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Research on the Application of Grey Prediction Model in the Development of Cross-border E-commerce Platforms for Rural Revitalization

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Abstract: ***Current challenges in agricultural product sales include domestic oversupply, rural technical talent shortages, insufficient market information, and inadequate insurance measures. This study employs the grey prediction model to forecast the development of agricultural product economies under the "RedComplex" platform while integrating red cultural heritage. Methods: A differential equation model was established to analyze historical trends in e-commerce platform growth and project platform quantities for the next two years. A multiple linear regression model was further applied to assess the impact of national policies on China's e-commerce development. Conclusions: The number of e-commerce platforms has surged in recent years, driven significantly by per capita disposable income and consumer confidence indices. Projections indicate 15 million platforms by 2025 and 20 million by 2026. Guided by the "Red Culture Empowering Agriculture" principle, integrated service platforms can enhance rural income. To remain competitive, the "RedComplex" platform requires multi-dimensional upgrades to foster industrial and cultural progress.***

Keywords: Rural revitalization, Red culture, Grey prediction, Multiple linear regression model.

1. Introduction

This study establishes mathematical models to predict e-commerce platform growth and support economic development in red culture regions. By purchasing agricultural products, consumers not only access high-quality goods but also contribute to preserving red cultural heritage. The "RedComplex" platform integrates agricultural sales with red cultural education and experiential activities—such as red tourism, rural lifestyle immersion, and historical exploration—to enhance product value.

Against the backdrop of the Rural Revitalization Strategy, Zhang Ying and Zhou Qingqiang [1] analyzed the challenges in agricultural product marketing from the perspective of its advantages under new media, proposing targeted innovative approaches and valuable insights for enhancing agricultural product marketing through new media channels. Huang Yin, Huang Xiangni, and others [2] utilized social network analysis based on express delivery outlet data from counties in Hunan Province (2012–2021) to measure the development level of county-level express networks, exploring the matching degree and evolutionary trends between these networks and agricultural development levels in the province. Fang Changyuan, Huang Haiyan, and others [3] employed a grey prediction model to forecast the output data of major agricultural products in Bijie City from 2011 to 2020, putting forward three key strategies: 1) balancing food security and economic development; 2) improving basic agricultural production conditions to enhance the supply capacity of major agricultural products; and 3) strengthening grassroots agricultural extension systems to boost farmers' sustainable development capabilities. Wang Zhuo and Yu Li [4] dissected the theoretical logic of the coupling between red culture inheritance and rural tourism development from four dimensions: conceptual alignment, policy support, material nourishment, and market promotion, constructing a coupling mechanism through industrial integration upgrading, talent cultivation, service quality enhancement, and ecological construction. Song Hongyuan, Jiang Changyun, and others [5] systematically expounded on the major principles and reform measures in the "three rural issues" (agriculture, rural areas, rural people) emphasized in the plenary session, aiming to provide theoretical support and policy references for deepening rural reforms in the new stage of Chinese-style modernization. Yan Xin, Ma Qianhong, and others [6] highlighted that improving the rural industrial system and transforming production models through agricultural modernization necessarily involves the comprehensive integration of scientific and technological elements into rural development. Huang Yuhua [7] promoted the innovative development of red culture and comprehensive rural revitalization in Yunkai Village by creating a "red culture +" integrated development path for agriculture, culture, and tourism, driving transformations in characteristic industries, rural tourism, research practices, and grassroots governance. Zhou Wenchao and Li Yingyi [8] investigated the impact of rural e-commerce on the integration of agricultural product supply chains from the perspective of domestic circulation development under the rural revitalization strategy, emphasizing the importance of rural logistics network construction and supply chain development to guide e-commerce growth. Wang Qinglan [9] revealed the critical role of digital e-commerce in optimizing supply chains, expanding sales channels, and enhancing brand influence for agricultural products, promoting the exploration of consumer demand and innovative transaction paths to achieve efficient, transparent, and sustainable agricultural trade. Dai Fenfei [10] stressed the importance of sales data analysis, user behavior analysis, customer data collection/management, and customer interaction/maintenance in e-commerce, which help deepen market understanding, optimize product promotion, and build stable customer relationships.

2. Methods

2.1 Analysis of Factors Influencing E-commerce Platform Development

Step1: For the convenience of subsequent description, the following definitions are made for the collected data.

Definition 1: Let x_0=(x_0(1), x_0(2), x_0(3), …, x_0(n)), where n=(1,2,…,12). x_0 represents the time-series data of China's e-commerce platform quantities from 2011 to 2022, serving as the reference sequence, with x_0(n) denoting the quantity in the n-th year.

Definition 2: Let x_i=(x_i(1), x_i(2), x_i(3), …, x_i(n)), where n=(1,2,…,12). x_i represents system behavior sequences including internet penetration rate, mobile payment penetration rate, consumer confidence index, per capita disposable income, new e-commerce platform quantity, sales growth rate, consumer purchase frequency, and market share from 2011 to 2022, with x_i(n) denoting the value in the n-th year.

Step2: Calculate the initial - point zero - image of the sequence x_i.

Definition 3: Let x_i(0)=($x_i^{(0)}$(1), $x_i^{(0)}$(2), …, $x_i^{(0)}$(k)), where k=(1, 2, …, 12). For i=0, $x_i^{(0)}$ represents the initial point zeroization of the reference sequence, with $xi^{(0)}$(k) calculated as:

$$x_i^{(0)}(k) = x_i(k) - x_i(1), (k = 1,2,3,\cdots\cdots,n) \quad (1)$$

where x_i(k) is the value of the k-th year in the original sequence.

Step3: Calculate the area S_i between the initial - point zero - image $x_i^{(0)}$ and the x-axis. The calculation formula is as follows:

$$s_i = \sum_{k=2}^{n-1} x_i^{(0)}(k) + \frac{x_i^{(0)}(k)+x_i^{(0)}(n)}{2}, (k = 1,2,3,\dots\dots,n) \quad (2)$$

Among them, $x_i^{(0)}$(k) represents the system behavior sequence of the origin-zeroed image.

Step4: Calculate the grey absolute correlation degree between sequences x_0 and x_i.

The grey relative correlation degree refers to the grey absolute correlation degree corresponding to the initial value image of each object. It reflects the proximity of the initial point change rates between each object and the ideal object.

The grey absolute correlation between each object and the ideal object is calculated as follows:

$$\varepsilon_{0i} = \frac{1+|s_0|+|s_i|}{1+|s_0|+|s_i|+|s_0-s_i|}, \varepsilon_{0i} \in (0,1] \quad (3)$$

The result represents the grey absolute correlation degree between sequences x_0 and x_i. A value closer to 1 indicates a stronger association between x_0 and x_i.

2.2 Polynomial Fitting Model

Step1: Perform polynomial fitting on the processed data.

$$f(x) = a_0 + a_1x^1 + a_2x^2 + \cdots\dots + a_nx^n \quad (4)$$

Suppose there are (x_1, y_1)(x_2, y_2)(x_3, y_3)….(x_m, y_m). f(x) represents the functional relationship that can satisfy these points on the curve of the change in the number of e - commerce platforms in China, and a_n represents the multiple - term coefficient of the variable x.

$$F(x) = \sum_{i=1}^{m}(y_i - f(x_i))^2 \quad (5)$$

Among them, y_i is the data of the number of e - commerce platforms in China, f(x_i) is the predicted value of the data of the number of e - commerce platforms in China. The smaller F(x) is, the closer yi and f(x_i) are.

Step2: Take the first - order derivative of formula (2) to get F'(x), find the zero point of the first - order derivative, and then take the second - order derivative. The calculation formulas are as follows:

$$F'(a_i) = \sum_{i=1}^{m}\left(2\cdot\left(y_i - \sum_{j=1}^{n}(a_j\cdot x_j)\right)\right)\cdot(-x_i^i) \quad (6)$$

$$F''(a_i) = \sum\left(2\bullet x_i^{i^2}\right) \quad (7)$$

Step3: Calculate the multiple - term coefficient a_j of the variable x.

In order to obtain a smooth function image, the Newton tangent method is used to obtain an approximate image. Select an initial approximate value x_0, calculate the function value f(x_0) and the derivative value f'(x_0), and use the equation of the tangent line to estimate the root of the function. The equation of the tangent line can be expressed as:

$$y - f(x_0) = f'(x_0)(x - x_0) \quad (8)$$

Set y=0 to find the intersection with the x-axis, leading to the next approximation:

$$x = x_0 - \frac{f(x_0)}{f'(x_0)} \quad (9)$$

Repeat the above process until the required accuracy is met. The calculation formula is shown in formula (5) as follows:

$$a_{ni} = a_{(n-1)i} - \frac{F(a_{ni})}{F'(a_{ni})}, (i=1,2,3\dots) \quad (10)$$

From the multiple - term coefficient a_n of x obtained above, the functional expression of this curve can be directly expressed. Substituting the corresponding x values for the next ten years, the predicted values can be directly obtained.

2.3 Establishment of the Multiple Linear Regression Model

Step1: Construct the multiple - linear regression equation.

Analyze the relationships between variables and the impacts of explanatory variables. In multiple - linear regression, assume there are p variables represented as x_1, x_2, x_3, ..., x_p, and the expression is as follows:

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \dots + \beta_px_p + \varepsilon \quad (11)$$

Among them, β_0 is the intercept, representing the expected value of the dependent variable when all independent variables are zero. β_1-β_p represent the regression coefficients of each variable, that is, the average change in the corresponding dependent variable when the independent variable changes by one unit. y represents the predicted variable y_1, and ε represents the error term, indicating the

random error that the model fails to explain.

If there are *n* samples, the expression is:

$$\begin{cases} y_1 = \beta_0 + \beta_1 x_{11} + \beta_2 x_{12} + \ldots + \beta_p x_{1p} \\ y_2 = \beta_0 + \beta_1 x_{21} + \beta_2 x_{22} + \ldots + \beta_p x_{2p} \\ \ldots \\ y_n = \beta_0 + \beta_1 x_{n1} + \beta_2 x_{n2} + \ldots + \beta_p x_{np} \end{cases} \quad (12)$$

Step2: Construct matrices.

In multiple - linear regression, matrices *X*, *Y*, and the regression - coefficient matrix β can be established from the above formulas for model calculation and solution. The matrix representation is as follows:

$$X = \begin{pmatrix} 1 & x_{11} & x_{12}\ldots & x_{1p} \\ 1 & x_{21} & x_{22}\ldots & x_{2p} \\ & & \ldots & \\ 1 & x_{n1} & x_{n2}\ldots & x_{np} \end{pmatrix}; Y = \begin{pmatrix} y_1 \\ y_2 \\ \ldots \\ y_n \end{pmatrix}; \beta = \begin{pmatrix} \beta_0 \\ \beta_2 \\ \ldots \\ \beta_p \end{pmatrix} \quad (13)$$

Since ε represents the error term, indicating the random error that the model fails to explain, an error matrix is further constructed for it. As shown in formula (14) below:

$$\varepsilon = \begin{pmatrix} \varepsilon_0 \\ \varepsilon_2 \\ \ldots \\ \varepsilon_p \end{pmatrix} \quad (14)$$

After constructing the above matrices, the relationship between the above 3 expressions and matrix *Y* can be expressed as follows:

$$Y = X \cdot \beta + \varepsilon \quad (15)$$

Among them, ε is the random error term, generally assumed to follow a normal distribution $\varepsilon \sim N(0, \sigma^2)$. That is, the multiple - linear regression equation with an expected value of 0 can be written as the following expression:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p \quad (16)$$

The β_1-β_p in the formula can also represent the parameters of the multiple - linear regression equation. In multiple - linear regression analysis, the regression coefficients β_1-β_p are the parameters to be estimated, which can be estimated by the least - squares method or other statistical methods.

Step3: Use the least - squares method to calculate the value of the regression coefficient β.

The least - squares method is an important tool in data analysis, which can easily obtain unknown data and make the error between the obtained data and the actual data small. After obtaining the matrix *Y* through $Y=X\cdot\beta$, the values of β_1-β_p in β can be solved by the least - squares method. The solution formula is as follows:

$$\beta = (X^T X)^{-1} X^T Y \quad (17)$$

From this formula, the intercept β and the regression coefficients β_1-β_p can be calculated.

3. Results and Analysis

3.1 Correlation Analysis of Factors Affecting the Development of E - commerce Platforms

3.1.1 Analysis of Factors Affecting the Development of E - commerce Platforms

The internet penetration rate and the mobile - payment penetration rate are the infrastructure for the development of e - commerce. Without the support of these two, it is difficult for e - commerce to achieve growth. Per capita disposable income and the consumer confidence index are the key factors affecting consumers' purchasing power and have a direct impact on e - commerce sales. The sales growth rate and market share are the core indicators for measuring the performance of e - commerce platforms, reflecting the market performance and competitive position of e - commerce. The user scale of the sinking market and the number of new e - commerce platforms reflect the expansion potential and competition pattern of the e - commerce market. Technology investment and R & D expenditure, as well as the cost of acquiring new users, more reflect the internal operation efficiency and long - term development potential of e - commerce platforms.

3.1.2 Correlation Analysis of Factors Affecting the Development of E - commerce Platforms

The grey comprehensive correlation degrees between each object and the ideal object can be obtained through calculation, and the calculation results are shown in Table 1.

Table 1: Relative Correlation Degrees between Each Object and Factors Affecting the Development of E-commerce Platforms

Object	Correlation Degree
Internet Penetration Rate	0.3964
Mobile - Payment Penetration Rate	0.6211
Consumer Confidence Index	0.8941
Per Capita Disposable Income	0.9216
Number of New E - commerce Platforms	0.4101
Sales Growth Rate	0.8013
Consumer Purchase Frequency	0.7559
Market Share	0.7629
Proportion of Live - commerce Sales	0.6847
User Scale of Sinking Market	0.4671
Technology Investment and R & D Expenditure	0.5186
Cost of Acquiring New Users	0.5702

It can be seen from the above table that the relative correlation degree of per capita disposable income is the highest at 0.9216, which is the most important factor affecting the development of e - commerce platforms in the current environment. The relative correlation degree of the internet penetration rate is the lowest at 0.3964, indicating the least impact. The relative correlation degrees of market share and consumer purchase frequency are close, indicating that they have similar impacts on the development of e - commerce platforms.

In a saturated market, per capita disposable income and the consumer confidence index become even more crucial factors as they directly influence consumers' purchasing decisions. The competition for sales growth rates and market shares becomes fiercer. E - commerce platforms need to innovate and optimize their services to attract and retain customers. Secondly, an increase in the consumer purchase frequency and the proportion of live - commerce sales can help e - commerce platforms find new growth opportunities in a saturated market. In addition, the penetration rate of mobile payments and technology investment in R & D expenditure

remain the keys to enhancing user experience and operational efficiency. The user scale of the sinking market and the number of new e - commerce platforms become potential growth points and new competitive areas when the market is saturated. Moreover, although the internet penetration rate is no longer the main driver of growth, it remains a fundamental prerequisite for the development of e - commerce.

3.2 Forecast Analysis of E - commerce Platform Development

Against the backdrop of the implementation of the Rural Revitalization Strategy, e - commerce has become one of the main driving forces. With the rapid development of technology and the gradual increase in the internet penetration rate, China's e - commerce industry has experienced rapid growth in recent years. Not only has the market scale continued to expand, but technological innovation and policy support have also provided strong impetus for its development. At the same time, the development of rural e - commerce and industrial e - commerce has also presented new opportunities for the future growth of the e - commerce industry.

The approximate image of the change trend of the number of e - commerce platforms in recent years is obtained by using the Newton tangent method, and the number of e - commerce platforms in 2025 and 2026 is predicted, as shown in Figure 1.

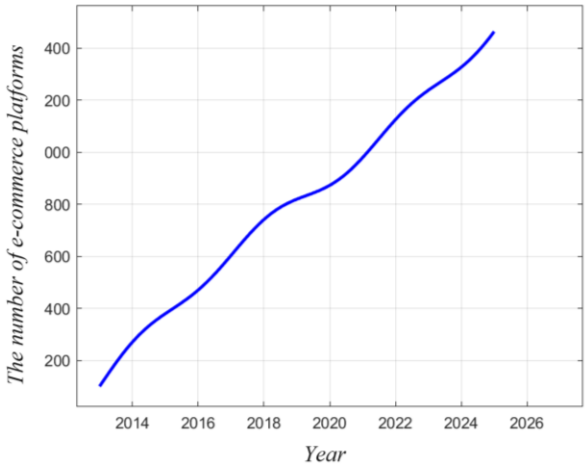

Figure 1: Curve Graph of the Number of E - commerce Platforms in China

This graph reflects that the number of e - commerce platforms in China has shown an upward trend in recent years. Using the multiple - term coefficients a_n of x obtained above, the functional expression of this curve can be directly represented. By substituting the corresponding x values for the next ten years, the predicted values can be directly obtained. It is predicted that the number of e - commerce platforms will reach 15 million in 2025 and 20 million in 2026.

3.3 Impact of National Policies on the Development of Chinese E - commerce Platforms

3.3.1 Some Relevant Policies Issued by the State in the Past Decade for the Healthy Development of Online and Offline Platforms

Online - offline Interaction and Innovative Development of Commercial Circulation: The General Office of the State Council put forward the opinions on promoting online - offline interaction and accelerating the innovative development and transformation and upgrading of commercial circulation.

Standardized and Healthy Development of the Platform Economy: Departments such as the National Development and Reform Commission issued several opinions on promoting the standardized, healthy, and sustainable development of the platform economy.

High - quality Development of Rural E - commerce: Nine departments including the Ministry of Commerce jointly issued the "Implementation Opinions on Promoting the High - quality Development of Rural E - commerce". This policy aims to cultivate about 100 rural e - commerce "leading counties" nationwide within five years, about 1,000 county - level digital circulation leading enterprises, about 1,000 county - level live - commerce bases, and about 10,000 rural e - commerce leaders.

Encouraging New E - commerce Formats and Innovative Business Models: The state actively encourages the development of new e - commerce formats, promotes the innovation of business models, and facilitates the research, development, application, and promotion of e - commerce technologies. In addition, it is committed to promoting the construction of the e - commerce credit system to create a market environment conducive to the innovative development of e - commerce.

Tax Policies: The State Taxation Administration has strengthened tax supervision over e - commerce platforms and issued the "Regulations on the Submission of Tax - related Information by Internet Platform Enterprises (Draft for Soliciting Opinions)". This policy not only affects the operating costs of platform enterprises but may also have a profound impact on the entire e - commerce ecosystem.

3.3.2 Sensitivity Analysis to Determine the Impact of National Policies on the Development of Chinese E - commerce Platforms

Highest Sensitivity: Encouraging new e - commerce formats and innovative business models. This policy directly affects the business models and development directions of e - commerce platforms. For e - commerce platforms that pursue innovation and market opportunities, this is the most sensitive and crucial policy.

Second - highest Sensitivity: Online - offline interaction and innovative development of commercial circulation platforms. This policy is related to how e - commerce platforms integrate online and offline resources and improve circulation efficiency, which has a significant impact on the overall operation of e - commerce and user experience.

Medium Sensitivity: Tax policies. The adjustment of tax policies directly affects the cost and profit margins of e - commerce enterprises and has a relatively large impact on enterprise management decisions.

Lower Sensitivity: Economic regulation and healthy

development. Although this policy is crucial for the long - term development of e - commerce platforms, its effects are more reflected at the macro level, and its direct impact on individual e - commerce platforms is relatively small.

Lowest Sensitivity: High - quality development of rural e - commerce. Although it is of great significance for the development of the rural e - commerce market, compared with other policies, its impact scope on the overall e - commerce platforms is relatively small, mainly targeting specific markets and fields.

In recent years, Chinese national policies have actively supported the development of e - commerce platforms. Through measures such as optimizing the tax and regulatory environment, promoting cross - border e - commerce, strengthening intellectual property protection, promoting green e - commerce, supporting rural and industrial e - commerce, strengthening international cooperation and market expansion, and promoting scientific and technological innovation and application, favorable development conditions have been created for the e - commerce industry. These policies have not only promoted the standardization and high - quality development of e - commerce platforms but also facilitated the online sales of agricultural products, enhanced the modernization level of the industrial chain, and promoted the internationalization process of the e - commerce industry, providing strong impetus for the continuous growth and transformation and upgrading of the Chinese e - commerce industry.

3.4 RedComplex Software

The “RedComplex” software is a unique application featuring prominent red culture, regional characteristics, and cultural connotations. By deeply exploring local red culture and combining it with local agricultural characteristics, it has two interfaces for consumers and farmers. It carefully selects agricultural products with red - culture and regional characteristics to meet consumers’ demands for high - quality, story - rich, and emotionally - engaging shopping experiences. Through this App, users can easily purchase red - themed agricultural products, such as “Special Agricultural Products from Revolutionary Holy Lands” and “Red Memory Series Delicacies”. The RedComplex software has the following features:

Inheriting Patriotic Education: Red - culture products have the responsibility to inherit the great spirit and rich culture formed by the Communist Party of China and the Chinese people during the revolutionary, construction, and reform periods, conduct patriotic education for future generations, and promote the core socialist values.

Preserving Historical Memories: Red - culture products should play an important role in preserving historical memories, witnessing historical events and figures, and providing important materials for future generations to study and research history. This platform incorporates local major events and red culture into product packaging during product development and shoots red - themed stories into short videos to preserve historical memories.

Spreading Cultural Values: Red - culture products display the great spirit and rich culture formed by the Communist Party of China and the Chinese people during the revolutionary, construction, and reform periods to the public through various forms, such as books, movies, memorial halls, and exhibitions. Red - culture products need to spread the cultural values and moral concepts contained therein to the public to promote the prosperity and development of social culture.

Stimulating Patriotic Enthusiasm: Through the dissemination and promotion of red - culture products, citizens’ patriotic enthusiasm can be stimulated, and national identity and national pride can be enhanced. Red - culture products showcase the heroic deeds and great spirit of the Chinese people during the revolutionary, construction, and reform periods, further uniting the strength of all people and striving for the realization of the Chinese Dream of the great rejuvenation of the Chinese nation.

Supporting Rural Revitalization: While developing, red - culture products should drive local economic development, support rural revitalization, and promote regional economic diversification. The purpose of this platform is to combine rural revitalization with red culture to narrow the urban - rural income gap.

Promoting International Exchanges: Red - culture products are not only precious cultural heritages of China but also bridges and bonds for international exchanges. Through the display and promotion of red - culture products, foreigners’ understanding and knowledge of China can be effectively enhanced. For example, red - themed short videos and red - story presentations can convey China’s history, culture, and values, enabling foreigners to have a more comprehensive understanding of China.

By purchasing agricultural products, consumers can not only enjoy high - quality agricultural products but also contribute to the inheritance of red culture, thus supporting the economic development of red - culture regions. The platform takes the initiative to shoulder the responsibility of red - culture education. Combining the sales of agricultural products with red - culture education and experience activities, such as red - themed tourism, rural - life experiences, and learning about red history, can increase the added value of products.

4. Conclusion

In recent years, the number of e - commerce platforms has been increasing. Per capita disposable income and the consumer confidence index have the greatest correlation with the changes in the number of e - commerce platforms. At the same time, it is predicted that the number of e - commerce platforms will continue to show an increasing trend in the future. The predicted values are 15 million in 2025 and 20 million in 2026. Adhering to the development concept of “red - culture leading and agricultural - economy revitalizing”, we provide guiding suggestions to relevant personnel in rural governments across the country. Through the red - culture - based agricultural - economic comprehensive service platform, more market opportunities and economic income can be brought to farmers. With the intensifying competition in e - commerce platforms in the future, the “RedComplex”

software should be upgraded mainly in aspects such as technological innovation, consumer experience, seamless online - offline integration, personal privacy protection, and payment - method innovation. By adhering to its original intention, it can promote the upgrading of the agricultural industry, carry forward and inherit red culture, enhance cultural confidence, and contribute to the realization of the Chinese Dream of the great rejuvenation of the Chinese nation.

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