Evolutionary Game Analysis of the Intelligent Upgrade of Rural E-commerce Logistics Under Government Incentive Policies

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Abstract. In the context of new quality productive forces, the intelligent upgrade of rural e-commerce logistics is key to advancing rural logistics development. This article utilizes evolutionary game theory to construct an evolutionary game model involving the government, rural e-commerce users, and logistics companies. The model is analyzed through numerical simulations using MATLAB software to explore the impact of different parameter changes on the evolutionary paths of the three parties. Results indicate that the size of government profits, incentive costs, and the strength of rewards and penalties are crucial factors affecting the strategic choices and evolutional stability of all parties involved. The benefits to participating entities are critical in influencing their strategic decisions; proactive encouragement, support, and promotion of artificial intelligence technology by the government, coupled with the establishment of scientifically sound incentive policies, can effectively promote the application of AI technology in logistics and spur the development of rural e-commerce logistics.

Keywords: New quality productive forces, Artificial Intelligence, Rural E-commerce Logistics, Evolutionary Game.

1 INTRODUCTION

With the continuous advancement of global economic integration and the rapid development of information technology, e-commerce demonstrates a sustained growth trend worldwide. The demand for online shopping among residents in China's rural areas is gradually increasing. The rise of rural e-commerce has become an important engine for rural economic development. Logistics is the fundamental guarantee for e-commerce operations; thus, the intelligent upgrade of rural e-commerce logistics is of utmost importance.

In September 2023, President Xi, during his inspection of the comprehensive revitalization of the Northeast in Heilongjiang, first proposed the important concept of "new quality productive forces." New quality productive forces are those characterized primarily by new technologies, new economies, and new business formats[1]. The essence

© The Author(s) 2024
V. Vasilev et al. (eds.), *Proceedings of the 2024 5th International Conference on Management Science and Engineering Management (ICMSEM 2024)*, Advances in Economics, Business and Management Research 306,
https://doi.org/10.2991/978-94-6463-570-6_93

of new quality productive forces centers on the use of artificial intelligence technology to drive intelligent iterations of productive factors, to meet diverse development needs[2]. In the rural e-commerce logistics sector, the empowering role of new quality productive forces has become increasingly apparent, primarily manifested in the deep integration of artificial intelligence technology with productive factors. Through upgrading intelligent infrastructure, optimizing resource allocation, enhancing logistics efficiency, thus promoting the development of rural e-commerce logistics.

The digital intelligence level of logistics enterprises is crucial for driving high-quality development of rural e-commerce logistics, requiring the involvement of multiple entities, including governments and businesses, for the application and upgrade of the next generation of artificial intelligence technologies[3][4]. Wongkhamdi and others posited that the Thai government's aid and support for e-commerce have significantly fostered the growth of small and medium-sized enterprises[5]. Liu et al argued that the development of artificial intelligence could promote steady economic growth and recommended increased funding and policy support for the AI industry[6]. In the practice of intelligent upgrading of corporate logistics in China, policies are mostly guidance-oriented, with fewer supportive policies regarding subsidies. Liu Renjun and others believed that the current government subsidies for intelligent upgrading of corporate logistics are insufficient. Using evolutionary game methods to analyze the interactive decision-making between the government and businesses, they suggested that governments should review and moderately adjust the subsidy amounts when establishing fiscal subsidy policies while also expanding the scope of tax incentives[7].

In conclusion, existing research is dedicated to promoting logistics development through policy or technological advancement, with most literature based on qualitative theoretical studies. Even those utilizing evolutionary game theory to analyze the intelligent upgrade of logistics typically consider only the perspectives of governments and companies, with few studies addressing the role of other stakeholders in facilitating logistics development. Therefore, this paper, grounded on evolutionary game theory and assuming limited rationality, introduces governments, rural e-commerce users, and logistic companies as principal stakeholders to analyze the dynamic game process among different entities.

2 EVOLUTIONARY GAME ANALYSIS

2.1 Model Assumptions

The development of rural e-commerce logistics involves various stakeholders, primarily the government, rural e-commerce users, and logistics companies. The government, as the economic policy maker, aims to promote and oversee the adoption of the new generation of artificial intelligence technology to foster industrial upgrades and enhance logistic efficiency. The government's incentive aims for rural e-commerce users are to increase their acceptance of artificial intelligence technology, demonstrating that the utility of logistical upgrades outweighs conventional logistics, and to provide subsidies; whereas, for logistics companies, the aim is to compensate for the incremental costs of technological upgrades and ensure a balanced budget. Rural e-commerce users, as the demand side for intelligent logistics services, aim to maximize their returns and enhance their core competitiveness. Moreover, technology adoption requires capital investment and exploration—if rural e-commerce users cannot perceive tangible benefits from the technological upgrade, they will ultimately abandon the choice of artificial intelligence technology. Logistics companies are the actual operators of the artificial intelligence technology upgrade, basing decisions on profit maximization, with the expectation that such upgrades will effectively improve logistics efficiency and strengthen market competitiveness.

The specific evolutionary game relationship between the participating entities is shown in Figure 1. The government acts as a promoter and supervisor of technological upgrading and can influence the evolution of the participants' behaviors. Therefore, this paper mainly explores the influence of the government's incentive and penalty measures on the stability of the system. Based on this, the following assumptions are made for the three-party game participants:

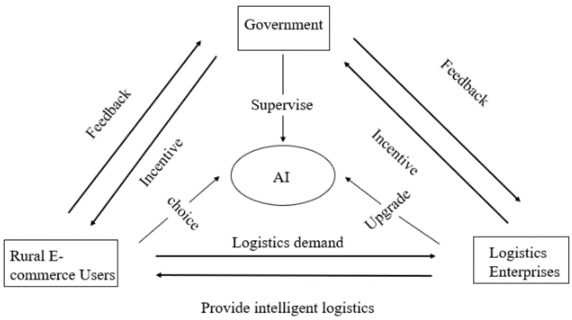


Fig. 1. Relationship Diagram of Game Participants.

Assumption 1: This paper considers a three-party game model composed of the government, rural e-commerce users, and logistics companies, with the three participants making strategic decisions under the premise of limited rationality and equal game status.

Assumption 2: The set of behavioral strategies for the stakeholders are: for the government {incentivize, not incentivize}; rural e-commerce users {choose, do not choose}; logistics companies {upgrade, do not upgrade}. Specifically, government incentives refer to measures taken to encourage companies to upgrade and use new generation artificial intelligence for logistic management and operations, whereas not incentivizing acknowledges traditional management and technologies; rural e-commerce users choosing artificial intelligence technology means cooperating with logistics companies that are upgraded with AI technology, not choosing would be to collaborate with traditional logistics companies; logistics companies' upgrading refers to adopting artificial intelligence technology upgrades and applying them to logistics management and operations, mainly reflected in intelligent warehousing, unmanned delivery, and integrated logistics services; not upgrading means the utilization of traditional technologies without upgrading.

Assumption 3: Assume that the probabilities of the government providing incentives, rural e-commerce users opting for AI technology, and logistics companies undergoing upgrades are respectively, while the probabilities of not providing incentives, not opting, and not upgrading are each *1-x*、*1-y*、*1-z* respectively, with being $x,y,z \in [0,1]$.

Assumption 4: Considering market changes and technological advancements, and based on the factors that affect the enterprise's intelligent transformation and upgrading, as indicated by Liu et al [8], which include government regulation, benefits, and costs, the input cost of rural e-commerce users when selecting logistics companies for technological upgrades is denoted as C_u. Meanwhile, collaborative utility is K_u ,efficiency improvement due to the selection of artificial intelligence technology is denoted as E_u and social benefits brought to e-commerce users after logistics companies upgrade their technology are denoted as W_u . At the same time, the cost for logistics companies to upgrade artificial intelligence technology is C_l , with benefits denoted as K_l and the implicit benefits such as brand value enhancement brought by artificial intelligence technology upgrades are E_l.

Assumption 5: Government initiatives seek to foster active engagement of rural e-commerce users and logistics firms in the intelligent advancement of rural e-commerce logistics. The government offers loans and subsidies, labeled as R_u to rural e-commerce users, and subsidies, labeled as R_l to logistics companies. It also levies fines, referred to as K_g ,on logistics companies that fail to upgrade. Meanwhile, the government incurs incentive costs, indicated as C_g.These initiatives gain recognition from higher authorities and society when employing incentive measures, with the associated benefits designated as E_g. The bolstering of government credibility, stemming from the technological advancements made by logistics companies, enhances its reputation, denoted as W_g.

Based on these assumptions, Table 1 details the parameters required for the model and their definitions.

Table 1. Definition of Parameters.

Parameter Category	Paramter Symbol	Parameter Meaning
Government	C_g	Costs incurred by the government for promoting technological upgrades in logistics enterprises and related legal regulations.
	K_g	Penalty amount imposed by the government on logistics enterprises that do not upgrade and still operate under traditional modes when implementing incentive strategies.
	E_g	Benefits such as rewards from higher-level departments and improved credibility brought by the government's incentive strategies.
	W_g	Enhancement of government credibility resulting from technological upgrades by logistics enterprises.
Rural E-commerce Users	C_u	Investment costs for rural e-commerce users when choosing to collaborate with logistics enterprises that have upgraded their technology.

continued table

Parameter Category	Paramter Symbol	Parameter Meaning
Rural E-commerce Users	K_u	Utility gained by rural e-commerce users when choosing to collaborate with technology-upgraded logistics enterprises.
	E_u	Enhancements in logistics solutions and management efficiency resulting from rural e-commerce users choosing to collaborate with technology-upgraded logistics enterprises.
	R_u	Incentives provided by the government, such as loans and subsidies, to e-commerce users who choose to collaborate with technology-upgraded logistics enterprises when implementing incentive strategies.
	W_u	Incremental societal benefits received by e-commerce users when logistics enterprises upgrade their technology.
Logistics Enterprises	C_l	Investment costs incurred by logistics enterprises for technological upgrades.
	K_l	Profits gained by logistics enterprises when collaborating with e-commerce users who choose to upgrade their technology.
	E_l	Implicit benefits such as increased brand value obtained by logistics enterprises when upgrading their technology.
	R_l	Incentives provided by the government, such as tax breaks and subsidies, to logistics enterprises when implementing incentives.

2.2 Model Construction

Based on the research assumptions stated above, a payoff matrix for the strategy set among the government, rural e-commerce users, and logistics companies is constructed as shown in Table 2.

Table 2. Payoff Matrix of the Tripartite Game.

Game Theory Actors' Strategies	Rural E-commerce Users Choose (y)		Rural E-commerce Users Do Not Choose (1-y)	
	Logistics Enterprises Upgrade(z)	Logistics Enterprises Do Not Upgrade(1-z)	Logistics Enterprises Upgrade(z)	Logistics Enterprises Do Not Upgrade(1-z)
Government Incentives(x)	E_g-C_g+W_g-R_u-R_l K_u+E_u+R_u-C_u+W_u K_l+E_l+R_l-C_l	E_g+K_g-C_g-R_u K_u+E_u+R_u-C_u -K_g	E_g-C_g+W_g-R_l W_u E_l+R_l-C_l	E_g-C_g+K_g 0 -K_g
Government Non-incentives(1-x)	W_g K_u+E_u-C_u+W_u K_l+E_l-C_l	0 K_u+E_u-C_u 0	W_g W_u E_l-C_l	0 0 0

Based on the payoff matrix in Table 2, further calculations are carried out to determine the expected payoffs of each stakeholder and the dynamic equations for strategy replication.

1) Replicator dynamics equation for the government:

Define the expected payoff for the government when choosing the "incentive" strategy as V_{11}, and the expected payoff when choosing the "non-incentive" strategy as U_{12}. Then, the government's average expected payoff can be represented as $V_1 = xV_{11} + (1-x)V_{12}$. Among them

$$V_{11} = yz(E_g - C_g + W_g - R_u - R_l) + y(1-z)(E_g + K_g - C_g - R_u) + (1-y)z(E_g - C_g + K_g) \quad (1)$$

$$V_{12} = yzW_g + (1-y)zW_g \quad (2)$$

The replicator dynamics equation $F(x)$ for the government is:

$$F(x) = \frac{dx}{dt} = x(V_{11} - V_1) = x(1-x)[E_g - C_g + K_g - yR_u - z(K_g + R_l)] \quad (3)$$

2) Replicator Dynamics Equation for Rural E-commerce Users:

Let the expected payoff for rural e-commerce users choosing to collaborate with logistics enterprises employing artificial intelligence models be denoted as V_{21}, and the expected payoff for rural e-commerce users not choosing to collaborate with logistics enterprises employing artificial intelligence models be denoted as V_{22}. Thus, the average expected payoff for rural e-commerce users, $V_2 = xV_{21} + (1-x)V_{22}$, can be represented as follows:

$$V_{21} = xz(K_u + E_u + R_u - C_u + W_u) + x(1-z)(K_u + E_u + R_u - C_u) + (1-x)z(K_u + E_u - C_u + W_u) + (1-x)(1-z)(K_u + E_u - C_u) \quad (4)$$

$$V_{22} = xzW_u + (1-x)W_u \quad (5)$$

The replicator dynamics equation $F(y)$ for rural e-commerce users is:

$$F(y) = \frac{dy}{dt} = y(V_{21} - V_2) = y(1-y)(R_u x + K_u + E_u - C_u) \quad (6)$$

3) Replicating Dynamic Equation for Logistics Enterprises

Let the expected payoff for logistics enterprises upgrading to artificial intelligence mode for logistics management be denoted as V_{31}, and the expected payoff for logistics enterprises not upgrading and continuing to use traditional modes be denoted as V_{32}. Thus, the average payoff for logistics enterprises, $V_3 = zV_{31} + (1-z)V_{32}$, can be represented as follows

$$V_{31} = xy(K_l + E_l + R_l - C_l) + x(1-y)(E_l + R_l - C_l) + (1-x)y(K_l + E_l - C_l) + (1-x)(1-y)(E_l - C_l) \quad (7)$$

$$V_{32} = -xyK_g - x(1-y)K_g \quad (8)$$

The replicator dynamics equation $F(z)$ for logistics enterprises is:

$$F(z) = \frac{dz}{dt} = z(V_{31} - V_3) = z(1-z)[x(R_l + K_g) + yK_l + E_l - C_l] \quad (9)$$

2.3 Evolutionarily Stable Strategy in Mixed Strategies

Ritzberger and Weibull proposed in 1995 that in multi-population evolutionary games, the system's evolutionarily stable strategy must be the Nash equilibrium of pure strategies[9]. Therefore, let F(x)=0，F(y)=0，F(z)=0， be the solution to the equilibrium points of the three-party evolutionary game. There are 8 equilibrium points in the domain D={0≤x≤1,0≤y≤1,0≤z≤1}, denoted as $A_1(0,0,0)$， $A_2(0,1,0)$， $A_3(0,0,1)$， $A_4(0,1,1)$，$A_5(1,0,0)$，$A_6(1,1,0)$，$A_7(1,0,1)$，$A_8(1,1,1)$. According to the stability principle of differential equations[10]and the research of Peng Zhengyin and others[11], it is necessary to analyze the stability of pure strategy equilibrium solutions and construct the Jacobian matrix as follows:

$$J=\begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix}$$

Among it，

$$J_{11}=(x-1)(C_g-E_g-K_g+yR_u+z(K_g+R_l))+x(C_g-E_g-K_g+yR_u+z(K_g+R_l)) \tag{10}$$

$$J_{12}=xR_u(x-1) \tag{11}$$

$$J_{13}=x(x-1)(K_g+R_l) \tag{12}$$

$$J_{21}=-yR_u(y-1) \tag{13}$$

$$J_{22}=-y(E_u-C_u+K_u+xR_u)-(y-1)(E_u-C_u+K_u+xR_u) \tag{14}$$

$$J_{23}=0 \tag{15}$$

$$J_{31}=-z(z-1)(K_g+R_l) \tag{16}$$

$$J_{32}=-zK_l(z-1) \tag{17}$$

$$J_{33}=-z(E_l-C_l+yK_l+x(K_g+R_l))-(z-1)(E_l-C_l+yK_l+x(K_g+R_l)) \tag{18}$$

According to Friedman's analysis, the stability of equilibrium points can be determined by examining the Jacobian matrix of the system[12]. Substituting the 8 equilibrium points into the Jacobian matrix, we analyze the stability of these 8 equilibrium points. When all eigenvalues corresponding to the Jacobian matrix, denoted by λ, are negative, the equilibrium point is considered asymptotically stable. If any eigenvalue is positive, the equilibrium point is deemed unstable.

Table 3. Eigenvalues and Evolutionary Stability of Equilibrium Points.

Equilibrium Points	λ_1	λ_2	λ_3	Stability Conditions	Status
$A_1(0,0,0)$	$E_g-C_g+K_g$	$E_u-C_u+K_u$	E_l-C_l	$E_g-C_g+K_g < 0$; $E_l-C_l<0$	ESS

continued table

Equilibrium Points	λ_1	λ_2	λ_3	Stability Conditions	Status
$A_2(0,1,0)$	E_g-C_g+K_g-R_u	C_u-E_u-K_u	E_l-C_l+K_l		Unstable Point
$A_3(0,0,1)$	E_g-C_g-R_l	E_u-C_u+K_u	C_l-E_l		Unstable Point
$A_4(0,1,1)$	E_g-C_g-R_l-R_u	C_u-E_u-K_u	C_l-E_l-K_l		Unstable Point
$A_5(1,0,0)$	C_g-E_g-K_g	E_u-C_u+K_u+R_u	E_l-C_l+K_g+R_l		Unstable Point
$A_6(1,1,0)$	C_g-E_g-K_g+R_u	C_u-E_u-K_u-R_u	E_l-C_l+K_g+K_l+R_l	C_g-E_g-K_g+R_u < 0; E_l-C_l+K_g+K_l+R_l < 0	ESS
$A_7(1,0,1)$	C_g-E_g+R_l	E_u-C_u+K_u+R_u	C_l-E_l-K_g-R_l		Unstable Point
$A_8(1,1,1)$	C_g-E_g+R_l+R_u	C_u-E_u-K_u-R_u	C_l-E_l-K_g-K_l-R_l	C_g-E_g+R_l+R_u<0	ESS

From Table 3, we can observe that the system has three types of evolutionarily stable states. $A_1(0,0,0)$ represents a passive or defective state of the system, which is unattainable. $A_6(1,1,0)$ indicates a scenario where rural e-commerce users choose artificial intelligence technology and collaborate with logistics enterprises employing artificial intelligence models, while the logistics enterprises do not upgrade their technology. However, this scenario does not align with reality. $A_8(1,1,1)$ represents a situation where, under government incentives and penalties, rural e-commerce users choose artificial intelligence technology and logistics enterprises upgrade their technology. This state is achievable under certain conditions.

3 NUMERICAL SIMULATION ANALYSIS

To more intuitively demonstrate the evolutionary paths and stable strategies of the three entities: government, rural e-commerce users, and logistics enterprises, this study adopts the method of controlling variables. It maintains a set of basic parameters unchanged while only varying the numerical value of a single parameter to observe the influence of parameter changes on the system's evolutionary outcomes. MATLAB is used to simulate the evolutionary paths of the three entities. Currently, the most feasible evolutionary outcome is $A_8(1,1,1)$, which represents (incentive, selection, upgrade). In this scenario, the government's incentive strategy plays a crucial role. Therefore, this section discusses the evolutionary scenarios of the three entities based on this background. The parameter E_g、C_g、K_g、R_u、R_l, representing government incentives, is selected as the focus of analysis. The impact of government behavior on system stability is emphasized.

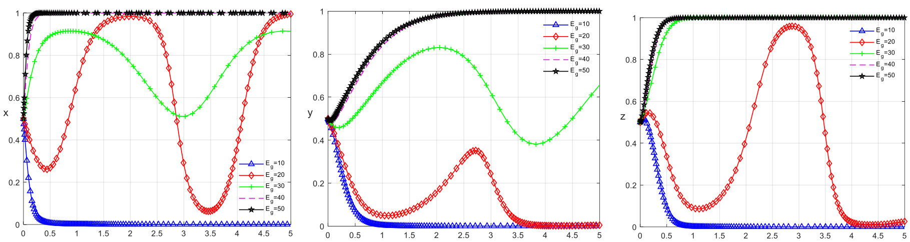
If $A_8(1,1,1)$ is the system's evolutionarily stable equilibrium solution, it must satisfy condition C_g-E_g+R_l+R_u<0，C_u-E_u-K_u-R_u<0，C_l-E_l-K_g-K_l-R_l<0. According to the assumptions of the evolutionary game model, the initial probabilities of the three entities are all set to 50%, with the basic parameters assigned as E_g=35，C_g=20，K_g=6，R_u=8，R_l=5，K_u=7，E_u=4，C_u=17，K_l=12，E_l=12，C_l=2.

3.1 Impact of Government's Implicit Revenue E_g on System Evolution

While keeping other parameters constant, we adjust the parameter E_g. Taking various values for E_g=10，E_g=20，E_g=30，E_g=40，E_g=50, we observe its influence on the strategic choices of the three entities, as depicted in Figure 2.

As the government's revenue increases, the strategic choices of the three entities tend to converge towards x=1、y=1、z=1, and the convergence speed increases with higher revenues. When E_g is relatively small, the strategic choices of the three entities all tend to converge towards x=0、y=0、z=0. As E_g gradually increases to 20, 30, the strategic choices of the three entities oscillate, exhibiting higher uncertainty. However, when E_g reaches 40, 50, the strategic choices of the three entities all reach an evolutionarily stable state. This suggests that as the government becomes more aware of implicit benefits such as rewards from higher-level departments and enhanced credibility, it places greater emphasis on credibility and recognition from higher authorities. Consequently, it believes that choosing incentive strategies is more conducive to the application of artificial intelligence technology in rural e-commerce logistics and promotes the development of rural e-commerce logistics.

In real-life scenarios, when the government perceives implicit benefits such as rewards and enhanced credibility from higher authorities more strongly, it significantly facilitates the advancement of rural e-commerce logistics, promotes the application of artificial intelligence technology, and fosters the growth of the logistics industry, thereby laying a robust foundation for future development.



（a）Proportions-Governments （b）Proportions-Rural E-commerce Users （c）Proportions- Logistics Enterprises

Fig. 2. Impact of Government's Implicit Revenue on the Strategic Choices of the Three Parties.

3.2 Impact of Government's Incentive Cost C_g on System Evolution

While keeping other parameters constant, we adjust the parameter C_g and set C_g=10，C_g=15，C_g=20，C_g=25，C_g=30 to observe its impact on the strategic choices of the three entities, as shown in Figure 3.

As C_g increases from 10 to 15, 20, the government's perception of costs gradually weakens, and the time taken to reach a stable state increases. The high-cost investment of the government in promoting artificial intelligence technology does not significantly affect the other two entities. The three entities still maintain the evolutionarily stable strategy of "incentive, selection, upgrade." When C_g increases to 30, none of the three entities reach a stable state, showing cyclical fluctuations. At this point, the three-party game lacks an evolutionarily stable point. It can be seen that increasing C_g has a significant negative effect on the government's choice of incentive strategies. When the government's cost C_g increases to a certain threshold, there is no stable evolutionary equilibrium point for the three entities. The government is unable to invest high costs in promotion and may choose to abandon the incentive strategy. Therefore, when implementing incentive strategies, the government needs to fully consider cost expenditure issues and maintain incentives within a reasonable range.

Therefore, in practical terms, governments must meticulously consider expenditure costs when formulating and executing incentive strategies, ensuring they remain within reasonable bounds. This practice enhances policy efficacy and sustainability, fosters technological innovation and industrial development, while also maintaining governmental fiscal prudence and public credibility.

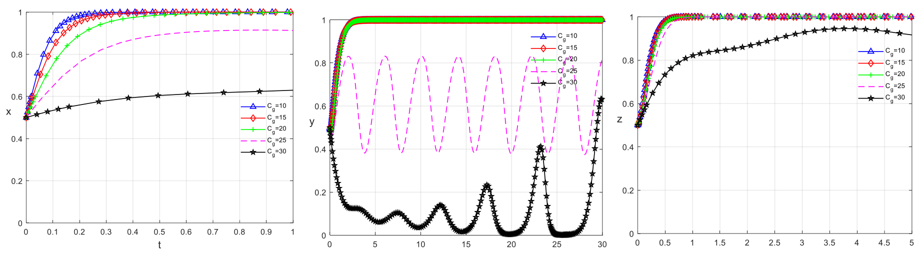


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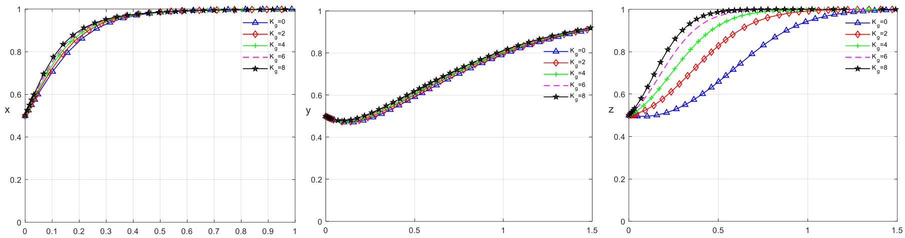
Fig. 3. Impact of Government's Incentive Cost on the Strategic Choices of the Three Parties.

3.3 Impact of Penalty Fine K_g on System Evolution for Logistics Enterprises

Keeping other parameters constant, adjust parameter K_g and set K_g=0，K_g=2，K_g=4，K_g=6，K_g=8 to observe the impact of parameter K_g variation on the strategic choices of the three-party game entities, as shown in Figure 4.

When K_g is set to 2, 4, 6, and 8, the system's evolutionary stable state remains unchanged. Increasing K_g does not significantly affect the rate at which the government and rural e-commerce users tend towards an evolutionarily stable state. However, the time taken for logistics enterprises to evolve to a stable state decreases, and the rate gradually increases. This is due to the enhanced perception of the penalty amount. In this scenario, to minimize losses, logistics enterprises would choose to upgrade their technology to avoid bearing high penalty pressure. This indicates that increasing K_g has a significant positive incentive effect on logistics enterprises to upgrade their technology. Furthermore, the primary purpose of the government's penalty fines for logistics enterprises is to encourage them to upgrade. However, In practical terms, fines do not necessarily act as effective incentives the higher they are. Excessive fines may reduce the government's credibility, thereby limiting the effectiveness of incentive strategies. Therefore, the government should appropriately and reasonably increase the level of penalties.

In practical scenarios, governments ought to strike a balance in crafting incentive policies. Moreover, they should facilitate the uptake and implementation of emerging technologies through non-financial means like training and technical assistance. This method not only propels the intelligent enhancement of rural e-commerce logistics systems but also secures the sustainable progression of rural e-commerce logistics.



（a）Proportions-Governments （b）Proportions-Rural E-commerce Users （c）Proportions- Logistics Enterprises

Fig. 4. Impact of Penalty Fine for Logistics Enterprises' Non-Upgrade on the Strategic Choices of the Three Parties.

3.4 Impact of Reward R_u for Rural E-commerce Users on System Evolution

Keeping other parameters constant, adjust parameter R_u and set R_u=4， R_u=6， R_u=8， R_u=10， R_u=12 to study its impact on the strategic choices of the three-party game entities, as shown in Figure 5.

As R_u gradually increases from 4, 6 to 8, 10, the system's stable state transitions from (1, 0, 1) to (1, 1, 1) three-party stable state. Continuing to increase to 12, the stable state of logistics enterprises remains unchanged, but the strategic choices of the government and rural e-commerce users exhibit cyclical fluctuations, showing higher uncertainty. Additionally, the government's adoption of incentive strategies fails to reach 1. At this point, the three-party game lacks an evolutionarily stable point. From the evolutionary process and results, it can be observed that moderately increasing R_u has a significant positive incentive effect on rural e-commerce users' choice of artificial intelligence technology, a slight negative effect on the government's incentive behavior, and no significant impact on the strategic choices of logistics enterprises. Therefore, when the government implements incentive strategies for rural e-commerce users, it is not necessarily beneficial to provide more economic subsidies. When R_u exceeds a certain threshold, the government may not be able to afford high economic subsidies and may choose to abandon incentive strategies. Moreover, excessive subsidies may lead to dependency among rural e-commerce users, reducing their initiative and hindering the intelligent upgrading and development of rural e-commerce logistics.

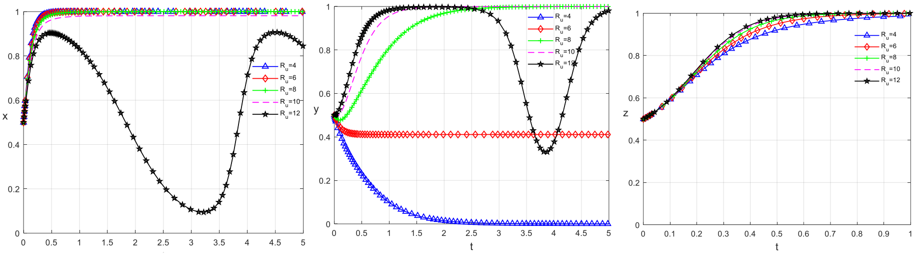


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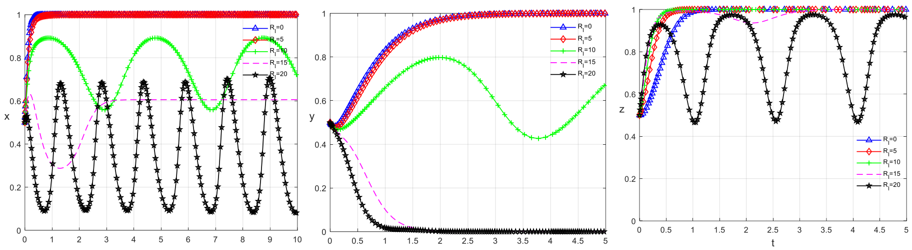
Fig. 5. Impact of Reward for Rural E-commerce Users on the Strategic Choices of the Three Parties.

3.5 Impact of Reward R_l for Logistics Enterprises on System Evolution

Keeping other parameters constant, we adjust parameter R_l and set R_l=0， R_l=5， R_l=10， R_l=15， R_l=20 to study its impact on the strategic choices of the three-party game entities, as shown in Figure 6.

As R_l increases from 0 to 5, the system remains in a stable state of (1, 1, 1) where all three parties are stable. For logistics enterprises, as R_l increases, the time taken for logistics enterprises to evolve to a stable state decreases. Continuing to increase R_l to 10, 15, logistics enterprises' stable state remains unchanged and the time to reach stability further decreases. However, the government and rural e-commerce users do not have a stable state; their strategic choices exhibit cyclical fluctuations. At R_l=20, none of the three-party game entities have a stable state. Both the government and logistics enterprises' strategic choices oscillate, while rural e-commerce users' strategic choice eventually becomes 0. The evolution results indicate that increasing R_l has a significant positive effect on incentivizing logistics enterprises to upgrade their technology for maximizing benefits. However, when government rewards exceed a certain threshold, strategies may change to avoid excessive economic burden. Therefore, In practical scenarios, the government's reward strategy for logistics enterprises should be scientifically reasonable to ensure high-quality development of rural e-commerce logistics and avoid excessive fiscal expenditure.



（a）Proportions-Governments （b）Proportions-Rural E-commerce Users （c）Proportions- Logistics Enterprises

Fig. 6. Impact of Reward for Logistics Enterprises on the Strategic Choices of the Three Parties.

4 CONCLUSIONS

Based on the theoretical framework of empowering rural e-commerce logistics with new quality productivity, this study utilizes the tripartite evolutionary game theory to construct a tripartite game model involving the government, rural e-commerce users, and logistics enterprises. The ideal stable evolutionary state requires meeting common interests and group interests, which is not easily achieved in the short term. It is an evolving process influenced by various factors of different sizes and magnitudes. Through MATLAB numerical simulations, the influence of relevant parameters on the strategic choices of the three parties is investigated, leading to the following conclusions:

（1）When the condition C_g-E_g+R_l+R_u<0，C_u-E_u-K_u-R_u<0，C_l-E_l-K_g-K_l-R_l<0 is satisfied, that is, when the sum of government costs and subsidies for rural e-commerce users and logistics enterprises is less than the implicit benefits such as the enhancement of government credibility, and when the benefits brought by rural e-commerce users choosing artificial intelligence technology and government subsidies exceed the input costs, and the cost of logistics enterprises upgrading artificial intelligence technology is less than the sum of government subsidies, brand enhancement, and penalties, the game model will converge to the equilibrium point A_8 (1,1,1). At this point, the three parties can achieve the ideal state of "government incentives, rural e-commerce users choosing technology, and logistics enterprises upgrading technology".

（2）For the government, implicit benefits E_g and costs C_g have a significant negative impact on the evolutionary results of government strategy choices. The government should improve regulations and measures related to artificial intelligence upgrades, increase publicity efforts for artificial intelligence technology, and formulate scientific and reasonable reward and punishment mechanisms. On one hand, the government should improve policies related to artificial intelligence technology and increase both online and offline publicity efforts for artificial intelligence technology policies, encouraging logistics enterprises to voluntarily improve their own technology and management conditions. On the other hand, the government can establish scientific and reasonable reward and punishment mechanisms. Without affecting credibility, some logistics companies that refuse to upgrade can be fined appropriately. Additionally, the government can increase fiscal rewards and subsidies appropriately, provide various tax incentives to rural e-commerce users who actively choose artificial intelligence technology and logistics enterprises that upgrade artificial intelligence technology, and ensure that incentive costs are controlled within a certain range to avoid excessive fiscal pressure.

Rural e-commerce users are highly sensitive to the subsidies provided by the government R_u, as well as the rewards R_l and penalties K_g imposed by logistics enterprises on the government. Within a reasonable range, higher government subsidies will increase the enthusiasm of both parties, while excessively high penalties will dampen the enthusiasm of logistics enterprises. Therefore, the government should adhere to the principle of moderation when implementing reward and penalty policies.

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