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Tripartite Evolutionary Game: Technological Innovation in Agricultural E-commerce Platforms

Abstract. *An in-depth analysis of the dynamic mechanism behind technical innovation in the agricultural e-commerce platform economy is crucial for the rapid development of rural economies. Based on the assumption of bounded rationality, this paper constructs a tripartite evolutionary game dynamic model involving the platform operator, the platform user, and the government to explain the decision-making mechanism for technological innovation diversification. The research findings indicate that the government's augmentation of subsidy and reward can facilitate the implementation of a beneficial partnership strategy between the operator and the user in the short term, but its long-term impact is constrained. Simultaneously, the substantial expenditure will impose a financial burden on the government, hindering the advancement of the game system towards (1,1,1). To foster tripartite cooperation, it is essential to synchronise the distribution of technological innovation resources among participants and improve the efficiency of the technological innovation process. The government ought to establish a differentiated reward and punishment system, improve the mechanism for market access and competition, and enforce dynamic supervision. The research offers a theoretical foundation for decision-making for the participants.*

Keywords: *technological innovation, agricultural e-commerce, evolutionary game theory, participant, mechanism.*

JEL Classification: C60, C70, O36.

1. Introduction

In the context of the knowledge economy, big data and internet technology have penetrated rural industries. Information technology has emerged as a catalyst for the shift from static to dynamic and from limited to unlimited competition in a rural industrial competitive environment (Frățilă et al., 2022). The practical use of technical innovation has already resulted in favourable impacts on the performance of the agricultural e-commerce economy. Online transaction e-commerce platforms supported by various forms of operational models such as B2B, B2C, C2C, etc. have overcome the geographical spatial constraints of rural areas, where cities are used as trading locations, and have resulted in the upgrading of traditional rural logistics supply chains into agricultural platform networks that integrate trading, logistics, and supporting services (Shcherbakov & Silkina, 2021; Ojstersek & Buchmeister, 2021). The e-commerce platform serves as a new agglomeration platform for rural commercial organisations, attracting and bringing together self-organising online

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business groups initiated by farmers. In order to optimise access to heterogeneous resources and competitive advantages, cross-disciplinary innovation participants with complementary re-sources consistently transcend geographical and organisational boundaries to establish innovation ecosystems with collaborative specialisation (Rietveld & Schilling, 2021; Wang et al.,2021). Each participant realises the dynamic process of value co-creation by integrating resources and coordinating differentiated services through the components, interaction rules, and mechanisms provided by the platform (Cenamor & Frishammar, 2021). The technology can facilitate value co-creation by empowering users, providing greater connectivity, offering more access to information, and enabling the quick dissemination of information in service ecosystems (Zhang et al., 2020). Given the significance of technological progression in the value co-creation process of platform organisations, it is imperative to explore the role and behavioural mechanisms of numerous participants in the development of agricultural e-commerce platform organisations.

The purpose of this paper is to investigate the dynamic process of the influence of key parameters in technological innovation cooperation, such as penalties, losses, costs, and additional incomes, using an evolutionary game model that serves as a theoretical reference for designing technological innovation mechanisms. Various strategic selections in the field of technological innovation will be explored. The findings of the investigation are of both theoretical and practical significance in the development of technological innovation mechanisms. The subsequent sections of this paper are structured in the following manner. Section 2 provides a concise overview of the research conducted on the operational mechanism of agricultural e-commerce platform organisations and the applicability of evolutionary game theory. Section 3 presents an overview of the research issues, hypotheses, and a tripartite evolutionary game model. Section 4 discusses the evolutionary stable tactics of the agricultural e-commerce operator, the agricultural e-commerce platform user, and the government in the cooperative game of technology innovation. Section 5 employs numerical simulation to illustrate the influence of parameters in the evolutionary game model across different scenarios. Section 6 provides a concise summary of the study's findings and offers pertinent recommendations.

2. Literature review

Currently, academics mostly concentrate their research on two features of the operational mechanism of agricultural e-commerce platform organisations. (1) The construction mechanisms of the agricultural e-commerce platform. Hong and Cui (2017) discovered that innovation of business models, such as production and development within agricultural e-commerce platforms that aligned with the interests of both the supply and demand sides, could enhance consumer stickiness in bilateral markets dominated by e-commerce platforms. Adiguzel (2021) suggested that the value-added network of e-commerce communities fractures as the number of heterogeneous economic participants and the scale of transactions increase. Cusumano et al. (2021) discovered that a lack of coordination in policy instruments resulted in duplication of e-commerce platforms, inconsistent technical standards, difficulties sharing information resources, and the emergence of the Matthew effect in the industry. (2) A standardised governance mechanism for digital platforms. Koo and Eesley (2021) found that the interaction and coordination innovation process was uncertain due to the participation of numerous heterogeneous virtual participants. To effectively deal with risks, multilateral relationships and collaboration mechanisms were established on the platform’s foundation, while platform operators designed rules for platform operations to improve the consistency and compatibility of participants' innovation behaviour (Jullien & Pavan, 2021). Loureiro et al. (2020) analysed that information exchange, knowledge sharing, and shared understanding among participants can influence and regulate participant behaviour at the cognitive level. Eloranta et al. (2021) explored advancements in technology and embedding on innovation behaviour control, thereby introducing new management tools. The study conducted by Wareham et al. (2014) demonstrated that the advancement of science and technology effectively improved the efficiency of resource matching and created the necessary conditions for synergy among diverse participants, thereby forming new avenues for value creation. Evolutionary economics emphasises symbiotic evolutionary relationships based on the assumption of limited rationality, and its dynamic characteristics provide a framework for studying the establishment of innovation ecosystems, as well as the mechanisms of interaction between participants and the environment (Lei et al., 2020). In this study, we continue to use this approach to elucidate the dynamic progression of the iterative game.

Nevertheless, the practical necessity of technological innovation has necessitated the transformation of traditional participants. In order to further the aforementioned research, it is imperative that we develop a comprehensive comprehension of the micro-perspective of participants and how e-commerce platforms participate in the technological innovation process.

3. Model specification

3.1 Model Description and Hypothesis

In a perfectly competitive market environment, the technological innovation of agricultural e-commerce platforms in China drives platform users other than consumers to process digital transformation and upgrading by data sharing and technological empowerment of platform operating entities. Platform operators have the ability to encourage platform users to innovate by using the spillover effect of innovative technology. However, the competitive behaviour of platform users and the decentralisation of power in the network market have led to the passive adoption of technological innovations and insufficient incentives for platform users to innovate in their own efforts. The value co-creation method determines that the platform operator has the authority to arrange the platform system and allocate the economic benefits of value co-creation (Benoit et al., 2017； Ortiz-Cerezo et al.,2022). Without government supervision, platform operators typically monopolise technology innovations to pursue more profits. The tripartite relationship has become progressively unbalanced.

Based on the game choice of tripartite participants and existing research on agricultural e-commerce technological innovation in China (Wu et al., 2020; Zhang et al., 2022), this study focuses on the horizontal cooperation of tripartite participants and the vertical administrative restrictions of direction are merged into the parametric hypothesis. This paper constructed a tripartite evolutionary game model involving the agricultural e-commerce operator, the agricultural e-commerce platform user, and the government.

3.2 Model Assumptions and Parameters of the Game Model

The agricultural e-commerce platform operator (hereinafter abbreviated as operator), the agricultural e-commerce platform user (hereinafter abbreviated as user), and the government are all characterised by constrained rationality. Due to the implementation of technical innovation on the platform, there is clear imbalance of information between the participants of the game. The participants' game strategies are matched randomly and the game are replayed.

Assumption 1. The set of strategies chosen by the operator, the user, and the government are (positive collaboration, negative collaboration), (positive collaboration, negative collaboration), and (supervision, lax supervision) respectively, with the corresponding probabilities{x ,1-x}, {y ,1-y} and {z ,1-z} (x,y,z∈[0,1]) respectively.

Assumption 2. When both the operator and the user opt for a positive collaboration strategy, they will both benefit from sharing certain advantages. At the same time, due to the different absorptive capabilities of the technical resource recipients and the heterogeneity of the data, the operator and the user will extract different values from the data and sources. The operator's gain from positive collaboration is denoted by $\partial\beta_1\gamma$. If the operator chooses the positive collaboration strategy, it will bring a cost of C_1 to the operator. Then, the user shall bear a part of the cost denoted by δC_1 for the operator to stabilise the cooperative relationship under the government supervision. Additionally, the choice of positive collaboration allows the operator to enhance their reputation, denoted by $F_1(F_1 > C_1)$, and obtain the reward of hC_1 provided by the government.

Assumption 3. The user will bear the cost, denoted by C_2, to engage in positive collaboration as it requires investing in technological innovation. Consequently, the revenue of the user choosing positive collaboration is $\partial\beta_2\gamma$. At the same time, the user will receive extra revenue for F_2 ($F_2 > C_2$) and a reward of P from the government. Similarly, the operator will be responsible for a portion of the cost denoted by δC_2 associated with positive collaboration for the user.

Assumption 4. When both the operator and the user engage in active innovation, the government will give appropriate rewards in direct subsidies, regular tax exemptions, and other specific incentive expenditures to encourage the adoption of positive innovative behaviours. When the government implements the supervision strategy, it encourages positive collaboration and provides a subsidy to the operator, which is denoted by hC_1. The strength of the incentive from the government is expressed by the variable h (0<h<1). Therefore, the user will receive P rewards from the government. If the government formulates the effective supervision, the behaviour incurs the cost C_3. Particularly, supervision can enhance the government's credibility, which is denoted by F_3 ($F_3 > C_3$). On the contrary, the parameter L_3 reflects the government's losses because of the operator's negative collaboration.

Assumption 5. In the process of technological innovation, an alliance between the operator and the user under government supervision is formed, influenced by limited rationality and information asymmetry, resulting in opportunistic behaviour in order to maximise self-interest. Earn speculative income through speculative self-interest activities such as false information disclosure or withholding private information. Speculative behaviours arise when the potential profit gained from engaging in negative collaboration outweighs the benefits of choosing a positive collaboration strategy. Currently, the operator or the user would bear a reduced cost of $(1-\beta_i)C_i$ ($<C_i$, i=1,2) and generate increased income of $(1-\beta_i)\partial\gamma$ ($>\partial\beta_i\gamma, i = 1,2$) (Ellwood et al.2022). However, if either the operator or the user engages in negative collaboration behaviour, it will result in losses L_i (i=1,2; $C_i < L_i$) for the other party involved.

The model parameters are summarised in Table 1.

Table 1. Definition of main parameters

Parameters	Definition	Range
β_1	The technical resources sharing degree coefficient of the platform	$1\geq \beta_1\geq 0$
β_2	The technical resources sharing degree coefficient of the user	$1\geq \beta_2\geq 0$
γ	The volume of technical resource exchanges	$\gamma > 0$
∂	The technical resources sharing benefit	$\partial > 0$
C_1	The cost of technology licencing and resource sharing paid by the operator to achieve the positive collaboration target	$C_1 \geq 0$
C_2	The cost of employee training and R&D expenses paid by the user participating in the positive collaboration	$C_2 \geq 0$
C_3	The cost of manpower, facilities, and financial resources paid by the government in regulatory measures	$C_3 \geq 0$
δ	The intensity coefficient of cost-sharing support in the positive collaboration	$1\geq\delta \geq 0$

Source: Authors' own creation.

Based on the above assumptions and parameter settings, this paper constructs the payment matrix for platform operator, platform user, and the government, as shown in Table 2.

Table 2. The payoff matrix of the tripartite model

Strategy choice		Platform user	Government: Supervision (z)	Government: Lax supervision (1-z)
Platform operator	Positive collaboration (x)	Positive collaboration (y)	$\partial\beta_1\gamma - C_1 + \delta C_1 - \delta C_2 + F_1 + hC_1$ $\partial\beta_2\gamma - C_2 + \delta C_2 - \delta C_1 + F_2 + P$ $F_3 - C_3 - hC_1 - p$	$\partial\beta_1\gamma - C_1 + F_1$ $\partial\beta_2\gamma - C_2 + F_2$ 0
		Negative collaboration (1-y)	$\partial\beta_1\gamma - C_1 + F_1 + hC_1 - L_1$ $(1-\beta_2)\partial\gamma - (1-\beta_2)C_2$ $F_3 - C_3 - hC_1$	$\partial\beta_1\gamma - C_1 + F_1 - L_1$ 0 0
	Negative collaboration (1-x)	Positive collaboration (y)	$(1-\beta_1)\partial\gamma - (1-\beta_1)C_1$ $\partial\beta_2\gamma - C_2 + F_2 + P - L_2$ $F_3 - C_3 - P - L_3$	0 $\partial\beta_2\gamma - C_2 + F_2 - L_2$ $-L_3$
		Negative collaboration (1-y)	$(1-\beta_1)\partial\gamma - (1-\beta_1)C_1 - L_1$ $(1-\beta_2)\partial\gamma - (1-\beta_2)C_2 - L_2$ $F_3 - C_3 - L_3$	$-L_1$ $-L_2$ $-L_3$

Source: Authors' own creation.

4. The tripartite stability strategy analysis

4.1 The Analysis of the Model

The expected payoffs are U_{O1} and U_{O2} of the operator when it chooses the "positive collaboration" and "negative collaboration" strategies, respectively.

$$U_{O1} = yz(\partial\beta_1\gamma - C_1 + \delta C_1 - \delta C_2 + F_1 + hC_1) + y(1-z)(\partial\beta_1\gamma - C_1 + F_1) + (1-y)z\,(\partial\beta_1\gamma - C_1 + F_1 + hC_1 - L_1) + (1-z)(1-y)(\partial\beta_1\gamma - C_1 + F_1 - L_1) \quad (1)$$

$$U_{O2} = yz[(1-\beta_1)\partial\gamma - (1-\beta_1)C_1] + (1-y)z[(1-\beta_1)\partial\gamma - (1-\beta_1)C_1 - L_1] + (1-y)(1-z)(-L_1) \quad (2)$$

The average expected payoff of the operator is:

$$\overline{U}_O = xU_{O1} + (1-x)U_{O2} \quad (3)$$

Therefore, the replication dynamic equation of the operator is:

$$F(x) = \frac{dx}{dt} = x(U_{O1} - \overline{U}_O) = x(1-x)[(1+z)\partial\beta_1\gamma + \delta yz(C_1 - C_2) + z(hC_1 - \partial\gamma + C_1 - \beta_1 C_1) - C_1 + F_1] \quad (4)$$

The expected payoffs are U_{u1} and U_{u2} of the user when it chooses the "positive collaboration" and "negative collaboration" strategies respectively.

$$U_{u1} = xz(\partial\beta_2\gamma - C_2 + \delta C_2 - \delta C_1 + F_2 + P) + (1-x)z(\partial\beta_2\gamma - C_2 + F_2 + P - L_2) + x(1-z)(\partial\beta_2\gamma - C_2 + F_2) + (1-x)(1-z)(\partial\beta_2\gamma - C_2 + F_2 - L_2) \quad (5)$$

$$U_{u2} = xz[(1-\beta_2)\partial\gamma - (1-\beta_2)C_2] + (1-x)z[(1-\beta_2)\partial\gamma - (1-\beta_2)C_2 - L_2] + (1-x)(1-z)(-L_2) \quad (6)$$

Similarly, the average expected payoff of the user is calculated:

$$\overline{U}_u = yU_{u1} + (1-y)U_{u2} \quad (7)$$

Therefore, the dynamic replication equation of the user is:

$$F(y) = \frac{dy}{dt} = y(U_{u1} - \overline{U}_u) = y(1-y)[z(x\delta C_2 - x\delta C_1 + xL_2 - x\partial\beta_2\gamma + xC_2 - xF_2 - \partial\gamma + C_2 - \beta_2 C_2 + \partial\beta_2\gamma) + (1+x)(\partial\beta_2\gamma - C_2 + F_2 - L_2)] \quad (8)$$

The expected payoffs of the government selecting "supervision" and "lax supervision" are U_{g1} and U_{g2}, respectively.

$$U_{g1} = xy(F_3 - C_3 - hC_1 - p) + (1-y)x(F_3 - C_3 - hC_1) + (1-x)y(F_3 - C_3 - P - L_3) + (1-x)(1-y)(F_3 - C_3 - L_3) \quad (9)$$

$$U_{g2} = (1-x)y(-L_3) + (1-x)(1-y)(-L_3) \quad (10)$$

The government's average expected payoff is:

$$\overline{U}_g = zU_{g1} + (1-z)U_{g2} \quad (11)$$

Thus, the corresponding dynamic replication equation is:

$$F(z) = \frac{\mathrm{d}z}{\mathrm{d}t} = z\left(U_{g1} - \overline{U}_g\right) = z(1-z)(F_3 - C_3 - yP - xhC_1) \quad (12)$$

4.2 Stability Analysis of the Tripartite Evolutionary Game

According to evolutionary stability theory (Kalman & Bertram,1960), the stability of the equilibrium point of the system can be judged by the stability of the eigenvalues of the Jacobi matrix of the system (Friedman,1991). Firstly, after jointly solving the equations, the Jacobi matrix of the game equations is derived by taking the first-order partial derivatives of x, y, and z in F(x), F(y), and F(z).

$$J = \begin{bmatrix} F'_x(x) & F'_y(x) & F'_z(x) \\ F'_x(y) & F'_y(y) & F'_z(y) \\ F'_x(z) & F'_y(z) & F'_z(z) \end{bmatrix} \quad (13)$$

Secondly, when all the dynamic replication equations are zero, the solution will result in eight equilibrium points for the strategies of three participants, which are

$E_1(0,0,0)$, E_2 $(0,1,0)$, $E_3(0,0,1)$, $E_4(1,0,0)$, $E_5(0,1,1)$, $E_6(1,1,0)$, E_7 $(1,0,1)$, and $E_8(1,1,1)$. According to the Lyapunov discriminant method, a Nash equilibrium solution is an evolutionary stability strategy (ESS) only when all the eigenvalues of the Jacobian matrix are negative. Therefore, if J have $\lambda<0$, the equilibrium point is stable. Conversely, if $\lambda>0$, the equilibrium point is unstable. If λ shows both positive and negative simultaneously, the equilibrium point is classified as a saddle point. The eigenvalues and stability of each equilibrium point are shown in Table 3.

Table 3. Evolutionary stability analysis for tripartite participants

Strategy	Eigenvalue	Stability
E_1（0,0,0）	$\lambda_1 = \partial\beta_1\gamma - C_1 + F_1 > 0$ $\lambda_2 = \partial\beta_2\gamma - C_2 + F_2 - L_2$ $\lambda_3 = F_3 - C_3 > 0$	Instability
E_2（0,1,0）	$\lambda_1 = \partial\beta_1\gamma - C_1 + F_1 > 0$ $\lambda_2 = C_2 + L_2 - F_2 - \partial\beta_2\gamma$ $\lambda_3 = F_3 - C_3 - P$	Instability
E_3（0,0,1）	$\lambda_1 = 2\partial\gamma\beta_1 + F_1 + hC_1 - \partial\gamma - \beta_1 C_1$ $\lambda_2 = 2\partial\beta_2\gamma + F_2 - \partial\gamma - \beta_2 C_2 - L_2$ $\lambda_3 = C_3 - F_3 < 0$	when $\lambda_1 < 0, \lambda_2 < 0$ are met to get ESS
E_4（1,0,0）	$\lambda_1 = C_1 - \partial\beta_1\gamma - F_1$ $\lambda_2 = 2(\partial\beta_2\gamma + F_2 - C_2 - L_2) > 0$ $\lambda_3 = F_3 - C_3 - hC_1$	Instability
E_5（0,1,1）	$\lambda_1 = hC_1 + F_1 + 2\partial\beta_1\gamma + \delta(C_1 - C_2) - \partial\gamma - \beta_1 C_1$ $\lambda_2 = \partial\gamma + \beta_2 C_2 + L_2 - 2\partial\beta_2\gamma - F_2$ $\lambda_3 = C_3 + P - F_3$	When $\lambda_1 < 0, \lambda_2 < 0, \lambda_3 < 0$ are met to get ESS
E_6（1,1,0）	$\lambda_1 = C_1 - \partial\beta_1\gamma - F_1$ $\lambda_2 = -2(\partial\beta_2\gamma + F_2 - C_2 - L_2)$ $\lambda_3 = F_3 - C_3 - P - hC_1 > 0$	Instability
E_7（1,0,1）	$\lambda_1 = -(hC_1 + F_1 + 2\partial\beta_1\gamma - \partial\gamma - \beta_1 C_1)$ $\lambda_2 = 2\partial\beta_2\gamma - \partial\gamma - \beta_2 C_2 - L_2 + F_2 + \delta(C_2 - C_1)$ $\lambda_3 = hC_1 + C_3 - F_3$	when $\lambda_1 < 0, \lambda_2 < 0, \lambda_3 < 0$ are met to get ESS
E_8（1,1,1）	$\lambda_1 = -(2\partial\beta_1\gamma + hC_1 + F_1 + \delta(C_1 - C_2) - \partial\gamma - \beta_1 C_1)$ $\lambda_2 = -(2\partial\beta_2\gamma + F_2 + \delta(C_2 - C_1) - \partial\gamma - \beta_2 C_2 - L_2)$ $\lambda_3 = hC_1 + P + C_3 - F_3$	when $\lambda_1 < 0, \lambda_2 < 0, \lambda_3 < 0$ are met to get ESS

Source: Authors' own creation.

4.3 The Model Analysis

In the supply chain system of the equipment manufacturing platform, the expected return of "subsidy" and "punishment" chosen by the government are:

The stability of the five equilibrium points is discussed as follows:

Scenario 1: If $\partial\gamma\beta_1 + F_1 + hC_1 - \beta_1 C_1 < (1-\beta_1)\partial\gamma$, $\partial\beta_2\gamma + F_2 - \beta_2 C_2 - L_2 < (1-\beta_2)\partial\gamma$, $E_3(0,0,1)$ is the ESS. It indicates that the speculative returns of the operator and the user outweigh the returns of positive collaboration. On the one hand, higher sharing costs and lower subsidies reduce the quantity and quality of technical resource sharing. On the other hand, the operator and the user choose a negative collaboration strategy due to higher speculative returns, so the government will tend to adopt a supervision stabilisation strategy.

Scenario 2: If $hC_1 + F_1 + \partial\beta_1\gamma + \delta(C_1 - C_2) - \beta_1 C_1 < (1-\beta_1)\partial\gamma$,$(1-\beta_2)\partial\gamma < \partial\beta_2\gamma + F_2 - \beta_2 C_2 - L_2$, $C_3 + \mathrm{P} < F_3$, $E_5(0,1,1)$ is the ESS. When cost-sharing and speculative returns are too high and subsidy incentives are insufficient, the operator will stabilise in adopting the negative collaboration strategy, and government supervision will fail. Meanwhile, government supervision provides the user with good rights protection and stabilises the adoption of a positive collaboration strategy.

Scenario 3: If $(1-\beta_1)\partial\gamma < \partial\beta_1\gamma + hC_1 + F_1 - \beta_1 C_1$, $\partial\beta_2\gamma + F_2 + \delta(C_2 - C_1) - L_2 - \beta_2 C_2 < (1-\beta_2)\partial\gamma$, $\mathrm{h}C_1 + C_3 < F_3$, $E_7(1,0,1)$ is the ESS. Due to the existence of a first-mover advantage, the operator tends to favour positive collaboration. However, with the cost-efficiency advantage of technological innovation formed by the operator, the user will receive less compensation and more losses to offset the redundancy of the user's interest protection. At this point, the user will choose a negative collaboration strategy. The benefit obtained by the government is greater than the sum of supervision costs and subsidies to the user, and the government adopts a stable supervision strategy.

Scenario 4: If $(1-\beta_1)\partial\gamma < \partial\beta_1\gamma + hC_1 + F_1 + \delta(C_1 - C_2) - \beta_1 C_1)$, $(1-\beta_2)\partial\gamma < \partial\beta_2\gamma + F_2 + \delta(C_2 - C_1) - L_2 - \beta_2 C_2$, $\mathrm{h}C_1 + P + C_3 < F_3$, $E_8(1,1,1)$ is the ESS. The operator and the user reduce costs through cooperation. The government supervision reduces the cost of data sharing between the operator and the user by increasing subsidy support and investment in technical infrastructure. On the other hand, the degree of complementarity between the operator and the user will be enhanced, and improving their core competitiveness will make the government's supervision more rewarding. Collaboration between the operator, the user, and the government is a necessary for realising the agricultural e-commerce technological innovation.

5. Numerical simulations

In order to conduct an in-depth analysis of the influence of different parameters on the evolution of the game system, the dynamic evolution of strategy selections of the operator, the user, and the government is simulated by using Vensim DSS software. Based on the current circumstances of each participant and the assumptions made in this research, the model parameters are initially assigned after consulting agricultural e-commerce experts and enterprise managers. Assume that

$$\beta_1 = 0.4, \beta_2 = 0.3, C_1 = 5, C_2 = 3, C_3 = 6, F_1 = 6, F_2 = 4, F_3 = 10, L_1 = 6, L_2 = 4, L_3 = 7, h = 0.4, \gamma = 0.6, P = 1, \partial = 5, \delta = 0.5.$$

Meanwhile, the initial probability of the tripartite evolutionary game is (0.5,0.5,0.5).

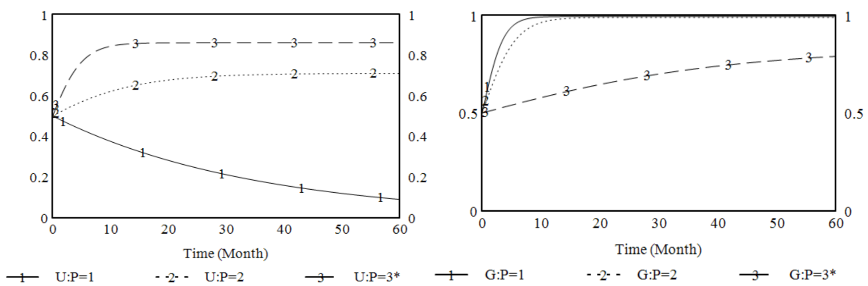
The simulation interval is set to 1 month, and the overall duration of the simulation is 60 intervals. Under the above parameter conditions, this paper analyses the impact of internal and external factors on evolutionary results.

5.1 The Influence of Rewards and Subsidies on Evolutionary Results

With other parameters fixed, the reward P is set as 1, 2, and 3, and the strength of the incentive coefficient h is set as 0.4, 0.6, and 0.8, respectively. The dynamic evolutionary track of the game system is shown in Figures 1 and 2, respectively.

From Figure 1, when P is low at the initial stage of evolution, both the user and the government will eventually evolve to choose the negative collaboration strategy and the lax supervision strategy, respectively. By increasing the rewards P, the convergence rate of the evolution path will be faster. However, as P continues to increase, the incentive effect on the user will gradually diminish. Nevertheless, the escalation of P hinders the pace of evolution towards the supervision strategy for the government, as the substantial reward imposes a significant strain on the fiscal expenditures of the government. Therefore, implementing an appropriate incentive system can incentivise the user to adopt the positive collaboration strategy in the short term and assist the government to make informed decisions based on the actual fiscal costs involved.

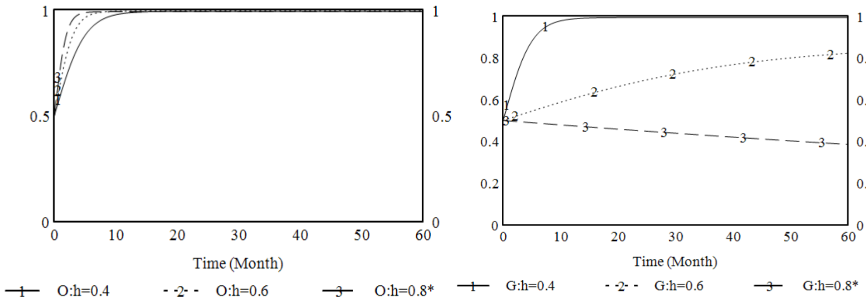
Figure 2(a) clearly demonstrates that the subsidy is an effective incentive for the operator to select the positive collaboration strategy to maximise their payoff. However, the substantial burden placed on the government by a high subsidy can lead to a decreased willingness to adopt supervision measures, as illustrated in Figure 2(b). The simulation results show that the subsidy incentives the operator and prompts them to actively carry out technological innovation and gradually become the leader of technological innovation practice.



(a) (b)

Figure 1. The influence of P on the behaviour of (a) the user and (b) the government

Source: Authors’ own creation.



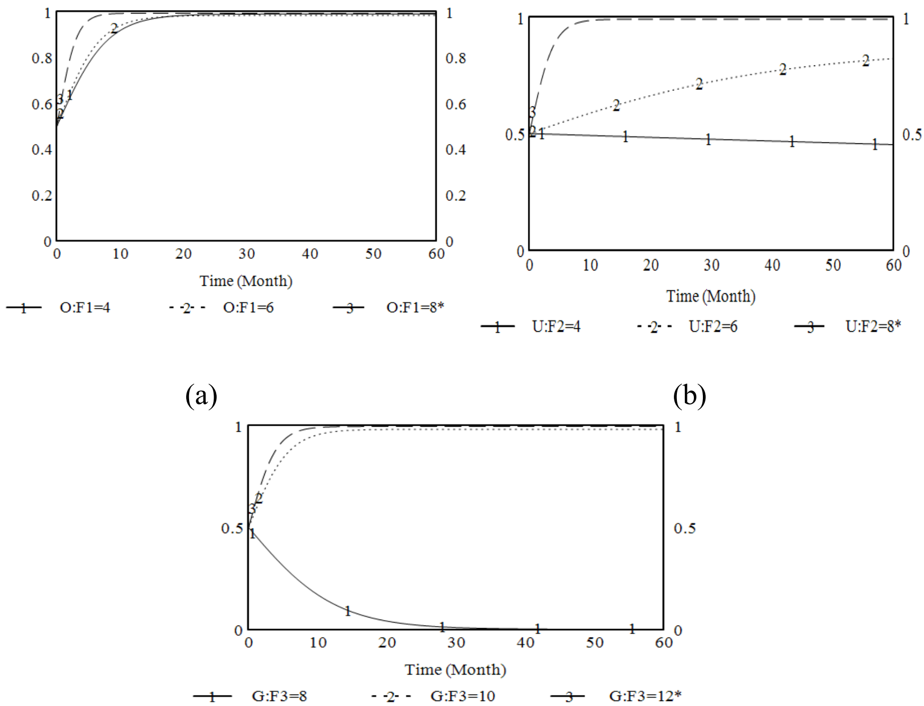
(a) (b)

Figure 2. The influence of h on the behaviour of (a) the operator and (b) the government

Source: Authors' own creation.

5.2 The influence of additional revenues on evolutionary results

The additional revenues F_1 and F_2 are set as 4, 6 and 8, respectively. In addition, F_3 is set as 8, 10 and 12. The evolution results of the corresponding technological innovation cooperation game system are shown in Figure 3.



(a) (b) (c)

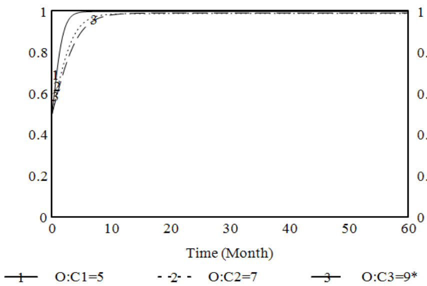
Figure 3. The influence of F_1, F_2 and F_3 on the behaviour of (a) the operator, (b) the user and (c) the government

Source: Authors' own creation.

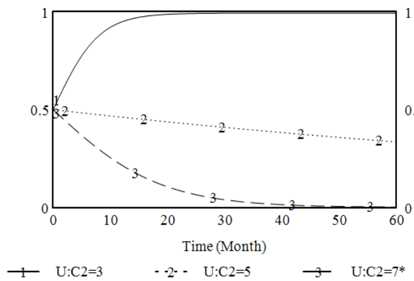
The evolution results of the obtained system analysed by simulation are shown in Figure 3. The enhancement of F_1 improves the operator's initiative and motivation to choose the positive collaboration strategy. Meanwhile, the operator demonstrates increased decisiveness in strategy evolution, resulting in a faster convergence to a stable strategy compared to other participants. When F_2 is high, the user is more likely to receive increased societal benefits. The user tends to select a positive collaboration strategy. Nevertheless, the user tends a disordered participation strategy in the initial stage of evolution. The influence of F_3 on the government's strategy choice is more pronounced. When F_3 is low, despite initially favouring lax supervision, the government is inclined to adopt the supervision strategy influenced by other players in the game. Moreover, the likelihood of the government opting for the supervision strategy increased with a higher value of F_3.

5.3 The influence of costs and losses on evolutionary results

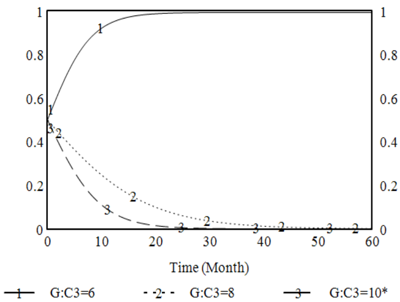
The costs C_1 is set as 5, 7 and 9, C_2 as 3, 5 and 7, and C_3 as 6, 8 and 10, respectively. Also, the loss L_2 is set as 4, 6 and 8, respectively. Other parameters remain the same. Figures 4 and 5 show the evolutionary path of the technological innovation cooperation game system.



(a)



(b)



(c)

Figure 4. The influence of C on the behaviour of (a) the operator, (b) the user and (c) the government

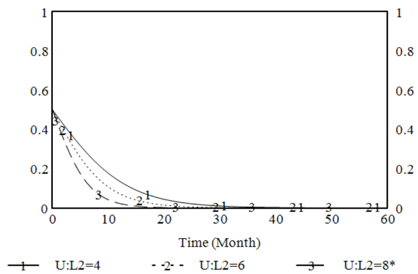


Figure 5. The influence of L_2 on the behaviour of the user

Source: Authors' own creation.

The following results can be drawn from Figure 4. The higher the cost is, the less the choice of positive collaboration willingness will be. Specifically, when the cost exceeds the benefit, such as $C_1 > F_1 + hC_1$, $C_2 > F_2 + P$, both the operator and the user will cease participating in the positive collaboration strategy, as shown in Figure 4. Due to the declining cost of supervision, such as $C_3 < F_3 - hC_1 - P$, the supervision strategy is more likely to be implemented considering enterprise earnings and social wealth. Furthermore, when $L_2 > F_2$, the user will choose a negative collaboration strategy as a result of the cost uncertainty of cooperation among participants in Figure 5.

6. Conclusions

In the agricultural e-commerce technological innovation context, a tripartite evolutionary game model is constructed to depict the cooperation between the agricultural of the e-commerce platform operator, the agricultural e-commerce platform user, and the government. This paper investigates the factors and paths that affect the tripartite decision-making options, and then uses numerical simulation to validate the theoretical results and the influence of key parameters on strategy evolution. The primary conclusions are as follows,

Firstly, in the tripartite game model, the strategic choices made by the participants have a mutual influence on each other. The effectiveness of synergy cooperation between the operator and the user can diminish the cost of technological innovation activities and increase profits for both parties. Simultaneously, government supervision will promote the continuation of the synergy cooperation strategy between the operator and the user. The government should guide the establishment of an integrated service platform for technological innovation and build a bridge of cooperation and communication between government departments and enterprises to ensure smooth information flow and tripartite coordination.

Secondly, coordinate resource allocation for technological innovation and improve its efficiency of technological innovation. The repeated configuration and disorderly supply of multiple technological innovation resources will lead the evolution of the tripartite cooperative game system to the disordered strategic combination. Strengthening the tripartite behaviours' coordination is necessary to achieve precise and efficient docking. First and foremost, improving the resource sharing between the operator and the user is essential for cost reduction and efficiency improvement. Moreover, we should emphasise the accuracy of resource and policy guarantees and build a process mechanism of technology research and development to promote. Ultimately, it is necessary to improve the operator and user response speed and the degree of specialisation in the transformation of technological achievements.

Thirdly, it is imperative to constantly optimise the supervision mechanism and strengthen the technological innovation policy system (Bashir et al., 2022; Widowaty et al.,2022). The government should fully leverage its guiding role, balance revenue and expenditure, and establish a differentiated reward and punishment mechanism. For one thing, the government should improve the selfdiscipline system of the agricultural e-commerce technology innovation industry, focus on the differences among enterprises, and deal with the non-compliant behaviour of enterprises. Furthermore, the government should improve the market access and competition mechanisms, cultivate diversified participants, and encourage healthy competition. Implementing tax, interest, subsidy, and other supportive policies can help the operator and the user reduce the cost of technological innovation and gradually establish an endogenous technological in-novation supply path. Finally, technological innovation policies and specific evaluation targets should be classified to ensure the operability of regulatory content and indicators, eliminate rent-seeking space, and effectively implement measures.

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