

A Tripartite Evolutionary Game Approach to Rural E-Commerce Development under the Digital Economy: Mechanism and Policy Implications.

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ABSTRACT

In the era of the digital economy, the high-quality development of rural e-commerce conforms to the trend of rural revitalization and urban-rural integration. As a link between small-scale farmers and the large market, rural e-commerce injects new impetus into the modernization of agriculture and rural areas by reconstructing the circulation system of agricultural products, activating rural resource elements, and cultivating new types of business subjects. Based on the dynamic game relationship among the three subjects of the government, e-commerce enterprises, and farmers, this paper constructs an evolutionary game model and conducts numerical simulations to explore the key factors influencing the coordinated development. The research findings are as follows: (1) The resource integration ability of e-commerce enterprises is positively correlated with the speed of system evolution, which can promote cooperation among the three subjects. (2) The government's fiscal subsidies and incentive supervision policies play an important role in activating the coordination among the three subjects. (3) The awareness of new e-commerce models among farmers is an important factor in the current high-quality development of rural e-commerce, which has a significant effect on accelerating the cooperation among the three subjects. (4) By establishing a dynamic supervision system based on credit ratings and following a composite governance path of "policy guidance - technological empowerment - community co-governance", a dynamic balance can be maintained between market vitality and consumer rights. This study provides practical guidance for resolving the coordination dilemma in the rural e-commerce ecosystem.

Keywords: Digital economy, rural e-commerce, high quality development, evolutionary game

(MSC2020) Codes: 91A22, 91A80, 90B50

1 | INTRODUCTION

During the pandemic, the sales of agricultural products were severely impacted. Since 2024, with the implementation of the high-quality development project of rural e-commerce, rural e-commerce has shown a favorable growth trend and has become the core engine for comprehensively promoting the rural revitalization strategy. In 2024, China's agricultural product e-commerce exceeded the target set in the "2024 Digital Village Development Work Points" for the online retail sales of agricultural products, reaching 679.78 billion yuan, with "Digital Commerce for Agriculture" helping agricultural products to move up the chain, and promoting the growth of rural and agricultural online retail sales by 6.4% and 15.8% respectively. With the continuous deepening of new agricultural productivity and the accelerated advancement of digital village construction, rural e-commerce has gradually embarked on a path of high-quality development. The "Three-Year Action Plan for Digital Commerce (2024-2026)" issued by the Ministry of Commerce proposes that to implement the rural e-commerce high-quality development project, it is necessary to cultivate several rural e-commerce live-streaming bases and county-level digital circulation leading enterprises, and organize and carry out related activities of rural live-streaming e-commerce. The "Opinions on Promoting the High-Quality Development of Rural E-commerce by the Ministry of Commerce and 9 Other Departments" in 2024 pointed out that it is necessary to follow the trend of digital economic development, and through the construction of a collaborative, innovative and efficient rural e-commerce ecosystem, smooth the economic circulation between urban and rural areas, and promote farmers' income increase and rural consumption [1]. The 2025 Central No. 1 Document once again emphasized the need to promote the high-quality development of rural e-commerce. Under the guidance of numerous policies, rural e-commerce has a clear development direction and shows vigorous momentum for high-quality development. However, due to the lagging digitalization level of infrastructure and the incomplete cold chain logistics system in rural areas, the efficiency of agricultural product sales and circulation is low, and the coordination among the subjects shows a "fragmented" feature. Against this background, analyzing the key variables that affect government policy supply, e-commerce enterprises, and farmers' participation decisions has become the core breakthrough to solve the predicament of high-quality development of rural e-commerce in the digital economy.

At the strategic intersection of the digital economy and rural revitalization, rural e-commerce has demonstrated significant economic and social value. Many scholars have conducted in-depth research on this. Regarding the role of rural e-commerce in increasing farmers' income and promoting consumption, Qin et al. believed that the development of rural e-commerce significantly boosts farmers' income growth [2], Wang et al. believed that rural e-commerce can expand market coverage and reduce transaction costs [3], Song and Cheng, through their research on the relationship between

e-commerce and the economic resilience of rural households, concluded that the participation of e-commerce enhances the economic resilience of rural households by facilitating the return of labor force to work and improving their information acquisition capabilities. Moreover, the effect is more pronounced in areas with a lower level of agricultural industry and a larger digital gap, as well as in rural households with diverse livelihood methods [4]. Sun investigated the impact degree and intrinsic mechanism of rural e-commerce on farmers' income, arguing that rural e-commerce can expand production scales, optimize the allocation of human capital, enhance the level of social capital, and unleash the potential of rural development. Therefore, it is advocated that the popularization and promotion of e-commerce in rural areas should be advanced [5].

The discussion on the responsibility of digital economy-driven rural e-commerce to undertake social responsibilities is also increasingly rich. Ding et al. [6] and Bai et al. [7] both concluded that the development of rural e-commerce has significantly enhanced residents' happiness. Wang and Jin believed that rural e-commerce industrial entrepreneurship can drive non-agricultural employment [8]. Yang and Han concluded that rural e-commerce can provide more resources for the countryside and promote urban-rural integration, significantly improving the level of innovation and entrepreneurship [9]. You believed that in the process of promoting employment, attention should be paid to supporting training and policy support [10]. In addition to promoting integrated development between urban and rural areas and facilitating employment and entrepreneurship, Tang et al. argued that with the assistance of digital inclusive finance, rural e-commerce has significantly increased the income of rural residents and narrowed the income gap between urban and rural areas. However, this effect may vary significantly due to differences in geographical location, digital technology, and the development level of e-commerce among different regions [11]. Chen et al. found that the digital economy can promote the development of rural e-commerce, thereby changing the traditional wholesale and retail models of agricultural products. At the same time, using rural e-commerce platforms can reduce the transportation costs of agricultural products and lower the terminal sales prices of agricultural products, thereby reducing the price fluctuations of agricultural products [12].

Regarding the construction of the rural e-commerce ecosystem, scholars analyze and discuss the existing problems and propose corresponding countermeasures. Based on the existing problems in the high-quality development of rural e-commerce, Yu and Li proposed three measures: constructing a new ecology for the high-quality development of rural e-commerce, establishing a new development structure, and developing new logistics models, aiming to continuously promote the high-quality development of rural e-commerce in the context of comprehensive rural revitalization [13]. Yang and Zhang, based on the digital economy leading the construction of rural e-commerce ecology, analyzed the problems faced by rural e-commerce development from the aspects of

agricultural product production, transportation, and sales, and proposed solutions [14]. Guo and Chen employed the entropy weight method and the obstacle factor diagnosis model to analyze the level of high-quality development of rural e-commerce in China under the new development concepts, as well as the main constraints. Finally, in response to the main constraints, corresponding development countermeasures were proposed from five aspects: innovation, coordination, openness, green development, and sharing [15].

Most studies on e-commerce using the evolutionary game method focus on core issues such as platform credit regulation, rural e-commerce logistics system, and multi-party cooperation mechanisms. Wang and Ren constructed an evolutionary game model involving the platform e-commerce, consumers, and the government's dynamic punishment and incentive mechanisms. They concluded that the government should combine the punishment mechanism and the incentive mechanism for moderate regulation, in order to achieve a dynamic balance in credit supervision. At the same time, it is necessary to note that consumers' reputation evaluations of platform e-commerce have two sides [16]. From the perspective of the development of rural e-commerce logistics, Fan et al. constructed a two-stage game model and found that the "shared logistics" model can reduce distribution costs, but the issue of benefit distribution needs to be addressed [17]. Liang and Zhang through the analysis of the government-enterprise game, proposed that a mixed distribution system combining government subsidies and market-oriented operation is more sustainable [18]. From the perspective of multi-party interaction, scholars have mostly focused on the interactions among the three subjects: consumers, merchants, and e-commerce enterprises. Liu et al. conducted a study on the cooperative behaviors of agricultural product suppliers, agricultural product e-commerce enterprises, and consumers from the perspective of traceability of agricultural product quality safety. They concluded that enhancing the quality control capabilities of e-commerce enterprises, strengthening government supervision and punishment measures, and enhancing consumers' awareness of rights protection can effectively promote the formation of a stable and positive operation model in each link of the supply chain [19]. Shi et al. established an evolutionary game model for merchants, consumers, and platform enterprises, and proposed suggestions such as constructing a platform governance system based on blockchain, encouraging merchants to utilize blockchain technology to enhance the transparency and traceability of their own businesses, and guiding consumers to participate in the construction of the blockchain online evaluation system, aiming to promote the modernization, intelligence, and efficiency of platform governance, and achieve high-quality development of e-commerce platforms [20].

Current research mainly focuses on the development paths and countermeasures of rural e-commerce, providing important references for subsequent studies. However, the research on the

game relationship and dynamic decision-making mechanism among the three main subjects - farmers at the production end, the government at the regulatory end, and e-commerce enterprises at the circulation end - is still insufficient. In view of this, this paper, while focusing on the government's incentives and supervision of rural e-commerce development, also pays attention to the influence of two important factors - the intensity of resource integration by e-commerce enterprises and the cognitive level of farmers towards new e-commerce models - on the high-quality development of rural e-commerce. By constructing a collaborative mechanism of government guidance, enterprise leadership, and farmer participation, it not only can solve the "information island" and "trust loss" problems in the traditional production and sales system, but also can effectively integrate the government's public service resources, the platform operation capabilities of e-commerce enterprises, and the local production advantages of farmers, forming a sustainable development model of data-driven production decision-making, intelligent logistics cost reduction and efficiency improvement, and regional brand value enhancement, ultimately achieving the synergy of agricultural product circulation efficiency and farmers' income increase.

2 | ANALYSIS OF GAME SUBJECTS

This paper defines the game subjects in the high-quality development of rural e-commerce as the government, e-commerce enterprises, and farmers. The three subjects promote the high-quality development of rural e-commerce through goal coordination and the interest game.

The government is the policy provider and digital infrastructure investor for the high-quality development of rural e-commerce. The government integrates rural e-commerce into the rural revitalization strategy through top-level design and provides high-quality public services to stimulate the participation motivation of e-commerce enterprises and farmers through institutional dividends [21]. However, during policy implementation, there may be problems such as excessive intervention, suppressing market vitality, and laissez-faire leading to disorderly competition and resource waste. Therefore, the core game strategy of the government lies in balancing the guiding strength of the "visible hand", requiring dynamic adjustment of incentives and penalties to build a system environment that combines efficiency and fairness, motivating e-commerce enterprises to strengthen resource integration, rewarding farmers for supervising the behavior of e-commerce enterprises, and maintaining the ecological environment of rural e-commerce high-quality development.

E-commerce enterprises are the core entities in the process of high-quality development of rural e-commerce. They are at the intersection of government policy guidance and farmers' practical needs. They need to leverage government policies to expand the rural market and fulfill their social responsibilities, while also coping with the cost pressures brought about by digital transformation. In the process of high-quality rural e-commerce development, e-commerce enterprises can adopt

strategies such as resource integration, technological upgrading, and institutional adaptation to help farmers shorten the circulation cycle for selling agricultural products, thereby significantly increasing farmers' direct income [22]. During the process of integrating resources and upgrading technology, e-commerce enterprises also gain more business and grow continuously. However, in the early stage of development, e-commerce enterprises' operation through digital technology requires a large investment of costs, resulting in low enthusiasm. They mostly maintain traditional operation models and pursue short-term profits. In the long run, this business model is not suitable for the high-quality e-commerce environment. Therefore, e-commerce enterprises should actively carry out resource integration or optimize cooperation mechanisms, ensuring reasonable returns while emphasizing the establishment of sustainable partnerships with farmers. This not only resolves the trust crisis caused by "short-term profit-seeking" in the game process but also lays the foundation for the long-term stable development of e-commerce.

Farmers, as the core practitioners and value-creating subjects of the digital development of e-commerce, focus on enhancing personal income and avoiding risks. Their depth of production decisions and market participation directly determine the development level of rural e-commerce. Under the dual constraints of the digital skills gap and market fluctuation risks, some farmers, due to insufficient technical understanding or high initial investment pressure, gradually lose their connection with the Internet market and tend to maintain production safety through conservative participation strategies [23]. To enhance the enthusiasm of farmers for deep participation, the government needs to improve their participation willingness to participate through skills training and direct incentives, while e-commerce enterprises can reduce the risks brought to farmers by market fluctuations through order insurance mechanisms. In the high-quality development of rural e-commerce, the deep participation of farmers not only reflects the standardized investment at the production end, but also requires optimizing production decisions through reverse optimization based on market demand information, forming a virtuous development model of "demand driving supply", allowing farmers to transform from primary producers to "agricultural entrepreneurs", and injecting digital endogenous driving force into rural revitalization.

The government reduces the cost of collaboration through institutional innovation, enterprises empower collaboration efficiency through digital technology, and farmers demonstrate collaborative value through production transformation. The three subjects adapt their strategies to transform adversarial games into symbiotic development. In the data-driven integration of production and sales, they achieve a win-win situation for public interests, commercial benefits, and individual well-being.

3 | MODEL CONSTRUCTION AND BASIC ASSUMPTIONS

3.1 | Model Construction

The behavioral choices of the government, e-commerce enterprises, and farmers will affect the effectiveness of the high-quality development of rural e-commerce. Based on this, a logical relationship diagram of the three subjects is constructed, as shown in Figure 1.

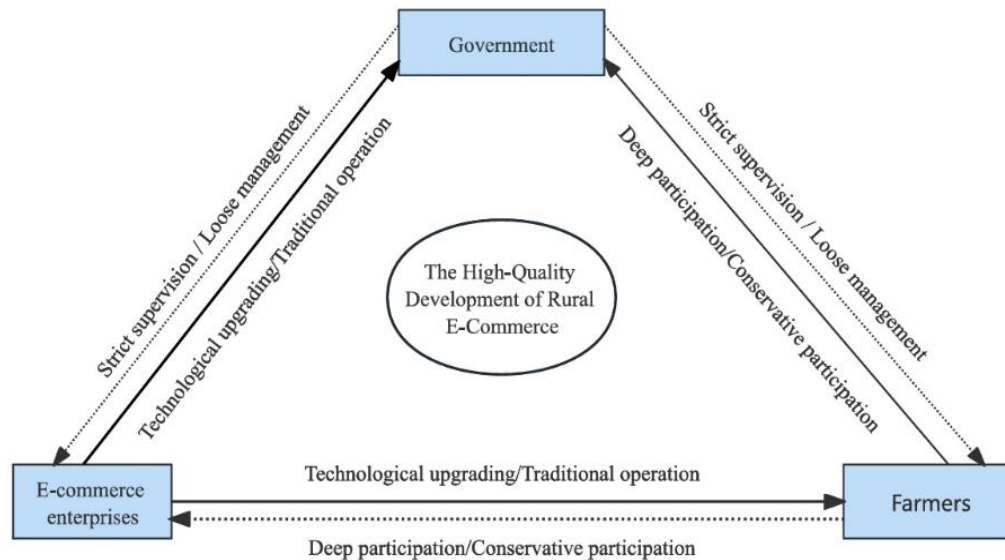


Figure 1. Logical Relationship Diagram of the Three Subjects

3.2 | Basic Assumptions

The Daxin County of Guangxi Province is actively exploring a distinctive path for rural revitalization through "e-commerce + points mini-program + agricultural products". The local e-commerce company has developed the "Aixiangxia" WeChat mini-program, which integrates functions such as party and community services, village affairs discussion points, and points shopping malls, providing farmers with convenient services for product point redemption and online and offline transactions of agricultural products. In the AI technology wave, Jiangyong County, through AI empowerment training for e-commerce, helps practitioners apply and improve operational efficiency. The Gansu Jihui Digital Technology Co., Ltd. uses advanced technologies such as AI and blockchain to deeply develop e-commerce live-streaming business, promoting the deep integration of digital technology and the agricultural industry. These specific cases provide a solid real-life basis for parameter setting. Based on this, this article combines the behavioral choices of the three parties in the game, makes the following assumptions, and organizes the meanings of relevant parameters as shown in Table 1. The game payment matrix of the three parties obtained through calculation is shown in Table 2.

Assumption 1: The government, e-commerce enterprises, and farmers constitute the core players in the game. Under the premise of bounded rationality, these three subjects continuously adjust their strategic choices, converging eventually to an evolutionary stable equilibrium in the dynamic evolutionary process. Each party's strategic selection is oriented toward achieving the optimal allocation of costs and benefits. For the sake of this analysis, other subjects that may influence the game system are excluded from consideration.

Assumption 2: The strategy set of the government consists of {strict supervision, loose management}, where the probability of the government strict supervision the high-quality development of rural e-commerce is x , and the probability of loose management is $1-x$; the strategy set of e-commerce enterprises consists of {technological upgrading, traditional operation}, where the probability of e-commerce enterprises conducting technological upgrading is y , and the probability of traditional operation is $1-y$; the strategy set of farmers consists of {deep participation, conservative participation}, where the probability of farmers deeply participating in the high-quality development of rural e-commerce is z , and the probability of conservative participation is $1-z$. Here, $x, y, z \in [0, 1]$, and all are related to t .

Assumption 3: The basic income obtained by the government for supporting the development of rural e-commerce is G . The cost when the government strictly supervises is $C1$, and the cost when it is leniently managed is $C2$. The cost of strict supervision is higher than that of lenient management, that is, $C1 > C2$. $T1$ represents the tax incentives provided by the government to e-commerce enterprises for technological upgrading, and $T2$ represents the point-based incentives provided by the government to deeply involved farmers. Specifically, when farmers actively use digital technologies or smart devices, the government issues point rewards that can be used to exchange for public services. S represents the social benefits obtained by the government when it strictly supervises and farmers deeply participate, such as improved employment environment, enhanced social cohesion, and increased digital inclusiveness.

Assumption 4: In the high-quality development of rural e-commerce, the intensity of resource integration by e-commerce enterprises, α , is a key parameter. When e-commerce enterprises adopt the traditional operation mode, the basic income obtained is $F1$, and the regular operating costs paid are $P1$. When e-commerce enterprises carry out technological upgrading, in addition to obtaining the basic income $F1$, they can also obtain the incremental income $F2$, and at the same time generate incremental costs $P2$. Both are positively correlated with α . Moreover, when farmers deeply participate, e-commerce enterprises actively conducting technological upgrading can further accumulate regional reputation value R . When farmers choose to deeply participate, the government

strictly supervises, while the e-commerce enterprises still maintain the traditional operation mode, the e-commerce enterprises have to pay the government's fine M .

Assumption 5: The awareness level of farmers towards the new e-commerce model is β . The level of awareness will affect farmers' behavioral choices, which in turn will influence the gains and costs they obtain. When farmers participate conservatively in the high-quality development of rural e-commerce, the gains they obtain are Q_1 , and the costs are H_1 . When farmers deeply participate in the high-quality development of rural e-commerce, on the basis of Q_1 , they can obtain an incremental gain of Q_2 , while generating an incremental cost of H_2 . These two are positively correlated with β . The incremental gain of farmers deeply participating in the high-quality development of rural e-commerce is greater than the incremental cost generated at this time, that is, $\beta Q_2 - \beta H_2 > 0$. When the government strictly supervises and the e-commerce enterprises adopt traditional operation methods, farmers can obtain supervision rewards L by reporting the e-commerce enterprises' passive participation.

Table 1. Parameters for Game System Settings

Symbol	Description
G	The basic income is obtained by the government through its support for rural e-commerce projects.
C_1	The cost of strict government supervision
C_2	The costs during periods of loose government regulation
M	Fines imposed by the government on e-commerce enterprises under deep farmer participation, strict government supervision, and traditional operation of e-commerce enterprises
S	Comprehensive social benefits are gained by the government under deep farmer participation and strict government supervision.
T_1	Tax incentives are provided by the government when e-commerce enterprises choose technological upgrading.
T_2	Points rewards are provided by the government to deeply engaged farmers.
α	Resource integration intensity of e-commerce enterprises
F_1	Basic benefits from e-commerce enterprises' choice of traditional operations
F_2	Incremental gains from e-commerce enterprises' adoption of technological upgrading
P_1	Costs incurred by e-commerce enterprises in choosing traditional operations
P_2	Additional operating costs for e-commerce enterprises in technological upgrading
R	Reputation of e-commerce enterprises when upgrading technology with deep farmer participation
β	Farmers' awareness of new e-commerce models
Q_1	Benefits for farmers choosing conservative participation
H_1	Operating costs incurred by farmers in conservative participation.
Q_2	Incremental gains for farmers opting for deep participation
H_2	Incremental costs incurred by farmers in deep participation.
L	Supervision rewards for farmers reporting e-commerce enterprises' passive participation under strict government supervision, deep farmer engagement, and enterprises' traditional operations

Table 2. Three-party Game Payment Matrix

Strategy combination	Government	E-commerce enterprises	Farmers
(Strict supervision, technological upgrading, deep participation)	$G+S-C_1-T_1-T_2$	$F_1+\alpha F_2-P_1-\alpha P_2+T_1+R$	$Q_1+\beta Q_2-H_1-\beta H_2+T_2$
(Strict supervision, technological upgrading, conservative participation)	$G-C_1-T_1$	$F_1+\alpha F_2-P_1-\alpha P_2+T_1$	Q_1-H_1
(Strict supervision, traditional operation, deep participation)	$G+S-C_1-T_2+M-L$	F_1-P_1-M	$Q_1+\beta Q_2-H_1-\beta H_2+T_2+L$
(Strict supervision, traditional operation, conservative participation)	$G-C_1$	F_1-P_1	Q_1-H_1
(Loose management, technological upgrading, deep participation)	$G-C_2$	$F_1+\alpha F_2-P_1-\alpha P_2+R$	$Q_1+\beta Q_2-H_1-\beta H_2$
(Loose management, technological upgrading, conservative participation)	$G-C_2$	$F_1+\alpha F_2-P_1-\alpha P_2$	Q_1-H_1
(Loose management, traditional operation, deep participation)	$G-C_2$	F_1-P_1	$Q_1+\beta Q_2-H_1-\beta H_2$
(Loose management, traditional operation, conservative participation)	$G-C_2$	F_1-P_1	Q_1-H_1

4 | RESULTS

4.1 | Solve the Replication Dynamic Equation

Assume that UG_1 represents the expected payoff of the government under strict supervision, UG_2 represents the expected payoff under loose management, and U_G represents the government's average expected payoff:

$$U_{G1} = (G - C_1 - T_1 - T_2 + S)yz + (G - C_1 + S - T_2 + M - L)(1 - y)z + (G - C_1)(1 - y)(1 - z) + (G - C_1 - T_1)y(1 - z) \quad (1)$$

$$U_{G2} = (G - C_2)yz + (G - C_2)y(1 - z) + (G - C_2)(1 - y)z + (G - C_2)(1 - y)(1 - z) \quad (2)$$

$$U_G = xU_{G1} + (1 - x)U_{G2} \quad (3)$$

The government's replication dynamic equation is:

$$\begin{aligned} F(x) &= dx/dt = x(U_{G1} - U_G) = x(1 - x)(U_{G1} - U_{G2}) \\ &= x(1 - x)[-T_1y + (S - T_2 + M - L)z + (M - L)zy + C_2 - C_1] \end{aligned} \quad (4)$$

Assume that UE_1 denotes the expected profit of e-commerce enterprises when engaging in technological upgrading, UE_2 denotes the expected profit when they opt for traditional operation, and UE denotes their average expected profit:

$$U_{E1} = (F_1 + \alpha F_2 - P_1 - \alpha P_2 + T_1 + R)xz + (F_1 + \alpha F_2 - P_1 - \alpha P_2 + T_1)(1-z)x + (F_1 + \alpha F_2 - P_1 - \alpha P_2 + R)(1-x)z + (F_1 + \alpha F_2 - P_1 - \alpha P_2)(1-x)(1-z) \quad (5)$$

$$U_{E2} = (F_1 - M - P_1)xz + (F_1 - P_1)(1-z)x + (F_1 - P_1)(1-x)z + (F_1 - P_1)(1-x)(1-z) \quad (6)$$

$$U_E = yU_{E1} + (1-y)U_{E2} \quad (7)$$

The replicator dynamics equation for e-commerce enterprises is as follows:

$$\begin{aligned} F(y) &= dy/dt = y(U_{E1} - U_E) = y(1-y)(U_{E1} - U_{E2}) \\ &= y(1-y)(T_1x + Rz + \alpha F_2 - \alpha P_2 + Mxz) \end{aligned} \quad (8)$$

Assume that UP1 denotes the expected payoff for farmers in deep participation, UP2 denotes the expected payoff in conservative participation, and UP denotes the average expected payoff for farmers:

$$\begin{aligned} U_{P1} &= (Q_1 + \beta Q_2 - H_1 - \beta H_2 + T_2)xy + (Q_1 + \beta Q_2 - H_1 - \beta H_2 + T_2 + L)(1-y)x \\ &\quad + (Q_1 + \beta Q_2 - H_1 - \beta H_2)(1-x)y + (Q_1 + \beta Q_2 - H_1 - \beta H_2)(1-x)(1-y) \end{aligned} \quad (9)$$

$$\begin{aligned} U_{P2} &= (Q_1 - H_1)xy + (Q_1 - H_1)(1-x)y + (Q_1 - H_1)(1-y)x \\ &\quad + (Q_1 - H_1)(1-x)(1-y) \end{aligned} \quad (10)$$

$$U_P = zU_{P1} + (1-z)U_{P2} \quad (11)$$

The replicator dynamics equation for farmers is as follows:

$$\begin{aligned} F(z) &= dz/dt = z(U_{P1} - U_P) = z(1-z)(U_{P1} - U_{P2}) \\ &= z(1-z)(\beta Q_2 - \beta H_2 + T_2x + Lx - Lxy) \end{aligned} \quad (12)$$

4.2 | Solution of the Equilibrium Point and Stability Analysis

By setting $F(x) = 0$, $F(y) = 0$, and $F(z) = 0$, eight pure strategy equilibrium points are derived: E1(0,0,0), E2(0,0,1), E3(0,1,0), E4(0,1,1), E5(1,0,0), E6(1,1,0), E7(1,0,1), and E8(1,1,1). According to Lyapunov's first criterion [24], if the eigenvalues ($\lambda_1, \lambda_2, \lambda_3$) in the Jacobian matrix after substituting the equilibrium point are all negative, then this equilibrium point is an Evolutionary Stable State. To further study the stability of the system, the corresponding eigenvalues are obtained by substituting each equilibrium point into the Jacobian matrix J. The eigenvalues of each equilibrium point are shown in Table 3:

$$J = \begin{pmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{pmatrix}$$

$$= \begin{pmatrix} (1-2x) \left[\begin{matrix} -T_1y + (S-T_2+M-L)z \\ +(M-L)zy + C_2 - C_1 \end{matrix} \right] & x(1-x)[-T_1 + (M-L)z] & x(1-x)[(S-T_2-L+M) + (M-L)y] \\ y(1-y)(Mz + T_1) & (1-2y)[\alpha(F_2 - P_2) + (R+Mx)z + T_1x] & y(1-y)(Mx + R) \\ z(1-z)(T_2 + L - Ly) & z(1-z)(-Lx) & (1-2z)(\beta Q_2 - \beta H_2 + Lx - Lxy + T_2x) \end{pmatrix} \quad (13)$$

Table 3. Equilibrium points and eigenvalues of the system.

Equilibrium point	λ_1	λ_2	λ_3
E1(0,0,0)	-C1+C2	$\alpha(F_2-P_2)$	$\beta Q_2 - \beta H_2$
E2(0,0,1)	-C1+C2+S-T2-L+M	$\alpha(F_2-P_2) + R$	$-\beta Q_2 + \beta H_2$
E3(0,1,0)	-C1+C2-T1	$-\alpha(F_2-P_2)$	$\beta Q_2 - \beta H_2$
E4(0,1,1)	C2-C1-T1+S-T2+2M-2L	$-\alpha(F_2-P_2) - R$	$-\beta Q_2 + \beta H_2$
E5(1,0,0)	C1-C2	$\alpha(F_2-P_2) + T_1$	$\beta Q_2 - \beta H_2 + L + T_2$
E6(1,1,0)	T1-C2+C1	$-\alpha(F_2-P_2) - T_1$	$\beta Q_2 - \beta H_2 + T_2$
E7(1,0,1)	C1-C2-M-S+T2+L	$\alpha(F_2-P_2) + R + M + T_1$	$-\beta Q_2 + \beta H_2 - L - T_2$
E8(1,1,1)	-C2+C1+T1-S+T2-2M+2L	$-\alpha(F_2-P_2) - M - T_1 - R$	$-\beta Q_2 + \beta H_2 - T_2$

From the above assumptions, it can be concluded that the cost of strict government regulation is higher than that of loose management, i.e., $C_1 > C_2$. The incremental gains for farmers from deeply participating in the high-quality development of rural e-commerce are greater than the incremental costs incurred at this time, i.e., $\beta Q_2 - \beta H_2 > 0$. Therefore, E2(0,0,1), E4(0,1,1), E7(1,0,1), and E8(1,1,1) have the possibility of systemic stability.

Situation 1: When $-C_1 + C_2 + S - T_2 - L + M < 0$ and $\alpha(F_2 - P_2) + R < 0$, the evolutionary stable point of the system is E2(0,0,1), and the stable strategy is (loose management, traditional operation, deep participation). At this time, the government spends more on fiscal expenditures to encourage the development of rural e-commerce, and the fines imposed on e-commerce enterprises and the social benefits obtained are relatively low. The government tends to adopt loose management for the high-quality development of rural e-commerce. When the incremental gains and reputation gains obtained by e-commerce enterprises cannot compensate for the incremental costs, e-commerce enterprises will choose to maintain the traditional operation mode. Farmers have a strong willingness to deeply participate in the high-quality development of rural e-commerce when they receive the government's

point rewards and supervision rewards. This stable state reflects that there are deep-seated contradictions, such as the attenuation of policy effects, the lack of enterprise technological upgrading, and the imbalance of the interest linkage mechanism in the high-quality development of rural e-commerce.

Situation 2: When $C2-C1-T1+S-T2+2M-2L<0$ and $-\alpha(F2-P2)-R<0$, the stable point of system evolution is $E4(0, 1, 1)$, and the stable strategy is (loose management, technological upgrading, deep participation). This equilibrium state indicates that the government adopts a lenient management strategy, and e-commerce enterprises actively carry out resource integration and deepen the participation of farmers. This brings a catalytic effect on the reputation of e-commerce enterprises, significantly increasing the incremental benefits of e-commerce enterprises, prompting e-commerce enterprises to carry out technological upgrading and actively participate in the high-quality development of rural e-commerce. Similarly, through the government's early policy publicity and the experience of deep participation, the economic benefits of farmers and their awareness of the new e-commerce model have also been greatly improved. Even without government incentives, farmers will also actively participate.

Situation 3: When $C1-C2-M-S+T2+L<0$ and $\alpha(F2-P2)+R+M+T1<0$, the stable point of the system is $E7(1, 0, 1)$, and the stable strategy is (strict supervision, traditional operation, deep participation). At this time, when the government actively provides farmers with bonus points and supervision rewards, farmers tend to deeply participate, while e-commerce enterprises, due to their passive participation, are subject to higher government penalties, reducing their enthusiasm for technological upgrading and tending to choose the traditional operation model. This stable state reflects that a development model relying solely on external government forces to drive with weak e-commerce enterprise motivation may affect the quality of rural e-commerce development.

Situation 4: When $-C2+C1+T1-S+T2-2M+2L<0$ and $-\alpha(F2-P2)-M-T1-R<0$, the stable point of the system is $E8(1, 1, 1)$, and the stable strategy is (strict supervision, technological upgrading, deep participation). Under this condition, the government introduces a dual-track mechanism of strict supervision and precise incentives, which can not only make up for fiscal expenditures but also reduce the costs of enterprise innovation and farmer participation, and enhance the willingness of all subjects to reach cooperation. The intensity of e-commerce enterprises' resource integration and incremental benefits form a positive feedback loop, which can accelerate the evolution speed. At this time, driven by the supervision rewards and net income higher than the level of conservative participation, farmers will more deeply integrate into the high-quality development process of rural e-commerce.

Based on the analysis of the current situation of rural e-commerce high-quality development, the government needs to use policy regulation to promote rural e-commerce development, and needs to rely on e-commerce enterprises to carry out technological upgrading to enhance the internal driving force for rural e-commerce high-quality development, thereby driving farmers to deeply participate. Therefore, this paper finds that the equilibrium point $E_8(1, 1, 1)$ conforms to the current reality of rural e-commerce high-quality development driven by the digital economy. This strategy combination can avoid the reduction in resource allocation efficiency caused by excessive government intervention and effectively suppress the risks triggered by market autonomy. Based on this optimal equilibrium point, this paper assigns parameters and identifies the key factors affecting the evolution trend of the system, providing a reference for the optimization of rural e-commerce high-quality development.

5 | NUMERICAL SIMULATION ANALYSIS

5.1 | Initial evolutionary path simulation

In the research on the high-quality development of rural e-commerce, the government, e-commerce enterprises, and farmers constitute the three-party dynamic game subjects. The behavioral choices of these three subjects are influenced by various factors. This study conducts numerical simulations based on the Python platform, focusing on examining the impact of core parameters on the system stability to verify the convergence validity of the evolutionary stable strategy. The specific parameter settings are as follows: $G = 50$, $C_1 = 20$, $C_2 = 10$, $M = 15$, $S = 30$, $T_1 = 10$, $T_2 = 5$, $F_1 = 100$, $F_2 = 25$, $P_1 = 50$, $P_2 = 12$, $R = 15$, $Q_1 = 40$, $H_1 = 30$, $Q_2 = 20$, $H_2 = 8$, $L = 6$, $\alpha = 0.2$, $\beta = 0.6$.

To verify the validity of the system stability results, when the parameter assignment satisfies the condition $-C_2+C_1+T_1-S+T_2-2M+2L<0$ and $-\alpha(F_2-P_2)-M-T_1-R<0$, the initial evolutionary path is shown in Figure 2. The strategies of the government, e-commerce enterprises, and farmers ultimately converge to $(1, 1, 1)$. At this time, situation 4 is verified.

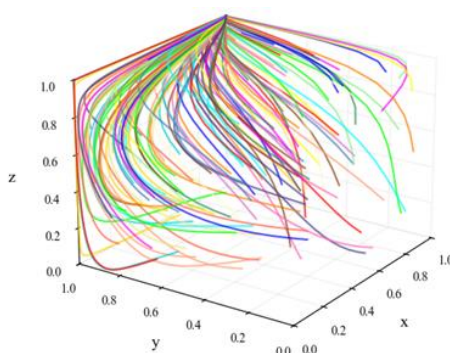


Figure 2: System Simulation Results

As shown in Figure 3, when the initial willingness of all subjects was 0.5, the collaborative evolution among the government, e-commerce enterprises, and farmers presented a phased characteristic. In the initial cooperation stage ($0 < t < 0.4$), although all three subjects had the initial willingness to participate, they had not yet achieved deep collaboration. During this stage, the government mainly promoted the start of the industry through exploratory policies such as financial subsidies and planning of e-commerce parks, but due to the weak logistics infrastructure and the lack of a standardized agricultural product system, the policy benefits could not be fully released. The e-commerce enterprises had to bear the high upfront costs for rural logistics network construction and e-commerce talent training, and the market expansion efficiency was low. The farmers, due to their insufficient e-commerce operation skills and doubts about the stability of the sales channels, held a cautious attitude towards online operations, and their behavior pattern presented the feature of "scattered trial and exploration". When $t > 0.4$, the three subjects achieved collaboration through dynamic adjustment.

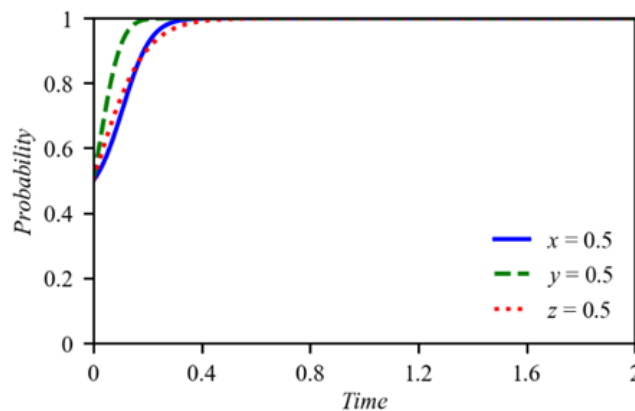


Figure 3. The Impact of Initial Intentions on System Evolution

5.2 | Sensitivity Analysis of Three-Party Evolutionary Game

5.2.1. The Impact of Initial Intentions of Different Subjects on System Evolution

From Figure 4, it can be concluded that the initial intentions of e-commerce enterprises and farmers remain unchanged. When the initial intentions of the government are set at 0.3, 0.5, and 0.9, respectively, the system evolution eventually converges to the government's strict regulatory strategy. Moreover, as the intensity of the strict regulatory intention increases, there is a significant positive correlation between policy strength and convergence speed. This phenomenon is in line with the trend of the government accelerating rural digital transformation in the context of rural revitalization, presenting the forward-looking guiding characteristics of the policy end under the "digitalizing agriculture" goal-driven approach. Although in reality, farmers may have insufficient e-commerce operation skills and e-commerce enterprises may have lagging application of digital tools,

the government will still, based on the macro goals of rural industrial revitalization and high-quality development, through dynamic logistics subsidies, brand incubation support, and other incentive mechanisms, promote rural e-commerce to develop in the direction of standardization, branding, and scale.

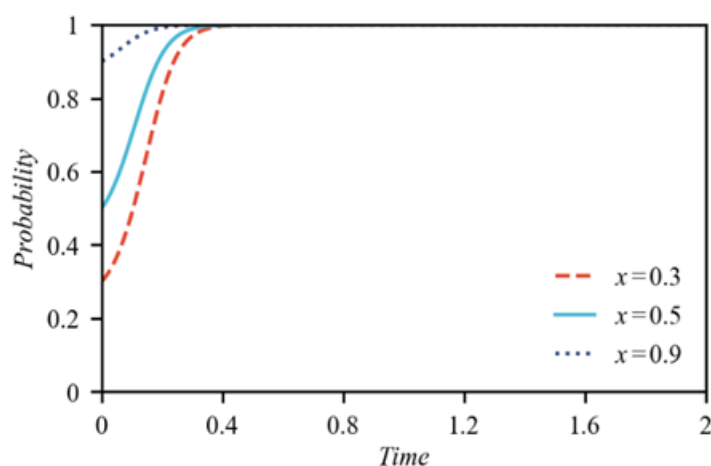


Figure 4. The Impact of the Government's Initial Intentions on System Evolution

From Figure 5, it can be concluded that the initial intentions of the government and farmers remain unchanged. When the initial intentions of e-commerce enterprises are set at 0.2, 0.5, and 0.8, respectively, as time progresses, the system evolves and eventually reaches a stable state, and the speed at which it reaches the stable state becomes faster and faster. This phenomenon indicates that, in the face of structural obstacles such as insufficient standardization of agricultural products and low logistics efficiency, e-commerce enterprises can still continuously evolve towards a more optimal, stable equilibrium through digital transformation and business model innovation, demonstrating the core role of e-commerce enterprises in rural revitalization. of E-commerce Enterprises on System Evolution.

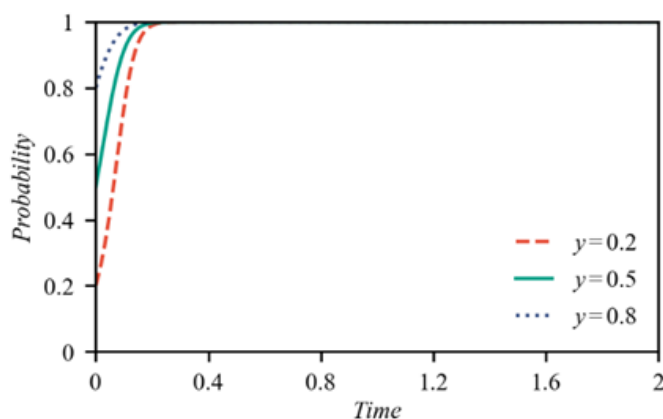


Figure 5. The Impact of Initial Intentions of E-commerce Enterprises on System Evolution

As shown in Figure 6, when the initial intentions of the government and e-commerce enterprises remain unchanged, and the initial intentions of farmers are preset at 0.2, 0.5, and 0.8, respectively, the system can all reach a stable state. When the initial intentions are relatively low, the speed at which the system reaches a stable state is the slowest in the evolution trend, indicating that farmers may have a lack of understanding or low trust in the new e-commerce operation model, logistics cost control, and platform rules. When the initial intentions reach a higher level, the rate at which the system reaches a stable state significantly increases. During this period, farmers reduce the psychological adoption cost through the social network of acquaintances, deeply participate in the high-quality development of rural e-commerce, promote the transformation of rural e-commerce to a demand-driven development model, and ultimately achieve deep synergy between the digital economy and rural industrial revitalization.

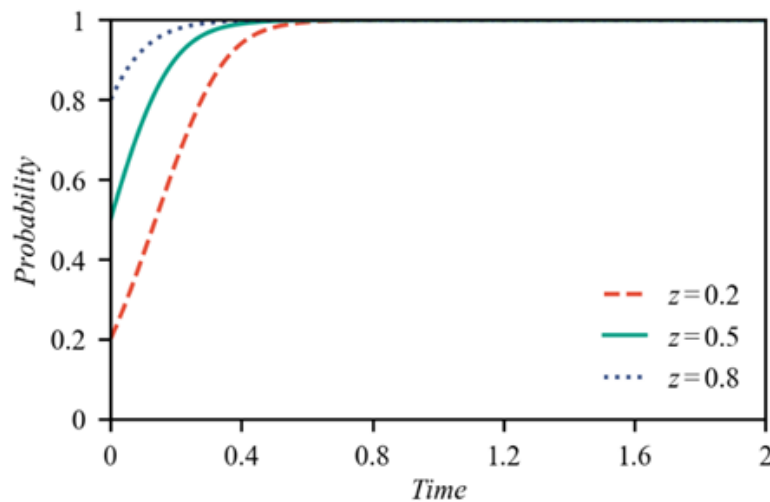


Figure 6. The Impact of Farmers' Initial Intentions on System Evolution

5.2.2. The Impact of the Intensity of Resource Integration α of E-commerce Enterprises on Their Behavioral Choices

The intensity of resource integration, denoted as α , is a crucial factor driving the high-quality development of the rural e-commerce industry. Therefore, analyzing the impact of changes in the intensity of resource integration on e-commerce enterprises is of great significance. As shown in Figure 7, when the intensity of resource integration for e-commerce enterprises is set at 0.2, 0.6, and 0.9, respectively, the system eventually reaches a stable state. As the value of the intensity of resource integration, α , increases, the rate at which the system reaches an equilibrium state becomes faster. When $\alpha = 0.2$, e-commerce enterprises invest insufficiently in supply chain optimization and channel deepening, resulting in low synergy efficiency between the upward movement of agricultural products and the downward movement of industrial products, and a slow evolution speed. As α

increases to 0.6, e-commerce enterprises accelerate the flow of factors through intelligent warehouse layout and logistics resource integration, thereby enhancing the evolution speed. In the high-integration intensity situation of $\alpha = 0.9$, the stabilization cycle of the system shortens, reflecting the positive effect of e-commerce enterprises' resource integration on the high-quality development of rural e-commerce.

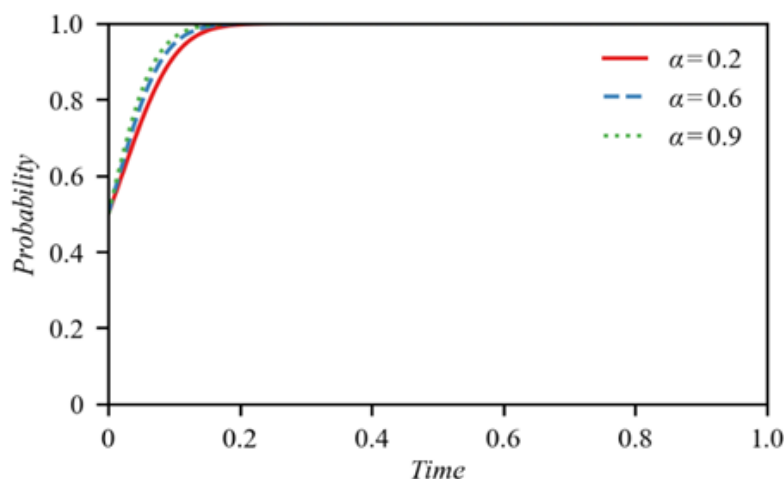


Figure 7. The Impact of the Intensity of Resource Integration α of E-commerce Enterprises on Their Behavioral Choices

5.2.3. The Impact of Government's Punitive Measures M on System Evolution

According to Figure 8, when the government's penalty intensity M for e-commerce enterprises is 15, 30, and 45, respectively, the system evolution can all converge to a stable state, and the increase in penalty intensity accelerates the convergence process. At $M = 15$, the service optimization response of e-commerce enterprises is sluggish, and the evolution speed is relatively slow; when $M = 30$, e-commerce enterprises accelerate the improvement of the quality control system and logistics response mechanism to avoid the risk of credit downgrade, and the convergence efficiency of the system improves; when the penalty mechanism is raised to 45, the rigid constraints force e-commerce enterprises to actively integrate resources, and at the same time enhance the participation willingness of the government and farmers, accelerating the evolution process. This also indicates that institutional supervision not only stimulates the internal driving force of e-commerce enterprises for digital upgrading, but also promotes the dynamic adaptation of multiple strategies, highlighting the important role of regulatory policies in coordinating the improvement of e-commerce quality.

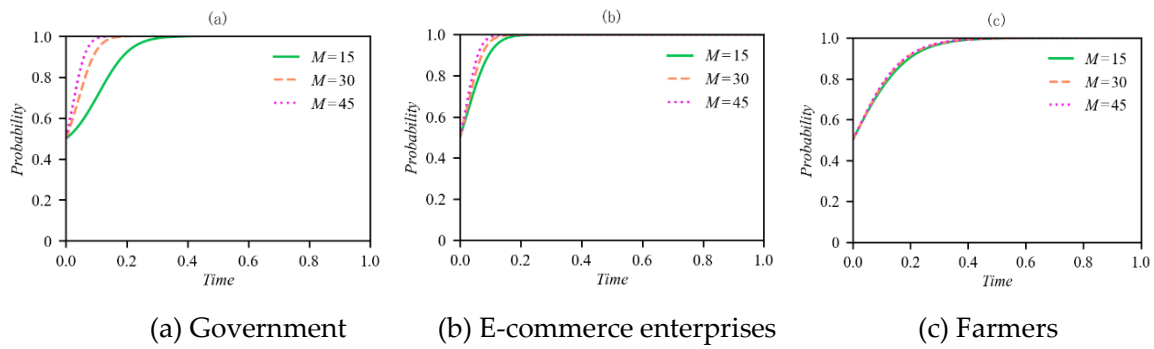


Figure 8. The Impact of Government's Punitive Measures M on System Evolution

5.2.4. The impact of the government's tax incentive policy T_1 on system evolution

As shown in Figure 9, when the government sets the tax incentive T_1 for e-commerce enterprises at 10, 15, and 20, the system evolution can all converge to a stable state. In the case of lower tax incentives, e-commerce enterprises tend to be relatively conservative in their investments in areas such as digital marketing and supply chain upgrading, and the evolution speed is relatively slow. As the tax incentive gradually increases, the policy dividends stimulate e-commerce enterprises to integrate resources and upgrade production capacity, which leads to an increase in the frequency of system strategy interaction and an optimization of convergence efficiency. When the tax incentive reaches a relatively high level, the institutional incentives form a strong guiding role. Under the favorable conditions of the policy, e-commerce enterprises actively adapt to the policy goals through technological upgrading and quickly enter a stable state. For the government, a lower tax incentive level can enable it to reach a stable state quickly, which reflects that the continuously increasing tax incentive level increases the fiscal burden. As the evolution time progresses, the government tends to reduce the tax incentives for e-commerce enterprises, reducing the fiscal pressure while reducing the dependence of e-commerce enterprises on policies. For farmers, the change in tax incentive level has a relatively small impact on their evolution speed, but they can all make deep participation choices in the high-quality development of rural e-commerce.

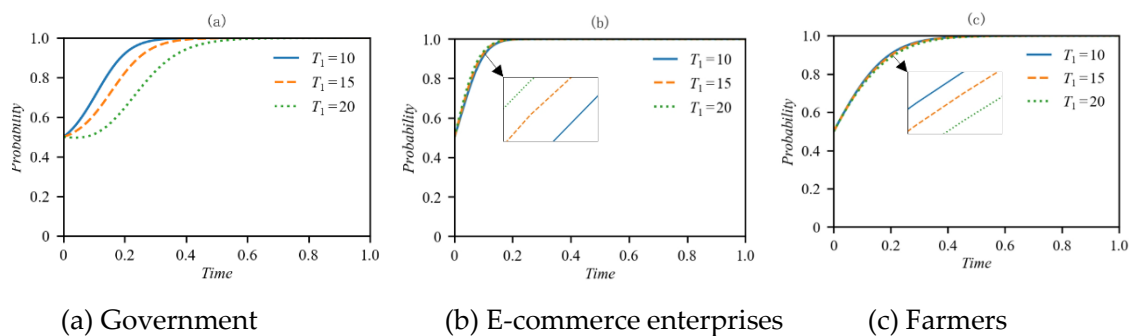


Figure 9. The impact of the government's tax incentive measure T_1 on the system evolution

5.2.5. The Impact of the Government's Reward Intensity T_2 for Farmers' Points on the Evolutionary Path of the System

From the analysis in Figure 10, it can be seen that when the value of T_2 is 10, 15, and 20, the system evolution can all converge to a stable state. When the reward intensity is low, the enthusiasm of farmers for deep participation is limited. When the reward is increased to 20, farmers actively use smart terminal applications and digital tools, thereby triggering the response mechanism of e-commerce enterprises in the technical application aspects, such as blockchain traceability systems and intelligent sorting systems, promoting the system to evolve towards a stable state and shortening the time for the system to reach the stable state. However, as the government faces an increase in financial pressure, its willingness to provide rewards gradually decreases, but the government still makes the choice to strictly supervise the high-quality development of rural e-commerce. This process reveals the deep driving effect of increasing the point reward intensity for farmers on the high-quality development of rural e-commerce, prompting the development of rural e-commerce to shift from "traffic expansion" to "quality increment".

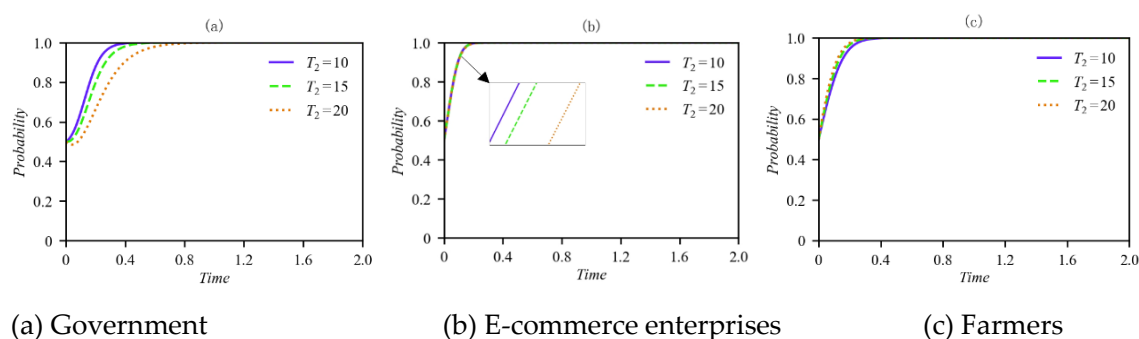


Figure 10. The Impact of the Government's Reward Points Intensity T_2 for Farmers on System Evolution

5.2.6. The impact of the β factor representing farmers' awareness of the new e-commerce model on farmers' behavioral choices

The cognitive level of farmers towards the new e-commerce development model is the key factor influencing whether they deeply participate in the high-quality development of rural e-commerce. Figure 11 shows that, over time, regardless of the initial cognitive level of farmers towards the new e-commerce model, they will eventually deeply participate in the high-quality development of rural e-commerce. When $\beta = 0.2$, the curve rises relatively slowly, indicating that a low level of cognition leads farmers to have doubts about the new e-commerce model and requires a longer period to change their concepts and try new strategies. When $\beta = 0.5$, the current cognitive level is at a medium level, farmers have a certain cognitive foundation, and the speed of deeply participating in the high-quality development of rural e-commerce will accelerate, but the promotion effect on the high-quality development of rural e-commerce is not yet sufficient. When $\beta = 0.8$, farmers have a high level of

cognition towards the new e-commerce model, and the evolution speed is the fastest. Within a relatively short period of time, they can choose to deeply participate. This shows that when farmers have a deep understanding of the new e-commerce model, they are more willing and more quickly to participate in the high-quality development of rural e-commerce.

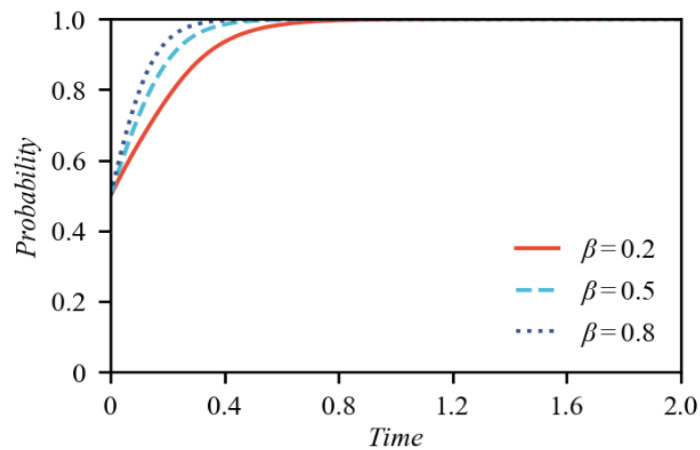


Figure 11. The impact of the β factor representing farmers' awareness of the new e-commerce model on farmers' behavioral choices

6 | CONCLUSION AND COUNTERMEASURES

6.1 | Research Conclusion

Based on the actual demand for the high-quality development of rural e-commerce, this paper constructs an evolutionary game model involving the government, e-commerce enterprises, and farmers. Key parameters are assumed, and the strategies of the three subjects and the influencing factors of system stability are discussed. The following conclusions are drawn:

First, by dynamically adjusting the intensity of incentive policies, the government can effectively stimulate the innovative vitality of the rural e-commerce market, promote the optimization of e-commerce supporting facilities, and the enhancement of farmers' participation intentions. The adjustment of incentive policies helps to form a strategic resonance among multiple subjects, demonstrating its core role in breaking through the low-end lock of the industry and cultivating sustainable competitiveness.

Second, the intensity of resource integration by e-commerce enterprises α is the core driving force for the high-quality development of rural e-commerce. The strengthening of resource integration enhances technological advantages and accelerates the evolution process of multiple subjects. It plays a significant role in breaking through the bottlenecks of rural e-commerce development and building a "enterprise - government - farmer" symbiotic ecosystem.

Thirdly, the punishment mechanism can effectively promote the high-quality development of rural e-commerce to evolve towards a balanced state. The increase in punishment intensity forces e-commerce enterprises to carry out digitalization and standardization management, and prompts the three subjects to reach collaboration. This also indicates that regulatory policies have significant value in balancing the high-quality development of rural e-commerce.

Fourth, the initial willingness synergy effect among the main subjects exhibits significant heterogeneity. When the initial willingness of any of the government, e-commerce enterprises, or farmers increases, the convergence speed of the system significantly accelerates, but the paths of action vary. The initial willingness of the government is positively correlated with the convergence speed, indicating its leading role as a system provider; the initial willingness of e-commerce enterprises increases, and the speed to reach a stable state accelerates, highlighting the effectiveness of resource integration in improving the quality of rural e-commerce development; however, when the initial willingness of farmers is below 0.5, a "cognitive damping" effect occurs, and their evolution speed is delayed compared to the baseline scenario, revealing the deep constraints of the cognitive gap on the high-quality development of rural e-commerce. Through the analysis of the evolution trend of farmers' awareness of new e-commerce models, it is concluded that the higher the farmers' awareness, the faster they can make decisions for deep participation, which provides a guiding path for resolving farmers' participation confusion.

6.2 | Research Countermeasures

1) The government should allocate incentive resources differently based on the characteristics of the rural e-commerce development stage and the level of digital economic development. Firstly, during the infrastructure construction period, priority should be given to strengthening logistics network coverage and digital skills training. In the mature operation period, efforts should shift to aggregating innovative elements and stimulating market vitality. At the same time, the government should break through the bottleneck of traditional financial supply, promote the formation of a mutually beneficial and mutually reinforcing pattern between rural e-commerce and digital inclusive finance, and inject vitality into farmers' income growth and rural sustainable development. Secondly, a system for rewarding farmers' supervision behavior with points should be designed, linking the points to substantive benefits such as production material subsidies and platform traffic rights. This will motivate farmers to supervise and force e-commerce enterprises to improve service quality. Finally, the penalty intensity should be dynamically adjusted to promote the digital development and standardized management of e-commerce enterprises, and to facilitate collaboration among the three subjects, achieving a balanced development under regulatory policies.

2) E-commerce enterprises should first enhance their resource integration efforts, leveraging advanced technologies such as big data and artificial intelligence to build precise marketing systems and intelligent logistics distribution systems suitable for the rural market. They should utilize digital technology to improve the operational efficiency and service quality of rural e-commerce. Secondly, e-commerce enterprises should actively establish close partnerships with farmers, cooperatives, and other supply entities, integrate high-quality agricultural product resources, and conduct customized production based on market demands to achieve precise matching between agricultural product production and sales. Finally, e-commerce enterprises should showcase scenes of field labor and the original ecological charm of products through short videos to enhance content appeal and increase brand exposure. They should also select and train their own e-commerce anchors, while connecting with large e-commerce platforms to secure traffic support, and create agricultural product brands with regional characteristics. They should deeply explore the cultural stories of the production areas and integrate them into brand building to enhance brand recognition and market influence, and reputation through unified packaging design and quality certification.

3) Farmers can participate in free training organized by local agricultural and rural departments as well as e-commerce enterprises, such as store operation, live-streaming skills, logistics coordination, etc., to enhance their e-commerce skills. They can also learn practical experience from the "e-commerce leaders" in their village and understand policies and market signals. Secondly, farmers should actively utilize short-video platforms, through "field live-streaming" and "agricultural records", to showcase the original ecology of products, and use "local narrative" to enhance trust. They should also regularly post product growth logs and promotional activities on the WeChat community to accumulate repeat customers and expand sales channels. During the sales process, they should utilize the "data tools" of e-commerce platforms to analyze popular product categories and consumer preferences, and guide production in reverse. With the support of the government and e-commerce enterprises, they can transform from "the end of the industrial chain" to "the value creation entity", ultimately promoting the high-quality development of rural e-commerce.

6.3 | Future Prospects

This study conducted a preliminary exploration of the collaborative mechanism for the high-quality development of rural e-commerce, but it has certain limitations: Firstly, in the parameter assignment, there is a lack of real data support; Secondly, there is a lack of actual case studies from different regions to verify the model; Finally, factors such as the protection of farmers' rights have not been considered. Future research can be carried out in the following directions: Firstly, by using technologies such as blockchain traceability and artificial intelligence quality inspection to simulate the multi-party collaborative mechanism in the quality traceability of agricultural products, and using

actual data for simulation to enhance practical significance; Secondly, establish a regional differentiated analysis framework that integrates governance factors to conduct comparative studies on cross-regional e-commerce projects; Finally, introduce rural cooperatives as a subject, and use organizational strength to safeguard the legitimate rights and interests of farmers.

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