 1, 2, 3 \quad (3)$$

In Equation (3), $y_{i,m,t}$ represents the proportion of m industries in region i in the GDP of the region in t year. The index shows that China's leading industries have gradually shifted from the primary industry to the secondary and tertiary industries, which is the connotation of industrial structure upgrading.

2.3.2. Explanatory Variables

This article takes the dummy variable treat as the explanatory variable. According to the document "Notice on the pilot work of low-carbon provinces and low-carbon cities" and the list of low-carbon cities and the establishment time in the first and second batch of notice documents of pilot cities in this category released later, the key independent variable treat*period is derived by us.

2.3.3. Control Variables

By referring to previous literature, this paper selects the following control variables:

(1) Economic Development Level (Pergdp). Per capita GDP is a more precise indicator of economic development compared to aggregate GDP. Higher per capita GDP generally signifies greater potential for industrial structure upgrading, as it reflects more comprehensive infrastructure and higher population quality, both of which are conducive to economic advancement.

(2) Informationization Level (Inform). This study calculates this variable as the ratio of per capita postal and telecommunications service volume to per capita GDP. Informationization level measures the extent to which modern communication and Internet technologies are integrated into daily life and production activities. In the era of technological revolution, higher levels of informationization can significantly facilitate industrial structure upgrading by enhancing productivity and innovation.

(3) Human Capital Level (human). The human capital level is measured by the ratio of students enrolled in higher education institutions to the total regional population. A higher educational attainment within a region implies a more skilled labor force, which increases the likelihood of generating transformative technologies. Technological innovation is a key driver of industrial structure transformation and upgrading.

(4) Urbanization Level (Urban). Urbanization is quantified by the proportion of urban residents to the total population. Urbanization is closely linked with industrialization, as higher urbanization levels typically indicate

more efficient industrial production. Accelerated urbanization suggests that rural areas are transitioning towards urban development, thereby enhancing regional development levels and facilitating industrial structure upgrading.

(5) Degree of Openness (Open). The degree of openness is measured by the ratio of actual foreign direct investment (FDI) to regional GDP. Greater openness can attract more foreign investment, leading to industrial transfer and technology spillover effects. These phenomena not only stimulate economic growth but also influence industrial structure adjustment through increased competition and knowledge diffusion. As shown in Table 1, these are the descriptive statistical results of variables.

Table 1. Descriptive statistics.

Variables	Observed Values	Mean Value	Standard Error	Minimum	Maximum
Rationalization of industrial structure	5698	0.318	0.256	0.001	1.964
Upgrading the industrial structure	5698	2.154	0.161	1.164	2.866
Level of economic development	5698	0.387	0.316	0.081	5.331
Informatization level	5698	0.302	0.417	0.003	6.025
Human capital level	5698	0.152	0.212	0.002	1.810
Level of urbanization	5698	0.362	0.166	0.075	1.001
Openness	5698	0.038	0.061	0.000	0.886

3. Empirical Analysis

3.1. Baseline Regression

Table 2 (1–2) shows the benchmark regression results of the pilot project's impact on the rationalization of industrial structure. Model (2) is based on model (1) by adding the cross-fixed effects considering region and year. The results show that the treat*period is negative and does not have statistical significance, that is, low-carbon city pilot can not promote the rationalization of industrial structure. The reason is that the pilot did not take into account the location advantage and targets in the development of industries, causing improper resource allotment and a feeble relationship between industries. This has had an adverse impact on the rationalization of local industrial structure. Therefore, the impact of the pilot on the rationalization of industrial structure is not significant.

Table 2. Impacts of low-carbon city pilot policies on industrial structure upgrading.

Variables	Industrial Structure Rationalization TL	Industrial Structure Rationalization TL	Upgrading of Industrial Structure AS	Upgrading of Industrial Structure AS
Models	**(1)**	**(2)**	**(3)**	**(4)**
Treat×period	−0.047 (0.115)	−0.051 (0.198)	−0.032 (0.013)	0.021 (0.004)
Control variable	yes	yes	yes	yes
City, year fixed effect	no	yes	no	yes
Observed values	5698	5698	5698	5698
R^2	0.288	0.368	0.287	0.408

Note: robust standard errors are in parentheses.

Table 2 (3) to (4) shows the baseline regression results of the impact of low-carbon city pilot on the upgrading of industrial structure. Model 4 adds the region-year cross-fixed effect on the basis of model 3. The

results show that the treat*period is 0.021, which is significant at 1% level, which proves that the low-carbon city pilot significantly promotes the upgrading of industrial structure, and indicates that the low-carbon city pilot speeds up the evolution of the leading industry transfer from agriculture to industry and service industry. In the process of building a low-carbon city, it is necessary to vigorously eliminate those contaminating processes, apparatuses and enterprises, and actively promote the development of strategic emerging industries, so as to promote the optimization and upgrading of local industrial structure.

3.2. Parallel Trend Test

The key prerequisite of the DID model is the parallel trends assumption, which posits that the trends in enterprise employment changes in pilot cities and non-pilot cities should be parallel prior to policy implementation. This study rigorously tests the parallel trends between the experimental group and the control group to ensure the validity of the low-carbon city pilot policy impact assessment. Given that policies typically require a substantial period from formulation to effective implementation, and policy adjustments also demand considerable time, policymakers need sufficient time to accurately convey their intentions. Additionally, it takes time for stakeholders to fully comprehend the policy information and make appropriate responses, gradually adapting to the new policy environment [13].

In 1993, Jacobson et al. utilized event analysis to study parallel trends and lagging periods. The equation can be written as:

$$upindustry_{i,t} = \alpha_0 + \sum_{k=-8}^{k=3} a_k \times treat_i \times period_k + \gamma X_{i,t} + \mu_t + \phi_i + \varepsilon_{i,t} \quad (4)$$

In Equation (4), “Period” is a dummy variable, indicating the years of the low-carbon city pilot program. The coefficient represents the disparity in industrial structure upgrading between the experimental group and the control group in the kth year since the initiation of the pilot. If the trend of a_k undergoes a marked increase or decrease during the period when $k > 0$, it implies that the experimental group and the control group were dissimilar prior to the policy implementation, not complying with the parallel trend assumption. If the trend of $a_k$is relatively smooth, it is in line with the parallel trend assumption.

The results are depicted in Figures 1 and 2. The coefficient estimates for each period prior to the implementation of the low-carbon city pilot policy were insignificant. The research sample passed the parallel trend test, indicating that there were no significant disparities between the enterprises in the pilot and non-pilot cities before the policy was implemented.

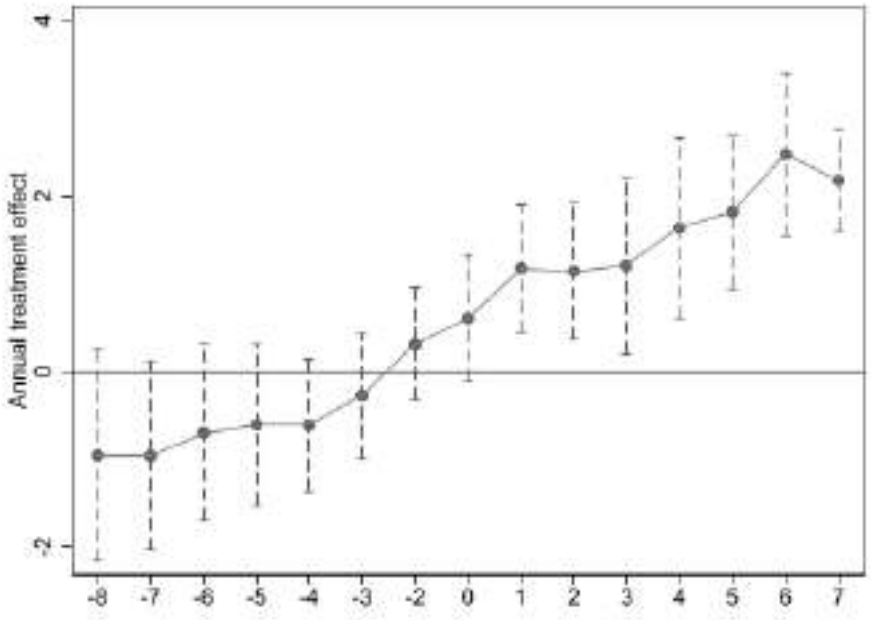

Figure 1. Annual treatment effect of AS.

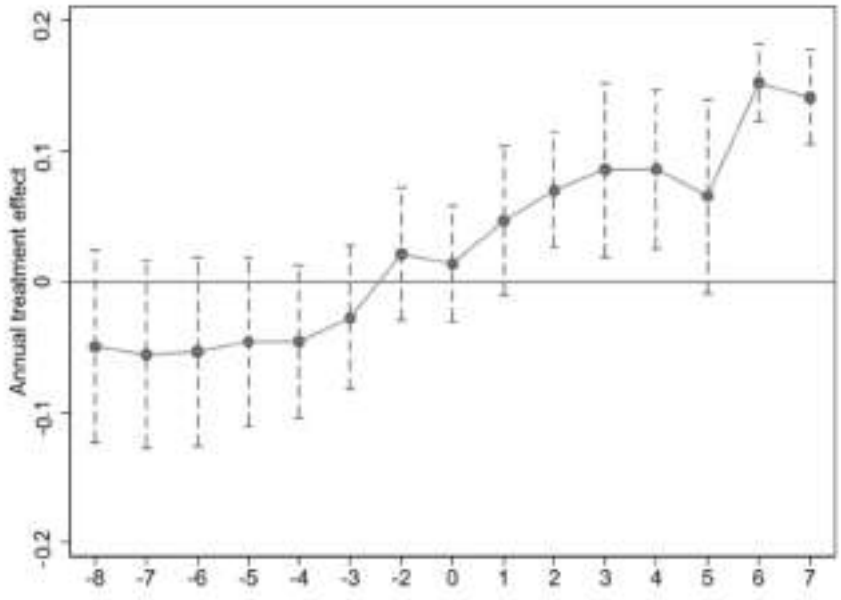

Figure 2. Annual treatment effect of TL.

3.3. Robustness Test

3.3.1. Placebo Test

To circumvent the potential influence of unobservable omitted variables on the benchmark regression results and thereby confounding the hypotheses, Chetty et al. resorted to an indirect placebo test [14]. In this vein, this paper emulates the previous approaches and implements a city placebo test. Among the 297 sample cities, 116 cities were randomly selected as low-carbon pilot cities, with the remainder classified as non-pilot cities. This procedure was replicated 500 times, yielding 500 regression coefficients and their corresponding *p*-values. Evidently, the estimated coefficients from the random samples are distributed approximately around 0 and adhere to a normal distribution, conforming to the expectations of the placebo test. Accordingly, it can be excluded that the benchmark estimation results of this paper are attributed to unobservable factors. The distribution of the regression coefficients is depicted in Figure 3.

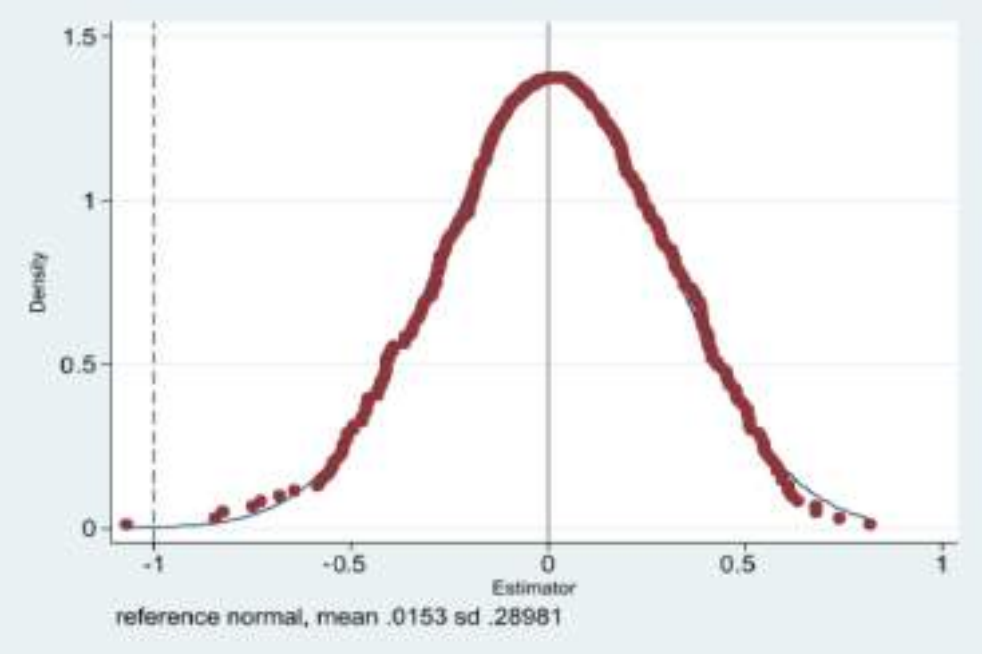

Figure 3. Kernel density distribution.

3.3.2. Re-Select Experimental Group and Control Group

The upgrading of the industrial structure in a region is not merely associated with pilot policies but also with differences in aspects such as the level of economic development. Consequently, leveraging the Regression Discontinuity methodology, this study establishes comparable treatment and comparison cohorts through a phased implementation strategy. Municipalities designated as low-carbon pilot zones were systematically categorized into three implementation waves: an initial cohort of 85 urban centers commencing in 2010, followed by 31 municipalities in 2013, and a subsequent cohort of 42 cities initiated in 2015. The analytical framework specifically designates the 2010 cohort (n = 82) as the treatment group, while utilizing the 2017 cohort (n = 42) as the counterfactual baseline.

Our econometric analysis employs panel data spanning 2000–2017, with regression outputs detailed in Table 3 (Columns 1–2). The empirical findings reveal a statistically significant negative correlation between policy implementation and industrial structural transformation, contrasted by a positive association with industrial structural rationalization. Crucially, the robustness of these estimates demonstrates insensitivity to geographical selection bias in control group construction.

Table 3. Instrument variable.

Variable	**Industrial Structure Rationalization TL**	**AIS for Upgrading Industrial Structure**
Models	**(1)**	**(2)**
Treat×period	−0.061 (0.137)	0.038 (0.007)
Control variable	yes	yes
City, year fixed effect	yes	yes
Sample size	1637	1637
R^2	0.1367	0.2505

Note: robust standard errors are in parentheses.

3.3.3. Effects of Other Policies

Concurrent policy interventions during the study period necessitate rigorous confounding control. Our analysis specifically addresses two notable initiatives: (1) The Ambient Air Quality Standards reform enacted in 2012 through inter-ministerial collaboration between the Ministry of Environmental Protection and the General Administration of Quality Supervision, which mandated full deployment of monitoring infrastructure across 74 priority municipalities (including provincial capitals and direct-administered cities) by Q4 2012; (2) The Innovation-Driven City Pilot program initiated in 2017, targeting 61 urban centers characterized by technology-intensive development paradigms with significant spatial spillover potential. To mitigate confounding effects, our fixed-effects framework incorporates policy-time interaction terms following the approach of Goodman-Bacon (2021). As evidenced in Table 4 (Specifications 1–4), the coefficient stability on treat×period remains consistent with baseline estimates in Table 1, demonstrating robustness against contemporaneous policy shocks. This persistence in statistical significance ($p < 0.05$ across specifications) confirms the exclusion restriction's validity in our quasi-experimental design.

Table 4. Robustness test.

Variables	Industrial Structure Rationalization TL	Industrial Structure Rationalization TL	AIS for Upgrading Industrial Structure	Industrial Structure Upgrading AIS
Models	**(1)**	**(2)**	**(3)**	**(4)**
treat×period	−0.034 (0.124)	−0.027 (0.052)	0.034 (0.003)	0.029 (0.012)
Control variable	yes	yes	yes	yes
City, year fixed effect	yes	yes	yes	yes
Sample size	5698	5698	5698	5698
R^2	0.291	0.187	0.178	0.305

Note: robust standard errors are in parentheses.

3.4. Heterogeneity Analysis

To investigate spatial variation in policy efficacy, we stratified 297 prefectural-level municipalities into two cohorts: 102 industrialized urban centers (coastal regions) and 195 emerging economies (central-western regions). The industrialized cohort predominantly locates in eastern China, whereas the developing cohort clusters in central-western territories. Empirical outputs documented in Table 5 (Specifications 1–4).

The low-carbon city pilot policy exerts heterogeneous effects on industrial structure upgrading across regions, with significantly stronger impacts observed in central-western cities compared to eastern counterparts. This regional disparity likely stems from the central-western regions' heavier reliance on emission-intensive industries. The policy serves as a transformative catalyst in less-developed areas through concentrated deployment of low-carbon technologies, generating a 1.8× multiplier effect on local economic revitalization. Conversely, in developed eastern regions, marginal returns diminish significantly, functioning primarily as supplementary optimization mechanisms. Notably, industrial structure rationalization exhibits statistically insignificant coefficients across all regions, underscoring the need for region-specific policy calibration.

Table 5. Heterogeneity analysis.

Variables	Eastern		Midwest	
	Industrial Structure Rationalization TL	**AIS for Upgrading Industrial Structure**	**TL for Rationalization of Industrial Structure**	**AIS for Upgrading Industrial Structure**
Models	(1)	(2)	(3)	(4)
treat×period	0.232 (0.115)	0.015 (0.006)	−0.568 (0.146)	0.023 (0.004)
Control variable	yes	yes	yes	yes
City, year fixed effect	yes	yes	yes	yes
Sample size	180	180	335	335
R^2	0.4736	0.4865	0.2255	0.2568

Note: robust standard errors are in parentheses.

3.5. Mechanism Analysis

Empirical analysis has confirmed that the pilot policy for low-carbon cities significantly promotes industrial transformation. To explore its underlying mechanism, this section focuses on the key transmission channels through which policy intervention influences the industrial structure. Theoretical derivation and empirical

testing jointly indicate that green technological innovation serves as the core mediating variable. Specifically, the pilot policy drives the dual processes of clean transformation in traditional industries and the cultivation of emerging environmental protection industries by establishing an incentive mechanism for low-carbon technology research and development. The mediation effect test confirms that technological innovation plays a crucial bridging role in the "policy incentive-structural upgrading" chain, with statistically significant transmission contributions.

This finding aligns with the theoretical expectations of innovation-induced environmental regulation: when policy design effectively stimulates enterprises' investment in green technology R&D, it can break through the energy efficiency bottleneck of traditional industrial upgrading and foster a coordinated development path of pollution control and industrial high-end advancement. The results of the mechanism analysis reveal, from a technical and economic perspective, the internal logic by which the low-carbon pilot policy facilitates the optimization of the industrial structure.

The examination of the policy's mechanism reveals that pilot cities can drive the optimization of industrial structure by leveraging the innovation of green technology paradigms. Specifically, the low-carbon technology research and development (R&D) system facilitates the clean transformation of traditional manufacturing and the strategic cultivation of energy conservation and environmental protection industrial clusters through a three-stage transmission path: "technology demonstration-process iteration-industrial diffusion". To verify this transmission mechanism, the empirical analysis employs the number of authorized green invention patents as a proxy variable for technological innovation and uses the number of approved green utility model patents for multiple robustness checks. The econometric results from models (1)–(2) in Table 6 indicate that the low-carbon pilot policy has a significantly positive stimulating effect on urban green technological innovation.

The mechanism verification results demonstrate that policy intervention achieves ecological reconstruction of industries by stimulating green technological innovation. Notably, the regression coefficients obtained using the instrumental variable method remain highly consistent with those of the benchmark model, which aligns logically with the original intent of the policy design. Under carbon constraints, the technology-driven upgrading of industrial structure generates a synergistic effect of pollution reduction and total factor productivity improvement. This dual dividend effect underscores the pivotal role of green technological innovation in resolving the "decarbonization-growth" paradox.

Table 6. Mechanism analysis.

Variables	**Number of Patent Applications for Green Inventions**	**Number of Green Utility Model Patent Applications**
Models	**(1)**	**(2)**
treat×period	0.156 (0.068)	0.428 (0.164)
Control variables	yes	yes
City, year fixed effect	yes	yes
Sample size	5698	5698
R^2	0.293	0.461

Note: robust standard errors are in parentheses.

4. Research Conclusions and Recommendations

Empirical analysis reveals that the low-carbon pilot zones significantly enhance industrial structural advancement while demonstrating limited efficacy in structural rationalization. Regional heterogeneity examination indicates spatial variation solely exists in structural upgrading impacts, with central-western municipalities exhibiting greater responsiveness than eastern counterparts. Mechanistic investigation demonstrates that eco-innovative technological progress serves as the principal transmission channel, verifying the pilot program's partial success in reconciling decarbonization and industrial modernization objectives.

The study's findings underscore the multifaceted implications of low-carbon urban initiatives on industrial transformation. To optimize policy effectiveness, the following evidence-based recommendations are proposed:

Enhancing Eco-Innovation Capabilities: Policy makers should establish comprehensive incentive mechanisms to accelerate green R&D investments. This involves transitioning industrial practices from end-of-pipe solutions to clean production paradigms through fiscal stimuli for eco-technologies. Concurrently, governments must strengthen intellectual property protection systems and cultivate innovation ecosystems through talent attraction programs and smart infrastructure development.

Differentiated Regional Implementation:

Central-Western Regions: Prioritize circular economy models in traditional industries through energy-efficient retrofitting and industrial symbiosis networks. Develop closed-loop industrial chains integrating resource recovery and emission minimization.

Eastern Coastal Areas: Leverage existing technological advantages to pioneer carbon-neutral industrial clusters, particularly in advanced manufacturing and digital service sectors.

Nationwide Coordination: Align local industrial planning with national strategic emerging sectors by implementing tiered environmental standards and green procurement policies. Special emphasis should be placed on nurturing renewable energy equipment manufacturing and smart grid infrastructure development.

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Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Conflicts of Interest

The author declares no conflict of interest.

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Article

Revitalizing Peking Opera: Bridging Tradition and Modernity through Marketing and Cultural Innovation

Yueqi Li

New York University, New York, NY 10012, USA

Abstract: Peking Opera is a quintessence of Chinese culture. It has experienced significant challenges in the modern era, since audience demographics is shifting and digital entertainment is rising. This paper explores the history, current challenges, and potential solutions for revitalizing Peking Opera. The author used marketing and consulting strategies. It is based on the "4Ps" (Product, Price, Place, Promotion) and "5Cs" (Customer, Company, Collaborators, Competitors, Context) concepts. The strategies include co-branding with popular consumer brands, adjusting ticket pricing for affordability, promoting via social media, and integrating modern elements such as fan culture and digital marketing. The paper also highlights the importance of inviting international artists to experience and promote Peking Opera globally. By using these strategies, Peking Opera can regain its position in the entertainment market.

Keywords: Peking Opera; market; decline; culture

1. Introduction

Peking Opera, one of the most representative arts of China, was known as "the quintessence of Chinese culture". Originating from the Qing dynasty, in 1790, Peking Opera absorbed techniques and methods various local operas, notably, the K'un Chu and the Hwei Ban. Peking Opera is divided into traditional opera and modern opera. Each play showcases a wonderful story in real life.

Peking Opera is composed of four typical role types: Sheng, Tan, Jing, and the court jester. Different roles have different characteristics, which represent a specific group of people [1].

Music is a dispensable part of Opera. The three main instruments are the Hu Chin, Erh Hu, and the Big Drum. "The Orchestra is to accompany all the movement of every actor or actress on the stage and the drummer is the conductor of the orchestra" [1].

From a hundred years ago, Peking Opera was open to all the public, across ages and social classes. However, Peking Opera faces challenges from different dimensions now. Gene Z in China barely knows about such art format and the original audience group has aged. Externally, with the development of technology, many allures distract the young generation. They are more willing to spend time on computer games, social media, and shopping. Those relatively low-cost entertainments are easier to enjoy. As people have already adapted to the fast-paced life, they lost the patience to sit down and watch this "old-fashioned" performance. Thus, few people would like to be fully devoted to Peking Opera.

Internally, Peking Opera has deficiencies in performance form. The long and slow tone bores the audience easily. The special pitch is hard for some people to accept. Each normal play is at least one and a half an hour, so

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it is a torment for people who don't have any background knowledge of this art.

2. History

Peking Opera has had a high status in Chinese society for centuries. As a traditional art that originated from the 18th century, it was supported by the government and normal people. However, it cannot follow the change of modern society.

The ticket price for Peking Opera is also not affordable to most of the audience, so fewer people walk into the theater for this art. It seemed to be doomed to fade out of the marketplace. It was unable to compete with the popularization of film, television, and diverse forms of pop culture [2].

3. Literature Review

Previous studies show that the government has realized this problem. Several related policies have been enacted. Mass Entrepreneurship and Mass Innovation (MEMI) was established, promoting an entrepreneurial solutionism to exploit market values and to speed up China's long-term goal of developing its economy through technological innovations [3].

Not only does Peking Opera face the problem of declining, but also the film industry. Mingxing Company brought the film industry to Chinese people's sights in the 20th century. It was not established with major investment by powerful industrialists or capitalists but with a small fund raised by its founders and prospective shareholders [4].

Fan culture can bring indispensable income to traditional culture. As audience participation has long been an indispensable component in the development of traditional opera, the contextualized fan culture is not a completely novel form but an extension of the traditional mode situated in the age of information. "The decrease of spatiotemporal restrictions and economic costs would help traditional opera become popular again" [2].

People who were employed in culture enjoy consuming Chinese art and culture. Artists possess more desire than normal audiences to learn Chinese Opera. Thus, NACTA (National Academy of Chinese Theatre Arts) should invite more foreign artist coming to China to learn it and then spread it to the world [5].

Some research has been done to find an effective way to spread traditional culture to the world. Relative data analyzing the action of introducing Chinese Opera to foreign artists and normal audiences proves that foreign artists can spread it quickly. This is a more efficient way to popularize Peking Opera globally.

The investment in the diversity of inheritance ways should be strengthened. The government should provide support in system and policy; the Education institution of Peking Opera should have its own characteristic, in order to improve teaching efficiency; sorting out and filing work should be done [6].

According to the data from a ten-year experiment, Chinese Opera is high art, so it's hard to be interpreted by normal audiences, even artists who focus on other arts. Artists possess more desire than normal audiences to learn Chinese Opera. People who were employed in culture like to consume Chinese art and culture [5].

4. Analysis

Peking Opera is worthy to be inherited. It contains the essence of Chinese culture. The story of each show is about Chinese traditional habits and popular stories. It tells audiences meaningful principles. The instrument Opera is special, it contains a hundred years of musicians' wisdom. It is not too late to overcome the temporary difficulties it faces.

Different from most of the previous studies that focus on solving the problems Peking Opera faces through culture studies, this paper is going to discuss them from the aspects of marketing and consulting.

The "4 Ps" marketing strategy, proposed by E. Jerome McCarthy, is the basic logic of solving a marketing dilemma. It's the abbreviation of the four key elements in marketing strategy: Product, Price, Place, and Promotion [7].

To cater to the entertainment market, Peking Opera, as a product that audiences should pay for, should change itself to a more attractive product. Co-branding is a good option. For example, co-branding with Hey

Tea, a popular Boba Tea brand in China, can help young people understand traditional culture when enjoying the drink. The Opera elements are designed on the packing of the cups. If people get boba tea, they will notice the elaborate decoration and may get curious about this culture.

The opera company should divide the ticket prices into different levels. Thus, people with less consumption power can also watch films by buying low-price tickets. This measure helped film art spread quickly. The price of one ticket for a Peking Opera performance is at least 30 dollars now. Many people cannot afford it. The method of Mingxing Company can be adopted.

Beijing, as the origin of Peking Opera, should be the main spot for popularizing this art. The peripheral products should not only be sold at the stores open in the theatre but also sold in normal markets. This helps Peking Opera break the stereotype of "expensive" and "extravagant".

Now, the ways of promoting Peking Opera are too boring and formalist. The government suggests posting posters on the walls beside the streets. However, the design of those posters is too simple and fails to attract pedestrians. To increase popularity, Peking Opera can open online stores to promote products. Furthermore, adapting the opera singing aria and combining it with pop music is an efficient way to popularize this art.

Fan culture brings commercial value to Peking Opera, driving the revenue for this art. As the main platform of fan culture, the internet is an indispensable way to spread this traditional art to more people around the world. With the development of TikTok, Instagram, YouTube, etc., popular internet celebrities' salaries are increasing. The income from operating the Peking Opera business is increasing. To be more competitive in the entertainment market, the Opera must be more proactive in advertising on social media and selling proprietary products including opera dolls, bookmarks with opera elements, and desserts that are carved as opera faces.

The five C market strategies focus on fulfilling customers' requirements. "The central placement of target customers reflects their defining role in the market; the other three entities--the company, its collaborators, and its competitors--aim to create value for these customers." As customers' preferences transfer to social media nowadays, the products of Peking Opera should follow this trend.

The government should encourage the set up of new small businesses that operate the industry of traditional opera. More people will start to set up their own cultural businesses, such as small theatres. It promotes Peking Opera to become an affordable production mode. This helps improve the Chinese GDP.

The competitors of traditional opera are what the young generation is addicted to nowadays, computer games, pop music, and social media, for example. Directly competing with them is impossible. Peking Opera should be combined with these modern elements. With these collaborations, Peking Opera can be recognized by more people. Thus, it can have a position in the entertainment market.

Furthermore, to spread Peking Opera globally, relative institutions in China should invite international artists. Watching this art in person helps them feel the deep connotation of it. Thus, NACTA (National Academy of Chinese Theatre Arts) should invite more foreign artist coming to China to learn it and then spread it to the world.

5. Conclusion

Peking Opera, faces several challenges during this modern and fast-paced era. Such decline is mainly attributed to the audience demographics shift and the booming of other digital entertainment, like social media and computer games. To help the opera overcome the dilemma, strategic adaptation is essential. The use of marketing strategies such as the "4Ps" and "5Cs" theories builds the bridge for Peking Opera between tradition and modernity. The approaches, like co-branding with popular consumer brands, adjusting ticket prices, varying distribution channels, and being active on social media, can decrease the gap with younger generations. Additionally, utilizing modern elements and combining with them, such as fan culture and digital marketing strategies, can amplify accessibility. Moreover, collaborating with international artists and institutions can spread the notability of Peking Opera globally.

These marketing and consulting strategies help Peking Opera regain its place in the entertainment market. Embracing these changes will not only revitalize Peking Opera but also reinforce its position as a beacon of Chinese cultural heritage for generations to come.

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Article

Research on the Impact of Equity Incentives on the Investment Behavior of M Listed Company

Xiujuan Zhang [1,2,*], Thillai Raja [1], Yixiao Xu [1] and Dan Chen [2]

[1] *Graduate School of Business, SEGi University, Kuala Lumpur 47810, Malaysia*

[2] *School of Economics and Management, Yunnan Technology and Business University, Kunming 651700, China*

Abstract: Investment plays an important role in the growth of modern enterprises. It is not only the cornerstone of sustainable development, but also the investment efficiency. Now China is in an important period of high-quality economic development and optimization of resource allocation, using equity incentive as a long-term incentive tool to improve corporate investment behavior and improve investment efficiency, is critical to the company's sustainability. In the context of China's long-term shift from an investment-driven economy to one that is "innovation-driven, service-oriented and consumption-driven", traditional enterprises are actively transforming to emphasize innovation investment, the rapid development of new enterprises emphasizes efficiency investment, which becomes the focus of "efficiency dispute" and "innovation dispute" among enterprises. The 14th five-year plan proposes to achieve high-quality development and give full play to the advantages of innovation-driven development. In this case, the equity incentive is a kind of long-term incentive mechanism which is helpful for the development of the enterprise, thus reduces the manager's short-sighted behavior, lets it be able to carry on the daily management activity from the company long-term development angle one kind of effective means and the mechanism. In this study, M listed company in the home appliance industry are selected as research cases. Through the analysis of the impact of equity incentives on the investment behavior of M listed company five times, although it did not make the amount of investment significantly increased, but every time to complete the plan of the exercise of the conditions, long-term exercise of the right to make the late return to a stable development. Under the incentive mechanism of stock right incentive, the interests of shareholders, managers and core employees of M listed company are tied up well, which makes all departments, whether shareholders or employees, make decisions, always for the future development and long-term interests of the enterprise, so through the way of equity incentives to improve their loyalty to the enterprise, enthusiasm and sense of responsibility. The conclusions can provide theoretical support and empirical evidence for enterprises to improve their investment behavior by using equity incentive, and provide reference for enterprises in the industry to design and implement equity incentive mechanism.

Keywords: investment activities; equity incentives; investment efficiency; sustainable development; interest binding; loyalty

1. Introduction

Equity incentives are a commonly used tool in enterprises to motivate employees to actively participate in company development and improve company performance [1]. Since the 1960s, American listed companies have

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* Corresponding: Xiujuan Zhang (AnnieZhangonly1@163.com)

been using equity incentives to motivate employees [2]. Since 1999, China has gradually implemented stock option incentives. However, due to lack of experience, inadequate systems, and low recognition, the development of equity incentives has been relatively slow [3,4]. In 2002, China officially introduced the policy of equity incentives,but due to its short implementation time, its development is not yet perfect [5]. In 2006, with the promulgation of the "Trial Measures for the Management of Equity Incentives for Listed Companies", it marked the official entry of equity incentives into the stage of corporate governance in China. More and more listed companies in China began to use equity incentives as an important measure for employee motivation [4,6,7]. After the 2008 stock reform, more listed companies in China began to transform equity incentives into a daily incentive method for executives, and made it more standardized [2]. From 2010 to 2015, an increasing number of listed companies launched equity incentive plans on the Growth Enterprise Market, with an absolute increase in the number and an average growth rate of 227% [8]. The "Management Measures for Equity Incentives of Listed Companies" was officially implemented in 2016, marking the increasing coverage of equity incentives in companies and the improvement of equity incentive mechanisms. According to statistical data, as of 30 June 2016, a total of 1211 equity incentive plan announcements have been issued by Chinese A-share listed companies, and ultimately 924 equity incentive plans from 688 A-share companies have been implemented. Among them, from 2014 to the first half of 2016, a total of 412 companies issued announcements on the implementation of equity incentive plans for the Fortune 500 companies [9]. More than a decade has passed, and now the equity incentive system has become a norm in China. As of the end of 2021, 3801 different forms of equity incentive plans have been launched in China's A-share market, and 808 listed companies have introduced equity incentive plans, an increase of 82% compared to last year [4]. Equity incentives usually include stock options, stock appreciation rights, etc. It is a long-term incentive mechanism adopted by enterprises to motivate and retain core talents for employees. Equity incentives have a dual effect of incentives and constraints, theoretically alleviating conflicts of interest between shareholders and executives, and motivating executives to operate the enterprise efficiently [10].

Against the backdrop of rapid global economic development, traditional industries have experienced overcapacity, resource waste, and frequent overinvestment. In contrast, environmental protection and high-tech industries have also experienced underinvestment and low proportions. With the increasing scarcity of resources, how to improve investment efficiency has become a widely concerned issue [11]. For enterprises, negative investment behaviors such as overinvestment, underinvestment, and frequent changes in investment direction can have a significant impact on the effectiveness of investment, reducing the efficiency of resource allocation and hindering the long-term development of the enterprise. Improving the investment efficiency of enterprises not only contributes to their sustained and stable profitability, but also helps them acquire core competitiveness and enhance their potential for sustainable development. At the same time, it can also increase the production efficiency of enterprises and make fund allocation more reasonable [4]. Especially as China is currently undergoing economic transformation, investment is an effective way to create shareholder wealth and stimulate economic vitality. Optimizing the investment structure is conducive to expanding domestic demand and promoting economic growth [12]. Due to the separation of ownership and management rights, the emergence of agency relationships in modern enterprises leads to deviations in the interests and goals of shareholders and management, which affects investment behavior. Over time, improper investment behavior not only hinders the long-term development of the enterprise, but also has a negative impact on the orderly operation of the capital market [7,12]. Therefore, it is necessary and important to study the impact of equity incentives on corporate investment behavior. Looking at the research results of scholars at home and abroad, most experts and scholars examine the execution effect of equity incentives from the perspective of the relationship between equity incentives and corporate performance, while there is little research on equity incentives and investment behavior, and there are also many differences in existing research. Some scholars believe that equity incentives are one of the effective ways to solve investment problems. They bind company interests with managers, promote better utilization of company resources by managers, and improve investment efficiency [5,13]. Some scholars insist that with the emergence of equity incentives, company executives have been given more attention, and conflicts of interest between shareholders and executives have been alleviated. Equity incentives also enable company executives to obtain certain shareholder rights, thereby changing their

relationship with the original shareholders and enabling them to enjoy the value of enterprise development together as a community of shared interests. Some scholars have also found that equity incentives do not significantly inhibit overinvestment behavior, but rather exacerbate underinvestment behavior to a certain extent. Alternatively, after implementing equity incentives, companies generally exhibit inefficient investment behavior of overinvestment [5]. It can be seen that there is still a lot of room for exploration on the impact of equity incentives on the investment behavior of listed companies.

M listed company is a representative enterprise in China's home appliance industry, which has not only experienced the booming development stage of the industry, but also the industry downturn stage caused by policy adjustments and other reasons. However, it can still maintain a good development momentum and become a leader in the industry, largely due to the implementation of reasonable equity incentive policies. The reason why M listed company was chosen as the object of this study is not only because of its leading position in the industry, but also because it implemented equity incentives earlier and has successfully implemented five equity incentive policies. On the basis of previous research on equity incentives and investment behavior, the author will conduct a detailed analysis of the specific situation of M listed company's five equity incentives and their impact on investment behavior, in order to explore how these incentive measures specifically affect the company's investment behavior. The author hopes to add new insights to the existing academic literature on the impact of equity incentives and investment behavior of Chinese listed companies, thereby enriching our understanding of the mechanism of equity incentives and providing some reference for other home appliance companies in formulating and implementing equity incentive plans.

2. Literature Review

Li & Fu [2] empirically studied the impact of CEO equity incentives on corporate investment efficiency and the moderating effect of financing constraints between the two. They found that CEO equity incentives have a significant negative impact on corporate investment efficiency, mainly reflected in overinvestment. However, financing constraints can alleviate the negative effects of both to a certain extent and improve corporate investment efficiency. Liu [4] analyzed whether executive equity incentives can alleviate inefficient investment behavior based on the principal-agent framework, and the role of executive overconfidence in alleviating inefficient investment behavior through executive equity incentives. The results showed that: first, executive equity incentives in listed companies in China have not effectively solved the problem of agency conflicts, but have increased the possibility of inefficient investment in the company; Second, irrational factors such as managerial overconfidence are important factors that constrain the effectiveness of equity incentive policies. Equity incentives may induce managerial overconfidence or exacerbate managerial overconfidence, which in turn may lead to decision-making errors and increase the likelihood of ineffective investments. Cheng et al. [14] found that equity incentives have a restraining effect on inefficient investment of companies at different stages of their lifecycle. Similarly, Chen [13] conducted an empirical study on relevant data of A-share listed companies in Shenzhen from 2016 to 2021 to verify the impact of executive equity incentives on inefficient investment and further investigate the role of executive power in this impact. The results showed that executive equity incentives can effectively curb ineffective investment and improve investment efficiency. In addition, executive power has a negative moderating effect on equity incentives and ineffective investments. Qi & Xu [5] pointed out in their analysis of the impact of equity incentives on H company's investment methods, scale, and efficiency that it is of great significance for companies to effectively guide investment behavior and improve investment efficiency through equity incentives. In modern enterprises, in order to improve the operational efficiency of the company, shareholders, as the owners of the company, are willing to hire professional managers as company operators to maximize shareholder interests. However, the accompanying issue is the widespread agency problem between executives and shareholders. To reduce agency costs, companies can take measures such as supervision and incentives. With the expansion of the company's scale, the cost of supervising agents is high due to the limited time, energy, and ability of shareholders. The use of incentive measures as a solution to reduce agency costs has been widely recognized [15]. An appropriate equity incentive system can weaken the self-interest behavior of management, promote management to invest according to the standard of maximizing

enterprise value, and improve the efficiency and effectiveness of investment. At the same time, attaching great importance to the compensation of the company's management and core employees, implementing incentive measures such as equity incentives, can alleviate conflicts of interest between shareholders, management, and employees. Therefore, according to a series of relevant research literature, companies that implement equity incentives have more effective and efficient investment behavior than companies that do not implement equity incentives, and executive equity incentives have a positive governance effect [9]. Chen [10] studied the governance effect of equity incentives on corporate investment efficiency and the ultimate control characteristics, as well as the governance effect of equity incentives with different types of controlling equity. It was found that there is generally a situation of insufficient investment in listed companies in China; Compared to state-owned holding companies, equity incentives have a stronger governance effect on underinvestment in non-state-owned holding companies; Implementing executive equity incentives can improve the underinvestment of enterprises, but it will exacerbate the situation of overinvestment; When the concentration of ultimate control is in a relatively controlled environment, it is more conducive to leveraging the governance effect of executive equity incentives on underinvestment; Compared to the separation of ownership and control, the matching of ownership and control by the ultimate controller is more conducive to promoting the governance effect of equity incentives, thereby more effectively suppressing inefficient investment. In addition, implementing long-term equity incentive plans for corporate executives can enable management to focus on investment and innovation for a longer period of time, ultimately improving the performance of the company. The proportion of management shareholding is positively correlated with a company's R&D investment and performance, indicating that implementing equity incentive mechanisms can enhance the rationality of a company's R&D investment, thereby improving its financial performance [16]. After studying 570 Chinese companies listed on the Growth Enterprise Market, Xu & Cheng [8] found a significant negative correlation between equity incentives and inefficient investments by executives of Growth Enterprise Market listed companies. This means that the development of equity incentive plans can coordinate conflicts of interest between management and shareholders. After forming a consistent utility function, management's investment behavior has been improved, and inefficient investment behavior has significantly decreased. In addition, when dividing inefficient investment into two forms: overinvestment and underinvestment, it was found that the impact of equity incentives on investment efficiency is mainly reflected in suppressing overinvestment. Equity incentives not only involve corporate executives, but also involve ordinary employees. Although most research mainly focuses on executives, there are also a few scholars who have taken a different approach to studying the relationship between equity incentives and ordinary employees. Li's [12] study found that the implementation of employee stock ownership plans can motivate employee shareholders to actively participate in the company's business activities and investment decisions, thereby improving the investment efficiency of the enterprise. Research and development investment can fill investment gaps, focus on the company's investment direction, and play an intermediary role in the impact of employee stock ownership plans on investment deficiencies.

Although people's understanding of equity incentives is not consistent so far, there are also many problems in the implementation of equity incentives. With the continuous development and innovation of domestic and foreign economic markets, the improvement of securities regulatory systems and laws and regulations, equity incentive policies will be more widely applied. China's research on equity incentives can draw on the thinking and analytical methods of Western countries, as well as the empirical research models used. Of course, while borrowing and learning, it is also necessary to fully understand the actual situation faced by Chinese enterprises and establish equity incentive mechanisms that are suitable for China's national conditions according to local conditions.

3. Relevant Concepts and Theoretical Foundations of Equity Incentives

3.1. Concepts Related to Equity Incentives

Equity incentive is the distribution of enterprise equity or the income generated from enterprise equity in a certain way to management personnel, business personnel, and technical backbone personnel who have

outstanding performance or made significant contributions to the production management process of the enterprise [1]. By allocating a portion of the company's equity and the profits generated from it, allowing them to participate in the company's management decisions, a management mechanism can be formed between the company and its employees, where both risks and benefits are shared. This can constrain their rights and obligations, thereby regulating potential conflicts between management, revenue, and control, and motivating employees in various departments of the company to be efficient and responsible for the long-term development of the company [4,6,8,10,17]. Equity incentives can be divided into two categories: stock options and restricted stock rewards. Stock options enable executives to purchase company stocks at a predetermined price, typically linked to the company's future development and emphasizing long-term performance. Restricted stock awards involve executives receiving company stock on the grant date, but must meet performance goals and time requirements to incentivize the achievement of short-term and long-term company goals [1]. The purpose of implementing equity incentives in enterprises includes: establishing a community of shared interests within the enterprise, reducing the probability of behaviors that harm the overall interests of the enterprise due to the pursuit of personal interests, and linking the overall interests of the enterprise with the personal interests of employees; Retain the core talent resources of the enterprise, while also attracting more talents to win reputation for the enterprise; Restricting the performance improvement of employees and the behavior of management, reducing conflicts between shareholders, authorized agents, and employees, and achieving the expected incentive effect and benefit expectations of the enterprise [2,6].

There is a principal-agent relationship between shareholders and executives of a company [7], but in this relationship, the information obtained between the principal and the agent is asymmetric, which makes the contract between shareholders and the agent unable to be fully realized. In this case, it is necessary to rely on the agent's own "moral self-discipline" [17]. The value goals that shareholders and authorized agents of a company want to achieve are not exactly the same, and there are also certain differences in the process of achieving value goals. For example, shareholders of a company hope to maximize the value of their equity holdings in the development process of the company, while authorized agents hope to achieve their own value in the company and maximize it [8]. Therefore, there will inevitably be conflicts between the shareholders of the enterprise and the entrusted agents, ultimately leading to the entrusted agents deviating from the interests of the principal and attempting opportunistic behavior, resulting in moral hazard and other adverse selection of the entrusted agents [18], thereby reducing the operational management level of the enterprise and weakening the expected effect of equity incentives initiated by the enterprise.

3.2. Theoretical Basis of Equity Incentives

3.2.1. Principal-Agent Theory

The principal-agent theory is one of the fundamental theories for analyzing and studying some of the problems between corporate equity incentives and agency relationships. In the 1930s, Burleigh and Mines proposed the "principal-agent theory", in which they believed that the agency problem in modern corporate management systems stems from the rift between shareholder ownership and management's management rights. Therefore, the management rights and ownership of a company should be separated, and the integration of these two rights has a greater impact on the development of the company. The business owner can retain the remaining claim rights while transferring management rights to more professional and powerful managers. However, because the management does not have ownership of the enterprise and shareholders do not directly participate in business activities, it is easy for the management to seek personal interests maximization and erode shareholder interests [10,12]. The core of the principal-agent theory is the "economic man" assumption, in which shareholders and executives of a company belong to the so-called "economic man" in social activities. Each role tends to take certain actions to seek benefits, avoid unfavorable factors, and maximize their own interests in economic activities. Generally speaking, corporate shareholders seek to increase the value of their invested capital, that is, to optimize the company's value, while executives seek high compensation and low risk, that is, to maximize personal value. Agency costs are caused by conflicts of interest between the two. The second assumption of this theory is that there is a problem of information asymmetry. Due to their information

advantages, agents often make decisions that are more favorable to themselves when conflicts of interest arise with shareholders, allowing them to maximize their advantages. This makes it difficult for principals to effectively supervise them [6,10].

The principal-agent problem caused by conflicts of interest and information asymmetry can easily lead to inefficient investment in enterprises, mainly manifested in two aspects: underinvestment and overinvestment. When a company faces a new investment project, managers are required to learn knowledge and skills related to the new project. Managers may be concerned about their high costs or the risk of damaging the company's reputation due to their failure, leading them to abandon the new project with a net present value greater than zero. This is considered underinvestment [10,12]. As the scale of enterprise operation expands, managers can obtain more resources and profits. In order to pursue profit maximization, managers will blindly expand their scale, pursue on-the-job consumption, and even invest in projects with negative net present value, which is overinvestment [10,12]. Another reason for overinvestment is that the company's past investment projects have generated a large amount of free cash flow. Ambitious managers, driven by political ambitions to establish a business empire, often refuse to distribute dividends to shareholders and instead invest in higher risk, potentially negative net present value investment projects [8]. Overinvestment may seem unreasonable, but it can help managers gain more non monetary returns, establish higher business credibility, and build stronger relationships [8]. In addition, due to relatively low salaries and excessive government intervention, executives of listed companies may overinvest. Due to executives' preference for a peaceful life, there may also be situations of insufficient investment, and even cases where corporate executives use investment as a cover to pave the way for personal interests [7].

The normative analysis of principal-agent theory emerged in the 1970s. Since the agency relationship between shareholders and agents of a company objectively exists, companies need to use their own effective cost management methods to reduce the agency costs generated by agency. Therefore, equity incentives have emerged in this exploration process, solving the problem of high agency costs brought about by the development of companies [7]. Granting partial equity to the entrusted company allows them to participate in the company's management decisions, by optimizing the income structure of the agent and combining it with the interests of the principal to reduce the inconsistency of utility between the two parties, promote the formation of a community of interests between executives and enterprise owners, and stimulate the agent's enthusiasm to pursue shareholder value maximization, alleviate agency conflicts, and improve enterprise performance [4,6].

3.2.2. Two-Factor Theory

The two factor theory, also known as the motivation hygiene theory, was proposed by American psychologist Herzberg in 1959. It refers to the factors that may cause employee dissatisfaction during the development process of a company, including motivational factors and hygiene factors. Motivational factors refer to factors that can satisfy and motivate people. Hygiene factors refer to factors that are prone to generate opinions and negative behaviors. Herzberg believes that these two factors are the main factors affecting employee performance. The content of hygiene factors includes company policies and management, supervision, salary, colleague relationships, and working conditions. These factors are all factors outside of work. If these factors are met, it can eliminate dissatisfaction and maintain the original work efficiency, but it cannot motivate people to behave more positively. Motivational factors are related to the job itself or its content, including achievements, appreciation, the meaning of the job itself, as well as challenges, sense of responsibility, promotion, and development. If these factors are met, they can create a great sense of motivation in people; If not satisfied, it will not generate dissatisfaction like hygiene factors.

The core of the two factor theory, as a classic motivation theory, is how to effectively motivate the management and employees of a company. According to the two factor theory, hygiene factors can only help managers maintain their current work status, while motivational factors can motivate managers to work more actively. Common motivational methods include promotion, development opportunities, etc. On the one hand, equity incentives can give managers more say and decision-making power; On the other hand, through a comprehensive evaluation system, the unity of management goals and corporate goals has been achieved [11].

Enterprises can develop compensation incentive plans for core talents based on this principle, among which the impact of wages and bonuses on employee emotions and work motivation is an important factor.

To achieve long-term incentive effects, an effective long-term incentive mechanism is needed. Equity incentives can stimulate employees' work motivation and improve corporate performance. The good or bad development of a company has a direct impact on employees' work attitude, efficiency, and creativity. In the increasingly fierce market competition, in order for enterprises to stand undefeated, they must form a unique core competitiveness. While cultivating talents, they must also retain them and establish and improve internal incentive systems. This is the expected goal that equity incentives aim to achieve.

4. Analysis of Equity Incentives Implemented by M Listed Company

4.1. Introduction to M Listed Company

M listed company is a multinational corporation established in 1968, which has subsidiaries, overseas institutions, and business units in many countries. The company was listed on the Shenzhen Stock Exchange in 2013 with a registered capital of 6.56 billion yuan and holds controlling stakes in multiple home appliance brands. After nearly 50 years of development, the company has achieved full industry chain coverage in the field of home appliances, while continuously developing towards intelligence and internationalization. M listed company attach great importance to technology research and development, product quality, and after-sales service quality, constantly seizing opportunities for product research and development innovation and structural upgrading. Due to closely following national policies and supply side structural reforms, the company's operating income has continued to grow and achieved stable growth. Despite the overall sluggish development of the home appliance industry in recent years, M listed company has maintained high performance growth. Looking back, the competition in the home appliance industry has always been extremely fierce. In the past 30 years of development, M listed company, born in a small town and starting from ordinary fan products, was able to develop into the industry leader. Its excellent corporate governance mechanism and bold and advanced incentive mechanism undoubtedly played a huge important role.

4.2. Implementation of Equity Incentives by M Listed Company

Since its listing on the Shenzhen Stock Exchange in 2013 through stock exchange absorption and merger, M listed company has implemented various equity incentive methods such as stock options, global partners, restricted stocks, and business partners. From 2013 to the end of 2018, five stock option incentive plans, four global partner shareholding plans, two restricted stock incentive plans, and one business partner shareholding plan have been implemented. M listed company has developed its own culture and characteristics on the path of equity incentives. Figure 1 shows the timeline and incentive methods of equity incentives for M listed company since its overall listing.

Figure 1. The timeline and incentive methods of equity incentives for M listed company since its overall listing.

4.2.1. The First Equity Incentive

M listed company approved the decision of "Stock Option Incentive Plan" at its first shareholders' meeting in 2014. Table 1 shows that this decision mainly adopts the method of using stock options to motivate internal

employees, but the stock options are derived from the targeted issuance of new shares by the company to the incentive targets. The new shares account for 2.41% of the total issued share capital of the enterprise, among which the first phase of incentive objects determined and assessed in the enterprise's equity incentive plan, and the exercise price of the granted stock options are 18.72 yuan/share. The number of stock options to be granted is 40.512 million, and the number of stocks is 40.602 million. Due to someone resigning before exercising their rights, the number of stock options issued was adjusted to 99.8625 million. The first equity incentive adopted a profit distribution method of 10 to 15 and 20 to 20. In 2014, the net profit reached 10.5 billion yuan, a year-on-year increase of 97.50% compared to the previous year. At the same time, the net profit generated after the first equity incentive increased and was not less than 15% of the net profit generated in 2013. The return on net assets also reached 29.49%, achieving the target of a return on net assets of not less than 20%. The higher the target, the stronger the profitability of the enterprise.

Table 1. Content of the first equity incentive.

incentive object	1 director, 1 board secretary, 287 R&D personnel, 189 manufacturing personnel, 110 marketing personnel, and 93 other business backbones, totaling 681 people.
incentive pattern	stock option
incentive scale	99.8625 million shares
exercise price	18.72 yuan/share
exercise conditions	The net profit growth rate in 2014 shall not be less than 15% compared to the previous year, and the return on equity shall not be less than 20%.
stock source	private placement

The data is sourced from Dongfang Wealth Network.

4.2.2. The Second Equity Incentive

According to Table 2, the recipients, quantity, and exercise price of the second stock option incentive plan of M listed company have all been adjusted. The grant date was 27 May 2015, and a total of 733 people received 83.79 million stock options, with the exercise price adjusted from 31.54 yuan/share to 30.54 yuan/share. The second phase of equity incentive also adopts a profit distribution method of 10 out of 10, divided into three exercise periods, with 2793 exercise shares in each exercise period. In 2015, the net profit was 12.71 billion yuan, with a net profit growth rate of 20.99% and a return on equity of 29.06%. The net profit growth rate in 2015 is not less than 15% of the previous year, and the return on equity is not less than 20%. The second equity incentive has been successfully completed.

Table 2. Content of the second equity incentive.

incentive object	1 board secretary, 112 R&D personnel, 274 manufacturing personnel, 125 marketing personnel, 47 information technology personnel, and 164 other business backbones, totaling 733 people.
incentive pattern	stock option
incentive scale	83.79 million shares
exercise price	30.54 yuan/share
exercise conditions	The net profit growth rate in 2015 shall not be less than 15% compared to the previous year, and the return on equity shall not be less than 20%.
stock source	private placement

The data is sourced from Dongfang Wealth Network.

M listed company has always been known for bold incentives, and since implementing the business unit system and hiring managers in 1997, it has adopted a profit sharing incentive model for managers. This incentive model is mainly based on cash incentives. Before the overall listing, some equity incentives were also provided through the listing platform, but the scope of incentives was not wide and the intensity was not significant. The salary structure of basic annual salary + performance bonus was relatively simple, and lacked long-term incentives. M listed company did not choose to directly increase the compensation of its core management team in the constantly changing market and increasingly fierce talent competition, but instead incentivized senior management through a "partner plan". The future development of M listed company has shifted from being a "home appliance enterprise" to a "technology group". This transformation will face multiple challenges such as improving internal operational capabilities, intensifying external competition, business model transformation, strategic adjustment, and technological progress. There is no clear pattern to follow, and the company cannot rely on the decisions of leaders to ensure its progress. Instead, more elite senior managers are needed to truly handle the company's business with the mindset of bosses. How to possess a boss mindset cannot rely solely on vision, mission, and values. It is necessary to have the concept of making senior managers truly bosses, and partners are born in such a context. In order to establish a long-term incentive mechanism for innovative core management team shareholding, promote and facilitate the transformation of the company's "manager" to "partner" identity, gather a group of era fighters and career leaders with common values, promote entrepreneurial spirit, promote the long-term stable development of the company, and achieve the unity of interests among all shareholders, a partner shareholding plan is launched, which is essentially a "performance stock". Through the arrangement of the "shareholding plan", the long-term interests of the company's core management team and shareholders are closely linked, and the participants of the shareholding plan are responsible for their own profits and losses, risks, and share responsibilities and values with shareholders, strengthening the common vision with the company. At the specific implementation level, it also reduces the company's cash incentive expenses. From 2015 to 2018, M listed company has launched four phases of partnership plans.

4.2.3. The Third Equity Incentive

From Table 3, we can see the third equity incentive situation of M listed company in 2016. A total of 929 company personnel were granted stock options, with 127.29 million stock options granted at an exercise price of 21.35 yuan per share. The third equity incentive adopts a profit distribution method of 10 to 5 and 20 to 20, divided into three exercise periods, with 4243 options in each exercise period. According to the 2016 financial statements, similar to the previous two equity incentives, both net profit and total operating revenue are on the rise. The net profit for 2016 was 14.68 billion yuan, an increase of 15.56% compared to the previous year, with a stable growth rate of over 15%. However, the return on equity was lower compared to 2014, at 26.88%.

Table 3. Content of the third equity incentive.

incentive object	347 R&D personnel, 220 manufacturing personnel, 149 marketing personnel, 55 information technology personnel, and 158 other business backbones, totaling 929 people.
incentive pattern	stock option
incentive scale	127.29 million shares
exercise price	21.35 yuan/share
exercise conditions	The net profit growth rate in 2016 shall not be less than 15% compared to the previous year, and the return on equity shall not be less than 20%.
stock source	private placement

The data is sourced from Dongfang Wealth Network.

4.2.4. The Fourth Equity Incentive

According to Table 4, the fourth equity incentive of M listed company in 2017 was granted to a total of

1463 managers and technical backbone personnel from various departments, with 98.274 million shares granted and an exercise price of 32.72 yuan per share. The fourth equity incentive adopts a profit distribution method of 10 out of 10. Compared with 2016, it continued to grow in 2017, with a net profit of 17.28 billion yuan and a growth rate of 2.14% compared to 2016. The annual average in 2016 was not less than 15%, and the return on net assets exceeded 20%.

Table 4. Content of the fourth equity incentive.

incentive object	576 R&D personnel, 320 manufacturing personnel, 118 quality personnel, and 458 other business backbones, totaling 1463 people.
incentive pattern	stock option
incentive scale	98.274 million shares
exercise price	32.72 yuan/share
exercise conditions	The net profit growth rate in 2017 shall not be less than 15% compared to the previous year, and the return on equity shall not be less than 20%.
stock source	private placement

The data is sourced from Dongfang Wealth Network.

M listed company first launched a restricted stock incentive plan in March 2017, mainly targeting middle and senior management. The stock source is the company's targeted issuance of new shares to incentive targets, and the funds are self raised by employees. Overall, it is a relatively standardized equity incentive plan among listed companies. Employees participating in restricted stock incentives need to be able to see the intensity and form of their annual returns. Although the stability is not as high as that of partner shareholding plans, it has a direct impact on the company's short and medium term performance. Restricted stocks can be offered to incentive recipients at half the market price, with strong incentives that require advance investment and stronger binding compared to options. In addition, restricted stocks are to some extent a supplement to the comprehensive incentive model, increasing the incentive strength for middle-level employees and making the equity incentive system of M listed company more perfect. From 2017 to 2018, M listed company has launched two restricted stock incentive plans.

4.2.5. The Fifth Equity Incentive

From Table 5, it can be seen that the fifth stock option incentive plan of M listed company intends to grant 62.08 million stock options to incentive objects, with 54.42 million options granted to 1328 incentive objects for the first time, accounting for 88.72% of the total, and 7 million options reserved, accounting for 11.28% of the total. The exercise price is 56.34 yuan/share. This incentive system adopts a profit distribution method of 10 out of 12, and M listed company also achieved a net profit of over 20 billion yuan in 2018, reaching 20.23 billion yuan, with a stable year-on-year growth rate of around 17%, and a stable return on equity of around 25%.

Table 5. Content of the fifth equity incentive.

incentive object	599 R&D personnel, 185 manufacturing personnel, 54 quality personnel, and 490 other business backbones, totaling 1328 people.
incentive pattern	stock option
incentive scale	54.42 million shares
exercise price	56.34 yuan/share
exercise conditions	The net profit growth rate in 2018 shall not be less than 15% compared to the previous year, and the return on equity shall not be less than 20%.
stock source	private placement

The data is sourced from Dongfang Wealth Network.

5. The Impact of Implementing Equity Incentives on Investment Behavior of M Listed Company

The impact of equity incentives implemented by M listed company on investment behavior is mainly analyzed through two indicators: investment income and return on equity. To facilitate readers' understanding of the meanings of these two indicators, the author specifically lists their meanings in Table 6:

Table 6. Meaning of indicators.

investment income	It refers to the net income obtained by enterprises or individuals from external investment minus the losses incurred during the investment process. Investment return is an important indicator for evaluating the profitability of an investment portfolio or individual investment, reflecting the returns that investors receive from their investments.
return on equity	It is an important indicator for measuring a company's profitability, representing the ratio of net profit to average shareholder equity. The calculation formula is: Return on Equity = Net Profit/Average Shareholders' Equity × 100%. The return on equity reflects a company's ability to use its own capital to generate profits. A higher return on equity usually means that a company has strong profitability and efficient use of funds, which can bring more returns to shareholders. Therefore, it is an important basis for investors to judge whether a company is worth investing in.

5.1. The Impact of the First and Second Equity Incentives on Investment Behavior

The first equity incentive was implemented in 2014, during which the investment return significantly increased, bringing certain economic benefits to the enterprise and resulting in a rapid increase in the return on equity. This indicates that the investment returns are increasing, and the total profit is also increasing. The second equity incentive was in 2015. Although there was a significant increase in investment returns, there was a clear downward trend in the return on equity. The economic benefits brought by investment did not show a clear upward trend, and there may still be a risk of decline. Please refer to Figure 2 for details. This to some extent reflects that the incentive system implemented by M listed company has not kept up with the times, and has not summarized the incentive system within a certain period of time. It has not made timely adjustments to possible problems. In other words, the incentive system implemented in this process is only a waste of effort and has not brought certain economic benefits to the enterprise. This is because the management of enterprises pursues short-term returns and chooses investment projects that quickly achieve equity goals, often ignoring the benefits of long-term investment projects. In addition, the scope of incentive targets is too small, leading to the departure of core and middle-level personnel. This is the result of prioritizing short-term gains and a narrow range of incentives. Therefore, enterprises can leverage the good momentum of development to mobilize more outstanding internal employees to participate in enterprise co construction, co creation, sharing, and sharing, and integrate the advantages of upstream and downstream parties to build their own industrial chain, in order to occupy a larger market share in industry segments. Another reason is that the performance indicators are too loose and the exercise conditions are not very strict. Equity incentives are designed to create appropriate conditions for a company to conduct business activities. When these conditions are met, shareholders, managers, and core technical personnel can benefit from them. However, this incentive is mainly aimed at employees who have made contributions to the production and operation management of the company and have outstanding performance. Performance is closely related to the application of equity incentives in listed companies, and only when the company meets performance requirements, shareholders and relevant managers of the enterprise have the right to receive compensation. Therefore, the profitability of existing incentive plans depends on whether the incentivized individuals have the ability to meet the conditions for exercising their rights.

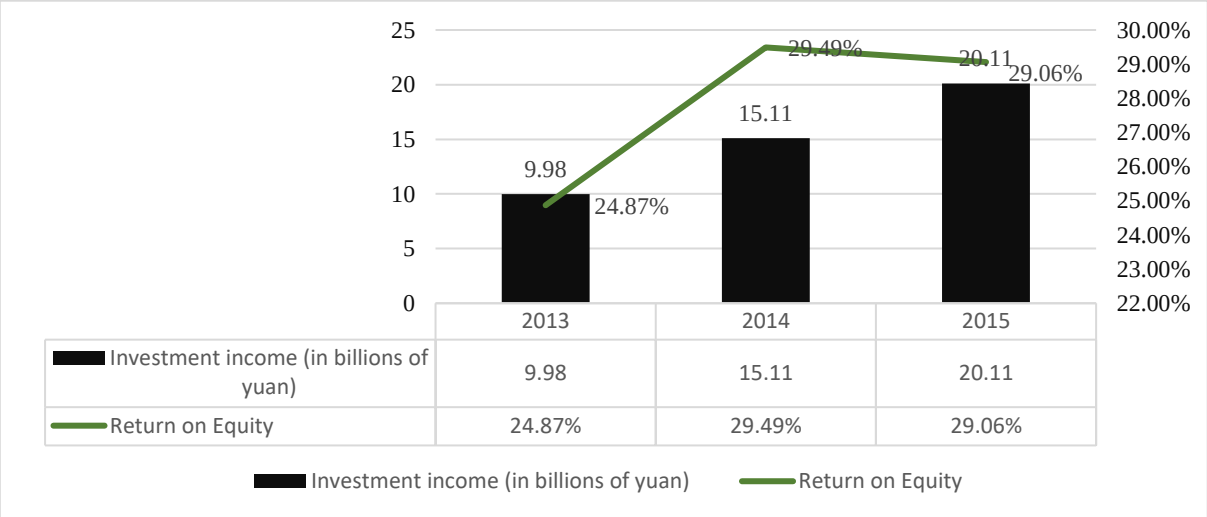

Figure 2. Changes in investment returns of the first and second equity incentives.

5.2. The Impact of the Third and Fourth Equity Incentives on Investment Behavior

From the previous table, it can be seen that from the first to the fourth equity incentives, except for the significant increase in investment returns and net asset returns from the first equity incentive, there was a clear downward trend from the second to the fourth, and then a stable downward trend. Please refer to Figure 3 for details. This indicates that the equity incentive is not suitable for the current M listed company and leads to inefficient investment of equity incentives. However, what is relatively good is that there was a significant rebound in investment returns in 2017, and the equity incentive system was adjusted and achieved good investment returns.

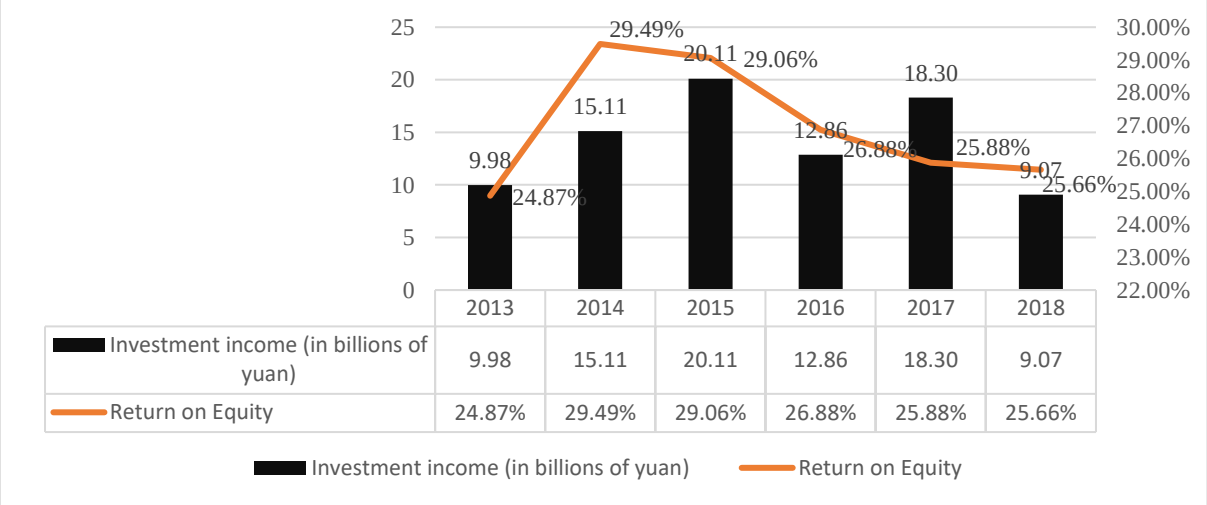

Figure 3. Changes in investment returns of the third and fourth equity incentives.

5.3. The Impact of the Fifth Equity Incentive on Investment Behavior

From the previous table, it can be seen that the fifth equity incentive in 2018 did not achieve much success, and the investment return significantly decreased, indicating that the company did not make significant investments that year, but still engaged in investment behavior and ensured the stability of the return on net assets. Compared with the significant decline and rise in previous times, the equity incentive this time has achieved a relatively stable equity incentive method, and has also correctly guided the contradictions between shareholders and managers of the enterprise. In the long-term persistence, results have also been seen. After improving the plan and making reasonable investments, the maximization of benefits can be achieved.

6. Optimization Suggestions for Equity Incentives of M Listed Company

6.1. Optimizing the Model of Equity Incentives

Companies should choose incentive methods that are suitable for their own development based on their own development status. There is no unified incentive model that can be applied to all companies, as there are differences in the actual situation of enterprises. For example, high-tech enterprises with limited financial strength in the early stages of establishment are suitable for using equity incentives to attract talent. Moreover, the effects that incentive models can produce can vary greatly, and the performance of the same incentive model can also differ at different stages of development in the same enterprise. At the same time, regular tracking of the company's financial data, attention to the effectiveness of equity incentives, and timely adjustments and corrections can effectively increase effective investment. In addition to using common restricted stocks and stock options, it is also necessary to continuously enrich their execution methods, adopt more diverse incentive methods, enhance their effectiveness, and maximize their utility. If the enterprise has a large scale, good reputation, a certain leadership role in the industry, and accurate performance forecasts with relatively small fluctuations, it is more suitable to use stock options; In contrast, companies with small scale, fast development speed, and good growth potential are more suitable for the form of restricted stocks. Finally, it should be recognized that equity incentives are not omnipotent. The value of shares granted to managers through equity incentives depends on the overall economic environment and industry prospects. Therefore, incentives for managers cannot rely solely on equity incentives.

6.2. Accurately Identify the Object of Motivation

In equity incentive plans, the incentive targets are the core, including the core personnel and key technical personnel of the enterprise. The size of a position does not necessarily indicate an individual's talent, therefore, companies should focus on key talents, not just management personnel. Through equity incentive schemes, incentivized personnel can become more diligent and responsible in their work, carefully consider various investment decisions, thereby reducing overinvestment in the enterprise. At the same time, it can ensure that the enterprise's business objectives are achieved and receive corresponding rewards. Like M listed company, through multiple incentive plans, it has established an equity structure where the interests of the management and all shareholders are aligned. The incentive targets not only include core executives such as the president and vice president, unit or department heads, but also important professional business backbones. From the functional distribution of incentive targets, it can be seen that R&D personnel have always accounted for a relatively large proportion, followed by manufacturing and quality personnel, while the proportion of marketing and information technology personnel is on a downward trend and is no longer disclosed separately. This is in line with the strategic transformation theme of "product leadership, efficiency driven, and global operation" officially implemented by M listed company throughout the group since 2012, promoting the company's transformation from marketing driven to innovation driven. After gradually addressing stability and reliability, technological leadership has become a new goal for M listed company.

6.3. Develop Appropriate Performance Indicators

Performance indicators reflect the effectiveness of equity incentives for employees. If the indicator is set too high, it will dampen the motivation of the incentive object and cause negative effects; If it is too low, it will squeeze the development space of the enterprise. Therefore, the formulation of performance indicators should be based on the actual development situation of the enterprise and linked to its future development strategy, paying more attention to the true value of the enterprise. Set dual assessment indicators for both individuals and enterprises, fully considering possible agency problems. Employees not only need to work hard to meet individual performance evaluations, but also need to constantly pay attention to how to help the enterprise improve profitability during the business process, motivate employees to continuously realize human capital value, and increase efficiency for the enterprise. In addition, performance indicators should also avoid a single form as much as possible. Enterprises can broaden the selection range of indicators other than finance, such as

non-financial indicators, dynamic indicators, and static indicators combined. For example, in the executive equity incentive schemes implemented by listed companies in China, most performance indicators are based on accounting performance or market performance, which cannot control the impact of other uncontrollable factors on company performance. Therefore, for the performance goals of managers, we should not only focus on their absolute performance, but also objectively evaluate the relationship between the level of responsibility of executives and company performance. For M listed company, the assessment of core executives is based on the overall return on equity; The indicators for middle and senior management are the same as those for ordinary employees, which assess the net profit of the group and also include assessments for the unit and individuals. In addition, performance indicators should not place too much emphasis on short-term benefits, and a long-term performance evaluation system should be developed.

6.4. Extended Effect of Continuous Equity Incentives

In the case of a relatively short term for equity incentives, different employees have varying degrees of control over whether various aspects of the enterprise can meet the assessment standards. Correspondingly, employees are more likely to use short-term operations to improve various aspects of the enterprise in order to achieve the assessment indicators. This obviously goes against the long-term goal of the enterprise and violates the original intention of implementing equity incentives to help the enterprise achieve sustainable development. Continuously implementing equity incentives is not only a confidence in the company's own strength, but also demonstrates a firm determination for future development. By providing continuous equity incentives to employees, companies can maintain team stability for a long period of time while continuing to attract and cultivate outstanding talents. By extending the period for employees to receive benefits and continuously expanding the coverage of incentives, we can better mobilize employees' work enthusiasm, improve the efficiency of value creation, and enable them to realize their own value while meeting their material needs. Enterprises can improve new incentive plans in a timely manner based on the actual situation in the early stage, so that the performance of the enterprise can maintain long-term stable growth.

7. Conclusions, Limitations, and Implications for the Industry

Although the equity incentives offered by M listed company did not result in a significant increase in its investment volume, it was able to fulfill the planned exercise conditions each time. Long term exercise resulted in a stable development of future returns. Under the incentive mechanism of equity incentives, the interests of shareholders, management personnel, and core employees of M listed company are well tied together. Therefore, all departments, whether shareholders or employees, must always consider the future development and long-term interests of the enterprise when making decisions, thereby improving their loyalty, enthusiasm, and sense of responsibility to the enterprise through equity incentives. Therefore, when choosing and formulating equity incentive plans, enterprises should choose an incentive mechanism that is suitable for themselves, which will be more conducive to improving the investment efficiency and core competitiveness of the enterprise.

This study selected M listed company in the home appliance industry as a research case to analyze the impact of its five implementation of equity incentives on investment behavior. Although M listed company is a representative enterprise in China's home appliance industry, this study still has some limitations. The first limitation is that the research object is only focused on M listed company, and although its equity incentive experience has certain reference value for other enterprises, it must be analyzed specifically in conjunction with the company's own situation. The second limitation is that there are various ways of equity incentives, and the effects of incentives are also different. However, this study did not explore the impact of equity incentive methods on investment. The third limitation is that this study did not adopt a qualitative research approach. Qualitative research may make the study more in-depth and provide more specific answers to the questions of "what" and "why". It is hoped that future scholars can make up for this limitation.

Despite the limitations mentioned above, the conclusions of this study can still provide reference and guidance for companies in the industry when designing and implementing equity incentive mechanisms.

First, adopt various methods to improve the equity incentive plan. Enterprises should improve and

standardize their equity incentive plans based on their actual situation, in order to maximize the role of equity incentives and guide managers and employees to make more effective and efficient investments [11,13,19–21]. When designing equity incentive plans, enterprises need to consider multiple factors and flexibly develop plans based on the abilities, experience, and years of experience of managers and employees, and innovate equity incentive measures in a timely manner. In addition, the market situation is unpredictable, and enterprises should not only consider the actual internal situation, but also pay timely attention to changes in the external environment [22]. At present, the main methods of equity incentives include restricted stocks and equity options, which have certain differences. Enterprises should choose the appropriate incentive method according to their own situation [23]. If the enterprise is large in scale, has a high reputation, is in a leading position in the industry, and has accurate and less volatile performance forecasts, then choosing equity options as an incentive method is relatively more suitable. If the scale of the enterprise is small and the development speed is fast, the incentive method of choosing restricted stocks is relatively more suitable [24]. In addition to using common restricted stocks, equity options, and other equity incentives, it is also necessary to continuously enrich the practical measures of equity incentives, adopt diversified incentive combinations, and maximize the effectiveness of equity incentives [13]. Attention should also be paid to the details of equity incentive exercise. Based on the continuous implementation of the plan, taking into account the characteristics of the development stage and objective influencing factors such as policy changes, appropriate adjustments can be made to the specific implementation to avoid the situation where “incentives” become “benefits”, so that the management level of the enterprise can be truly reflected, and equity incentives can truly promote the development of the enterprise. Enterprises in different industries have different characteristics. When designing equity incentives, it is necessary to consider industry characteristics and avoid blindly copying them [25–27].

Second, more consideration should be given to the value of the enterprise in designing performance evaluations. Performance indicators reflect the effectiveness of equity incentives for employees. If the indicator is set too high, it will dampen the motivation of the incentive object and cause negative effects; If it is too low, it will squeeze the development space of the enterprise [28]. Therefore, the formulation of performance indicators should be based on the actual development situation of the enterprise and linked to its future development strategy, paying more attention to the true value of the enterprise [29]. Performance evaluation indicators need to consider both financial and non-financial indicators. In terms of financial indicators, net profit, operating income, price to earnings ratio, price to book ratio, etc. can be considered; Non financial indicators can help narrow the space for executives to manipulate equity incentive plans, and also enable executives to have a long-term vision, thereby promoting the stable development of the enterprise in the future. At the same time, performance evaluation indicators should not only emphasize short-term benefits, but also establish long-term performance evaluation indicators to improve employees’ short-sighted behavior, enhance investment effectiveness and efficiency, promote sustainable development of enterprises, and improve long-term performance of enterprises [30]. In addition, according to statistics, the performance conditions in the senior management equity incentive plans currently implemented by listed companies in China are mostly based on accounting performance or market performance, which may not be able to control the impact of other uncontrollable factors on the company’s performance. Therefore, performance indicators should not be solely based on absolute performance as the sole criterion, but should objectively evaluate the relationship between the level of responsibility of senior managers and corporate performance [31].

Third, strengthen the supervision within and outside the enterprise. Existing research has shown that some corporate managers may use their authority to intervene in the content of executive stock incentives, designing executive stock incentive plans in a direction that is beneficial to themselves, such as changing the exercise or unlocking conditions in the incentive plan and intervening in the rules for granting shares [10,32]. This behavior greatly reduces the effectiveness of executive equity incentives, goes against the original intention of executive equity incentives, and has a negative impact on the growth and development of the enterprise. Although giving senior managers the ability to link their interests with the collective interests of shareholders and the company, as their shareholding ratio increases, senior managers also have greater power to control the development of the company and seek personal benefits. Therefore, enterprises need to establish active and effective internal and

external supervision mechanisms, regularly track financial data, pay attention to the effectiveness of equity incentive system implementation at any time, adjust and correct problems in a timely manner, and truly expand effective investment. Only through the mutual efforts of internal and external supervision mechanisms can the self-interest behavior of the ultimate controller and senior managers be effectively constrained. How to strengthen internal and external supervision? Internally, it is necessary to maintain the independence of the supervisory board and the board of directors, especially independent directors, clarify the division of their respective powers, strengthen comprehensive tracking and management of the entire investment activity cycle, and eliminate loopholes such as embezzlement. At the same time, establish audit standards to prevent the abuse of executive equity incentive projects, conduct reasonable evaluations of executive equity incentives, comply with laws, regulations, and procedures, ensure that shareholder interests are not harmed, and guard against managers' behavior of damaging corporate value due to their own interests [4]; Externally, relevant regulatory departments should improve the information disclosure system, formulate strict supervision policies, and increase supervision efforts. The report issued by certified public accountants can theoretically have a certain restraining effect on inefficient investment of enterprises in order to increase their attention. As one of the external supervisory agencies, accounting firms should pay attention to their own independence construction, create fair and impartial information communication channels, which can provide decision support for investors and strive for more investment opportunities for truly valuable enterprises [3,33–36].

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The data that support the findings of this study are available from the first author upon reasonable request.

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Conflicts of Interest

The authors report there are no competing interests to declare.

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Article

Agricultural Product Price Prediction Based on the Quadratic Decomposition of CEEMDAN-VMD

Yuchun Jiang [1,*], Qixiang Miao [2] and Man Tang [3]

[1] *Guizhou University of Finance and Economics, Guiyang 550025, China*

[2] *Qingdao City University, Qingdao 266106, China*

[3] *Guizhou University of Finance and Economics, Guiyang 550025, China*

Abstract: Focusing on agricultural futures price forecasting, a prediction method based on quadratic decomposition is proposed in this paper in response to the non-stationarity, unstructured nature, and nonlinearity of agricultural price-time series data. Then drawing on the successes of deep learning in other financial domains, the quadratic decomposition of CEEMDAN-VMD that effectively addresses the non-stationarity of agricultural price-time series is introduced. And by constructing the CEEMDAN-SE-VMD-LSTM model, the paper performs an in-depth decomposition and refined processing of daily agricultural price data, successfully capturing the subtle characteristics of price fluctuations to achieve higher precision in forecasting. Moreover, the results indicates that the CEEMDAN-VMD model outperforms the comparative models in terms of forecasting accuracy for the three types of agricultural commodities.

Keywords: agricultural futures prices; financial time series prediction; quadratic decomposition; LSTM

1. Introduction

In recent years, the global climate system has shown increasing instability, with frequent extreme weather events becoming significant factors affecting agricultural production and market prices of agricultural products. Particularly during the cyclical transitions between La Niña and El Niño, plenty of regions have experienced unprecedented rapid reversals of drought and flood disasters, posing a severe challenge to global agricultural production. Besides, geopolitical conflicts, especially the Russia-Ukraine conflict, have had profound impacts on the global agricultural market. As a key grain-producing region, Ukraine's disrupted production has led to a tight international grain supply. Concurrently, the conflict has driven up the prices of agricultural inputs, increased production costs, and disrupted supply chain stability, collectively pushing up the prices of agricultural products. Therefore, agricultural product price forecasting is crucial for agricultural production and market stability. Accurate forecasting can help farmers plan their planting structures and sales strategies rationally, avoiding resource wastage due to blind production or market supply and demand imbalances. Moreover, accurate forecasting can provide a scientific basis for the government to formulate agricultural policies and regulate the market, which is beneficial for ensuring farmers' profits and consumers' rights. Additionally, agricultural product price forecasting can also promote collaborative development along the agricultural industry chain and enhance the overall efficiency of agriculture. Therefore, performing researches on agricultural product

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* Corresponding: Yuchun Jiang (1269266425@qq.com)

price forecasting and improving the accuracy and timeliness of forecasts is of great significance for promoting sustainable agricultural development and ensuring national food security.

In the traditional field of time series forecasting, such as ARIMA and VAR, the construction of these classic models often relies on the assumption of linear transformation of data. However, due to the inherent nonlinearity, non-stationarity, and multi-periodicity of agricultural product price-time series data, these traditional models struggle to capture their complex changes, leading to limited prediction accuracy and difficulty in comprehensively addressing the challenges of non-stationary and nonlinear forecasting.

With the emergency of machine learning and deep learning technologies, especially when they are combined with signal decomposition technology, new perspectives and effective pathways have been provided to address the aforementioned issues. Huang's proposed Empirical Mode Decomposition (EMD) method has opened up new horizons for signal and time series analysis [1]. However, subsequent research has found that EMD suffers from the problem of modal aliasing, affecting the decomposition effect. To overcome this deficiency, Huang and Wu developed the Ensemble Empirical Mode Decomposition (EEMD) algorithm, significantly improving the phenomenon of modal aliasing. Furthermore, the Complementary Envelope Empirical Mode Decomposition (CEEMD) proposed by Yeh et al., optimized the reconstruction error and decomposition completeness of EEMD [2]. Meanwhile, the Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) proposed by Torres further reduces the residual noise in the intrinsic mode functions and reconstruction error, enhancing the precision and stability of the decomposition [3]. In addition, the Variational Mode Decomposition (VMD) method proposed by Dragomiretskiy, as an adaptive and non-recursive nonlinear decomposition technique, can efficiently separate white noise in time series, achieving effective noise reduction of the signal [4].

Numerous scholars have combined the aforementioned decomposition techniques with deep learning models, achieving prominent improvements in forecasting accuracy across various domains. For instance, Ling et al. conducted comparative studies on Chinese pork price data using multiple decomposition methods, validating the superiority of the decomposition framework in enhancing prediction accuracy [5]. And Yang et al. delved into the differences in the interconnectivity between China's agricultural futures market and other financial markets at various time scales based on the EEMD method [6]. Concurrently, several researchers have further enhanced predictive performance by integrating decomposition techniques such as CEEMD and VMD with deep learning models like LSTM and Support Vector Regression (SVR) [7,8].

The proposal and application of quadratic decomposition have brought new breakthroughs in time series forecasting. This approach, by combining different decomposition algorithms, significantly reduces the non-stationarity and complexity of time series to a greater extent. Niu and Ji proposed a decomposition method based on Seasonal-Trend Decomposition using Loess (STL) and Variational Mode Decomposition (VMD), combined with the Support Vector Regression of Grey Wolf Optimizer (GWO-SVR), to achieve accurate forecasting of electricity demand [9]. This method captures the seasonal and trend components of the time series through STL, and further decomposes the remaining part through VMD, thereby revealing the intrinsic characteristics of the time series more finely. Liu and Mi proposed that they constructed a hybrid model combining VMD, Singular Spectrum Analysis (SSA), Long Short-Term Memory (LSTM) neural network, and Extreme Learning Machine (ELM) for wind speed prediction [10], which first uses VMD and SSA for a two-stage decomposition of the wind speed time series, then uses LSTM and ELM to predict the decomposed components separately, and finally combines the predicted results. Experimental results show that the accuracy of this hybrid model, which combines two decomposition algorithms, is significantly higher than that of hybrid models combining only one decomposition algorithm, further validating the effectiveness of the two-stage decomposition process in improving prediction accuracy. The further promotion of quadratic decomposition and deep learning algorithms, Cheng et al. combined VMD and EEMD, significantly improving the predictive ability through secondary processing of the participating components. Yan and Mu applied the quadratic decomposition technology of CEEMDAN and VMD to accurately predict the ultra-high frequency financial time series of iron ore futures [11]. Zhang, Zhu, and Fan et al. applied quadratic decomposition technology to the prediction of carbon emission trading prices, air quality, outpatient flow, and other fields, all of which

verified the advantages of the integration of quadratic decomposition and deep learning models in forecasting [12–14].

In summary, the combination of quadratic decomposition technique with deep learning models has demonstrated exceptional predictive capabilities across various domains, providing new perspectives and methodologies for the prediction of agricultural product prices. This approach is expected to play an increasingly vital role in the field of agricultural product price forecasting. Based on the aforementioned literatures, this paper proposes a quadratic decomposition method using CEEMDAN, SE, and VMD, which decomposes the price-time series of three agricultural products—soybeans, corn, and cotton—into a series of Intrinsic Mode Functions (IMFs) to sufficiently reduce the non-stationarity of agricultural product time series while avoiding the loss of valuable information. Subsequently, a prediction model is constructed using the Long Short-Term Memory (LSTM) neural network, and its effectiveness is verified through fitting and validation to assess the predictive performance.

The innovation of this paper lies not only in the initial application of quadratic decomposition technique to the prediction of agricultural futures prices, but also in the integration of quadratic decomposition with deep learning, which brings a completely new perspective and superior predictive capabilities to the field of agricultural price forecasting. Through the decomposition of time series data two or more times, the introduction of quadratic decomposition technique in agricultural futures price prediction allows for a deeper exploration of hidden patterns and trends within the data. Compared to traditional single-level decomposition, this multi-level and multi-resolution decomposition method can more accurately capture subtle price changes and long-term trends, thereby enhancing the accuracy and stability of forecasts. This paper also empirically validates the effectiveness of quadratic decomposition technique in the prediction of agricultural futures prices. By comparing and analyzing with other forecasting methods (such as single decomposition models, traditional time series models, etc.), the paper demonstrates the advantages of quadratic decomposition technique in terms of forecasting accuracy, stability, and robustness, thereby strengthening the persuasiveness of the conclusions.

2. Materials and Methods

2.1. Data Sources

This paper utilizes data from 1 July 2014 to 1 July 2024, for the futures prices of soybeans, corn, and cotton in China, among which the soybean and corn prices are based on the daily closing data from the Dalian Commodity Exchange, while the cotton prices are derived from the daily data of the Zhengzhou Commodity Exchange. And the data was downloaded and processed using the Tushare data platform through Python for the main continuous contract data. The price trends for soybeans, corn, and cotton are depicted in Figure 1.

This paper employs Python to perform CEEMDAN decomposition on the raw data, clusters and integrates the Intrinsic Mode Functions (IMFs) based on entropy values, categorizing them into high-frequency, mid-frequency, and low-frequency sequences. Then high-frequency data undergoes a secondary VMD decomposition, with the matrix input into the LSTM forecasting model, while the mid-frequency and low-frequency sequences are vectorially input into the forecasting model to obtain the final prediction results. The results indicate that the quadratic decomposition model outperforms other comparative models in terms of agricultural product price forecasting performance.

2.2. Framework of the Proposed Model

The framework for agricultural futures price forecasting using the CEEMDAN-SE-VMD-LSTM model encompasses four main components: data preprocessing and decomposition, sample entropy calculation and clustering integration, high-frequency as well as mid-low frequency sequence forecasting, and model evaluation. The model framework is depicted in Figure 2.

The specific steps for forecasting are as follows:

Step 1: Data Preprocessing and Decomposition

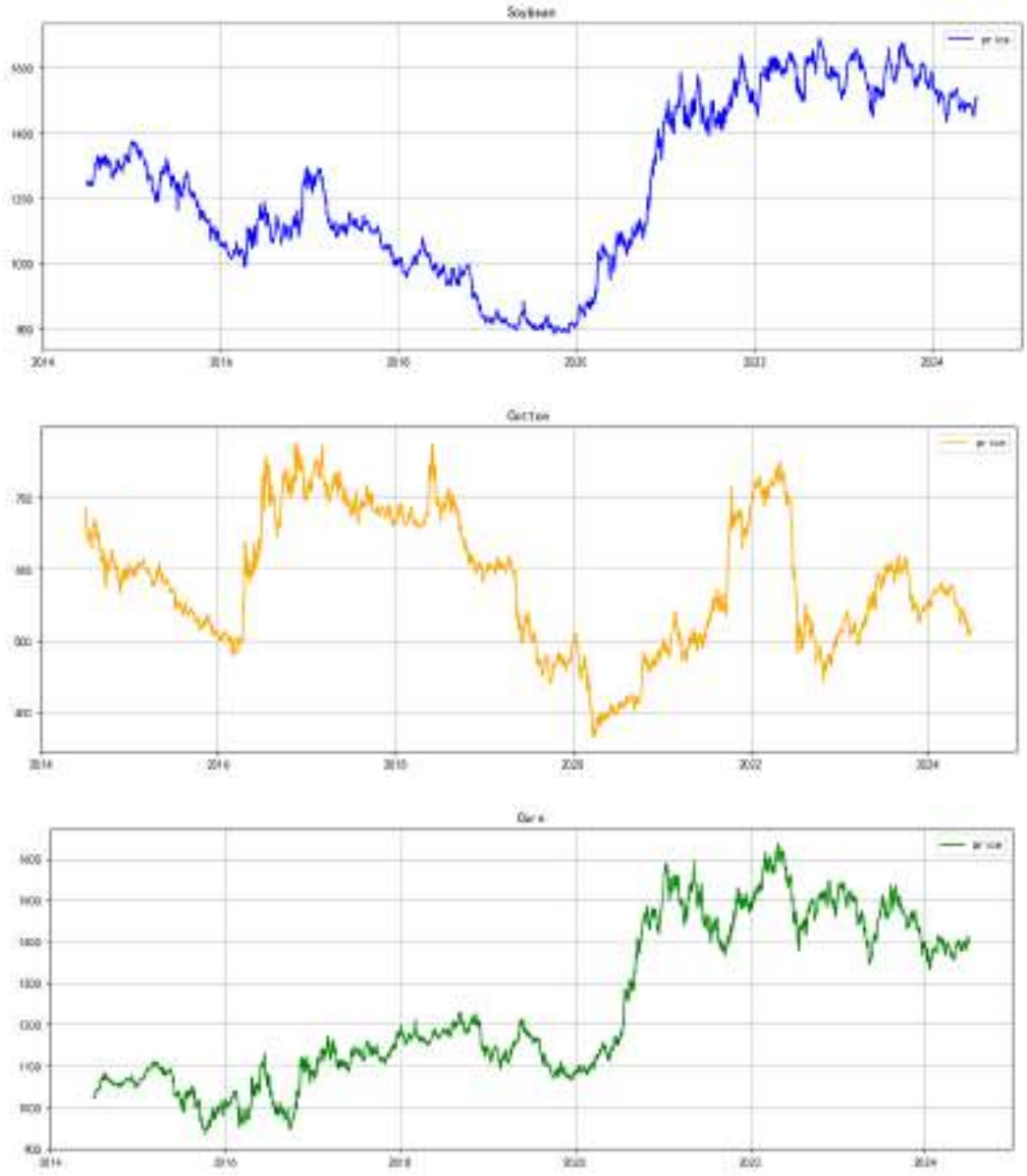

Figure 1. China's soybean, corn, and cotton futures price trends from 2014–2024.

The agricultural futures price data is subjected to CEEMDAN (Complete Ensemble Empirical Mode Decomposition with Adaptive Noise) to obtain a series of Intrinsic Mode Functions (IMFs).

Step 2: Sample Entropy Calculation and Clustering Integration

The sample entropy of the aforementioned IMF components is calculated, and clustering integration is performed based on the entropy values. Then the IMF components are categorized into high-frequency data Co-IMF0, mid-frequency sequence Co-IMF1, and low-frequency sequence Co-IMF2.

Step 3: High-frequency Sequence Processing and Forecasting

High-frequency data Co-IMF0 is subjected to Variational Mode Decomposition (VMD) to further decompose its frequency components. The VMD decomposition results are then input into the LSTM forecasting model, yielding evaluation metrics.

Step 4: Mid and Low-frequency Sequence Processing and Forecasting

The LSTM model is applied to forecast the decomposed low-frequency sequences. Vectors of Co-IMF1 and Co-IMF2 are input into the LSTM for forecasting, resulting in predicted outcomes and evaluation metrics. The experimental workflow is shown in Figure 2.

Step 5: Model Results

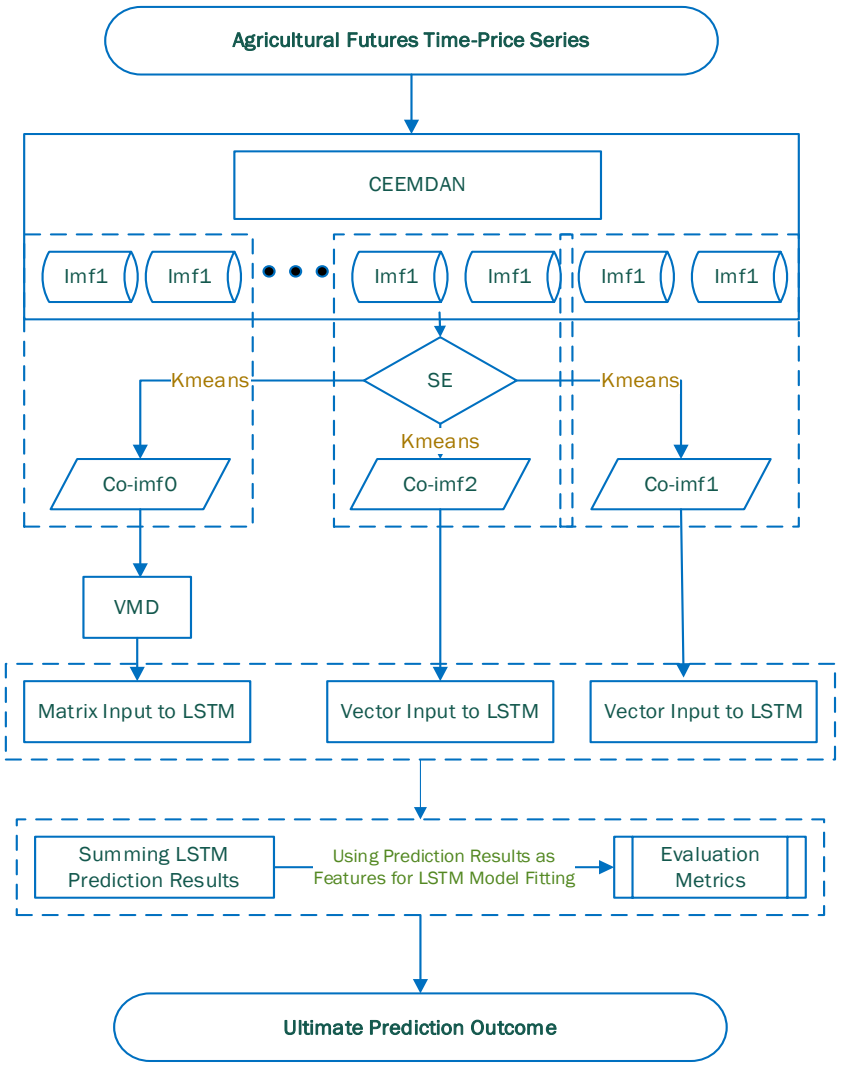

Figure 2. Framework of the proposed model.

The performance of the CEEMDAN-SE-VMD-LSTM model is evaluated by calculating the Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and R-squared (R^2).

2.3. Decomposition Algorithm

2.3.1. CEEMDAN

The CEEMDAN algorithm is an improved version of the EMD. CEEMDAN enhances the EMD decomposition by introducing adaptive noise and ensemble averaging technique, addressing issues such as modal aliasing, endpoint effects, and decomposition instability. EMD serves as the foundation for signal time-frequency analysis, capable of decomposing signals without presetting basis functions. Through iteration, EMD strips the signal into multiple Intrinsic Mode Functions (IMFs) and a residual term. Then the IMFs capture local characteristics at different time scales, simplifying the signal structure and providing a solid foundation for subsequent processing. The related steps are as follows:

Step 1: The original signal $X(t)$ is traversed to identify all the extrema, which are typically the local maximum and minimum values of the signal. Subsequently, cubic spline interpolation is used to connect the maxima and minima, forming two smooth curves. The maxima are connected to form the upper envelope curve, denoted as $X_{max}(t)$; the minima are connected to form the lower envelope curve, denoted as $X_{min}(t)$.

Step 2: Interpolation calculation. For each time point 't', calculate the values of the upper envelope curve $X_{max}(t)$ and the lower envelope curve $X_{min}(t)$ at time 't'. Compute the average of the upper and lower envelope values $X_{avr}(t)$:

$$X_{avr}(t) = \frac{X_{max}(t) + X_{min}(t)}{2} \quad (1)$$

Step 3: The component obtained from the i decomposition is denoted as $m_i(t)$ and the component obtained from the first decomposition is represented as $m_1(t)$, which is the difference between the original function $X(t)$ and the average of the upper and lower envelope curves $X_{avr}(t)$.

$$m_1(t) = X(t) - X_{avr}(t)$$

Step 4: Assess the IMF conditions. Analyze $m_1(t)$ based on two conditions for an IMF: (a) the number of extrema and the number of zero crossings must be equal or differ by at most one over the entire dataset, and (b) at any point in time, the mean value of the upper and lower envelopes defined by the local maxima and minima must be zero. If these conditions are met, designate $m_1(t)$ = IMF_1 and end the current iteration. If the conditions are not met, repeat steps 1 to 3 for $m_1(t)$, i.e., find the upper $m_{1max}(t)$ and lower envelopes $m_{1min}(t)$ and calculate the new difference $m_{11}(t)$.

$$m_{1avr}(t) = \frac{m_{1max}(t) - m_{1min}(t)}{2} \quad (2)$$
$$m_{11}(t) = m_1(t) - m_{1avr}(t)$$

Step 5: Repeat the aforementioned steps and continue iterating until the obtained component meets the conditions for an Intrinsic Mode Function (IMF). Let the number of repetitions be denoted as 'k'; then the difference after the $m_{1k}(t)$ repetition is the first IMF, denoted as $imf_1(t)$. IMF_1 represents the IMF with the highest frequency in the decomposition of the original data. Subsequently, subtract $imf_1(t)$ from the original signal sequence $X(t)$.

$$m_2(t) = X(t) - imf_1(t) \quad (3)$$

Repeat the process of $m_2(t)$ to extract the next IMF, continuing until the remaining signal $m_n(t)$ becomes a monotonic function or no more IMFs can be decomposed.

Step 6: When the n_{th} decomposition is reached, a residual component $res(t)$ with special properties is left behind. This residual component exhibits a monotonically increasing or decreasing characteristic, essentially capturing and reflecting the overall trend of the original data sequence. The final decomposition formula of EMD is as follows:

$$X(t) = imf_1(t) + imf_2(t) + \ldots + imf_n(t) + res(t) \quad (4)$$
$$= \sum_{i=1}^{N} imf_i(t) + res(t), i = 1, 2, \ldots, N$$

CEEMDAN is an improved algorithm of EMD decomposition, which aims to address issues such as modal aliasing, endpoint effects, and instability in decomposition that exist in EMD by introducing adaptive noise and ensemble averaging technique. Through multiple iterations, CEEMDAN gradually extracts the Intrinsic Mode Functions (IMFs) of the signal, ultimately obtaining a set of stable and meaningful decomposition results.

The CEEMDAN decomposition performs EMD on the original signal to obtain the first Intrinsic Mode Function (IMF) component. In each iteration, adaptive noise is added to the remaining signal, followed by EMD decomposition. The newly decomposed IMF components are combined with the results from the previous iteration. The number of iterations is determined based on preset stopping criteria. Then an overall average of all IMF components obtained from the iterations is performed to eliminate the noise impact. The related steps are as follows:

Step 1: Add white noise and perform preliminary decomposition. Randomly generated Gaussian white noise is added to the original data *X(t)*, resulting in *M* noisy datasets:

$$X_j(t) = X(t) + \varepsilon_1 E_1\left(\omega_j(t)\right), j = 1, 2, \ldots, M \quad (5)$$

In the process, *X(t)* represents the original data sequence, $\varepsilon_i \omega_j(t) (i = 1, 2, \ldots, \mathrm{N}; j = 1, 2, \ldots, \mathrm{M})$ denotes the Gaussian white noise, which follows a normal distribution. The term ε_i indicates the weight coefficient of the Gaussian white noise, i is the current processing iteration. $\omega_j(t)$ represents the Gaussian white noise added, j is the number of times white noise has been added, M is the maximum number of noise processing iterations. $E(\sim)$ stands for the Empirical Mode Decomposition process.

Step 2: Perform EMD decomposition on these M noisy datasets, and extract the first Intrinsic Mode Function (IMF) from each sequence, denoted as imf_1^j.

$$imf_1(t) = \frac{1}{M}\sum_{j=1}^{M} imf_1^j(t), j = 1, 2, \ldots, M \tag{6}$$

Step 3: Calculate the difference between the original data and the first IMF to obtain the residual $r_1(t)$ after the first decomposition:

$$r_1(t) = X(t) - imf_1(t) \tag{7}$$

Repeat the process of adding white noise and performing EMD decomposition on the residual $r_1(t)$ to obtain the second IMF sequence $imf_2(t)$:

$$imf_2(t) = \frac{1}{M}\sum_{j=1}^{M} E_2\left(r_1(t) + \varepsilon_2 E_2\left(\omega_j(t)\right)\right), j = 1, 2, \ldots, M \tag{8}$$

Step 4: Proceeding in this manner, iterate through the calculations to obtain subsequent IMF sequences $imf_i(t)$ and residuals $r_i(t)$ (I = 1, 2, ⋯, N):

$$imf_i(t) = \frac{1}{M}\sum_{j=1}^{M} E_i\left(r_{i-1}(t) + \varepsilon_i E_i\left(\omega_j(t)\right)\right), j = 1, 2, \ldots, M \tag{9}$$

$$r_i(t) = r_{i-1}(t) - imf_i(t) \tag{10}$$

Step 5: when $i = N$, end iteration. When the final residual $r_N(t) = res(t)$ is obtained, the original data *X(t)* can be expressed as the sum of all IMF components and the trend item:

$$X(t) = \sum_{i=1}^{N} imf_i(t) + res(t), i = 1, 2, \ldots, N \tag{11}$$

CEEMDAN decomposition enhances the adaptability of the decomposition process by introducing adaptive noise and iterative updating, effectively suppressing modal aliasing and improving decomposition accuracy. Compared to EEMD, it reduces unnecessary decomposition iterations, thereby increasing computational efficiency.

2.3.2. VMD

VMD employs the Alternating Direction Method of Multipliers (ADMM), an efficient optimization algorithm, to solve the constructed variational problem. Through continuous iterative optimization, it gradually approaches the optimal solution, thereby accurately extracting the central frequency and bandwidth of each modal function, achieving effective decomposition of the signal. The steps are as follows:

Step 1: Initialize the parameters, $\{\hat{\mu}_k^1\}$, $\{\omega_k^1\}$, $\{\hat{\lambda}^1\}$, $(n \leftarrow 0)$

Step 2: Execute the loop, incrementing $n = n + 1$, and for all $\omega \geqslant 0$, ensure that:

$$\hat{\mu}_k^{n+1} = \frac{\hat{f}(\omega) - \sum_{ik}\hat{\mu}_k^{n+1}(\omega) - \sum_{ik}\hat{\mu}_k^n(\omega) + \frac{\hat{\lambda}^n(\omega)}{2}}{1 + 2\alpha\left(\omega - \omega_k^n\right)^2} \tag{12}$$

$$\omega_k^{n+1} = \frac{\int_0^\infty \omega\left|\hat{\mu}_k^{n+1}(\omega)\right|^2 dw}{\int_0^\infty \left|\hat{\mu}_k^{n+1}(\omega)\right|^2 dw} \tag{13}$$

Step 3: For all $\omega \geqslant 0$, ensure that condition (2)–(16) is met, where γ is the noise tolerance.

$$\hat{\lambda}^{n+1}(\omega) = \widehat{\lambda^n}(\omega) + \gamma\left[\hat{f}(\omega) - \sum_k \hat{\mu}_k^{n+1}(\omega)\right] \tag{14}$$

Step 4: Pre-set the judgment precision and repeat steps 2 and 3 until the constraint conditions are satisfied.

$$\frac{\sum_k \left\| \hat{\mu}_k^{n+1} - \hat{\mu}_k^n \right\|_2^2}{\left\| \hat{\mu}_k^n \right\|_2^2} \varepsilon \tag{15}$$

VMD employs an iterative process to dynamically update the central frequencies and bandwidths of the IMF components until the preset termination conditions are met. By adaptively dividing the frequency bands according to the spectral characteristics of the signal, VMD precisely extracts k IMF components, effectively avoiding modal aliasing and enhancing the precision of the decomposition.

2.4. Forecasting Algorithm: LSTM Neural Network

The LSTM network is utilized to process sequential data, leveraging its complex internal cell states and three gating mechanisms (forget gate, input gate, and output gate) to achieve selective transmission and memory control of information. The LSTM determines the retention of old information through the forget gate, adds new information through the input gate, and controls the output of information to the hidden state through the output gate. This effectively addresses the gradient problem associated with RNNs and is suitable for data prediction tasks involving long-term dependencies (As shown in Figure 3).

(1) The Forget Gate determines how much information from the previous cell state needs to be forgotten or retained. It receives the hidden state *h* from the previous moment and the input *x* from the current moment, and outputs a value between 0 and 1 through a sigmoid function $\sigma(x) = (1 + e^{-x})^{-1}$. A value of 0 indicates complete forgetting of information, while a value of 1 indicates complete retention of information. The sigmoid function's output value is multiplied by the cell state C_{t-1}, thereby deciding how much of the old information is retained.

(2) The Input Gate (Update Gate) determines how much new information should be added to the cell state at the current moment, operating in parallel with the Forget Gate. It also receives the previous hidden state h_{t-1} and the current input $X(t)$, and decides on an update proportion through a sigmoid function. Concurrently, another input transformation through the tanh function generates new candidate information, which is then multiplied by the output of the Input Gate to obtain the actual amount of new information to be added.

(3) Output Gate determines how much information from the current cell state should be output to the hidden state h_t. The output gate, based on the previous hidden state h_{t-1} and the current input $X(t)$, uses a sigmoid function to decide the output proportion. Concurrently, the cell state undergoes a nonlinear transformation through a tanh function, which is then multiplied by the output of the output gate to obtain the final hidden state output.

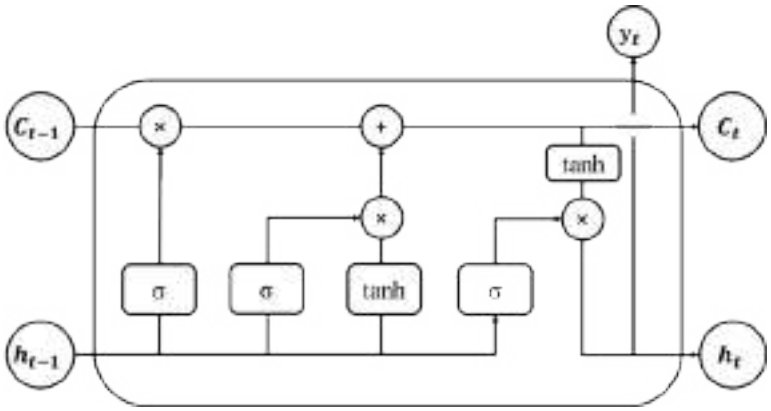

Figure 3. The Internal Structure of an LSTM Model Neuron.

2.5. Model Training and Algorithm Implementation

2.5.1. Model Parameter Configuration

The empirical study employs Python language to implement all algorithms (CEEMDAN, VMD, SE, and LSTM) in the VSCode compiler. The machine learning section utilizes Scikit-learn, which is a collection of high-quality machine learning algorithms featuring a variety of functionalities required throughout the entire machine learning process, from data preprocessing to model training, evaluation, and parameter tuning. The deep learning section employs Keras, a high-level neural networks API that is solidly built upon the TensorFlow backend, providing robust support for the rapid construction and training of deep learning models. Detailed development environment as shown in Table 1.

Table 1. Development Environment.

Component	Description
CPU	AMD Ryzen 7 7735H
RAM	16 GB
Operating System	Windows 11 64-bit
Programming Language	Python 3.11
IDE	Visual Studio Code (VSCode)
Libraries/Frameworks	PyEMD, sampen, vmdpy, Keras

In the CEEMDAN decomposition, the number of trials adding white noise is set to trials = 10, the number of clusters in the cluster analysis is num_clusters = 3, the sample entropy length is mm = 1, the similarity tolerance is r = 0.1, and the number of clusters for k-means is kmeans_num = 3, representing high, medium, and low frequencies, respectively. For the high-frequency sequence VMD, the bandwidth parameter is alpha = 2000, the noise tolerance parameter is tau = 0, the number of IMFs obtained from VMD decomposition is K = 10, and the convergence tolerance is tol = 1×10^{-7}.

The LSTM network comprises three layers, with each layer containing 128, 64, and 32 neurons, respectively. Except for the last layer, each LSTM layer returns the output for the entire sequence. All LSTM layers utilize the hyperbolic tangent (tanh) activation function, which outputs values between − 1 and 1. Following each LSTM layer, a Dropout layer is added with a dropout rate of 0.2 to prevent overfitting of the model. The Dense fully connected layer employs the tanh activation function. The initial learning rate of the model is set to 0.001, with adam as the optimizer, and Mean Squared Error (MSE) is used as the loss function.

To effectively prevent model overfitting, this study employs the EarlyStopping callback function mechanism. Within this mechanism, the patience value is meticulously set to one-tenth of the total number of training epochs, and then multiplied by 5 to establish the threshold for early stopping. If the validation loss does not show a significant decrease over 5 consecutive training epochs defined by the patience value, the training process will be prematurely terminated to avoid the model from becoming overly fitted to the training data.

Additionally, this study introduces the learning rate decay callback function to address the issue of the validation loss becoming stagnant. Unlike the patience value setting in early stopping, the learning rate decay section directly sets the patience value to one-tenth of the total number of training epochs. When the validation loss does not show improvement within one-tenth of the total number of epochs, the learning rate decay callback function will automatically trigger, reducing the learning rate by a preset proportion. This adjustment strategy helps the model break free from the constraints of potential local optima, thereby promoting further model optimization and exploring superior performance outcomes.

2.5.2. Assessment of Accuracy

The performance of the model is evaluated using four key metrics: the Root Mean Square Error (RMSE), the Mean Absolute Percentage Error (MAPE), the Mean Absolute Error (MAE), and the Coefficient of Determination (R^2). The smaller the values of RMSE, MAPE, and MAE, the better the fitting effect of the model. The R^2 reflects the goodness of fit of the model, with values closer to 1 indicating a better fit.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{y}_i - y_i\right)^2}{n}} \tag{16}$$

$$MAPE = \frac{100\%}{n}\sum_{i=1}^{n}\left|\frac{\hat{y}_i - y_i}{y_i}\right| \tag{17}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\hat{y}_i - y_i\right| \tag{18}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(\hat{y}_i - y_i\right)^2}{\sum_{i=1}^{n}\left(\bar{y}_i - y_i\right)^2} \tag{19}$$

In the context, y_i represents the true value of the sequence, $\hat{y}_i$ represents the predicted value of the sequence, $\bar{y}_i$ represents the mean of the sequence, and n represents the total number of forecasted data points.

3. Results

3.1. Descriptive Statistics of Agricultural Product Prices

It can be seen from the above Table 2 that the sample size for each of the three agricultural products is 2432. The maximum value of soybean futures prices is 1689.47, with a minimum value of 785.81, indicating a relatively large price fluctuation range. The maximum value of corn futures prices is 1653.80, but the minimum value is relatively higher at 934.56, with a smaller price fluctuation range compared to soybeans. The maximum value of cotton futures prices is 777.80, and the minimum value is 366.27, which has the smallest price fluctuation range among the three. The standard deviations for soybeans, corn, and cotton are 264.70, 191.01, and 93.94, respectively. The kurtosis values for all three agricultural products are less than 3, suggesting that their price distributions are flatter than the normal distribution, with fewer extreme values in the data. The skewness values for soybeans and cotton are close to 0, indicating that their price distributions are relatively symmetric. The skewness value for corn is 0.374, with a slight right skew, suggesting that there are relatively more high-value numbers in its price distribution.

Table 2. Statistical Characteristics of Agricultural Product Futures Prices.

	Sample Size	Maximum	Minimum	Standard Deviation	Kurtosis	Skewness
Soybeans	2432	1689.47	785.81	264.70	−1.26	−0.005
Corn	2432	1653.80	934.56	191.01	−1.37	0.374
Cotton	2432	777.80	366.27	93.94	−0.94	−0.015

3.2. Decomposition Results

Taking the soybean futures price data as an example, the original data was decomposed using the CEEMDAN method, employing the pyEMD package in Python for the decomposition. The time series decomposition of the soybean futures price yielded 8 Intrinsic Mode Functions (imf0–imf7) and 1 residual term (imf8), as shown in Figure 4. The CEEMDAN decomposition results indicate that no obvious mode mixing is present in the individual Intrinsic Mode Functions.

The high-frequency Intrinsic Mode Functions (IMFs) concentrate more details of the soybean futures time series, including noise, making them more complex and less predictable than the low-frequency IMFs. Cluster analysis is performed on imf0 – imf7 using Symbolic Entropy (SE). Figure 5 and Table 3 display a series of clustering results. Each component is assigned a cluster number, with imf0 and imf1 assigned to Cluster 0, imf2 to Cluster 2, and imf3 to imf7 to Cluster 1. Through K-means clustering of the original data, where each component represents a specific dimension of the data, Cluster result 0 indicates that the component is assigned to the high-frequency sequence during the clustering process, Cluster result 1 indicates that the component is assigned to the low-frequency sequence, and Cluster result 2 indicates that the component is assigned to the mid-frequency sequence.

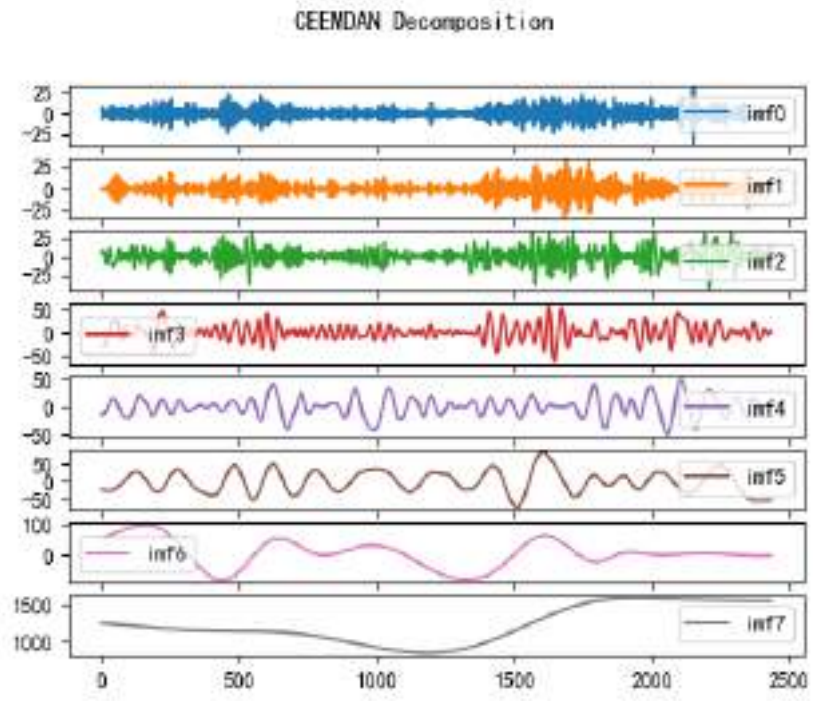

Figure 4. The CEEMDAN Decomposition Results of Soybean Futures Price-Time Series.

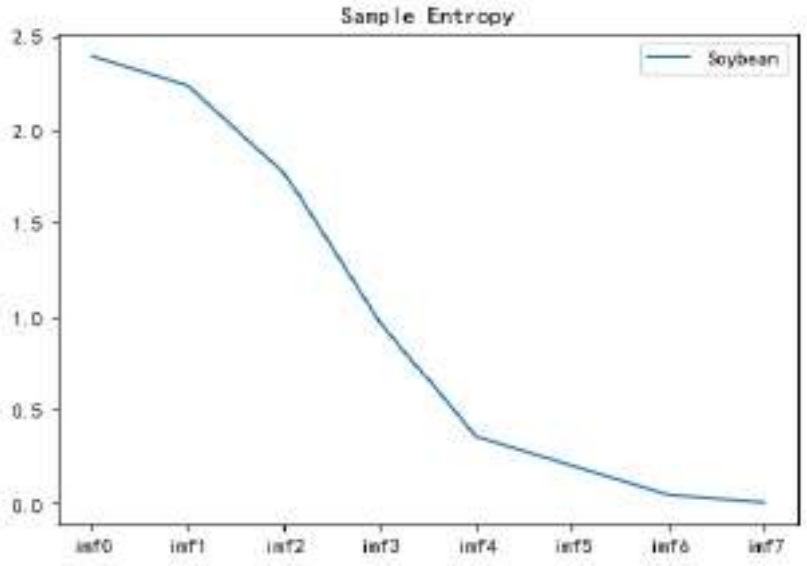

Figure 5. Sample entropy and clustering results.

Table 3. Sample Entropy and Clustering Results.

Component	Clustering Result
imf0	0
imf1	0
imf2	2
imf3	1
imf4	1
imf5	1
imf6	1
imf7	1

Based on the clustering results, sequences of different frequencies are integrated, with the integration results shown in Figure 6. co-imf0 represents the high-frequency sequence, co-imf1 represents the mid-frequency sequence, and co-imf2 represents the low-frequency sequence. The high-frequency sequence co-imf0 is subjected to Variational Mode Decomposition (VMD), which further decomposes and reduces complexity, eliminating noise. In the VMD decomposition process, the parameter K = 10 indicates that the maximum number of VMD results is expected to be 10, as shown in Figure 7. The decomposed Intrinsic Mode Functions (IMFs) are reshaped and input as matrices into the LSTM model, while the vectors of co-imf1 and co-imf2 are also input into the LSTM to obtain the final forecast results.

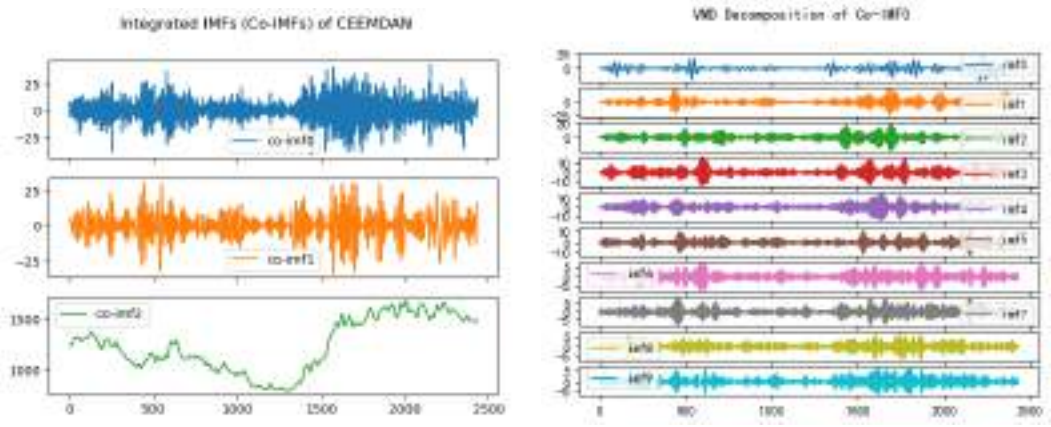

Figure 6. co-imf0 Decomposition Results.

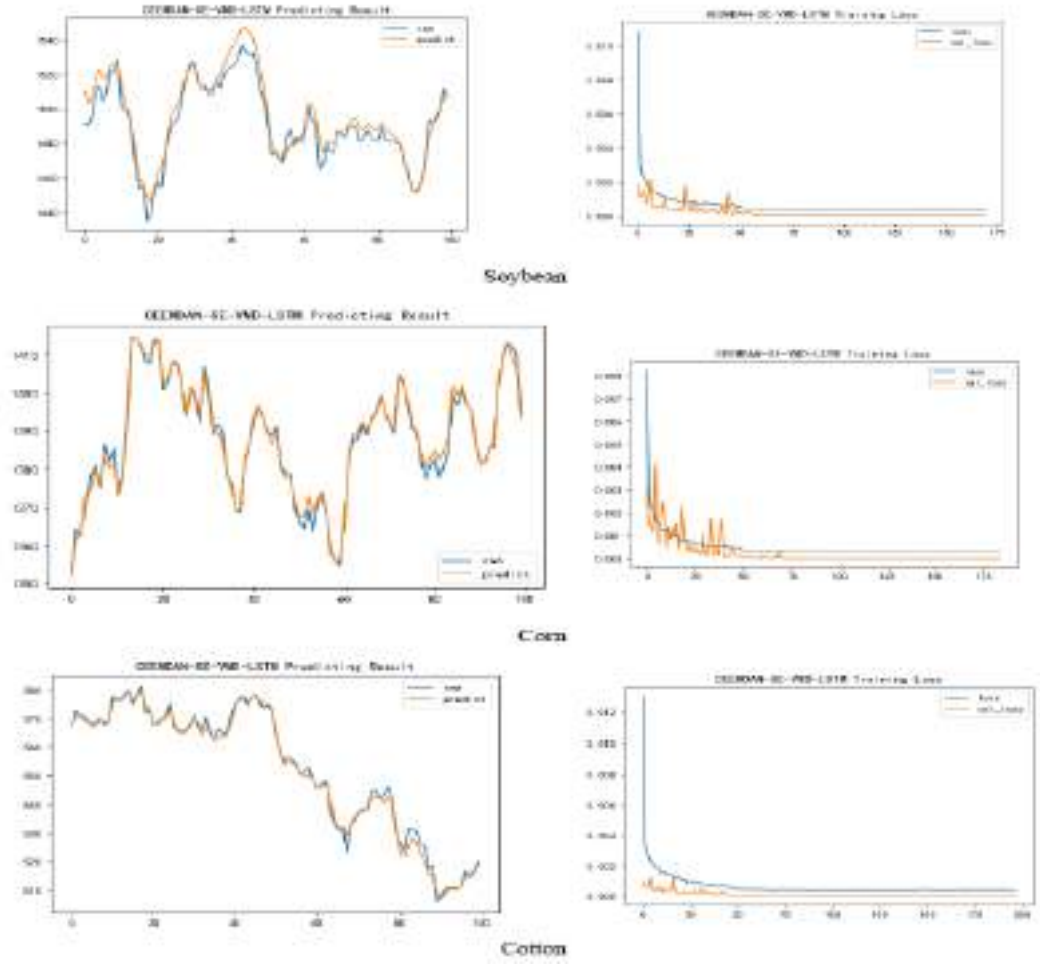

Figure 7. Predicting Result and Training Loss.

3.3. Forecasting Results of Modes

The input of co-imf0, co-imf1, and co-imf2 into the LSTM model yields the forecast results, which are then summed to obtain the predictive outcomes of the CEEMDAN-SE-VMD-LSTM model. The CEEMDAN-SE-VMD-LSTM model's predictions for three agricultural products (soybeans, corn, and cotton) include metrics such as the Mean Absolute Percentage Error (MAPE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Coefficient of Determination (R^2), with the results presented in Table 4, and the forecast outcomes and loss rates depicted in Figure 7.

For soybeans, the Mean Absolute Percentage Error (MAPE) is 0.0063, the Mean Absolute Error (MAE) is 0.0049, the Root Mean Square Error (RMSE) is 0.0057, and the Coefficient of Determination (R^2) is 0.9495.

For corn, the predictive performance is even more outstanding, with a MAPE of only 0.0029, an MAE of 0.0019, an RMSE of 0.0025, and an R^2 as high as 0.9864, indicating a very strong model fit and predictive capability for corn data.

For cotton, the MAPE is 0.0082, the MAE is 0.0035, the RMSE is 0.0047, and the R^2 reaches 0.9923, which is also a very high value, suggesting that the model also performs excellently in processing cotton data.

Therefore, the CEEMDAN-SE-VMD-LSTM model has achieved good performance metrics in the forecasting of these three agricultural products, demonstrating the effectiveness and accuracy of the model.

Table 4. predictions for three agricultural products.

Agricultural Products	Indicators	CEEMDAN-SE-VMD-LSTM
Soybeans	MAPE	0.0063
	MAE	0.0049
	RMSE	0.0057
	R^2	0.9495
Corn	MAPE	0.0029
	MAE	0.0019
	RMSE	0.0025
	R^2	0.9864
Cotton	MAPE	0.0082
	MAE	0.0035
	RMSE	0.0047
	R^2	0.9923

4. Discussion

To validate the performance of the quadratic decomposition deep learning model in forecasting the prices of three agricultural product futures, the predictive performance of the non-decomposed LSTM, CEEMDAN-LSTM, VMD-LSTM, and CEEMDAN-SE-VMD-LSTM models are compared using four different metrics to measure the models' forecasting effectiveness. The results are presented in Table 5. Figure 8 contrasts the fit quality R^2 of the three agricultural product predictions by the five models.

In all metrics, the LSTM model performed the worst, with errors in MAPE, MAE, and RMSE significantly greater than those of other models. And a negative R^2 indicates that the fit of the standalone LSTM model is very poor, especially in the prediction of soybean prices. To further verify the predictive effect of the LSTM model on agricultural products, a Convolutional Neural Network (CNN) and Long Short-Term Memory Network (LSTM) combined model, CNN-LSTM, is applied to the price prediction of three agricultural products. The results from the table show that CNN-LSTM has made improvements in the prediction of corn and cotton, but the outcomes are still not as good as those of the subsequent decomposition models.

Table 5. Comparison of Model Prediction Results.

Agricultural Products	Indicators	LSTM	CNN-LSTM	CEEMDAN-LSTM	VMD-LSTM	CEEMDAN-SE-VMD-LSTM
Soybean	MAPE	15.2905	10.7965	0.0848	0.0250	0.0063
	MAE	0.1342	170.2799	0.0587	0.0225	0.0049
	RMSE	0.01416	176.1069	0.0670	0.0296	0.0057
	R^2	−3.9463	−8.3669	0.6175	0.7821	0.9495
Corn	MAPE	4.0259	2.1155	0.0448	0.0311	0.0029
	MAE	0.0291	30.4035	0.0313	0.0219	0.0019
	RMSE	0.0354	36.3886	0.0367	0.0259	0.0025
	R^2	0.7822	0.5325	0.7666	0.8828	0.9864
Cotton	MAPE	8.4403	2.4148	0.0860	0.0253	0.0082
	MAE	0.0336	12.9731	0.0319	0.0102	0.0035
	RMSE	0.0438	17.0694	0.0420	0.0135	0.0047
	R^2	0.7870	0.8092	0.8064	0.9800	0.9923

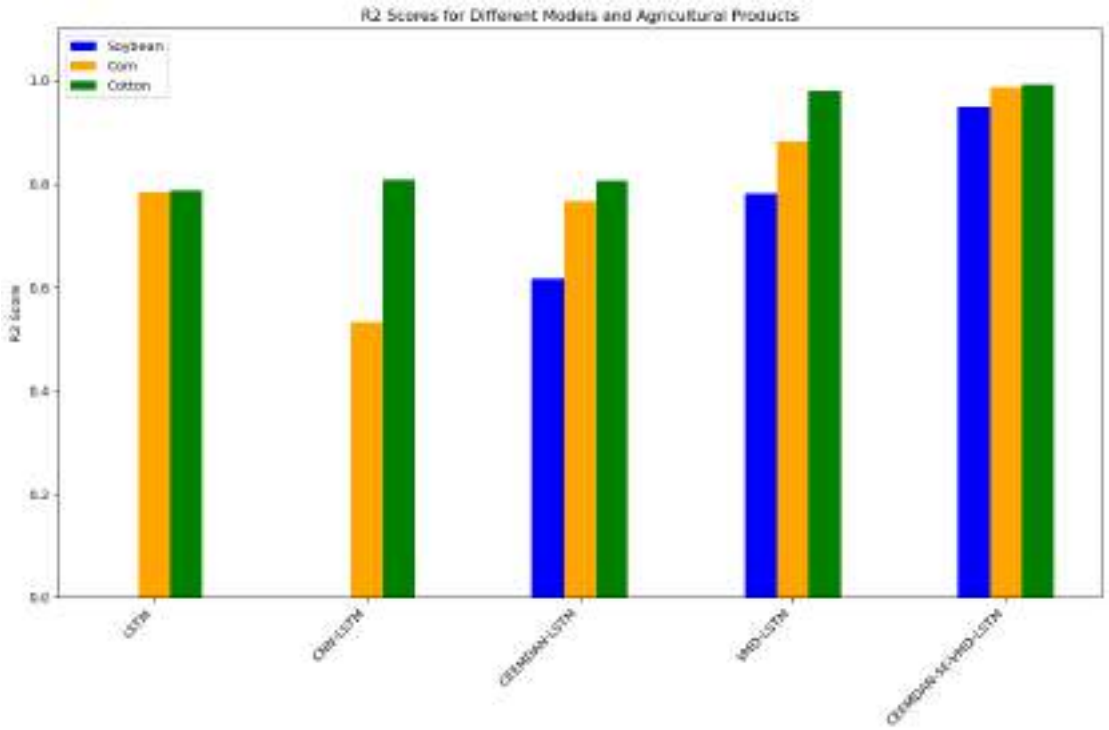

Figure 8. R^2 Scores for Different Models and Agricultural Products.

In the primary decomposition models, the performance of the CEEMDAN-LSTM model is significantly enhanced, particularly in terms of MAPE, MAE, and RMSE. The VMD decomposition also notably improves the performance of the LSTM model, outperforming the CEEMDAN-LSTM model across all four metrics: MAPE, MAE, RMSE, and R^2. It is evident that for non-linear and non-stationary price series of agricultural products, VMD decomposition is markedly more effective than CEEMDAN decomposition in primary decomposition models. The quadratic decomposition model, which combines CEEMDAN and VMD decompositions, achieves the best performance in all metrics. Then the CEEMDAN-SE-VMD-LSTM model demonstrates a significant improvement in evaluation metrics for the price prediction of soybeans, corn, and

cotton compared to the two primary decomposition models. Specifically, for soybeans, the R^2 increases from 0.6175 and 0.7821 to 0.9495, representing a precision enhancement of 53.76% and 21.66%, respectively; for corn, the R^2 increases from 0.7666 and 0.8828 to 0.9864, indicating a precision enhancement of 28.67% and 11.74%, respectively; and for cotton, the R^2 increases from 0.8064 and 0.9800 to 0.9923, showing a precision enhancement of 23.03% and 1.26%, respectively. The CEEMDAN-SE-VMD-LSTM model has exhibited extremely high predictive accuracy in the forecasting of agricultural product futures prices.

5. Conclusion

This study addresses the forecasting issue of futures prices for three agricultural products: soybeans, corn, and cotton, by proposing the CEEMDAN-SE-VMD-LSTM hybrid model. By integrating CEEMDAN and VMD signal decomposition techniques, the model effectively overcomes the limitations inherent in the original LSTM model when dealing with complex time series data. Experimental results demonstrate that the hybrid model has achieved significant effectiveness in forecasting the futures prices of the three agricultural products, with R^2 values exceeding 94%, showing higher predictive accuracy compared to other comparative models.

The introduction of CEEMDAN and VMD decomposition techniques successfully extracts valuable information from time series data and effectively reduces noise and redundant components, providing clearer and more effective input features for the LSTM model's accurate predictions. Moreover, the combination of quadratic decomposition algorithms with deep learning technology further enhances the model's predictive accuracy and robustness. The CEEMDAN-SE-VMD-LSTM model proposed in this study exhibits exceptional forecasting performance and practical value in the prediction of agricultural product futures prices, offering strong support for risk management and investment decision-making in the agricultural product market.

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Author Contributions

Y. J.: conceptualization, methodology; Q. M.: data curation, writing—original draft preparation; M. T.: visualization, investigation. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

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Article

Logistics Demand Forecast in Shandong Province Based on Grey Forecast

Wenqing Ji

School of Economics and Management, Qingdao University of Science and Technology, Qingdao 266100, China

Abstract: This paper takes the logistics demand in Shandong Province as the research object, selects the freight turnover volume as the key indicator. After collecting and sorting out the logistics data in recent years, it analyzes and builds models by using the grey prediction model to clarify its development trend and obtain the prediction results, which show that the freight turnover volume gradually increases in the future and the logistics demand presents a growing trend. This research has important guiding significance for the logistics planning and resource allocation in Shandong Province, and is conducive to the relevant departments to reasonably arrange resources and improve logistics efficiency.

Keywords: Shandong province; logistics demand; grey forecast; cargo turnover

1. Introduction

In the context of economic globalization and the rapid logistics industry development, the accurate prediction of logistics demand has become a crucial task in supply chain management and logistics planning. In the complex and changeable market environment, accurate prediction of logistics demand can help enterprises to scientifically plan resources, improve operational efficiency, reduce costs, and then gain a competitive advantage in the fiercely competitive market. Therefore, logistics demand prediction has become a hot spot of common concern in the academic and practical fields.

Shandong Province is a strong economic province and a key logistics hub in China. Accurately predicting its logistics demand is of great significance to the economic development of the region and the good operation of the logistics industry. However, because logistics demand is affected by many factors such as economic development, population growth, and industrial structure changes, it is difficult and challenging to predict. Therefore, it is extremely critical to explore a feasible and accurate logistics demand forecasting method. Grey prediction is a prediction method based on incomplete information, which is widely used in many fields such as economic prediction and social development prediction. The main idea is to gray the existing data and construct a mathematical model to infer the future development trend. Compared with the traditional mathematical model, the grey prediction method has certain advantages in the case of less data and strong uncertainty.

Many scholars in academia have carried out different research on logistics demand forecasting. Wang Caifeng [1] established GM(1,1) model to predict the logistics demand of Tibet Autonomous Region based on the actual data of cargo turnover in Tibet Autonomous Region. Yin Yanwei, Xiang Ga, Ren Yawei [2] take Shenyang as an example, based on the grey GM(1, 1) model to predict the logistics demand of the northeast

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Corresponding: Wenqing Ji (1263250223@qq.com)

region, and by comparing with the actual value, the feasibility of the model is verified. Wang Meng, Li Xin [3] used the GM(1,1) model to predict the logistics demand of British agricultural products. Xia Wenhui [4] used the historical data of freight volume in Chongqing to construct GM(1,1) model to predict the freight volume and its development trend in Chongqing in the next ten years.;At the same time, Gu Jiamin [5] predicted the logistics demand of related cities based on the grey prediction method, and the accuracy of the logistics demand prediction results obtained was high. Chen [6] selected Guangxi freight volume and cargo turnover as the influencing factors of Guangxi logistics demand. Xu Zhao [7] studied the forecasting method of urban logistics demand, and took Wuxi City as a case to predict the freight volume of Wuxi City in the next few years. Based on the existing research, this paper uses the grey prediction method to predict the logistics demand of Shandong Province, and provides decision support for the logistics planning and resource allocation of Shandong Province.

2. Introduction of Grey Forecasting Model

Grey prediction model is a unique prediction method, which is based on grey system theory. In the real world, there are many systems with incomplete information and scarce data, and the grey prediction model has good applicability to such systems. Tracing its origin, it was born in the 1980 s. It is a highly innovative achievement created by Chinese scholars through in-depth research and exploration. Since its inception, with the passage of time, the grey prediction model can predict the development trend of various economic indicators in many fields, especially in the economic field, and provide a strong reference for enterprises to formulate strategic planning and the government to carry out macro-control. In the social field, it can be used for population growth trend prediction, social phenomenon change analysis, etc., to help social management and policy formulation; in the field of environment, the prediction of environmental quality changes, resource consumption trends, etc., providing key support for the implementation of environmental protection and sustainable development strategies, etc., has been widely used in prediction and decision support.

The core point of this model is that it can skillfully process and transform those incomplete data sequences by using a special gray processing method, and further construct the corresponding mathematical model on this basis. With this model, we can reasonably infer and predict the future development trend of the system based on the current data. Its inherent basic assumption profoundly reflects the characteristics of the system, that is, there is often a special gray area in the whole development process of the system. This gray area covers those unknown and incomplete information parts. Because these information are difficult to obtain directly or clearly grasp, it is necessary to conduct in-depth and detailed analysis and prediction of existing data. In this way, we can excavate and reveal the inherent laws hidden behind these data.

Compared with the traditional prediction methods, the traditional prediction methods are often more stringent in data requirements, and a large number of complete and accurate data are needed to make more accurate predictions, while the grey prediction model shows unique advantages. When faced with the dilemma of missing data, it can still work on limited existing data ; under the condition of large uncertainty, that is, when the fluctuation of data is frequent and the relationship between data is vague, the grey prediction model can make a relatively reasonable and valuable prediction for the future development of the system by virtue of its unique theory and method system, so as to stand out among many prediction methods and become a powerful tool for dealing with the prediction problem of incomplete information and uncertain system.

2.1. Model Establishment Process

Set the reference data column: $x^{(0)}=(x^{(0)}(1),x^{(0)}(2),x^{(0)}(3),\cdots x^{(0)}(n))$

Accumulate it once and generate:

$$x^{(1)}=(x^{(1)}(1),x^{(1)}(2),x^{(1)}(3),\cdots,x^{(1)}(n))=(x^{(1)}(1),x^{(1)}(1)+x^{(1)}(2),x^{(1)}(2)+x^{(1)}(3),\cdots,x^{(1)}(n-1)+x^{(1)}(n))$$

$$x^{(1)}(k)=\sum_{i=1}^{k}x^{(0)}\ (i)(k=1,2,3,\cdots,n)$$

Among them.

Find the mean value sequence: $z^{(1)}=0.5x^{(1)}(k)+0.5x^{(1)}(k-1),k=2,3,4,\cdots,n$

Now: $z^{(1)}=(z^{(1)}(2),z^{(1)}(3),z^{(1)}(4),\cdots,z^{(1)}(n))$

Remember: $a=[a,u]^T, y=(x^{(0)}(2),x^{(0)}(3),\cdots,x^{(0)}(n))^T, B=\begin{bmatrix}-z^{(1)}(2) & 1\\ -z^{(1)}(3) & 1\\ \vdots & \vdots\\ -z^{(1)}(n) & 1\end{bmatrix}$,

It can be concluded from the least square method: $\hat{a}=(B^TB)^{-1}B^TY$

Finally,the grey prediction model can be obtained as: $\hat{x}^{(1)}(k)=(x^{(0)}(1)-\frac{u}{a})e^{-a(k-1)}+\frac{u}{a}$

2.2. Model Calibration

(1) Test for residuals: Let the residuals be $\varepsilon(k)$ calculate $\varepsilon(k)=\frac{x^{(0)}(k)-\hat{x}^{(0)}(k)}{x^{(0)}(k)}, k=1,2,\cdots,n$

If $\varepsilon(k) < 0.2$, it can be considered to meet the general requirements; If $\varepsilon(k) < 0.1$, it can be considered to meet higher requirements.

(2) The deviation value test of the ratio: First of all, by the reference data $x^{(0)}(k-1), x^{(0)}(k)$, so$\rho(k)=1-\left(\frac{1-0.5a}{1+0.5a}\right)\lambda(k)$.

The grade ratio is calculated $\lambda(k)$, and the corresponding technical deviation is obtained by using the development coefficient a. If $\rho(k) < 0.3$, it can be considered to meet the general requirements; If$\rho(k) < 0.1$, it can be considered to meet higher requirements.

3. Logistics Demand Forecast of Shandong Province

This paper collects the data of cargo turnover in Shandong Province from 2003 to 2022 through the National Statistical Yearbook of China Statistical Bureau, and draws a scatter plot accordingly.

From the scatter plot provided (as shown in Figure 1), we can clearly observe that during 2000–2007, the trend line formed by the data points shows a relatively stable and regular upward trend, and its growth rate remains within a relatively reasonable range. The fluctuation is small, which is in line with the logic of general economic development and gradual growth of logistics demand. However, when time entered 2008, the data points began to show a sharp upward trend, which was in stark contrast to the previous trend. This rise is not a gradual and sustainable growth, but a leap-forward and mutational growth model. Taking the data of 2007 as a reference, the growth rate of cargo turnover in 2008 is far beyond the normal growth level of previous years. In the subsequent 2009–2012 period, this abnormal growth trend has not been alleviated, but continued to intensify. The data points are high and convex on the scatter plot, forming obvious faults with the data points of the previous and subsequent years. This means that in these four years, the growth rate of cargo turnover in Shandong Province is extremely fast, far from the normal growth track.

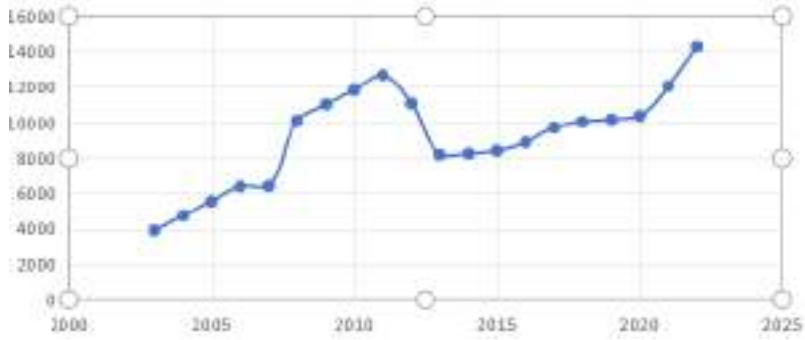

Figure 1. Scatter plot of cargo turnover in Shandong Province from 2003 to 2022.

From the point of view of the distribution density of data points, the data points of 2008–2012 are more dense than other years and distributed in a higher numerical range, which indicates that the turnover of goods has achieved rapid and concentrated growth during this period. At the same time, compared with the growth

trend consistency of adjacent years, the growth anomaly in 2008–2012 broke the stability of the overall data trend, making the whole data series show a growth model that is obviously uncoordinated with the previous and subsequent stages during this period.

This abnormal growth may be caused by a combination of factors. On the one hand, it may be closely related to the changes in the macroeconomic environment at that time. For example, in 2008, when the global financial crisis broke out, countries adopted economic stimulus policies, and China was no exception. Large-scale economic stimulus plans may have prompted Shandong Province to increase investment in infrastructure construction and industrial production, which led to a substantial increase in cargo turnover. On the other hand, factors such as industrial restructuring, changes in the logistics industry itself, and changes in policy orientation may also play a central role in this period, jointly triggering the abnormal growth of cargo turnover data. However, this abnormal growth trend is significantly different from the trend of other years in the scatter plot, which has a great impact on the stability and predictability of the overall data, so it needs to be eliminated. After eliminating anomalies, the required data table (see Table 1) is obtained, and the GM(1,1) model is established to predict and analyze the logistics demand trend of Shandong Province in the next five years.

Table 1. Shandong's cargo turnover from 2003 to 2022.

Year	2003	2005	2006	2007	2013	2014	2015
Turnover of goods (billions of tons of kilometers)	3908.9	5551	6387.4	6413.4	8194.15	8253.03	8418.04
Year	2016	2018	2019	2020	2021	2022	
Turnover of goods (billions of tons of kilometers)	8884.34	10,052.2	10,166.42	10,377.4	12,049.7	14,273.49	

3.1. Establishment of Logistics Demand Model

(1) Initialize the modeling original sequence:

$$x^{(0)} = (3908.9, 4752.5, 5551, 6387.4, 6413.4, 8194.15, 8253.03, 8418.04, 8884.34, 9719.46, 10052.2, 10166.42, 10377.4, 12049.7, 14273.49)$$

(2) One cumulative generation:

$$x^{(1)} = (3908.9, 8661.4, 14212.4, 20599.8, 27013.2, 35207.35, 43460.38, 51878.42, 60762.76, 70482.22, 80534.42, 90700.84, 101078.24, 113127.94, 127401.43)$$

(3) The sliding average generates a sequence:

$$z = (6285.15, 11436.9, 17406.1, 23806.5, 31110.275, 39333.865, 47669.4, 56320.59, 65622.49, 75508.32, 85617.63, 95889.54, 107103.09, 120264.685)$$

(4) The B matrix and Y matrix are calculated, and the prediction model can be obtained as follows:

$$\hat{x}(k) = (3908.9 = 73892.9.64)e^{0.067932347(k-1)} - 73892.9064$$

3.2. Logistics Demand Model Test

According to the above calculation formula of residual error and stage ratio deviation value, the calculation results of residual error and stage ratio deviation value can be obtained (Table 2):

It can be seen from the data in the figure that the residuals meet $\varepsilon(k) < 0.2$. which means that the deviation between the predicted value of the model and the actual cargo turnover data of Shandong Province is small, and

Table 2. Calculation results of residuals and ratio deviations.

Year	2003	2004	2005	2006	2007	2013	2014	2015
residual	0.00	−0.15	−0.05	0.02	−0.05	0.12	0.07	0.02
Ratio deviation value	0.00	0.22	0.05	0.02	0.15	0.27	0.27	0.01
Year	2016	2017	2018	2019	2020	2021	2022	
Residual	0.01	0.03	0.00	−0.06	−0.11	−0.03	0.07	
Ratio deviation value	0.04	0.04	0.06	0.02	0.01	0.14	0.02	

the model has high accuracy in capturing the trend of data change. The grade ratio deviation values all meet $\rho(k) < 0.3$, which fully indicates that the mathematical relationship constructed by the model can better fit the internal change law of the cargo turnover data in Shandong Province. Based on the test results of the two indicators of residual error and grade ratio deviation value, it can be seen that the model meets the general requirements and has the ability to predict the logistics demand of Shandong Province.

4. Prediction Results and Explanation

According to the model, the forecast results of logistics demand in Shandong Province from 2023 to 2027 can be obtained. In 2023, the logistics demand of Shandong Province is expected to be 14,155.921 billion tons km, which reflects the scale of cargo transportation turnover in Shandong Province in that year. By 2024, logistics demand will grow to 15,150.982 billion tons of kilometers, compared to 2023 has a certain degree of improvement, showing the logistics industry in this year may appear expansion trend. In 2025, the predicted logistics demand will further rise to 16, 215.989 billion tons and kilometers, which means that the logistics industry in Shandong Province will show a sustained growth trend in these three years, which may be related to local economic development, industrial restructuring and business activity. The forecast value of logistics demand in 2026 is 17,355.857 billion tons km, which continues to maintain the growth momentum compared with the previous year, indicating that the logistics market still has a strong driving force for development during this period. More enterprises may participate in the logistics business, or existing enterprises have expanded their own logistics business scale. By 2027, it is predicted that the logistics demand of Shandong Province will reach 1,857,585 billion tons of kilometers, reaching the highest value in the five-year forecast period, which is fully demonstrated.

According to the existing data and forecast data, the logistics demand curve of Shandong Province in recent decades can be drawn (as shown in Table 3).

Table 3. Logistics demand forecast of Shandong Province from 2023 to 2027.

Year	2023	2024	2025	2026	2027
Turnover of goods (billions of tons of kilometers)	14,155.921	15,150.982	16,215.989	17,355.857	18,575.850

The orange curve in the figure is the predicted value curve, and the blue is the actual value curve. According to the scatter plot, it can be seen that there is little difference between the predicted value and the actual value, which can also prove that the prediction model meets the requirements, and the prediction results have certain feasibility (as shown in Figure 2).

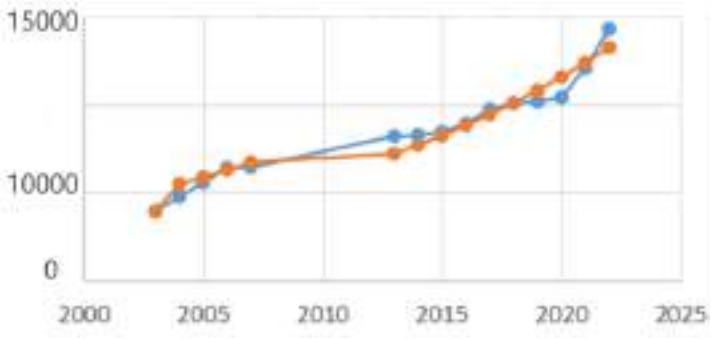

Figure 2. Scatter plot of actual value and predicted value comparison.

5. Policy Proposal

The forecast of logistics demand in Shandong Province based on grey prediction can enable us to predict and recognize the future development of logistics demand. Based on these prediction conclusions, the following policy recommendations can be made to help the development of the logistics industry in Shandong Province

and optimize the allocation of resources.

(1) Strengthening the construction of logistics infrastructure: In view of the forecast that the logistics demand in Shandong Province is gradually rising, the government needs to increase investment in logistics infrastructure, covering roads, railways, ports and storage facilities. By improving the efficiency and efficiency of logistics infrastructure, it can meet the growing logistics demand and enhance the convenience and reliability of logistics transportation.

(2) Promote the use of logistics information and technology: With the increasing demand for logistics, logistics information and technology applications will become the core elements to enhance logistics efficiency and reduce costs. The government can guide logistics enterprises to strengthen the construction of information system and improve the collection, transmission and management level of logistics information. Moreover, encourage logistics enterprises to adopt cutting-edge logistics technologies such as Internet of Things, big data analysis, and artificial intelligence to optimize logistics operation processes and improve cargo tracking and distribution efficiency.

(3) Optimize the cultivation and management of logistics talents: The demand for high-quality talents in the logistics industry is increasing day by day. The government should enhance the cooperation with universities and vocational education institutions, and cultivate and introduce logistics professionals. In addition, we will strengthen the training and skills upgrading of logistics practitioners and enhance their operational management and supply chain coordination capabilities. In addition, build a complete logistics talent management system, attract and retain high-quality logistics talents, and provide strong support for the sustainable development of the logistics industry.

(4) Promote the collaborative development of the logistics industry: The growth of logistics demand does not depend on the unilateral efforts of a single enterprise or institution, but on the collaborative operation of the entire logistics industry chain. The government can focus on promoting the construction of logistics industrial parks and promoting cooperation and coordinated development among logistics enterprises. At the same time, it urges logistics enterprises to build close cooperation with suppliers, customers, transportation enterprises and other relevant parties, create an efficient supply chain network, and improve the overall logistics efficiency.

(5) Strengthen policy support and supervision measures: In order to promote the steady development of the logistics industry, it is necessary for the government to formulate relevant policy support and supervision measures. For example, build a sound logistics market access mechanism to encourage and support the development of private logistics enterprises; strengthen the supervision of logistics service quality and improve the service level of logistics industry; promote the green development of the logistics industry, and advocate the implementation of low-carbon logistics and energy conservation and emission reduction actions.

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Article

Research and Simulation on Improving Methods for Optimizing Local Catering Revenue Forecast

Jiayi Meng

Industrial Engineering and Management, Qingdao University of Science and Technology, Qingdao266000, China

Abstract: Accurately predicting catering income is of great significance for promoting domestic economic development. The traditional cointegration analysis prediction method is difficult to accurately describe the causal relationship between catering income and local economic development, resulting in poor prediction effects. This study proposes a catering income optimization prediction method based on time series. Firstly, it tests the cointegration of catering income and local economic development time series data, constructs a two-variable autoregressive model, and then uses the Granger method to test the causal relationship. Calculate the proportion of the catering industry as a direct influencing factor, and count the correlation effect to form an optimized prediction model. Taking the data of Yan'an City from 2014 to 2023 as an example, simulated by eviews 5.0 software, the results show that this model is superior to the comparison algorithm in prediction accuracy, error rate, stability and time efficiency. The conclusion is that this method can effectively improve the accuracy of catering income prediction and contribute to local economic research and planning.

Keywords: catering income prediction; time series analysis; cointegration and Granger test

1. Introduction

The catering industry is a labor-intensive industry that can provide a large number of employment opportunities. According to the data of the National Bureau of Statistics, in 2019, the number of employees in China's catering industry reached 10.65 million, accounting for 4.3% of the national employment. The development of the catering industry can not only create employment opportunities but also improve the quality and level of employment. With the improvement of people's living standards, the demand for catering services is constantly increasing [1]. The catering industry not only provides basic dietary needs but also offers diversified and personalized catering services, promoting consumption upgrading. At the same time, the development of the catering industry has also driven the development of related industries such as food processing and tableware manufacturing [2]. The catering industry is an important force in driving domestic consumption. With the development of China's economy, people's income levels and consumption levels are constantly rising, and the consumption demand of the catering industry is also constantly increasing [3]. The development of the catering industry can promote the growth of domestic consumption and drive the stable growth of the economy. The catering industry is an important part of the local economy. The catering cultures and special dishes in different regions have attracted a large number of tourists and consumers, promoting the

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Corresponding: Jiayi Meng (1553813945@qq.com)

development of the local catering industry and cultural industries [4]. At the same time, the development of the catering industry has also driven the development of related industries such as agriculture and fishery. In conclusion, the impact of the catering industry on China's economy is very significant [5]. The development of the catering industry can create employment opportunities, promote consumption upgrading, drive domestic consumption, and promote local economic development, which is of great significance for the stable growth and sustainable development of China's economy [6–8]. Therefore, it is very meaningful to calculate the proportion of the local catering industry and thus judge the factors affecting the local economy.

2. Principles of Prediction

In the process of forecasting local catering industry revenue, we first calculate regional catering revenue and the growth rate of catering revenue. We then obtain the characteristics of catering revenue's promotion on the local economy, describe the change patterns between catering revenue and economic growth, and establish a catering revenue prediction model. The specific steps are detailed as follows:

Assuming that NP represents the value added by the catering industry, CCS represents the connectivity between the catering industry and other industries, and DW represents the elasticity of catering revenue, we use Equations (1) and (2) to calculate regional catering revenue and the growth rate of catering revenue.

$$Q_{jp} = \frac{D_{DS} \times w''}{C_{cs}} \times TES \times N_p DW \tag{1}$$

$$W'' = \frac{D_{DS} \times w''}{C_{cs}} \times \frac{TES \times N_p Q_{JP}}{DW} \tag{2}$$

In this formula, N_p represents the added value of the catering industry, W'' represents the local final demand for catering, and TES represents the income effect of the catering economy. Assuming that X represents the degree of dependence of the catering industry on other industries, we use Equation (3) to obtain the characteristics of how catering income promotes the local economy.

$$\phi'' = \left(Q_{JP} \cdot W^*\right) \frac{\varphi \times \kappa}{\left(H \cdot \chi\right)} \times \beta \tag{3}$$

In this formula, φ represents the equilibrium relationship between restaurant revenue and restaurant growth, κ represents the income effect of the catering industry, H represents factors affecting the development of the catering industry, χ represents the comprehensive employment coefficient of the catering industry on other industries, and β represents the lagged structure between restaurant revenue and economic growth. Using Equation (4), we construct a model for predicting restaurant revenue.

$$NA = \frac{vr \times \phi''}{W^*} \otimes Q_{JP} \cdot DW \tag{4}$$

In this formula, vr represents the pattern of change between restaurant revenue and economic growth.

However, traditional methods cannot accurately describe the causal relationship between restaurant revenue and local economic development, nor can they accurately predict restaurant revenue. A new method for optimizing restaurant revenue prediction based on time series is proposed.

3. A Time Series-Based Method for Optimizing and Predicting Restaurant Revenue

3.1. Vector Autoregression Model of Two Variables: Catering Revenue and Local Economy

During the process of optimizing and predicting restaurant revenue through modeling, obtain time series data on restaurant revenue and local economic growth. Conduct cointegration tests on the time series data for restaurant revenue and economic development. Establish a vector autoregression model for restaurant revenue and economic development variables, and test the causal relationships between the models. The specific steps are detailed as follows:

Before conducting cointegration tests on the time series data for restaurant revenue and economic development, it is necessary to test the stationarity of each time series separately. This step aims to avoid high R^2 values in spurious regressions between the time series variables of restaurant revenue and economic development. Assuming that B represents the standard for judging regional economic growth, use Equation (5)

to calculate the level of economic growth in a region with restaurants.

$$p_a(X,A)=\frac{B\cdot\Omega}{\mu_n\cdot R^2}\cdot\frac{\beta^{y}\times U_n}{M^{\notin}} \tag{5}$$

In the formula, Ω represents total restaurant revenue, μ_n denotes the random disturbance affecting the dynamic system of variables, β^{y} represents the impact of economic lag variables in the economic region on current variables, U_n represents the availability of variable data, and M indicates the order of integration of the time series data for restaurant revenue and economic growth.

Assuming that the time series of restaurant revenue is first-order integrated, and the time series of economic growth data is second-order differenced, then use Equation (6) to obtain time series data for restaurant revenue and economic development that are stationary.

$$P\left(v/\eta_1\right)=\frac{\xi\left[\sum_{i=1}^{k}\eta_{1i}\right]}{\Gamma\left(\eta_{1i}\right)\ell}\mathrm{Y}_1{}^{\eta_{1i}-1} \tag{6}$$

In the equation, η_{1i} represents the cointegration relationship between catering revenue and regional GDP, Γ denotes the random disturbance term, Y represents the n-dimensional endogenous variable, and k indicates the lag period of economic growth. Using Equation (7), a vector autoregressive model is constructed for catering revenue and economic development variables.

$$P^{L}=\frac{u_{1n}-u_{jn}}{t_{ES}\times P\left(\gamma/\eta_1\right)}\cdot pa(X,A) \tag{7}$$

In the formula, u_{1n} represents the dining consumer's propensity to consume, u_{jn} represents the scale of consumption, and t_{ES} represents the second-order difference sequence of the economic growth data series.

Assuming that W^* represents the second-order difference sequence of the economic growth data series, it can be determined that the economic growth time series is second-order integrated, expressed by Equation (8).

$$W^{*}=\frac{\hbar\times\theta^{\beta}}{P^{L}\cdot p_a(X,A)} \tag{8}$$

In the formula, $\hbar$ represents the extension of the autoregressive model, and θ^{β} denotes the optimal lag period selection for the relationship between catering revenue and economic growth. From Equation (8), it can be concluded that if the orders of integration of the local catering revenue and economic growth time series data differ, then the two variables are not cointegrated. If, however, the two time series are cointegrated, it indicates that there exists a long-term equilibrium relationship between them. The cointegration between the local catering revenue and economic growth time series can be defined as another way of expressing their long-term equilibrium relationship.

Using Equation (9) to test the causality between local catering revenue and economic growth.

$$\gamma_t=\frac{Y_t-\partial_{\beta}}{W^{*}} \tag{9}$$

In the formula, Yt represents the logarithm of local economic GDP and total restaurant revenue, δ denotes the stationary time series of the stochastic variable of local restaurant income and economic growth, and β represents heteroscedasticity phenomena in the time series.

3.2. Establishment of an Optimized Restaurant Revenue Prediction Model Based on Correlation Effects

The impact of restaurant revenue is defined as the influence of the restaurant industry on per capita domestic income. Since the expenses incurred by diners at dining destinations directly become the income of local enterprises, and restaurant revenue gradually permeates into the local economic system based on its related industries, it can drive the overall economic improvement of the region. Therefore, the local restaurant effect can be expressed as both direct and indirect impacts of the restaurant industry on the local economy. Based on the causal relationship between local restaurant income and economic growth obtained in Section 3.1, calculate the proportion of the restaurant industry and define the result as the direct influencing factor of the restaurant industry on the local economy. Integrate the industrial correlation effects of local restaurants to establish an optimized restaurant revenue prediction model, with specific steps detailed as follows:

Assume that X_j represents the catering output value of various economic sectors in the catering destination, and Y_j represents the added value of catering. Using γ_t obtained in Section 3.2, calculate the proportion of the catering industry using Equation (10).

$$\vartheta = \frac{\left(X_j \cdot Y_j\right)}{\gamma_t} \cdot \frac{\left(G_j \cdot X_J\right)}{C \cdot A} Y \tag{10}$$

In the formula, A represents the direct input coefficients between industries, G_j represents the final demand for catering services, Y represents the foreign exchange effect generated by the catering industry, and C represents the foreign exchange income from catering. The linkage effect of the catering industry is defined as the complex and inseparable economic ties between the catering industry and other industries. The local catering industry's industrial linkage effect is analyzed from several aspects, including input structure, intermediate input rate, and intermediate demand rate.

(1). Input structure of the catering industry

The input structure of catering is defined as the cost structure that the catering sector incurs when purchasing intermediate products and utilizing production factors from various industrial sectors for production purposes. It reflects the production technology linkages between the catering industry and related departments through the mode of intermediate product inputs. This effect is measured using the direct input coefficients of the catering industry on other production sectors, expressed by Equation (11).

$$a_{ij} = \frac{X_{ij}}{X_j} \times X_j \cdot \vartheta^{\circ} \tag{11}$$

In the formula, X_{ijs} represents the consumption of product i by industry j, and X_j represents the total input of industry j.

(2). Intermediate demand rate for the catering industry

This intermediate demand rate is the ratio of the total intermediate demand for a certain product by per capita domestic economic activity to the total demand for that product by society. A high intermediate demand rate indicates that the industry has a greater nature of providing intermediate products, which can be expressed using Equation (12).

$$h_{ij} = \frac{a_{ij} \cdot \vartheta^{\circ}}{\left(X_j \cdot Y_j\right)} \gamma_t \tag{12}$$

(3). Intermediate input rate in the catering industry

If the intermediate input in the catering industry is low, then the corresponding value-added rate is higher; conversely, if the intermediate input rate in the catering industry is high, the value-added rate is lower. This relationship can be expressed using Equation (13).

$$k_i = \frac{X_{ij}}{N_i + X_{ij}} h_{ij} \tag{13}$$

In the formula, Ni represents the total input into the industry. Based on the aforementioned explanation, use Equation (14) to construct the optimal revenue prediction model for the catering industry.

$$Q^{\otimes} = \frac{k_i \cdot h_{ij}}{h_{ij} \cdot \gamma_t} \times a_{ij} \tag{14}$$

4. Experimental Evidence Demonstrates

To demonstrate the validity of the proposed time-series-based revenue optimization prediction modeling method for the catering industry, an experiment was conducted. The study used Xi'an city's catering revenue data from 2014 to 2023 to empirically examine the relationship between catering revenue and economic growth. The simulation tool employed for this experiment was EViews 5.0 software.

4.1. Comparison of Prediction Accuracy for Restaurant Revenue Optimization Using Different Algorithmic Mossssdels

We constructed restaurant revenue optimization prediction models using the algorithm proposed in this paper and the algorithm from reference [9]. We compared the accuracy of different algorithmic models for restaurant revenue optimization prediction. The comparison results are shown in Figure 1.

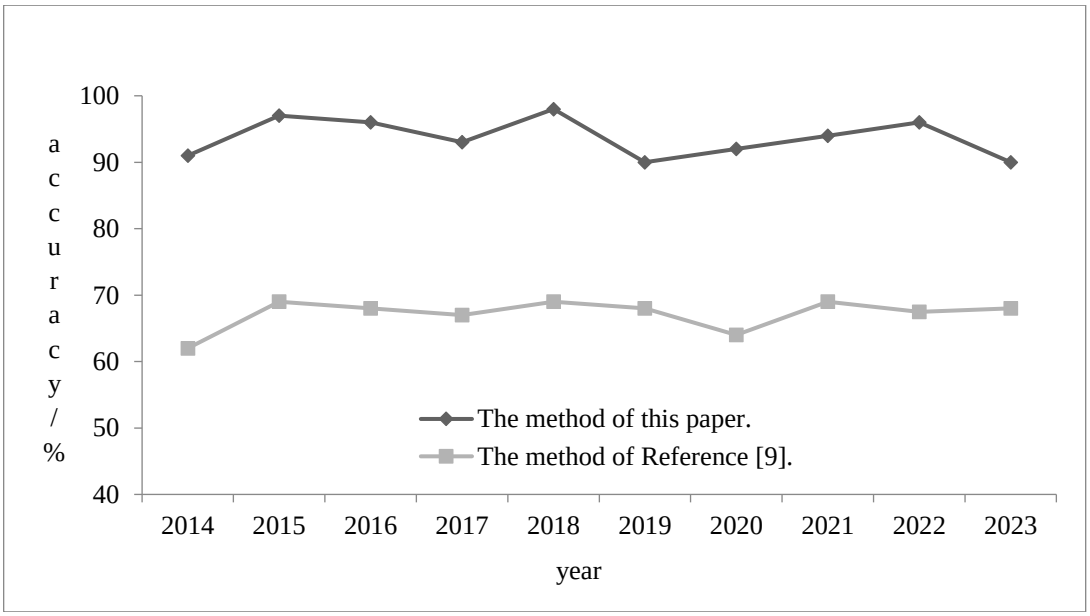

Figure 1. Comparison of accuracy among different models.

Figure 1 presents a clear and distinct comparison that clearly demonstrates the superiority of the precision in optimizing restaurant revenue prediction when using the algorithm model proposed in this paper over that of the time series test conducted with the algorithm model from reference [9]. The underlying reason for this significant disparity can be traced back to the fundamental steps involved in the model construction process. When implementing the algorithm proposed in this paper to establish the model, a crucial initial step is taken. Specifically, comprehensive cointegration tests are meticulously carried out on the time series data of both restaurant revenue and local economic indicators. This process is of utmost importance as it plays a pivotal role in enhancing the reliability and validity of the model.

By performing these cointegration tests, potential spurious relationships between the variables are effectively identified and eliminated. This helps to establish a more solid foundation for the model, ensuring that the relationships captured are genuine and meaningful. As a result, the precision of optimizing restaurant revenue prediction is significantly enhanced, providing more accurate and reliable forecasts. This not only benefits the academic research in this field but also has practical implications for businesses and policymakers who rely on accurate revenue predictions to make informed decisions.

4.2. Comprehensive Effectiveness of Precision Models for Optimizing Restaurant Revenue Forecasting under Different Algorithms

In this research, both the algorithms proposed in this paper and those sourced from reference [9] were systematically employed to construct restaurant revenue optimization prediction models. This dual approach was adopted to comprehensively assess and compare their capabilities in predicting restaurant revenue.

To gain a more profound understanding of their performance, a detailed comparison was made regarding the error rate (%), stability (%), and time efficiency (%) of the two models based on different algorithms. The error rate is a crucial indicator that reflects the deviation between the predicted values and the actual values, directly influencing the reliability of the model. A lower error rate indicates a higher level of accuracy in the prediction. Stability is another vital aspect. A stable model is one that can maintain consistent performance over different

data sets and time periods. It ensures that the predictions are not overly sensitive to fluctuations in the input data, providing more reliable and trustworthy results. Time efficiency is also of great significance, especially in practical applications where timely predictions are often required. A model with high time efficiency can quickly process the data and generate predictions, saving valuable time and resources.

Based on the comprehensive comparison of these three key aspects, the comprehensive effectiveness of establishing restaurant revenue optimization prediction models using the two different algorithms was thoroughly evaluated. The detailed results of this evaluation are vividly presented in Figures 2–4, which offer a clear visual representation of the performance differences between the two models, enabling researchers and practitioners to make more informed decisions regarding the selection and application of the most suitable algorithm for restaurant revenue prediction.

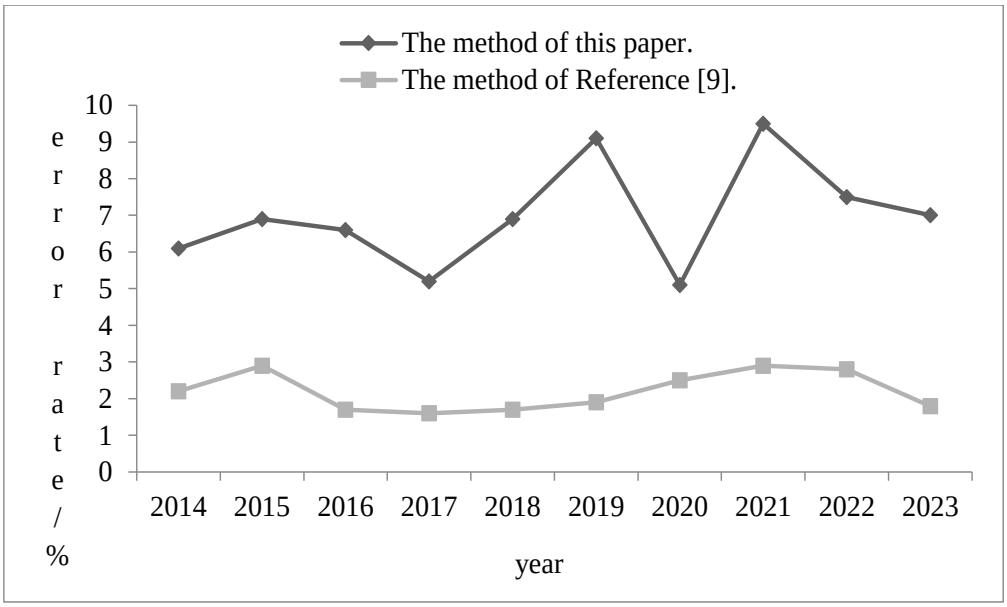

Figure 2. Comparison of modeling error rates for different algorithms.

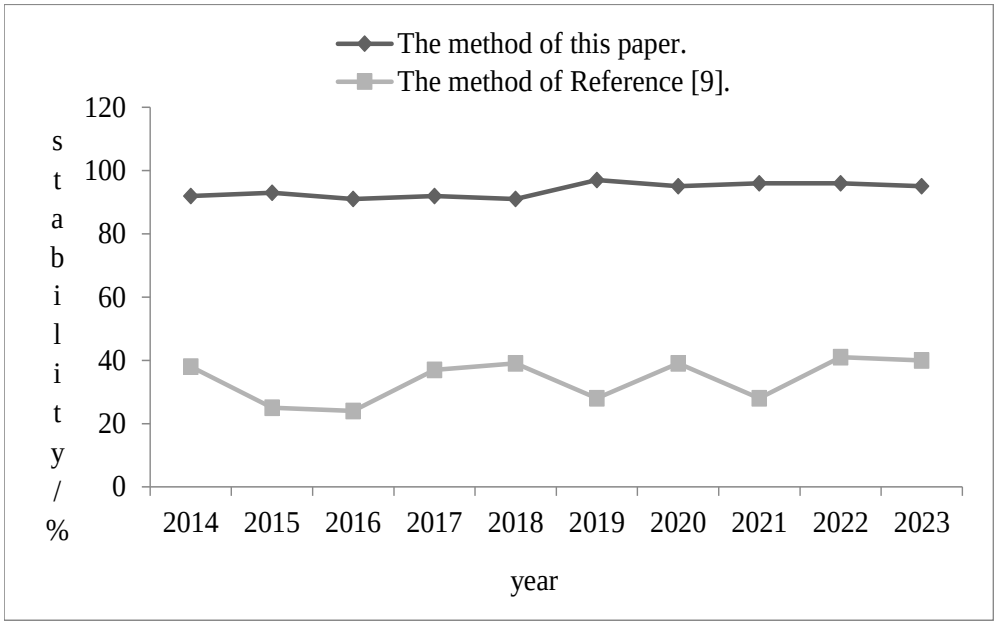

Figure 3. Comparison of modeling stability among different algorithms.

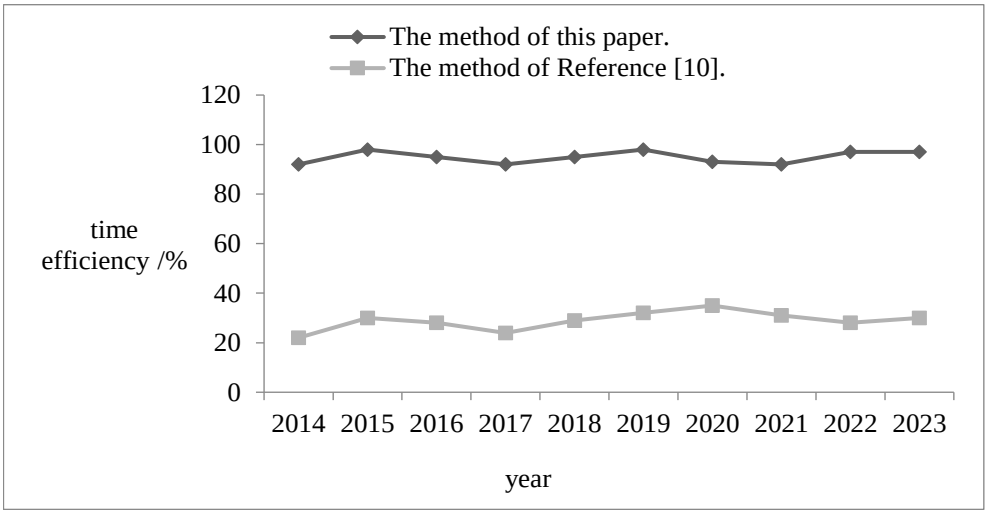

Figure 4. Comparison of modeling time efficiency among different algorithms.

A detailed analysis of Figures 2–4 provides a more in-depth understanding of the performance differences between the two algorithms. It becomes evident that the comprehensive effectiveness of the restaurant revenue optimization prediction model developed with the algorithm proposed in this paper surpasses that of the model based on the algorithm from reference [9,10] by a significant margin.

The key reason behind this superiority lies in the unique approach adopted during the model construction process. When utilizing the proposed algorithm to build the precision model for restaurant revenue optimization prediction, a series of meticulous steps are carried out. Firstly, a vector autoregression model is carefully constructed, taking into account the two crucial variables—restaurant revenue and local economy. This model serves as the foundation for capturing the complex dynamic relationships between these variables.

Subsequently, the Granger causality test is applied to rigorously examine the causal relationship between restaurant revenue and local economy. This test helps to identify the direction and strength of the influence, providing valuable insights into the underlying mechanisms. By accurately determining the causal linkages, the model can better capture the essence of the data and make more reliable predictions.

Furthermore, the proportion of the catering industry is precisely calculated. This step is of great significance as it allows for a more accurate assessment of the direct impact of the catering industry on the local economy. Based on this calculated proportion, a comprehensive statistical analysis of the correlation effect of local catering revenue is conducted. This involves exploring various aspects such as the interdependencies with other industries and the potential spillover effects. Through this detailed analysis, a more refined and accurate restaurant revenue optimization prediction precision model is successfully established, which in turn leads to better performance in terms of prediction accuracy, error rate control, stability, and time efficiency.

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Article

Qingdao Port Throughput Prediction-Based on Grey Prediction Model

Yanping Yang

College of Economics and Management, Qingdao University of Science and Technology, Qingdao266100, China

Abstract: Since Qingdao has been integrated into the “Belt and Road” initiative, the throughput of Qingdao Port has been developing rapidly, but at the same time, the rapid growth of throughput has overwhelmed port infrastructure. Therefore, it is of great significance to measure the throughput scale and study the development trend of throughput. Based on the data of cargo throughput and container throughput of Qingdao port from 2019 to 2022, the grey prediction GM(1,1) model was established and tested using EXCEL, Pycharm64, MATLAB, and mathematical modeling methods. The model is proven to be available, and the cargo and container throughputs of Qingdao Port from 2023 to 2026 are predicted. The results show that the cargo and container throughputs of Qingdao Port increase annually, and the development potential of container transportation is huge. The port department should strengthen the planning and design of the port’s throughput capacity, improve it, and meet the growing actual needs of the port.

Keywords: Qingdao port; throughput; grey prediction model

1. Introduction

Ports play a key role in economic development, as an important part of international trade. Qingdao Port is one of the most important ports in China and one of the busiest ports in the world. The container throughput of Qingdao Port in 2020. In 2020, the cargo throughput of Qingdao Port ranked fifth globally, container throughput ranked sixth globally, and first in Northeast Asia. In 2021, Qingdao Port’s cargo and container throughput will rank fifth in the country. In 2022, Qingdao Port’s cargo and container throughput will rank fourth in the country. Forecasting the throughput of Qingdao Port is of great significance for understanding the development trend of China and global trade, formulating logistics strategies, and optimizing resource allocation. Port throughput is affected by many factors, including domestic and foreign economic situations, trade policy, route arrangement, cargo demand, and transportation technology. The change in these factors complicates and makes the prediction of port throughput challenging. The accurate prediction of port throughput is of great significance for port operations and management. This can help the port formulate reasonable plans and strategies to adapt to the changing cargo flow and to make resource allocation, equipment scheduling, and personnel arrangements in advance. In addition, throughput prediction plays a guiding role in port development planning, port expansion, and the decision-making of freight companies. To accurately understand the future development trend of cargo throughput and container throughput of Qingdao Port and develop a good port development plan, it is necessary to establish a prediction model with high accuracy to predict the cargo throughput and container throughput of

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Corresponding: Yanping Yang (779673085@qq.com)

Qingdao Port.

For the prediction of port throughput, relevant experts and scholars also use different methods, including statistical analysis methods based on historical data, such as time series analysis, regression analysis, etc., as well as prediction models based on machine learning and artificial intelligence, such as neural networks, support vector machines, random forests, etc. This paper takes Qingdao Port as the research object. Because many factors affect port cargo and container throughput, the quantification of many influencing factors is difficult. In the case where the internal and external influencing factors of port throughput cannot be known and there are not many analytical samples available, it is reasonable to use the grey prediction model to construct the throughput prediction model of Qingdao Port from the historical data of port cargo throughput and container throughput. The GM(1, 1) model has the advantages of requiring a small number of data samples and a high short-term prediction accuracy [1]. Therefore, this study uses the grey GM(1,1) model to predict and analyze the cargo throughput and container throughput of Shenzhen Port from 2023 to 2026 based on the data of cargo throughput and container throughput of Shenzhen Port from 2019 to 2022 to provide scientific and accurate methods and models. It provides a practical reference for port departments to make scientific decisions and helps port managers and decision makers make reasonable predictions, plans, and decisions to promote the sustainable development and economic prosperity of ports.

At present, in the study of port throughput, the artificial neural network model is mainly used to predict the freight volume of Florida port in the United States (Klodzinski & Al-Deek, 2015) [2], the multiple linear regression and three-layer BP neural network model are used to predict the throughput of Fangcheng port (Fan Linsheng et al., 2015) [3], and the gray Markov model and ARMA-weighted Markov model are used to predicting the throughput of the port (Shi Leilei, 2015) [4]. Using system clustering and typical index analysis, the main influencing factors were selected, and a multiple regression model was established to predict the throughput of Yingkou Port (Li Guizhi et al., 2015) [5]. Using a regression model, the GDP data of Fujian Province were used to predict the cargo throughput of coastal ports in 2020 (Lin Jian, 2016) [6]. The ant colony algorithm was used to optimize the BP neural network model, fuzzy neural network prediction model, RBF prediction model, and BP prediction model to predict the throughput of a port. The ant colony algorithm optimizes the BP neural network model with the fastest convergence speed (Li, 2020) [7].

2. The Application of GM(1,1) Model in Qingdao Port Throughput Prediction

The data for this study are from the "China Port Statistics" (Table 1). For the convenience of research, the letters *g* and *C* are used to represent the cargo throughput and container throughput respectively, where the cargo throughput is represented by g_{SZ} and the container throughput is represented by C_{SZ}.

Table 1. Data of cargo throughput and container throughput of Qingdao Port from 2019 to 2022.

Year	2019	2020	2021	2022
Cargo throughput (10 million tons)	57.74	60.46	63.03	65.75
Container throughput (10 million TEU)	2.101	2.201	2.371	2.567

2.1. Stage Ratio Test and Modeling Feasibility Judgment

2.1.1. Establish Port Cargo Throughput and Container Throughput Data Time Series

According to the gray prediction model, the established time series of port cargo throughput and container throughput data are as follows:

$$X^{(0)}g_{sz} = \left(X^{(0)}g_{SZ}(1), X^{(0)}g_{SZ}(2), X^{(0)}g_{SZ}(3), X^{(0)}g_{SZ}(4) \right) = (57.74,\ 60.46,\ 63.03,\ 65.75)$$

$$X^{(0)}C_{sz} = \left(X^{(0)}C_{SZ}(1), X^{(0)}C_{SZ}(2), X^{(0)}C_{SZ}(3), X^{(0)}C_{SZ}(4) \right) = (2.101,\ 2.201,\ 2.371,\ 2.567)$$

2.1.2. Get the Grade Ratio

Run with the matlab code according to the following formula:

$$\lambda g_{SZ}(k)=\frac{X^{(0)}g_{SZ}(k-1)}{X^{(0)}g_{SZ}(k)}$$

The code was run with the results as shown belows:

$$\lambda g_{SZ}(k)=\left(\lambda g_{SZ}(2),\lambda g_{SZ}(3),\lambda g_{SZ}(4)\right)=(1.0471,1.0425,1.0432)$$

ditto,

$$\lambda C_{SZ}(k)=\frac{X^{(0)}C_{SZ}(k-1)}{X^{(0)}C_{SZ}(k)}$$

After running with matlab code, the level is obtained as follows:

$$\lambda C_{SZ}(k)=\left(\lambda C_{SZ}(2),\lambda C_{SZ}(3),\lambda C_{SZ}(4)\right)=(1.0476,1.0772,1.0827)$$

2.1.3. Grade Ratio Judgment

Calculate the maximum and minimum values of the level ratio and determine whether it is within a predetermined range. The predetermined range is as follows:

$$\lambda g(k)\in\left(e^{-\frac{2}{n+1}},e^{\frac{2}{n+1}}\right),\lambda C(k)\in\left(e^{-\frac{2}{n+1}},e^{\frac{2}{n+1}}\right)$$

From the stage ratio obtained in Section 2.2.2, it can be seen that, Because all $\lambda C_{SZ}(k)$ and $\lambda C_{SZ}(k)$ are in the boundary region $[0.6703,\ 1.4918]$, the GM(1,1) model with $X^{(0)}g_{sz}$、 $X^{(0)}C_{sz}$ are satisfactory.

2.2. Construction of GM(1,1) Model

2.2.1. Make an Accumulation of the Original Data

Through the running results of pycharm software, it can be seen that:

$$X^{(1)}g_{GZ}(k)=\sum_{m=1}^{k}X^{(0)}(m)\,(k=1,2,3,4)$$

$$X^{(1)}g_{SZ}=(X^{(1)}g_{SZ}(1),X^{(1)}g_{SZ}(2),X^{(1)}g_{SZ}(3),X^{(1)}g_{SZ}(4))$$

Then: $X^{(1)}g_{SZ}=(57,\ 74,\ 118.2,\ 181.23,\ 246.98)$

Similarly, the running results of pycharm software show that

$$X^{(1)}C_{GZ}(k)=\sum_{m=1}^{k}X^{(0)}(m)\,(k=1,\ 2,\ 3,\ 4)$$

$$X^{(1)}C_{SZ}=(X^{(1)}C_{SZ}(1),X^{(1)}C_{SZ}(2),X^{(1)}C_{SZ}(3),X^{(1)}C_{SZ}(4))$$

Then: $X^{(1)}C_{SZ}=(2.101,\ 4.302,\ 6.67,\ 9.24)$

2.2.2. Construct Data Matrix and Data Vector

Data matrix *Bg* and data vector *Yg* are constructed.

Then:

$$\begin{cases}Z^{(1)}g_{GZ}(2)=\frac{1}{2}\left[X^{(1)}g_{GZ}(1)+X^{(1)}g_{GZ}(2)\right]=\frac{1}{2}[57.74+118.2]=87.97\\ Z^{(1)}g_{GZ}(3)=\frac{1}{2}\left[X^{(1)}g_{GZ}(2)+X^{(1)}g_{GZ}(3)\right]=\frac{1}{2}[118.2+181.23]=149.71\\ Z^{(1)}g_{GZ}(4)=\frac{1}{2}\left[X^{(1)}g_{GZ}(3)+X^{(1)}g_{GZ}(4)\right]=\frac{1}{2}[181.23+246.98]=214.11\end{cases}$$

So we get:

$$Yg_{GZ}=\begin{bmatrix}X^{(0)}g_{GZ}(2)\\X^{(0)}g_{GZ}(3)\\X^{(0)}g_{GZ}(4)\end{bmatrix}=\begin{bmatrix}60.46\\63.03\\65.75\end{bmatrix}$$

$$Bg_{sz}=\begin{bmatrix}-Z^{(0)}g_{GZ}(2) & 1\\-Z^{(0)}g_{GZ}(3) & 1\\-Z^{(0)}g_{GZ}(4) & 1\end{bmatrix}=\begin{bmatrix}-87.97 & 1\\-149.71 & 1\\-214.11 & 1\end{bmatrix}$$

Data matrix *Bc* and data vector *Yc* are constructed.

Then:

$$\begin{cases} Z^{(1)}C(2) = \frac{1}{2}\left[X^{(1)}g_{GZ}(1) + X^{(1)}g_{GZ}(2)\right] = \frac{1}{2}[2.101 + 4.302] = 3.2015 \\ Z^{(1)}gC_{GZ}(3) = \frac{1}{2}\left[X^{(1)}g_{GZ}(2) + X^{(1)}g_{GZ}(3)\right] = \frac{1}{2}[4.302 + 6.67] = 5.4875 \\ Z^{(1)}gC_{GZ}(4) = \frac{1}{2}\left[X^{(1)}g_{GZ}(3) + X^{(1)}g_{GZ}(4)\right] = \frac{1}{2}[6.67 + 9.24] = 7.9565 \end{cases}$$

So we get:

$$YC_{GZ} = \begin{bmatrix} X^{(0)}g_{GZ}(2) \\ X^{(0)}g_{GZ}(3) \\ X^{(0)}g_{GZ}(4) \end{bmatrix} = \begin{bmatrix} 2.201 \\ 2.371 \\ 2.567 \end{bmatrix}$$

$$BC_{sz} = \begin{bmatrix} -Z^{(1)}g_{GZ}(2) & 1 \\ -Z^{(1)}g_{GZ}(3) & 1 \\ -Z^{(1)}g_{GZ}(4) & 1 \end{bmatrix} = \begin{bmatrix} -3.2015 & 1 \\ -5.4875 & 1 \\ -7.9565 & 1 \end{bmatrix}$$

2.2.3. Least Squares Estimation for Parameter Series

The least squares estimation of the parameter sequence Pg = $(a, b)^T$

$$P^{\wedge}g_{GZ} = (a^{\wedge}b^{\wedge})^T = (Bg_{GZ}{}^T Bg_{GZ}{}^T)^{-1} Bg_{GZ}{}^T Yg_{GZ}{}^T = \begin{pmatrix} -0.0419 \\ 56.7638 \end{pmatrix}$$

So get a = -0.0419, b = 56.7638.

Similarly, the least squares estimation of the parameter sequence Pc = $(a, b)^T$

$$P^{\wedge}C_{GZ} = (a^{\wedge}b^{\wedge})^T = (BC_{GZ}{}^T B_{GZ}{}^T)^{-1} BC_{GZ}{}^T YC_{GZ}{}^T = \begin{pmatrix} -0.077 \\ 1.9524 \end{pmatrix}$$

So get a = -0.077, b = 1.9524

2.2.4. Modeling

According to the parameters obtained in part 2.2.3, the gray prediction model is established as follows:

$$X^{(0)}g_{SZ}(k) - 0.0419Z^{(1)}g_{SZ}(k) = 56.7638$$

$$X^{(0)}C_{SZ}(k) - 0.077Z^{(1)}C_{SZ}(k) = 1.9524$$

The time response sequence is solved as

$$X^{\wedge(1)}g_{GZ}(k+1) = \left(X^{(0)}g_{GZ}(1) - \frac{a^{\wedge}}{b^{\wedge}}\right)e^{-a^k} + \frac{b^{\wedge}}{a^{\wedge}}$$

$$X^{\wedge(1)}C(k+1) = \left(X^{(0)}C_{GZ}(1) - \frac{a^{\wedge}}{b^{\wedge}}\right)e^{-a^k} + \frac{b^{\wedge}}{a^{\wedge}}$$

2.2.5. Find the Generated Sequence Value and Model Reduction Value

Find the generated sequence value $X^{\wedge(0)}g(k+1)$ and the model reduction value $X^{\wedge(0)}g(k+1)$

Substituting k = 1, 2, 3 into the time response function, we can get $X^{\wedge(1)}g_{GZ}(k+1)$:

$$X^{\wedge(1)}g_{SZ} = (57.74,\ 118.2,\ 181.23,\ 246.98)$$

(Where $X^{\wedge(1)}g_{GZ}(1) = X^{\wedge(0)}g_{GZ}(1) = X^{\wedge(0)}g_{GZ}(1) = 57.74$)

$X^{\wedge(0)}g_{GZ}(k) = X^{\wedge(1)}g_{GZ}(k) - X^{\wedge(1)}g_{GZ}(K-1)$ is generated by decrement.

The reduction value is obtained:

$$X^{\wedge(0)}g_{GZ} = (X^{\wedge(0)}g_{GZ}(1), X^{\wedge(0)}g_{GZ}(2), X^{\wedge(0)}g_{GZ}(3), X^{\wedge(0)}g_{GZ}(4)) = (57.74,\ 60.44,\ 63.03,\ 65.73)$$

Similarly, Find the generated sequence value $X^{\wedge(1)}C_{GZ}(k+1)$ and the model reduction value $X^{\wedge(0)}C_{GZ}(k+1)$

Substituting k = 1, 2, 3 into the time response function, we can get $X^{\wedge(1)}C_{GZ}(k)$:

$$X^{\wedge(1)}C_{GZ} = (2.101, 4.302, 6.673, 9.24)$$

(Where $X^{\wedge(1)}C_{GZ}(1) = X^{\wedge(0)}C_{GZ}(1) = X^{\wedge(0)}C_{GZ}(1) = 2.101$)

$X^{\wedge(0)}C_{GZ}(k) = X^{\wedge(1)}C_{GZ}(k) - X^{\wedge(1)}C_{GZ}(K-1)$ is generated by decrement.

The reduction value is obtained:

$$X^{\wedge(0)}g_{GZ}=(X^{\wedge(0)}g_{GZ}(1),X^{\wedge(0)}g_{GZ}(2),X^{\wedge(0)}g_{GZ}(3),X^{\wedge(0)}g_{GZ}(4))=(2.1010,2.1977,2.3737,2.5637)$$

2.3. Model Test

2.3.1. Cargo Throughput

As we know above, the original and forecast values of the cargo throughput of Qingdao Port from 2019 to 2022 are shown in the table below (As shown in Table 2):

Table 2. Inspection Table of Cargo Throughput of Qingdao Port.

Year	2019	2020	2021	2022
Raw value	57.74	60.46	63.03	65.75
Predicted value	57.74	60.44	63.03	65.73

The average residual $e=0.007387$

The variance of historical data $S_{12}=8.8456$

The residual variance $S_{22}=8.2043\times10^{-5}$

The minimum error probability $P=1>0.95$

The mean square deviation ratio $C=\frac{S_{22}}{S_{12}}=9.275\times10^{-6}<0.35$(as shown in Table 3)

Table 3. Model Accuracy Level.

Model accuracy level	Mean square deviation ratio
Level 1 (Excellent)	C ⩽ 0.35
Level 2 (Pass)	0.35 < C ⩽ 0.50
Level 3 (Basic Pass)	0.50 < C ⩽ 0.65
Level 4 (Fail)	C > 0.65

It was verified that the model error was small and that it could be predicted.

2.3.2. Container Throughput

Also known from the above, the original and forecast values of the container throughput of Qingdao Port from 2019 to 2022 are shown in the table below (as shown in Table 4):

Table 4. Inspection Table of Container Throughput of Qingdao Port.

Year	2019	2020	2021	2022
Raw value	2.101	2.201	2.371	2.567
Predicted value	2.101	2.1977	2.3737	2.5637

The average residual $e=0.00019$

The variance of historical data $S_{12}=0.03133$

The residual variance $S_{22}=6.24919\times10^{-6}$

The minimum error probability $P=1>0.95$

The mean square deviation ratio $C=\frac{S_{22}}{S_{12}}=0.000199<0.35$(as shown in Table 3)

It was verified that the model error was small and that it could be predicted.

2.4. Qingdao Port Throughput Forecast

According to the gray model, the throughput of Qingdao Port from 2022 to 2026 was predicted, and the following results were obtained (as shown in Table 5):

Table 5. Data of cargo throughput and container throughput of Qingdao Port from 2023 to 2026.

Year	2023	2024	2025	2026
Cargo throughput (10 million tons)	68.54867	71.48484	74.54677	77.73986
Container throughput (10 million TEU)	2.76886	2.99049	3.22987	3.48841

3. Conclusion and Discussion

According to the relevant data of cargo throughput and container throughput of Qingdao port, we established a GM(1, 1) grey prediction model to predict the future throughput. Through the analysis of the model, we obtained the average phase residual error and accuracy index, which verified the availability and accuracy of the model. Specifically, the forecast results of the model show that the cargo throughput and container throughput of Qingdao port will continue to grow in the next few years.

According to the forecast data, the cargo throughput of Qingdao port is expected to increase by about 20 million tons in 2026 compared with 2019, while the container throughput is expected to increase by about 13.874 million TEUs. This growth trend is similar to that of Shenzhen Port, and the cargo throughput and container throughput of the latter also show an increasing trend year by year. This shows that with the continuous development of global trade and the prosperity of the regional economy, the demand for port throughput capacity will continue to increase. However, the increasing throughput of Qingdao port will inevitably cause great pressure on the carrying capacity of the port. Although the throughput growth of Qingdao Port is gratifying, the design and planning of its cargo throughput capacity and container throughput capacity lag behind the actual development needs. This mismatch may lead to congestion in the peak period of the port, affecting the timely transportation of goods and the overall operational efficiency of the port. Therefore, the design and planning of Qingdao Port‘s throughput capacity must be adapted to the actual needs to improve the comprehensive benefits of the port. To this end, the port management department should formulate corresponding strategies and measures based on the results of the prediction model to ensure that port facilities and services can meet future needs. This includes upgrading the existing facilities, adding new handling equipment, optimizing the operation process, etc.

Through the accurate prediction of the future development trend of Qingdao port cargo throughput and container throughput, the port department can provide scientific reference for the future development strategy of the port, the planning and construction of container terminals and other major decisions. This not only helps to improve the operational efficiency of the port, but also promotes the sustainable development of the port and ensures that Qingdao Port maintains its advantages in the fierce market competition. In summary, the establishment of GM(1,1) grey prediction model provides important theoretical support and practical guidance for the future development of Qingdao Port. Through scientific prediction and reasonable planning, Qingdao Port can better cope with future challenges and achieve efficient and sustainable development.

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Conflicts of Interest

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Article

Research on BG Group's Working Capital Management under Financial Sharing Mode

Xiujuan Zhang [1,2,*], Thillai Raja [1], Yixiao Xu [1] and Na Lu [2]

[1] *Graduate School of Business, SEGi University, Kuala Lumpur 47810, Malaysia*

[2] *School of Economics and Management, Yunnan Technology and Business University, Kunming 651700, China*

Abstract: In recent years, with the rapid development of the domestic market, many companies have achieved tremendous growth. However, the continuous growth of the group company has also led to many challenges in its branch structure, such as decreased efficiency in financial management and increased costs. These challenges have become obstacles to the further development of group companies, and many group companies have begun to take corresponding measures to address these challenges. Among them, the emergence of the financial sharing center brings a glimmer of hope for the group company to cope with these challenges. It can not only quickly integrate the company's financial resources, but also effectively control operational risks, reduce operating expenses, and enhance the company's strength. BG Group, as a model in the domestic steel industry, has made significant progress since launching its financial sharing model. Its successful cases can not only provide reference for similar companies, but also provide important guidance for future investment and financing. Through horizontal and vertical analysis of BG Group's financial data over the years, identify its shortcomings in working capital management and propose corresponding optimization suggestions to improve the efficiency of the group's working capital management.

Keywords: financial sharing center; group company; BG Group; steel industry; working capital management; efficiency

1. Research Background

Working capital management is an important pillar of corporate finance [1], but also the core of the daily work of enterprises. The main idea of working capital management is the ability to meet short-term debt and operating expense [1]. Through the good working capital management, can make the enterprise internal environment efficient, stable, orderly, thus ensuring the smooth development of daily operations. Working capital management is also important in optimizing corporate profitability [1]. Compared with Western developed countries, working capital management in China is relatively weak, and the influence of cultural embeddedness and informal institutions on economic activities is more widespread and profound in China than in the west [2]. As an important part of our country's economy, the steel industry has accounted for more than 10% of our country's GDP for a long time, its working capital needs are higher than those of the general industry [3]. At the same time, the steel industry is a typical resource-consuming industry. Producing products requires a large amount of mineral resources, such as coal and iron ore, but due to the uneven distribution and

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* Corresponding: Xiujuan Zhang (AnnieZhangonly1@163.com)

limited resources of these mineral resources, its procurement of raw materials, production and sales of products across a longer distance, which the management of steel enterprises put forward higher requirements, need to better achieve the rapid transmission of information and the establishment of a more scientific and effective management system. Therefore, it is more difficult for the steel enterprises to manage working capital, and it is more important for improving enterprise benefit [3]. BG Group, as a "leader" in China's steel industry, is the largest and most modern steel joint venture in China. With its comprehensive advantages in integrity, talent, innovation, management, and technology, it has established its position as a world-class steel joint venture in the international steel market. BG Group is still able to achieve high economic benefits even with the increasing pressure on business, the covid-19 pandemic, and the increasing emphasis on environmental protection, the effective management and control of working capital can be said to be an important reason for the development of the group.

With the continuous advancement and deepening of economic globalization, enterprises have made some achievements in management, and achieved better market competition performance. As the scale grows, more and more enterprises start to set up branches. However, the establishment of the branch causes the development of the enterprise to be hindered by the low efficiency of financial management and the high cost of financial management. In this context, some enterprises began to try to set up financial sharing center. Through the financial sharing center model, it can effectively coordinate the financial resources of the group, standardize the financial management process, reduce operating costs, and improve the ability and quality of financial personnel, make it play a more important role. According to China's Ministry of Finance, large companies and enterprise groups with a large number of subsidiaries need to explore and use information technology to improve the efficiency of accounting operations, and gradually establish financial sharing service centers. This provision supports and encourages the implementation of a financial sharing model by large and medium-sized enterprises in China [4]. In 2005, ZTE established China's first financial sharing service center in Shenzhen [4,5]. Subsequently, the financial sharing service soon expanded among the domestic large and medium-sized enterprises. In 2009, BG Group Shared Service Centre was officially launched, dedicated to providing all the group's subsidiaries with comprehensive financial services. By looking at BG Group's implementation of financial sharing, we can further explore the evolution of its financial sharing model history, better insight into its working capital changes. Although some literatures have recorded the working capital management of some listed companies, the working capital management of the steel industry group companies has not been fully explored, there are few researches on working capital management under financial sharing mode. Therefore, in this study, we will take BG Group as an example to investigate the working capital management under the financial sharing model by comparing the changes of working capital management performance in recent years, this paper raises the question that this research wants to solve: How does the implementation of financial sharing affect the working capital management of the company? What is the mechanism of action? The research results will provide reference for other similar enterprises to improve working capital management performance through financial sharing.

The research is divided into six main parts: research background, literature review, BG Group's motivation and mode of financial sharing, BG Group's working capital management analysis under the financial sharing model, BG Group's working capital management under the financial sharing model and optimization measures, conclusion. First of all, literature review mainly reviews and summarizes the problems of working capital management; How the financial sharing model helps enterprises better manage working capital. Second, it introduces BG Group's motivation of implementing financial sharing and the organizational structure of its financial sharing center. Third, it analyzes BG Group's working capital management from the perspective of factors and capital structure. Fourth, find out the shortage of working capital management under BG Group's financial sharing mode and put forward some measures to optimize it. Finally, it is the conclusion of the thesis to summarize the changes brought by BG Group's working capital management.

Our research will contribute to existing scientific research in two ways. First, we summarize the extensive theoretical and empirical results, which represent the status and problems of working capital management in domestic and foreign companies up to now. Second, we put forward how to use the financial sharing model to

optimize the management of working capital, which will provide reference for other companies in the same industry.

2. Literature Review

Working capital management, also called short-term financial management, refers to the management method that enterprises implement under the guidance of working capital policy. Scientific financial control measures and rational distribution of current assets and liabilities can not only greatly improve the financial situation of enterprises, but also achieve the continuous growth of financial income. Financial sharing is a way of financial management, which can be centralized management of finance, accounting, capital and so on. This way can make the process of financial accounting and financial settlement scale, so as to improve the efficiency of financial management and reduce the cost of enterprises. Therefore, the management transformation under the financial sharing mode is regarded as the "industrialization revolution" of the financial industry. Under financial sharing model, different departments or organizations can share financial data, processes, technology and human resources to achieve more efficient financial management and service delivery. The implementation of this model usually involves the establishment of a unified financial platform, the development of standardized processes and norms, the integration of information systems and technologies, and the training and development of human capabilities [6]. There are abundant literatures on working capital management both at home and abroad, but the research on financial sharing is much more enthusiastic at home than abroad. From the 1950s to the 1980s, scholars began to find ways to optimize working capital management. From the 1990s to the early 21st century, the research on working capital management began to converge globally. By 1993, China began to implement the internationally recognized accounting system and introduced the concept of working capital from abroad, and in the 1990s domestic scholars began to study the management of working capital [7].

In the early days, the efficiency study of working capital management was only based on a single factor index, such as accounts receivable, inventory, accounts payable and so on. However, these single factor indicators can only explain several major internal factors, such as current liabilities, current assets and so on. Therefore, some scholars began to call that the management of working capital should be a comprehensive management of these factors, and should consider the relationship between current assets and current liabilities, the relationship between the preparation of current assets and corresponding capital should be explored from the overall perspective, how to make a reasonable working capital allocation through this relationship. Some scholars especially point out that the working capital management of cross-regional sales companies is not only related to current liabilities and current assets, but also based on process, from source management of suppliers to production management of intermediate links, then to the improvement of working capital management performance, this is the whole process of working capital management. To assess the management capability of working capital, Gitman first proposed the indicator of cash flow period, which refers to the number of days from the initial purchase of production materials' cash information to the final sale of products. However, it did not take into account the impact of current liabilities on working capital. In response to this deficiency, Richard & Laughlin proposed that the efficiency of working capital management can be reflected through the cash cycle. The cash cycle is expressed as the value of accounts receivable turnover plus inventory turnover, minus accounts payable turnover. This may include the impact of current liabilities on working capital, in order to comprehensively reflect the overall status of the company's working capital management. Some domestic scholars refer to this cash cycle as the "working capital turnover period" [7].

According to Wang [8], there are many problems in the management of working capital, such as insufficient working capital, unreasonable capital structure and lack of high-quality financial personnel, enterprises should fundamentally attach importance to and improve the working capital management system, improve the level of knowledge of financial personnel. In view of the importance of working capital for enterprises and the harm brought to enterprises by improper management of working capital, Chen [9] pointed out that in today's rapidly developing market environment, whether the working capital management of an enterprise is proper and efficient has a great influence on the later development prospect of the enterprise. The integrity of the capital chain is the foundation of the survival of the enterprise, and the damage of the problem of the capital chain to

the enterprise will be disastrous, the centralized management and allocation control of the funds of each business unit can reduce the occurrence of financial risks and enhance the capital management ability of enterprises. Yang [10]'s research reveals that there is a positive correlation between the level of working capital management and the profitability of enterprises, that is, when the growth rate of working capital is relatively high, more economic value is created for enterprises. Many scholars hold the same supportive attitude to the necessity of the financial sharing center model for the working capital management of enterprises. Fan [11] believes that as one of the important products in the era of information-based management, the financial sharing center must take information technology as its carrier and play the role of integrating a large amount of data into a unified planning, ensure the utilization and dissemination of information resources, and achieve rational transportation and content sharing among various departments. Therefore, enterprises can make full use of the advantages of financial sharing center to achieve effective management of working capital.

Prša [12] sees the impact of working capital management on corporate wealth, arguing that increased working capital investment can reduce business risk, but has an adverse impact on profitability, and vice versa. Prasad et al. [13] to use the working capital efficiency multiplier as a measure of direct profitability in working capital management. Working capital efficiency multipliers represent financial performance variables such as return on assets, investment capital, return on equity, total operating income, and net operating income. The lower working capital efficiency multiplier indicates the higher working capital efficiency. Naumoski [14] analyzed the impact of effective working capital management on corporate profitability using a sample of 720 companies from Balkans. He defines dependent variables as operating margins, including inventory turnover, days due, days due and cash conversion cycles, as the most comprehensive indicators of working capital management. The results show that the days of accounts payable and the cash conversion cycle have a statistically significant negative impact on the profitability of the company. On the other hand, the number of days due and unpaid has a statistically significant positive impact on profitability. The results also show that south-eastern European companies can improve their operating profitability by reducing the days of accounts receivable outstanding and the cash conversion cycle, as well as by delaying the days of accounts payable in good business relationships. Working capital management is one of the key areas of financial management, according to Vukovi'c & Jakši'c [15]. Vukovi'c & Jakši'c [15] used multiple regression analysis to determine the impact of such variables as current ratios, current liabilitiestotal assets and total liabilitiestotal capital on the return on assets of the Republic of Serbia food industry in 2014. The results show that most of the analysis variables have a significant impact on profitability.

At present, domestic scholars agree that through business process reengineering, the financial sharing model can help enterprises operate more efficiently, better coordinate the group's financial resources, standardize financial management processes, and reduce operating costs, and it can improve the ability and quality of financial personnel, realize the transformation of financial function as well as the transformation of strategy, and finally enhance the core competitiveness of enterprises [4]. Through the understanding and comparison of domestic and foreign materials, the author finds that the discussion of working capital management under the financial sharing model are quite similar, and the discussion methods and concrete contents are also similar, compared with foreign countries, the domestic discussion is more extensive and in-depth, and the discussion of different types of problems is more specific.

3. The Motivation and Model of Financial Sharing in BG Group

Motivation 1: driving change and strengthening financial management. BG Group's financial information quality is poor due to poor communication and Information asymmetry between its subsidiaries, which makes it difficult to make accurate decisions. It needs to find new financial management models to develop in the long run. Therefore, the financial sharing service comes into being. BG's scale is huge, the subsidiary company member is numerous, the personnel distribution is complex. Financial staff workload and simplification, resulting in lower efficiency. In addition, the lack of a unified financial accounting system between the subsidiaries, increasing the difficulty of financial management. If the company's different business processing standards communication is not timely, especially between the upper and lower levels of effective

communication, easy to lead to a rapid response to the latest changes in the market, affect the efficiency and effectiveness of business processing.

Motivation 2: improve the efficiency of financial resources allocation. Through the financial sharing model, the enterprise can optimize the allocation of resources, divide the responsibilities of employees, according to different functional departments and different advantages of employees to play, and improve the efficiency of the use of enterprise resources. The former financial management model has a negative impact on the resource utilization efficiency of each subsidiary.

Motivation 3: strengthen the control of enterprise financial risk. BG Group's various subsidiaries, there is a lack of effective communication and organizational fragmentation problems, in strict control of risk is facing great difficulties. By means of financial sharing, a perfect risk early-warning mechanism can be set up to take effective measures to ensure the real-time exchange of financial data between each subsidiary and headquarters.

BG Group is very strict in financial sharing management, currently has a total of 8 series and 46 functions. These functions are divided into 242 sub-processes, each sub-process corresponding to a post type, covering the accounting can share the main process. Such settings greatly reduce the likelihood of errors, and also better accountability, forcing employees to minimize errors. At the same time, job refinement can also make financial personnel for accounting accurate grasp, will work detailed, so that the task is better, make accounting more clear and transparent, so that the decision-making will be more accurate and effective. BG financial sharing center consists of eight different organizational structures, they are: from purchase to payment, from product sales to payments, from fees to taxes, from scanning to special services, from general ledger to statements, from systems to operations. After the initial application of the financial sharing center, the original 100 finance only need a few dozen people to complete, for the general financial staff requirements have also been reduced, the cost of human resources has been greatly reduced. After the establishment of some time, BG group combined with the characteristics of the company, the Financial Sharing Center model has been adjusted appropriately. After fully considering the separation of physical document flow and information flow, a unified scanning center is set up in the tax documents group, this allows accounting information to be obtained and accounting files to be generated, and the most important original documents to be kept in the original branch or subsidiary for archiving and future reference as required by law.

4. Analysis of Working Capital Management under the Financial Sharing Model of BG Group

4.1. Analysis of Working Capital Management Based on Factor Perspective

4.1.1. Analysis of Account Receivable Turnover Period

With the development of the industry, the amount of the receivables generated by credit sales is also increasing, which requires enterprises to take effective measures to recover these receivables as quickly as possible, so as to turn them into real wealth. In the same industry, the accounts receivable turnover of shorter days of business is usually more competitive. Based on BG Group's 2009–2021 financial statements data, we can get Table 1, Figure 1:

Table 1. 2009–2021 accounts receivable turnover period data.

Year	Account Receivable Turnover Period (days)	Industry Average (days)
2009	13.15	6.25
2010	10.95	6.48
2011	11.09	8.24
2012	14.63	11.52
2013	18.81	12.63
2014	20.48	14.29
2015	21.11	19.95
2016	18.01	15.62

Table 1. Cont.

Year	Account Receivable Turnover Period (days)	Industry Average (days)
2017	17.15	11.05
2018	14.74	9.60
2019	14.68	11.55
2020	13.24	11.54
2021	10.91	8.09

Data source: Oriental Fortune Website.

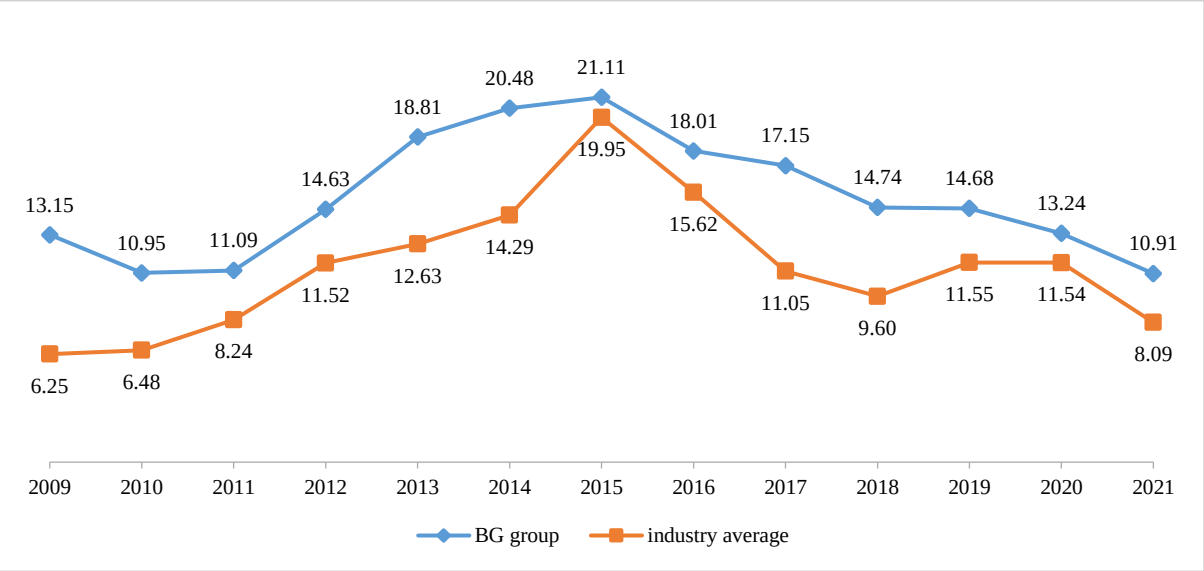

Figure 1. 2009–2021 accounts receivable turnover period data.

On the basis of the data in Table 1 and Figure 1, we can see that despite the large cyclical changes in accounts receivable, in particular some fluctuations in 2009–2010 and a sustained rise in 2010–2013, as the model of financial sharing becomes more and more mature, the cyclical changes of accounts receivable become more smooth. In horizontal comparison, BG Group and industry trends tend to be the same, but BG Group accounts receivable turnover is generally higher than the industry average, indicating that the efficiency of accounts receivable turnover is lower than the industry level, corporate credit policies are less stable and bad-debt risk is higher than the industry average, limiting BG's efficiency in managing its money.

4.1.2. Analysis of Accounts Payable Turnover Period

By calculating the turnover of accounts payable, we can estimate the conditions under which the enterprise can support its normal economic situation, so as to avoid excessive financing of banks. Based on BG Group's 2009-2021 financial statements data, we can get Table 2, Figure 2:

Table 2. 2009–2021 accounts payable turnover period data.

Year	Accounts Payables Turnover Period (days)	Industry Average (days)
2009	52.26	56.73
2010	36.93	48.82
2011	34.18	47.34
2012	40.55	66.03
2013	38.12	58.35
2014	41.63	67.96

Table 2. Cont.

Year	Accounts Payables Turnover Period (days)	Industry Average (days)
2015	50.93	58.55
2016	41.53	53.26
2017	48.43	57.45
2018	40.23	57.45
2019	40.87	52.06
2020	45.85	56.31
2021	45.29	50.13

Data source: Oriental Fortune Website.

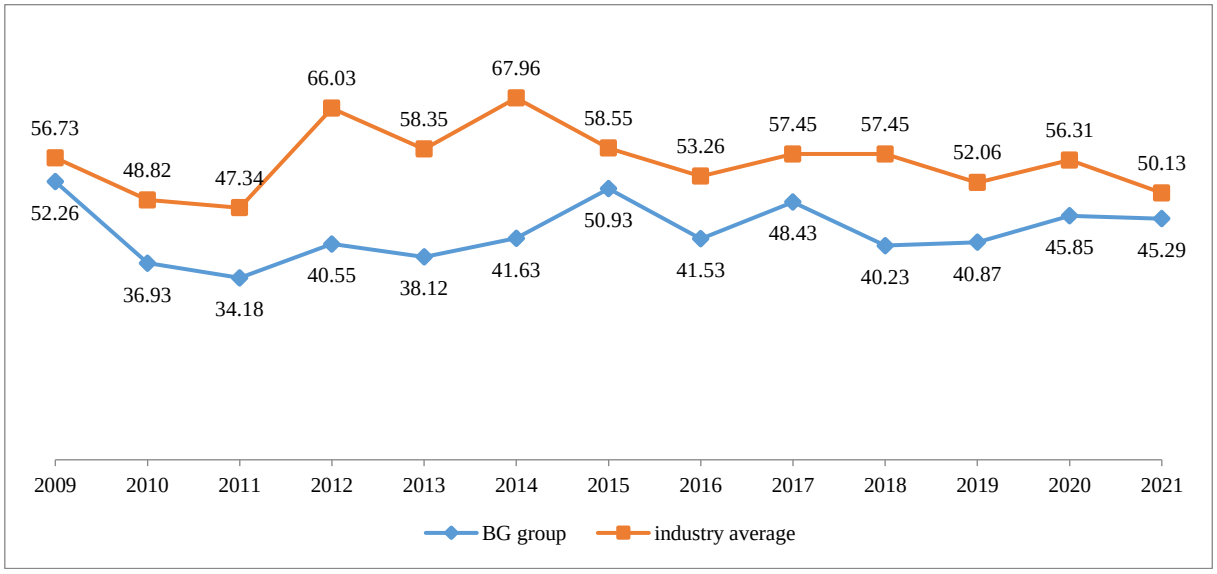

Figure 2. 2009–2021 accounts payable turnover period data.

Based on the data in Table 2 and Figure 2, we can see that the BG group accounts payable turnover period was stable during the implementation of the financial sharing model, this shows that the group has found a stable development strategy for its own. By way of horizontal comparison, BG Group's accounts payable have been less liquid than other enterprises, which indicates that BG Group has been able to utilize the resources needed for its internal economic activities, investment of energy and investment costs are much higher than other enterprises, working capital management efficiency is low.

4.1.3. Analysis of Inventory Turnover Period

Inventory turnover period refers to the total amount of time an item spends in circulation in financial records. In general, the length of this indicator is proportional to the velocity of circulation. If the circulation of goods faster, it is more circulation. The shorter the time that the inventory occupies the fund, the higher the efficiency of inventory management. Based on BG Group's 2009–2021 financial statements data, we can get Table 3, Figure 3:

Table 3. 2009–2021 inventory turnover period data.

Year	Inventory Turnover Period (days)	Industry Average (days)
2009	87.24	66.76
2010	69.26	63.66
2011	66.86	65.86
2012	67.43	79.02

Table 3. Cont.

Year	Inventory Turnover Period (days)	Industry Average (days)
2013	62.85	85.90
2014	61.70	101.94
2015	60.70	108.10
2016	60.30	96.85
2017	64.54	72.34
2018	56.24	62.10
2019	56.71	71.83
2020	57.01	71.30
2021	50.69	52.70

Data source: Oriental Fortune Website.

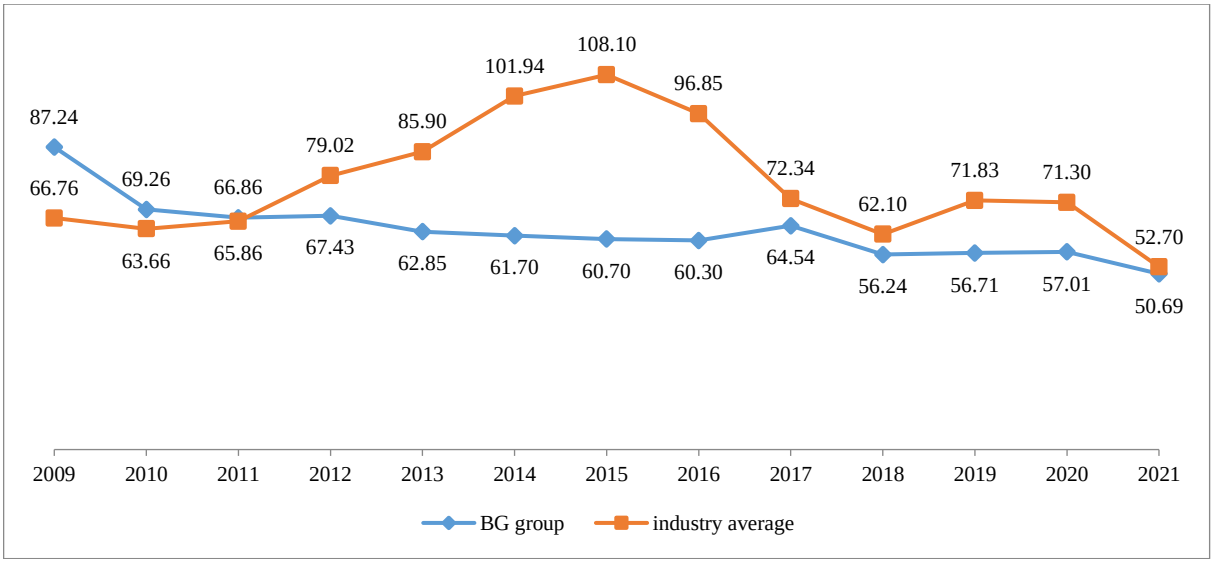

Figure 3. 2009–2021 inventory turnover period data.

From the data in Table 3 and Figure 3, we can see that BG Group's inventory turnover period was above the industry average in 2009 and 2010 during the initial period of the FSC system coming online, but with the stabilization of the financial system, group inventory turnover period continues to decline and is below the industry average. This shows that BG Group, with the support of the financial sharing center Big Data Technology, has developed an inventory control plan that matches the overall plan of the group and ensures the effective use of inventory, this reduces liquidity risk and prevents the risk of reputational damage due to sharp fluctuations in customer demand.

4.1.4. Analysis of Working Capital Turnover Period

The liquidity of capital is an important index to measure the financial management ability of an enterprise. By calculating the liquidity of inventory and accounts receivable, we can get Table 4, Figure 4:

Table 4. 2009–2021 working capital turnover period data.

Year	Working Capital Turnover Period (days)	Industry Average (days)
2009	48.13	16.28
2010	43.28	21.32

Table 4. Cont.

Year	Working Capital Turnover Period (days)	Industry Average (days)
2011	43.77	26.76
2012	41.51	24.51
2013	43.54	8.30
2014	40.55	−12.29
2015	30.88	−67.42
2016	36.78	−79.49
2017	33.26	−24.39
2018	30.75	−5.77
2019	30.52	−8.60
2020	24.40	−4.17
2021	16.31	−0.81

Data source: Oriental Fortune Website.

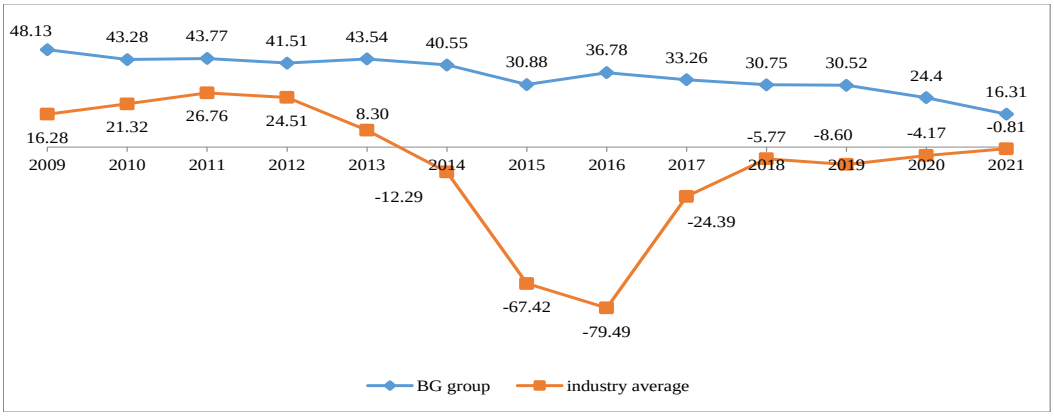

Figure 4. 2009–2021 working capital turnover period data.

Based on the data in Table 4 and Figure 4, we can see that BG Group's working capital turnover period shows a downward trend, which indicates that BG Group has been implementing the financial sharing model, there has been a marked improvement in the efficiency of capital management. Compared with the industry average level, BG Group's working capital turnover period has been improved, but its capital management level still lags behind the industry. Therefore, BG Group in the process of promoting financial sharing, must be constantly improved to achieve better results.

4.2. Analysis of Working Capital Management Based on Capital Structure

The establishment of financial sharing center can better optimize the company's capital structure, and can significantly improve the company's economic performance. Table 5 shows BG Group's financial structure from 2009 to 2021:

Table 5. financial structure Unit ($100 million).

Year	Current Assets	Current Liabilities	Total Assets	Net Working Capital	Current Assets Ratio	Current Liabilities Ratio
2009	527	707	2011	−180	26.21%	35.16%

Table 5. Cont.

Year	Current Assets	Current Liabilities	Total Assets	Net Working Capital	Current Assets Ratio	Current Liabilities Ratio
2010	689	732	2161	−43	31.88%	33.87%
2011	792	988	2311	−196	34.27%	42.75%
2012	697	844	2209	−147	31.55%	38.21%
2013	781	946	2267	−165	34.45%	41.73%
2014	744	983	2287	−239	32.53%	42.98%
2015	699	919	2341	−220	29.86%	39.26%
2016	1386	1703	3591	−317	38.60%	47.42%
2017	1333	1632	3502	−299	38.06%	46.60%
2018	1207	1337	3359	−130	34.89%	39.80%
2019	1375	1381	3459	−6	39.75%	39.92%
2020	1476	1295	3578	181	41.25%	36.19%
2021	1494	1374	3804	120	39.27%	36.12%

Data source: Oriental Fortune Website.

4.2.1. Analysis of Internal Structure of Current Assets

Current assets refer to the assets that an enterprise can cash out or use in one business cycle of one year or more. The speed of cash out of current assets is one of the main indexes to measure the operating effect of an enterprise's working capital. Current assets include accounts receivable, prepaid accounts, inventory and monetary funds. Based on BG Group's 2009–2021 financial statements data, we can get Table 6, Figure 5:

Table 6. internal structure of current assets.

Year	Accounts Receivable	Advance Payment	Inventory	Monetary Funds
2009	10.56%	7.78%	55.98%	10.72%
2010	9.77%	7.93%	55.15%	13.43%
2011	8.82%	6.69%	47.22%	14.90%
2012	12.27%	5.34%	41.46%	25.74%
2013	14.47%	3.92%	39.82%	19.62%
2014	13.44%	3.93%	36.02%	24.46%
2015	13.10%	5.95%	33.62%	18.31%
2016	11.18%	8.08%	35.79%	6.96%
2017	9.08%	6.02%	29.63%	13.43%
2018	10.69%	5.26%	34.47%	14.17%
2019	7.94%	3.64%	29.31%	11.49%
2020	6.66%	3.44%	26.77%	11.86%
2021	8.17%	3.89%	33.13%	13.39%

Data source: Oriental Fortune Website.

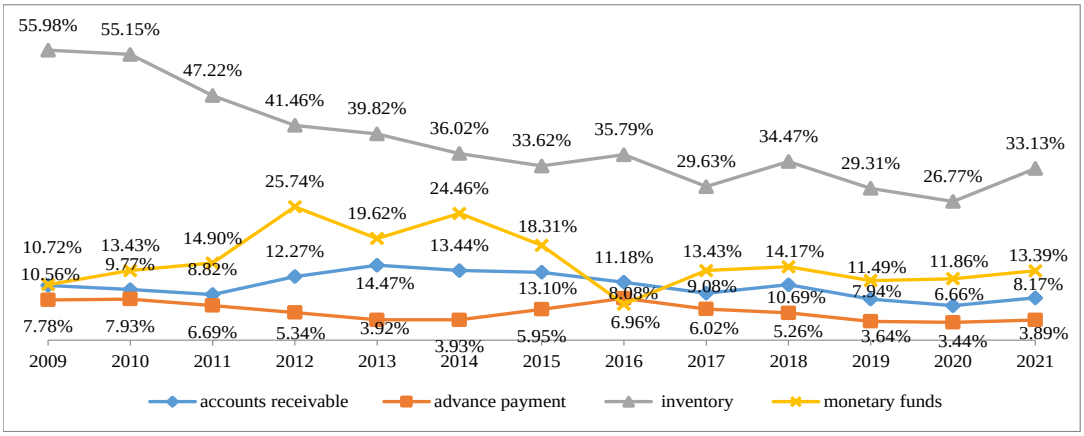

Figure 5. diagram of the internal structure of current assets.

Based on the data in Table 6 and Figure 5, we can see that the ratio of accounts receivable to advances has remained relatively balanced, while the ratio of inventories has decreased from 60.54 per cent in 2009 to 33.13 per cent in 2021, this shows that the shortage of inventory is being effectively eased. According to the statistics in Table 6, BG Group's liquid assets structure has started to become more reasonable. In the process of financial sharing project, the group's team and employees can make better use of these technologies, so that the economic vitality and social impact of the enterprise more concentrated. In addition, BG Group's internal structure of funds has also been appropriately improved, the proportion of current assets is increasing, the enterprise's economic situation has been in a relatively stable state.

4.2.2. Analysis of Internal Structure of Current Liabilities

Current liabilities are an important financial resource that reflects a company's total debt over a period of time. Different current liabilities can help us better understand the company's sources of funds, and predict the efficiency of the company's use of funds. According to their own business strategy, enterprises should formulate a scientific debt management program in line with the actual situation. Based on BG Group's 2009 – 2021 financial statements data, we can get Table 7, Figure 6:

Table 7. internal structure of current liabilities.

Year	Accounts Payable	Advance Payment	Short-Term Borrowing
2009	26.31%	15.56%	34.37%
2010	26.23%	16.12%	32.24%
2011	19.53%	10.93%	39.37%
2012	22.16%	13.27%	37.44%
2013	19.23%	12.68%	36.47%
2014	20.24%	11.70%	32.04%
2015	23.29%	13.60%	29.49%
2016	20.55%	16.03%	30.59%
2017	17.89%	13.54%	36.95%
2018	21.91%	17.05%	28.80%
2019	21.30%	14.92%	9.49%
2020	26.71%	--	9.65%
2021	34.57%	--	7.93%

Data source: Oriental Fortune Website.

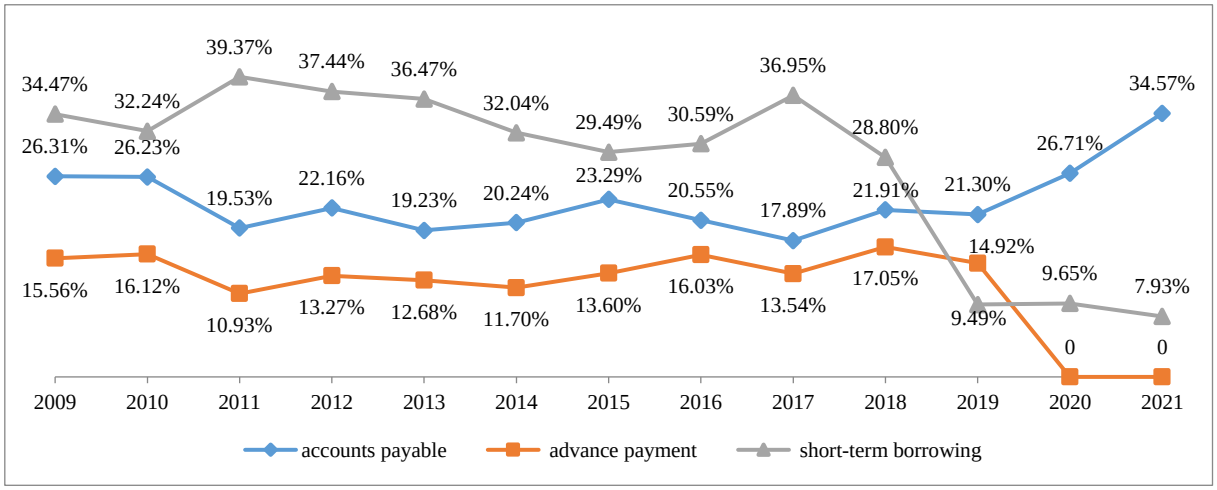

Figure 6. diagram of internal structure change of current liabilities.

Based on the data in Table 7 and Figure 6, we can see that the increase in advance collection indicates that BG Group's actual control and management capability is increasing during the process of trade agreement. This shows that BG Group has been successful in using its business reputation to trade more effectively and has reduced the financial burden arising from the use of commercial bills of exchange, BG group not only received more funds, but also more interest-free loans, greatly improved the efficiency of the company's capital operations.

5. Shortcomings and Optimization Measures of Working Capital Management under Financial Sharing Model of BG Group

5.1. Slow Turnover of Accounts Receivable

When analyzing the working capital management of BG Group, it was found that the company has a large amount of accounts receivable, which limits the efficiency of working capital management. As the scale of a company's accounts receivable expands, the risk of bad debts also increases. We can predict that due to this reason, although BG Group will adjust its credit policies and expand its market share, they will still not be able to bring significant returns. The use of financial sharing to handle accounts receivable cannot fully and effectively solve the problem, for example, the company's business transaction center is not established according to the prescribed standards, and the collection and payment of accounts receivable are not well supervised [16,17].

5.2. Significant Increase in Risks Brought about by Centralized Fund Processing

BG Group has established a financial shared center to centrally manage the funds of all its subsidiaries, thereby reducing the risk of centralized fund processing. However, there are also some potential issues. First, excessive concentration of funds may result in companies being unable to utilize them effectively, increasing the cost of capital for their subsidiaries; Second, due to insufficient allocation of funds to subsidiaries, there may be a shortage of funds. When the funds of multiple subsidiaries are closely linked, there will be a problem of risk transfer. If the funds of one subsidiary are used improperly, it will lead to financing difficulties for other subsidiaries, thereby affecting the overall efficiency of capital flow. If a company fails to handle financial risks in a timely manner, this dispersed risk will quickly transform into a risk for the entire group, greatly hindering the overall development of the company [18,19].

6. Optimization Measures for Working Capital Management under BG Group's Financial Sharing Model

6.1. Develop A Comprehensive Accounts Receivable Management System

BG Group should strengthen the management of accounts receivable, conduct detailed evaluations of customer information and reputation, and remind customers to prevent bad debts from having an adverse impact

on the company's cash flow. For customers with a high reputation, it is important to maintain and consolidate cooperation with them in order to achieve a win-win situation. At the same time, for credit sales business, dedicated personnel should be arranged to keep good records and increase monitoring of accounts receivable to reduce bad debt losses. For loyal customers who have long-term cooperation, it is best to adopt a more flexible credit policy to make them feel the integrity of the company, maintain a good relationship with the company, and have long-term business dealings [20].

6.2. Improve Risk Control System and Reduce Concentration Risk

BG Group must strengthen its internal controls, establish a sound financial risk management system, and regularly hold relevant training activities to improve employees' financial literacy. At the same time, establish a strict supervisory body to regularly review financial statements, promptly detect financial anomalies, take effective measures in a timely manner, and effectively mitigate financial risks. To effectively reduce the financial pressure on enterprises, effective measures should be taken, such as adjusting the structure of liabilities reasonably, expanding financing channels, reducing financial pressure, and providing support for the sustained growth of enterprises [21,22].

In short, BG Group lacks reference experience in building a financial shared service center, and the construction of the shared center itself is a very complex process that will not go smoothly. In this process, continuous adjustments and improvements are needed to identify various problems in the implementation process. First, the company should establish a rigorous fund sharing procedure and provide training to all employees to ensure compliance with the procedure and standardize operations. Second, continuously revise the existing accounting treatment process that is not in line with the company's development status to adapt it to the company's development status. Finally, establish a risk prevention and warning system, and immediately handle situations that do not comply with business processes to reduce the likelihood of risk occurrence [23].

7. Conclusions, Limitations, and Implications for the Industry

The financial sharing model adopted by BG Group from 2009 to 2021 has achieved significant improvements in working capital management. The author will continue to pay attention to BG Group's significant practices in this field and make it a key research area for the future. BG Group's accounts receivable turnover period is significantly higher than the industry average, which has brought huge profits to the company. However, due to the instability of corporate credit policies, the company's bad debt risk is relatively high. In contrast, BG Group's accounts payable turnover period has remained relatively stable, close to the industry average, and has remained at a low level throughout the year. With the development of the industry, the inventory turnover period is also constantly changing, and after adopting the financial sharing model, this change is more obvious, and the inventory turnover period has been effectively maintained. The turnover period of working capital has always been higher than that of the same industry, but after the implementation of the shared center, the enterprise's working capital has been significantly improved. By establishing a financial sharing model, BG Group not only effectively solves the problem of inventory backlog, but also provides an effective strategic guidance for the development of the enterprise, making the internal capital structure of the group more scientific and reasonable.

This study adopts a case study approach to analyze the problems in working capital management under BG Group's financial sharing model, and proposes optimization measures based on this analysis. Although this case-based research method has the advantages of gaining a deeper understanding of the research object, providing real cases, and discovering specific problems, it also has some significant limitations: First, there is a lack of universal applicability. The results of case studies are often limited by specific contexts and conditions, making it difficult to directly generalize to other environments. Second, there is a high demand for case quality. The success of a case largely depends on the quality of the chosen case. High quality cases require representativeness, typicality, and completeness, but they are often difficult to obtain and limited in quantity. Third, there is a strong subjectivity. The results of case analysis are influenced by the subjective judgment and cognitive experience of researchers, which may lead to diversity and inconsistency in the analysis results.

Although there are limitations mentioned above, the conclusions of this study can still provide reference and guidance for companies in the industry to use financial sharing models to manage operating funds.

First, in order to improve the efficiency of enterprise fund management, it is possible to strengthen inventory supervision, control inventory quantities reasonably, and enhance the turnover efficiency of inventory in procurement, production, and marketing processes [24]. The big data function of financial sharing can help enterprises better achieve the above goals. For example, by utilizing financial sharing, it is possible to more accurately grasp the preferences and demand of the target group, summarize the production and sales situation of each round of the enterprise, take customers as the starting point, scientifically and reasonably complete the procurement of raw materials, and thus perfectly link market demand with the quantity of finished products. By utilizing financial sharing, it is possible to view the production cycle, type, and quantity of products in real time, and keep track of the dynamic changes in finished products at any time, thereby reducing waste caused by product backlog. By utilizing financial sharing, it can also enhance the timeliness of information transmission among various departments, encourage them to work together, communicate information between the finance and marketing departments, adjust production plans in a timely manner according to changes in market demand, and improve inventory turnover efficiency [25].

Second, utilizing financial sharing platforms to connect with corporate clients can enhance the matching degree between sales channels and business processes [26]. When selecting cooperative enterprise clients, it is necessary to conduct in-depth investigations into the client's background, strengthen credit management, improve and perfect the client's credit file, classify the client based on their financial status and credit level, and formulate credit policies according to the level. Enterprises should adhere to the basic principle of "collecting all receivables", focus on both daily management and key projects, increase collection efforts, focus on breaking through and reducing collection risks, promote repayment from key customers, and ensure profits with cash flow. At the same time, enterprises can use financial sharing platforms to develop supplier evaluation standards, optimize supplier management systems, strictly enforce supplier admission, assessment, and exit mechanisms, increase supplier control, and conduct comprehensive assessments and evaluations of suppliers, striving to establish long-term cooperative relationships with suppliers with high evaluations. Utilize a financial sharing platform to monitor and warn of accounts payable, control the repayment amount and deadline of accounts payable in a timely manner, and avoid excessive use of supplier funds that may cause difficulties in turnover and affect the establishment of a win-win partnership with suppliers [27].

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The data that support the findings of this study are available from the first author upon reasonable request.

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Conflicts of Interest

The authors report there are no competing interests to declare.

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