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Game Analysis of Competition and Cooperation Strategies in Agricultural Product Markets

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Abstract In the modern market environment of agricultural products, the relationship between producers and marketers is becoming more and more complex, with competition due to conflict of interests and cooperation due to common market goals. In this paper, we use the evolutionary game theory to construct a model of competitive and cooperative strategy selection between agricultural producers and marketers, and analyze the strategy evolution path and stability conditions of both parties by establishing replicated dynamic equations. The study sets the normal revenue range of producers and marketers as 17000-30000, the excess profit range as 4500-8000, and the cooperative marketing cost range as 1300-2500, and utilizes Matlab R2017a to verify the numerical simulation. The results show that the system exists two evolutionary stabilizing strategies, i.e., (Competition, Competition) and (Cooperation, Cooperation), when both parties' cooperation gain is greater than competition gain and the default cost is high enough; when the default cost is low, the system exists only one stabilizing strategy, i.e., (Competition, Competition). The simulation time is set to 0-50 units, and the initial cooperation ratio varies in the range of 0.2-0.8. Normal revenue, excess profit and cooperative marketing probability are positively correlated, while cooperation cost is negatively correlated with cooperation probability. The study shows that the evolutionary game theory can effectively explain the strategic choice behavior of agricultural marketing subjects and provide theoretical basis for the formulation of reasonable marketing cooperation strategies.

Index Terms Evolutionary game theory, agricultural marketing, competitive cooperation strategy, replication dynamic equation, strategy selection, numerical simulation

I. Introduction

In the marketing of agricultural products, cooperation and competition are common phenomena, and enterprises and individuals need to consider the relationship between cooperation and competition while pursuing their own interests [1], [2]. And game theory provides an analytical tool that can provide reference value for cooperation and competition in agricultural marketing [3].

Game theory is an important sub-field of economics, and its core problem is the interaction of individuals and their choice of strategies when facing decisions [4], [5]. In game theory, cooperation is an important concept, which involves the strategies and behaviors adopted by individual participants in reaching common goals [6], [7]. And cooperation and competition are interdependent and mutual constraints. In agricultural marketing, enterprises often need to compete with competitors as well as cooperate with suppliers and partners [8], [9]. Cooperation and competition influence each other and interact with each other to determine the market position and performance of agricultural products, and through the models and methods of game theory, agricultural marketing behaviors and possible outcomes can be predicted more accurately [10]-[12].

In terms of cooperation, game theory can help us analyze when cooperation is optimal, how to develop cooperation strategies, and how to reach cooperation agreements [13], [14]. By analyzing partners' behavior, benefits, and information transparency, we can determine the optimal cooperation strategy and avoid potential risks and uncertainties in agricultural marketing [15], [16]. As for competition, game theory can help us predict the behavior and possible strategies of competitors [17]. By constructing a game model, we can analyze competitors' benefits, motives, and possible action paths, which helps agricultural product marketing to develop appropriate competitive strategies and improve its competitive advantage [18]-[20].

This study adopts evolutionary game theory as an analytical framework to construct a model for the evolution of competitive cooperation strategies between agricultural product producers and marketers. Firstly, it establishes the payment matrices of both parties and sets the revenue structure under different strategy combinations, and then it applies the replicated dynamic equation to describe the evolution process of strategy selection and analyze the conditions and paths for the system to reach an evolutionary stable state. The evolutionary stable strategies under various parameter conditions are determined through theoretical derivation, and numerical simulation is used to verify the validity of the theoretical analysis results. Finally, we analyze the influence mechanism of key factors such as normal return, excess profit and cooperation cost on marketing cooperative relationship, which provides scientific basis for agricultural marketing subjects to formulate reasonable competitive cooperation strategy.

II. Research methodology on competition and cooperation strategies in agricultural marketing

II. A. Evolutionary game theory

In classical game theory, participating subjects are perfectly rational and interact using complete information. However, in reality, it is very difficult to create a completely rational and complete information environment. In the existence of competitive and cooperative systems, due to the participating subjects' own situation, the external environment and other factors will lead to the game for the more complex information is incomplete and the participating subjects for the limited rationality of the situation. Evolutionary game theory is based on the assumption of limited rationality and incomplete information of the participants, to analyze the trend of the evolution of the strategic choices of the subjects involved in the interests, and explore how to achieve the equilibrium results of the process [21]. The main elements involved in evolutionary game theory are explained as follows:

(1) The main body of the game: the main body of the game refers to the main body of interest involved in the game analysis with different decision-making choices, and the strategic choices between different game subjects will affect their mutual interests and each other's decision-making choices. In this study, the subjects of the two-party game are Xi'an International Port Area and other inland ports. The subject of the three-party game is the introduction of the government factor on the basis of the two parties. All the three parties have interest relations with each other.

(2) Strategy set: Strategy set refers to the set of options for the game subject to make decisions in the game analysis. According to the actual situation of the subject of the game, the strategy set of different subjects may be different.

(3) Game equilibrium: game equilibrium refers to the process of seeking to maximize the interests of the subject of the game in the game analysis, its different strategy choices affect their own or each other's benefits. The subject of the game will gradually move towards the result that the interests of all parties have reached equilibrium in the change of decision-making choices.

(4) Evolutionary stable strategy (ESS): Evolutionary stable strategy means that in the process of the game, based on limited rationality, the subject of the game can not find the optimal strategy and the optimal equilibrium point at one time. Therefore, the evolutionary game process is a two-party through continuous decision-making, trial and error to find the subject of both sides will converge to a certain strategy state, that is, stable strategy [22].

(5) Replication dynamics equation: used to describe the game process, replication dynamics refers to the game subject according to other subjects to choose, change their own initial strategy, choose more favorable strategy process. That is, the dynamic differential equation of the frequency or frequency of a certain strategy has been adopted to ensure that the evolutionary stable strategy for the evolutionary equilibrium, can be expressed as:

$$F(k)=\frac{dx_k}{dt}=x_t[u_k-u_s],k=1,2,3...k \tag{1}$$

(6) The payoff function: also known as the payoff function, refers to the payoff that each participating subject can obtain in the game according to the type and choice of strategy he or she belongs to. The purpose of calculating the payoff function is to explore the optimal strategy of the participating subjects, i.e., the strategy that maximizes their utility in the set of strategies.

II. B. Evolution of cooperative-competitive relationships

II. B. 1) Evolutionary Stabilization Strategies and Replicator Dynamics

Evolutionary game theory starts from finite rationality and takes the group as the object of study, which believes that individuals in reality cannot accurately know whether their behaviors are optimal compared with other individuals in the group, and that individual decision-making is realized through the dynamic process of imitation and learning among individuals. The basic idea of evolutionary stabilization strategy is: assuming that there exists a large group that chooses a particular strategy and a mutant small group that chooses a different strategy, this mutant small group enters into the large group to form a mixed group, if the payment received by the mutant small group in the mixed group is greater than that received by the individuals in the original group, then the small group is able to intrude into the large group, and vice versa. invade the larger group and disappear during evolution. When used to study group behavior, the disappearance of a small mutant group means that the small group changes its strategy and chooses the same strategy as the large group. If a group is able to eliminate the intrusion of any small mutant group, then the group is said to have reached an evolutionary stable state, and the strategy chosen by the group is the evolutionary stable strategy.

An evolutionarily stable strategy $x \in A$ is evolutionarily stable if $\forall y \in A, y \neq x$, there exists an $\overline{\varepsilon}_y \in (0,1)$, inequality:

$$u[x, \varepsilon y + (1-\varepsilon)x] > u[y, \varepsilon y + (1-\varepsilon)x] \tag{2}$$

holds for any $\varepsilon \in (0, \overline{\varepsilon}_y)$. where A is the payoff matrix when individuals in the group play: y denotes the mutation strategy: $\overline{\varepsilon}_y$ is a constant associated with the mutation strategy y called the intrusion bound: $\varepsilon_y + (1-\varepsilon)x$ denotes the choice evolution A mixed population consisting of a population with a stabilization strategy and a population with a selection mutation strategy.

In the process of biological evolution, when different populations compete for the same survival resource in the same living environment, the result is that only those populations that obtain higher fitness can survive, and those that obtain lower fitness are eliminated in the competition. Therefore, when the fitness of a strategy is higher than the average fitness of the group, the strategy will develop in the group, which is the basic idea of replicator dynamics [23]. In the process of repeated games between groups in order to survive, the strategy selection adjustment can be simulated by the "replication dynamics" mechanism of biological evolution game of "selection strategy-evolution-selection of new strategy-re-evolution". Replication dynamics are actually dynamic differential equations that describe how often a particular strategy is used in a population:

$$\frac{1}{x_i}\dot{x}_i = [f(s_i, x) - f(x, x)] \tag{3}$$

Eq. (3) is an imitator replication dynamic equation (RDE). Where $f(s_i, x)$ denotes the expected payment obtained by an individual in the group who chooses a pure strategy when the individuals in the group play a random matching anonymous game, $f(x,x) = \sum x_i f(s_i, x)$ denotes the average expected payment of the group, t refers to the time, $\dot{x}_i$ denotes the derivative of x_i with respect to time t, and $\frac{1}{x_i}\dot{x}$ denotes the growth rate of the strategy over time.

II. B. 2) Modeling the Evolution of Cooperative Competitive Relationships

The marketing channel cooperative competition game contains producer groups and seller groups, and the feasible strategies and benefits of the two groups are different, so the game is an asymmetric game with multi-group interactions. Each game is a cooperative game in which a member of the producer group is randomly paired with a member of the seller group, and each group member has two pure strategy choices, i.e., the producer group can choose either cooperation or competition, and the probability of choosing cooperation is x and the probability of choosing competition is $1-x$. The seller group may also choose to cooperate or compete, and let the probability of choosing to cooperate be y and the probability of choosing to compete be $l-y$.

π_1, π_2 denote the normalized returns obtained by the group of producers and the group of sellers, respectively, when they adopt a competitive strategy. R_1, R_2 denote the excess profits obtained when the two parties of the game adopt cooperative strategies, respectively. R_1, R_2 denote the costs incurred by the two parties to the game as a result of cooperation, respectively. Assuming that $R_1 > 0, R_2 > 0, C_1 > 0, C_2 > 0$, it is clear that based on the economic effects available to cooperative competition, there are: $R_1 > C_1 \cdot R_2 > C_2$.

Similar to biological systems, marketing channel systems evolve over time in the interaction of external environmental changes and internal structural adjustments. At the micro level, the strategy choices of marketing channel system actors are made in a space with uncertainty and limited rationality, and each other's strategies interact with each other. Therefore, an evolutionary game model is formed by these players repeatedly playing the game at each stage. Drawing on the idea of natural selection in biological systems, the dynamics of the replicators of a population in evolutionary game theory is assumed to be such that the growth rate of a strategy depends on its fitness, and the strategy that generates higher returns has a higher growth rate. Thus, economic agents in the system of marketing channels can also increase by imitation and experimentation those strategies that are applied successfully.

The group of producers chooses the cooperative strategy with the degree of adaptation:

$$e_1 A\{y, 1-y\}^T \tag{4}$$

where $e_1 = [1,0]$, denotes that the producer group selects a cooperative strategy with probability 1. A is the revenue matrix of the producer group:

$$A = \begin{bmatrix} \pi_1 + R_1 - C_1 & \pi_1 - C_1 \\ \pi_1 & \pi_1 \end{bmatrix} \tag{5}$$

Then:

$$e_1 A\{y,1-y\}^T - \{1,0\}\begin{bmatrix} \pi_1 + R_1 - C_1 & \pi_1 - C_1 \\ \pi_1 & \pi_1 \end{bmatrix}$$
$$\{y,1-y\}^T = y(\pi_1 + R_1 - C_1) + (1-y)(\pi_1 - C_1) \tag{6}$$

The average fitness of the producer group is:

$$(x,1-x)A(y,1-y)^T = (x,1-x)\begin{bmatrix} \pi_1 + R_1 - C_1 & \pi_1 - C_1 \\ \pi_1 & \pi_1 \end{bmatrix}(y,1-y)^T \tag{7}$$

According to the definition of the replicator dynamic equation, the growth rate $\frac{1}{x}\dot{x}$ of the producer group choosing a cooperative strategy should satisfy the following equation:

$$\frac{1}{x}\dot{x} = e_1 A\{y,1-y\}^T - \{x,1-x\}A\{y,1-y\}^T \tag{8}$$

To wit:

$$\dot{x} = x(1-x)\{1,-1\}A\{y,1-y\}^T \tag{9}$$

Organizing is available:

$$\dot{x} = x(1-x)(yR_1 - C_1) \tag{10}$$

Similarly, considering the growth rate of the group of sellers choosing the cooperative strategy $\frac{1}{y}y$, it can be obtained:

$$\dot{y} = y(1-y)(xR_2 - C_2) \tag{11}$$

Let $\dot{x} = 0, \dot{y} = 0$, the equilibrium points of differential equations (10) and (11) describing the group dynamics of the cooperative competitive system of marketing channels are easily obtained as $O(0,0), A(1,0), (0,1), C(1,1)$ and $D(x_D, y_D)$. Among them:

$$x_D = \frac{C_2}{R_2}; \quad y_D = \frac{C_1}{R_1} \tag{12}$$

We take partial derivatives of $\dot{x}$ and j with respect to x and y, respectively, to obtain the Jacobian matrix of the cooperative-competitive system of marketing channels as:

$$J = \begin{bmatrix} (1-2x)(yR_1 - C_1) & x(1-x)R_1 \\ y(1-y)R_2 & (1-2y)(xR_2 - C_2) \end{bmatrix} \tag{13}$$

The determinant of J is $detJ = a_1 1a_{22} - a_{12}a_{21}$ i.e. $trJ = a_{11} + a_{22}$.
Among them:

$$I = -C_2(1 - \frac{C_2}{R_2})C_1(1 - \frac{C_1}{R_1}) \tag{14}$$

The dynamic process of the cooperative-competitive game of the marketing channel system is shown in Figure 1. The line formed by the two unstable equilibrium points A, B and the saddle point D is the critical line for the system to converge to different states, in the upper right of the line the system will converge to the cooperative relationship. In the lower left of the fold line the system will converge to a competitive relationship. Since the evolution of the marketing channel system is a long process, it is possible to maintain a situation where cooperative and competitive strategies coexist for a long period of time.

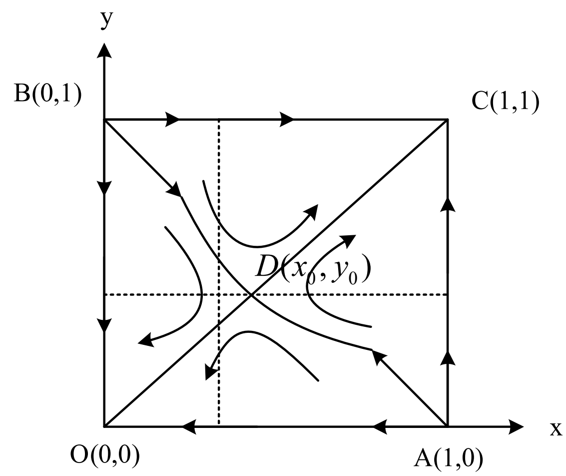


Figure 1: The dynamic process of competitive game of marketing channel system

II. C.Analysis of Evolutionary Stabilization Strategies

The payment matrix of the competitive strategy evolution game for agricultural producers and marketers constructed in this paper is shown in Table 1.

Table 1: Payment by both parties

		Vendor group	
		Cooperation (y)	Competition $(1-y)$
Producer group	Cooperation (x)	$R_A + \alpha\Delta R - m_A$ $R_B + (1-\alpha)\Delta R - m_B$	$R_A + Q - m_A - n_A$ $R_B + E_B - Q$
	Competition $(1-x)$	$R_A + E_A - Q$ $R_B + Q - m_B - n_B$	R_A, R_B

II. C. 1) Evolutionary stabilization strategies of producers

From equation (15), the equation of replication dynamics of agricultural producers is given as:

$$F(x) = \frac{dx}{dt} = x(U_{A1} - \bar{U}_A) = x(1-x)[y(\alpha\Delta R - E_A + n_A) + Q - m_A - n_A] \tag{15}$$

(1) When:

$$y_0 = \frac{m_A + n_A - Q}{\alpha\Delta R - E_A + n_A} \tag{16}$$

At this point $F(x) = 0$ indicates that no matter how the probability of the producer choosing to cooperate changes, it will have no effect on the outcome of the evolutionary game and the system will be in a stable state.

(2) When:

$$y \neq \frac{m_A + n_A - Q}{\alpha\Delta R - E_A + n_A} \tag{17}$$

Let $F(x) = 0$, the producer's replicated dynamic equation can be obtained by the producer's replicated dynamic equation can be obtained by the derivation of the producer's replicated dynamic equation with 2 stable points, $x = 0$ and $x = 1$:

$$\frac{dF(x)}{dx}=(1-2x)[y(\alpha\Delta R-E_A+n_A)+Q-m_A-n_A] \tag{18}$$

According to the stability theorem of differential equations, it can be seen that if a certain strategy adopted by the producer is a stable strategy, its replication dynamic equation must satisfy $\frac{dF(x)}{dx}<0$. At this point, the parameters in $\frac{m_A+n_A-Q}{\alpha\Delta R-E_A+n_A}$ are discussed.

a) When $\alpha\Delta R-E_A+n_A, m_A+n_A-Q$ is anomalous, $\frac{m_A+n_A-Q}{\alpha\Delta R-E_A+n_A}<0$, and because $y\in[0,1]$, then $y>\frac{m_A+n_A-Q}{\alpha\Delta R-E_A+n_A}$, when $\frac{dF(x)}{dx}|x=0>0, \frac{dF(x)}{dx}|x=1<0$. At this point $x=1$ is an evolutionarily stable strategy.

b) When $0<\alpha\Delta R-E_A+n_A<m_A+n_A-Q$, $\frac{m_A+n_A-Q}{\alpha\Delta R-E_A+n_A}>1$, and because $y\in[0,1]$, then $y<\frac{m_A+n_A-Q}{\alpha\Delta R-E_A+n_A}$, at which point $\frac{d}{F}(x)dx|_{x=0}<0, \frac{dF(x)}{dx}|_{x=1}>0$. At this point $x=0$ is an evolutionarily stable strategy.

c) When $0<\alpha\Delta R-E_A+n_A<\frac{1}{m_A+n_A-Q}$, $0<\frac{m_A+n_A-Q}{\alpha\Delta R-E_A+n_A}<1$, and because $y\in[0,1]$. If $y<\frac{m_A+n_A-Q}{\alpha\Delta R-E_A+n_A}$, at this point $\frac{dF(x)}{dx}|_{x=0}<0, \frac{dF(x)}{dx}|_{x=1}>0$. At this point $x=0$ is an evolutionarily stable strategy. If $y>\frac{m_A+n_A-Q}{\alpha\Delta R-E_A+n_A}$, at this point $\frac{dF(x)}{dx}|_{x=0}>0, \frac{dF(x)}{dx}|_{x=1}<0$. At this point $x=1$ is an evolutionarily stable strategy.

II. C. 2) Evolutionary stabilization strategies for marketers

From equation (15) the marketer's replication dynamics equation is:

$$F(y)=\frac{dy}{dt}=y(U_{B1}-\bar{U}_B)=y(1-y)[x((1-\alpha)\Delta R-E_B+n_B)+Q-\mathrm{m}_B-n_B] \tag{19}$$

(1) When:

$$x_0=\frac{m_B+n_B-Q}{(1-\alpha)\Delta R-E_B+n_B} \tag{20}$$

At this time $F(y)=0$, indicating that no matter how the probability of the marketer's choice of cooperation changes, it will not have an impact on the outcome of the evolutionary game, and the system will be in a stable state.

(2) When:

$$x_0\neq\frac{m_B+n_B-Q}{(1-\alpha)\Delta R-E_B+n_B} \tag{21}$$

Let $F(y)=0$, 2 stable points, $y=0$ and $y=1$, can be obtained by the marketer's replication dynamics equation, which is derived from the marketer's replication dynamics equation:

$$\frac{dF(y)}{dy}=1-2y[x((1-\alpha)\Delta R-E_B+n_B)+Q-m_B-n_B] \tag{22}$$

Similarly, it follows that if a particular strategy adopted by the marketer is a stabilizing strategy, its replication dynamic equation must satisfy $\frac{dF(x)}{dy}<0$. At this point, each parameter in $\frac{m_B+n_B-Q}{(1-\alpha)\Delta R-E_B+\eta_B}$ is discussed.

a) When $(1-\alpha)\Delta R - E_B + n_B, m_B + n_B - Q$ is heteroscedastic, $\frac{m_B + n_B - Q}{(1-\alpha)\Delta R - E_B + n_B} < 0$, and since $x \in [0,1]$, then $x > \frac{m_B + n_B - Q}{(1-\alpha)\Delta R - E_B + n_B}$, at which point $\frac{dF(y)}{dy}|_{y=0} > 0$ and $\frac{dF(y)}{dy}|_{y=1} < 0$. At this point $y = 1$ is an evolutionarily stable strategy.

b) When $0 < (1-\alpha)\Delta R - E + m + n < m + n - Q$, $\frac{m_B + n_B - Q}{(1-\alpha)\Delta R - E_B + n_B} > 1$, and since $x \in [0,1]$, then $x < \frac{m_B + n_B - Q}{(1-\alpha)\Delta R - E_B + n_B}$, at which point $\frac{dF(y)}{dy}|_{y=0} < 0$ and $\frac{dF(y)}{dy}|_{y=1} > 0$. At this point $y = 0$ is an evolutionarily stable strategy.

c) When $0 < (1-\alpha)\Delta R - E_B + n_B < \frac{1}{m_B + n_B - Q}$, $0 < \frac{m_B + n_B - Q}{(1-\alpha)\Delta R - E_B + n_B} < 1$, also because $x \in [0,1]$. If $x < \frac{m_B + n_B - Q}{(1-\alpha)\Delta R - E_B + n_B}$, then $\frac{dF(y)}{dy}|_{y=0} < 0$ and $\frac{dF(y)}{dy}|_{y=1} > 0$. At this point $y = 0$ is an evolutionarily stable strategy. If $x > \frac{m_B + n_B - Q}{(1-\alpha)\Delta R - E_B + n_B}$, at this point, $\frac{dF(y)}{dy}|_{y=0} > 0$ and $\frac{dF(y)}{dy}|_{y=1} < 0$. At this point $y = 1$ is an evolutionarily stable strategy.

II. C. 3) Evolutionary stability analysis of producers and marketers

The following system of replicated dynamic equations can be obtained:

$$\begin{cases} F(x) = \frac{dx}{dt} = x(U_{A1} - \bar{U}_A) = x(1-x)[y(\alpha\Delta R - E_A + n_A) + Q - m_A - n_A] \\ F(y) = \frac{dy}{dt} = y(U_{B1} - \bar{U}_B) = y(1-y)[x((1-\alpha)\Delta R - E_B + n_B) + Q - \min_B - n_B] \end{cases} \tag{23}$$

Let the above equation $F(x) = 0, F(y) = 0$. It can be concluded that the game system has five equilibrium points in the two-dimensional plane $s = \{|(x,y)|, 0 \le x, y \le 1\}$, which are A(0,0), B(0,1), C(1,0), D(1,1), and E(M,N). Where $M = \frac{m_B + n_B - Q}{(1-\alpha)\Delta R - E_B + n_B}, N = \frac{m_A + n_A - Q}{\alpha\Delta R - E_A + n_A}$.

In a dynamically evolving system, the stability of each equilibrium point can be obtained by analyzing the local stability of the Jacobi matrix of the system replicating the set of dynamic equations. If each equilibrium point makes the value $detJ > 0$ and the trace $trJ < 0$ of the Jacobi matrix, then the equilibrium point is a stable strategy (ESS) of the evolutionary game. The equilibrium is unstable when the value $detJ > 0$ as well as the trace $trJ > 0$. The remaining cases are saddle points. The Jacobi matrix of this system is:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} \tag{24}$$

Among them:

$$\begin{aligned} \frac{\partial F(x)}{\partial x} &= (1-2x)[y(\alpha\Delta R - E_A + n_A) + Q - m_A - n_A] \\ \frac{\partial F(x)}{\partial y} &= x(1-x)(\alpha\Delta R - E_A + n_A) \\ \frac{\partial F(y)}{\partial x} &= y(1-y)(1-\alpha)\Delta R - E_B + n_B) \\ \frac{\partial F(y)}{\partial y} &= (1-2y)[x(1-\alpha)\Delta R - E_B + n_B) + Q - m_B - n_B] \end{aligned} \tag{25}$$

This Jacobi matrix corresponds to $detJ$ and trJ respectively:

$$\begin{aligned} detJ = &(1-2x)[y(\alpha\Delta R - E_A + n_A) + Q - m_A - n_A] \\ &\times(1-2y)[x(1-\alpha)\Delta R - E_B + n_B) + Q - m_B - n_B] \\ &-x(1-x)(\alpha\Delta R - E_A + n_A) \\ &\times y(1-y)(1-\alpha)\Delta R - E_B + n_B) \end{aligned} \quad (26)$$

$$\begin{aligned} trJ = &(1-2x)[y(\alpha\Delta R - E_A + n_A) + Q - m_A - n_A] \\ &+(1-2y)[x(1-\alpha)\Delta R - E_B + n_B) + Q - m_B - n_B] \end{aligned} \quad (27)$$

The Jacobi matrix values $detJ$ and traces trJ for each equilibrium are shown in Table 2.

Table 2: The Jacobian values of each equilibrium point

Equilibrium point	$detJ$	trJ
$A(0,0)$	$(Q - m_A - n_A)*(Q - m_B - n_B)$	$2Q - m_A - n_A - m_B - n_B$
$B(0,1)$	$(\alpha\Delta R - E_A + Q - m_A)*(m_B + n_B - Q)$	$\alpha\Delta R - E_A - m_A + m_B + n_B$
$C(1,0)$	$(m_A + n_A - Q)*[(1-\alpha)\Delta R - E_B + Q - m_B]$	$m_A + n_A + (1-\alpha)\Delta R - E_B - m_B$
$D(1,1)$	$(\alpha\Delta R - E_A + Q - m_A)*[(1-\alpha)\Delta R - E_B + Q - m_B]$	$-(\Delta R - E_A + 2Q - m_A - E_B - m_B)$
$E(M,N)$	K	O

Among them:

$$K = -\frac{(m_A + n_A - Q)^2(m_B + n_B - Q)(E_A + m_A - Q - \alpha\Delta R)(E_B + m_B - Q - (1-\alpha)\Delta R)}{(\alpha\Delta R - E_A + n_A)^2((1-\alpha)\Delta R - E_B + n_B)} \quad (28)$$

From the above table, it can be seen that $E(M,N)$ of the points has a trace of 0, then it is definitely not a stable point of the evolving system. Therefore the remaining four points are mainly analyzed. The stability analysis of the equilibrium point is shown in Table 3.

Table 3: Analysis of equilibrium stability

Equilibrium point	Stability	Condition
$A(0,0)$	ESS	$m_i + n_i > Q(i = A,B)$
$B(0,1)$	ESS	$m_B + n_B < Q$ and $\alpha\Delta R - E_A + Q - m_A < 0$
$C(1,0)$	ESS	$m_A + n_A < Q$ and $(1-\alpha)\Delta R - E_B + Q - \mathrm{m}_B < 0$
$D(1,1)$	ESS	$\Delta R - E_A - E_B + 2Q - m_A - \mathrm{m}_B > 0$
$B(0,1)$ and $C(1,0)$	ESS	$m_i + n_i < Q(i = A,B)$
		$\Delta R - E_A - E_B + 2Q - m_A - \mathrm{m}_B < 0$
$A(0,0)$ and $D(1,1)$	ESS	$m_i + n_i > Q(i = A,B)$
		$\Delta R - E_A - E_B + 2Q - m_A - \mathrm{m}_B > 0$

Let $h = \Delta R - E_A - E_B + 2Q - m_A - m_B, f_A = \alpha\Delta R - E_A + Q - m_A, g_A = m_A + n_A - Q$, $f_B = (1-\alpha)\Delta R - E_B + Q - m_B, g_B = m_B + n_B - Q$. Where $h = f_A + f_B$ represents the difference in net returns when both parties choose a cooperative strategy versus when both choose a competitive strategy, f_A represents the difference in net returns when the producer chooses a cooperative strategy versus a competitive strategy, and f_B represents the difference in net returns when the marketer chooses a cooperative strategy versus a competitive strategy. g_A represents the value of the producer's revenue loss when the marketer defaults and chooses a competitive strategy, and g_B represents the value of the marketer's revenue loss when the producer defaults and chooses a competitive strategy.

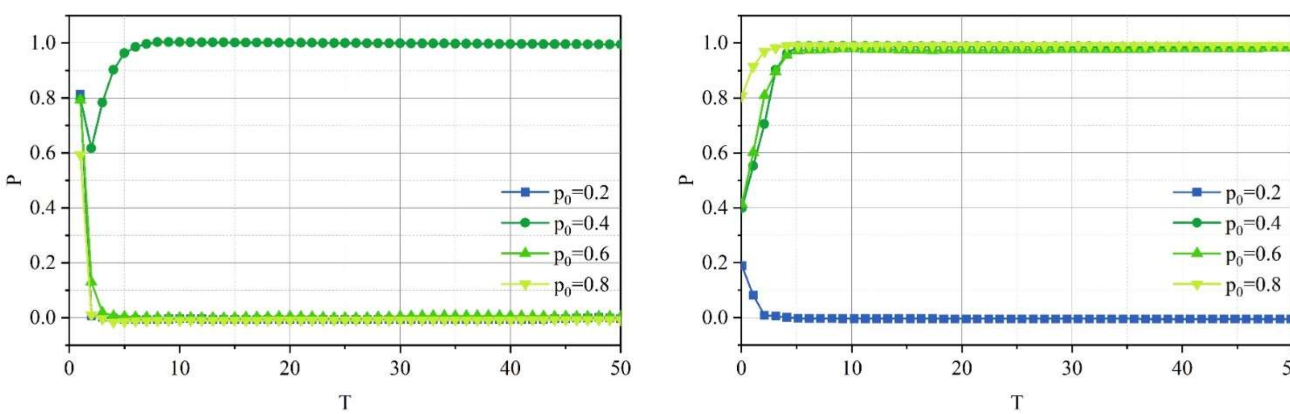
Through the above analysis, it can be obtained that when $f_i(i = A,B) > 0$, that is, both parties choose cooperation strategy when the revenue is greater than the revenue when choosing competition strategy, at this time both parties prefer to choose cooperation strategy, when $g_i(i = A, B) > 0$, that is, in the process of cooperation, one party defaults on choosing the competition strategy, the default payment it pays to the party that is being defrauded is smaller than the defaulted party's up-front cooperation investment cost and revenue loss due to being defaulted, at this time the defaulted party will also tend to choose the competitive strategy.

III. Simulation testing

In order to further verify the above evolutionary game results, Matlab R2017a is now used to simulate the evolutionary game model under different situations. Considering the lack of practical significance of systematic simulation on the negative return of the marketer in the case of perfect competition or the negative return of the producer in the case of perfect cooperation. Therefore, case (1) $\Pi_{cc}^R - \Pi_{nc}^R > 0, \Pi_{cn}^R - \Pi_{nn}^R < 0, \Pi_{cc}^M - \Pi_n^M > 0$ and case (2) $\Pi_{cc}^R - \Pi_{nc}^R < 0, Pi_{cn}^R - \Pi_{nn}^R < 0, \Pi_c^M - \Pi_{cn}^M > 0$ when the conditions are set for system simulation, to simulate the trajectory of the evolution of both parties' competing strategies after the introduction of the own agricultural products by marketers.

In the following, we conduct numerical simulation for case (1) and case (2), the initial time of simulation is 0 and the end time is 50, the initial proportion p_0 of marketers choosing to carry out cooperation is 0.2, 0.4, 0.6, 0.8, respectively, and the initial proportion q_0 of producers choosing to carry out cooperation is 0.3 and 0.8, respectively.

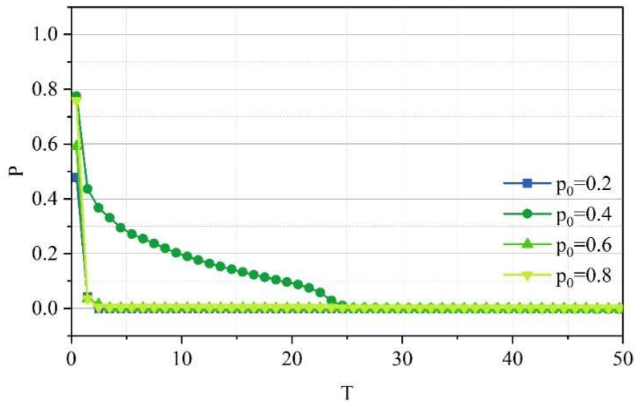
The output simulation results of case (1) are shown in Fig. 2, with (a) and (b) representing the evolutionary stabilization strategies of the producer and the marketer, respectively. It can be seen that under the parameter settings of case (1), there are two evolutionary stabilization strategies in the evolutionary game model, which are (competition, competition) and (cooperation, cooperation), and that an increase in the proportion of marketers choosing to engage in cooperation accelerates the system's convergence to (cooperation, cooperation), and vice versa, when the initial proportion of producers choosing to engage in cooperation remains unchanged. An increase in the proportion of producers choosing to cooperate accelerates the convergence of the system to (cooperation, cooperative) and vice versa (competition, competitive) when the initial proportion of marketers choosing to cooperate is constant.



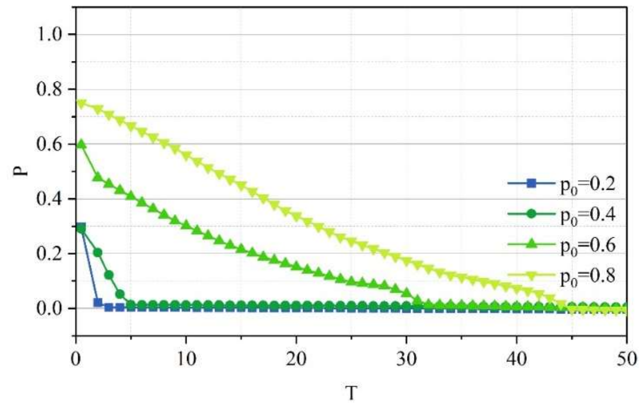
(a) Manufacturer (b) Marketer

Figure 2: Case 1 output simulation results

The output simulation results of case (2) are shown in Fig. 3, with (a) and (b) denoting the evolutionary stable strategies of the producer and the marketer, respectively. Under the parameter setting of case (2), the evolutionary game model has an evolutionary stable strategy as (competition, competition), the initial proportion of producers choosing to engage in cooperation does not avoid the system to converge to (competition, competition), and the increase of its initial proportion can only slow down the convergence speed of the system, and similarly the initial proportion of marketers choosing to engage in cooperation does not avoid the system to converge to (competition, competition), and the increase of its initial proportion can only slow down the convergence speed of the system. Similarly the initial proportion of marketers choosing to cooperate cannot avoid the system converging to (competition, rivalry), and an increase in its initial proportion can only slow down the rate of system convergence.



(a) Manufacturer



(b) Marketer

Figure 3: Case 2 output simulation results

IV. Analysis of factors affecting competition and cooperation

Taking the cooperative marketing between a producer and a marketer as an example, we analyze the effects of normal return π, excess profit R, and cooperative marketing cost C on the cooperative marketing between the producer and the marketer. According to the real situation and the assumption conditions of the model, it is assumed that the producer and the marketer adopt the cooperative marketing strategy to obtain the normal revenue π [17000, 30000], the excess profit R [4500, 8000], the cooperative marketing cost C [1300, 2500], and the initial state of both parties is the same.

In accordance with the above parameter assumptions, Matlab software is used for numerical simulation to analyze the effects of each parameter on cooperative marketing between producers and marketers.

(1) The effect of normal revenue on producer-marketer cooperative marketing

The effect of normal revenue on producer-marketer cooperative marketing is shown in Figure 4. The probability of cooperative marketing increases with the increase of normal gain π, which indicates that the higher the probability that producers and marketers maintain the long-term cooperative contractual relationship if they abide by the agreement to cooperate normally in the process of cooperative marketing. That is, the stronger the willingness of producers and marketers to maintain the long-term cooperative marketing relationship will be, and the higher the probability of cooperative marketing will be.

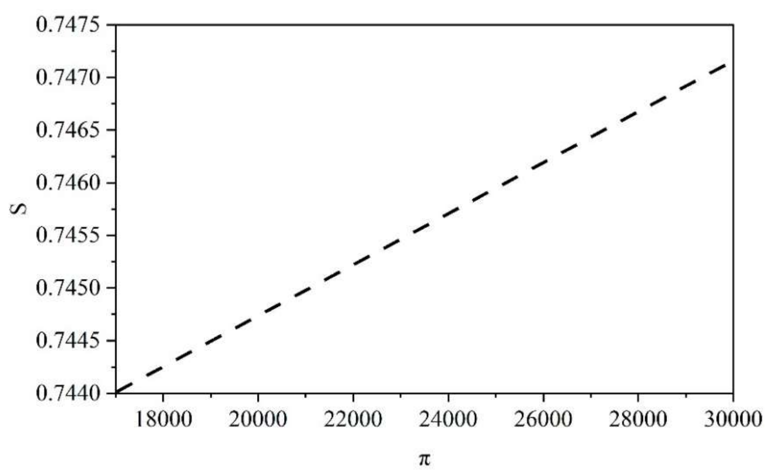


Figure 4: The impact of π on the marketing of production companies and marketers

(2) The effect of excess profit on producer-marketer cooperative marketing

The effect of excess profit on producer-marketer cooperative marketing is shown in Figure 5. Producer-marketer cooperative marketing increases with the increase of excess profit R, indicating that the larger the expected excess profit of producer-marketer cooperative marketing, the greater their motivation for cooperative marketing, and the higher the probability that both parties choose cooperative marketing.

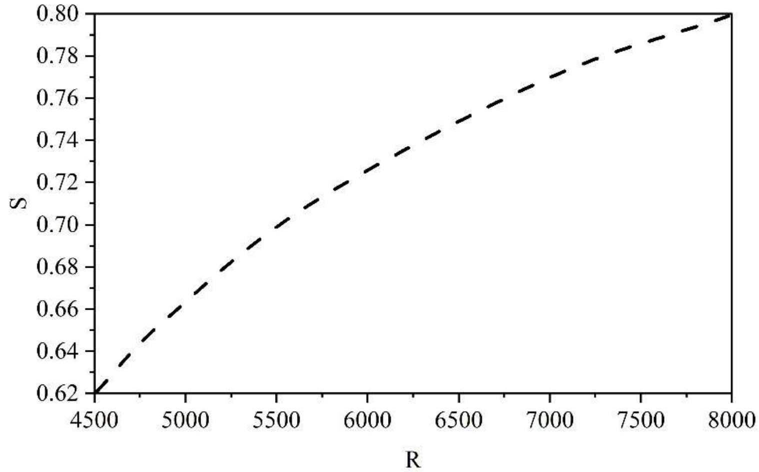


Figure 5: The impact of R on the marketing of production companies and marketers

(3) The effect of cooperation costs on producer-marketer cooperative marketing

The effect of cooperation cost on producer-marketer cooperative marketing is shown in Figure 6. The probability of cooperative marketing increases with the increase of cooperative marketing cost C, which indicates that the larger the expected excess profit of cooperative marketing between producers and marketers, the greater their motivation for cooperative marketing, and the higher the probability that both parties choose cooperative marketing.

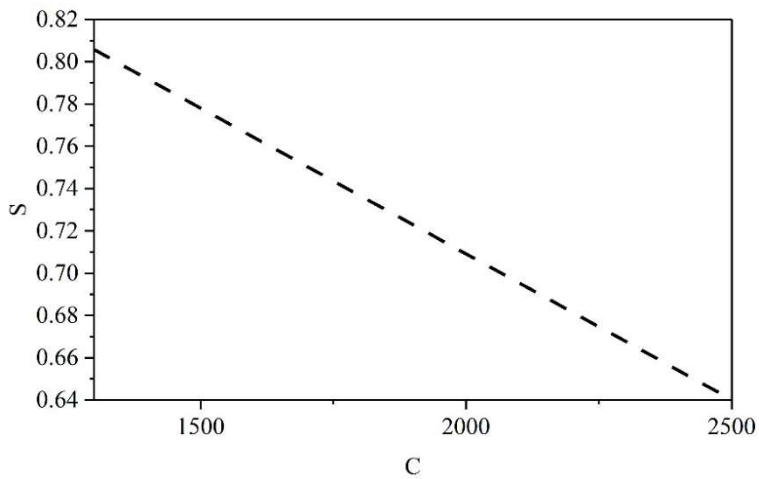


Figure 6: The impact of C on the marketing of production companies and marketers

To summarize, normal return π, excess profit R, cooperative marketing cost C and other factors will have an impact on producer-marketer cooperative marketing.

Normal revenue π is positively correlated with the establishment of cooperative marketing relationship, i.e., the fairer the contract between the producer and the marketer, the stronger the willingness to cooperate, the lower the probability of breach of contract between the producer and the marketer and the stronger the willingness to cooperate in the long term before the cooperative marketing.

Excess profit is positively related to the establishment of cooperative marketing relationship, i.e., the greater the excess profit generated by cooperative marketing, the more producers and marketers tend to cooperate in marketing.

Cooperative marketing cost C is negatively related to the establishment of cooperative marketing relationship, i.e., the smaller the cost generated by cooperative marketing, the more manufacturers and marketers are inclined to implement cooperative marketing strategies such as joint promotions, sharing of channel resources, joint pricing, etc., which will promote the success of marketing, increase market share, and enhance the competitiveness of the market.

V. Conclusion

Through the analysis of evolutionary game theory, this study found that there are obvious path-dependent characteristics and parameter sensitivity in the strategy selection evolution of agricultural product producers and marketers. When the normal return is set in the range of 17000-30000, the possibility of maintaining long-term cooperative contractual relationship between the two parties is significantly increased, and the probability of cooperative marketing shows a significant positive correlation with the normal return. When the excess profit varies within the range of 4500-8000, the cooperation motivation of producers and marketers increases with the increase of excess profit, and the probability of the two parties choosing cooperation strategy reaches the maximum value when the excess profit reaches the upper limit value. The cooperative marketing cost is controlled within the range of 1300-2500, and the probability of cooperation increases by about 15% on average for every 100 units of cost reduction, indicating that reducing the cost of cooperation is an effective way to promote marketing cooperation. Simulation results show that in the evolutionary process of 50 time units, the setting of the initial cooperation ratio has a decisive influence on the final equilibrium state, and the system is bound to converge to the cooperative equilibrium state when the initial cooperation ratio exceeds the critical value. The evolutionary game model can accurately predict the strategy evolution trajectory under different parameter conditions, providing a quantitative analysis tool for the decision-making of agricultural marketing subjects. The stability of the marketing cooperative relationship depends on the fairness of the revenue distribution mechanism and the effectiveness of the default penalty mechanism, and only under the reasonable institutional framework can the agricultural marketing subjects realize the long-term stable cooperative relationship.

References

[1] Koptaeva, G. P., Shinet, G. G., & Agabekova, G. N. (2019). Agricultural economy: development of crop production and its competitiveness. OF SOCIAL AND HUMAN SCIENCES, 91.

[2] Tomashuk, I. (2023). Competitiveness of agricultural enterprises in market conditions and ways of its increase. Green, Blue and Digital Economy Journal, 4(1), 64-81.

[3] Agbo, M., Rousselière, D., & Salanié, J. (2015). Agricultural marketing cooperatives with direct selling: A cooperative–non-cooperative game. Journal of Economic Behavior & Organization, 109, 56-71.

[4] Samuelson, L. (2016). Game theory in economics and beyond. Journal of Economic Perspectives, 30(4), 107-130.

[5] Tu, X., Zhu, K., Luong, N. C., Niyato, D., Zhang, Y., & Li, J. (2022). Incentive mechanisms for federated learning: From economic and game theoretic perspective. IEEE transactions on cognitive communications and networking, 8(3), 1566-1593.

[6] Aumann, R. J. (2024). Irrationality in game theory. In INTERACTIVE EPISTEMOLOGY (pp. 335-350).

[7] Raj, A., Biswas, I., & Srivastava, S. K. (2018). Designing supply contracts for the sustainable supply chain using game theory. Journal of cleaner production, 185, 275-284.

[8] Hoffmann, W., Lavie, D., Reuer, J. J., & Shipilov, A. (2018). The interplay of competition and cooperation. Strategic Management Journal, 39(12), 3033-3052.

[9] Hannah, D. P., & Eisenhardt, K. M. (2018). How firms navigate cooperation and competition in nascent ecosystems. Strategic Management Journal, 39(12), 3163-3192.

[10] He, J., & Huang, J. (2017). Product market competition in a world of cross-ownership: Evidence from institutional blockholdings. The Review of Financial Studies, 30(8), 2674-2718.

[11] Candemir, A., Duvaleix, S., & Latruffe, L. (2021). Agricultural cooperatives and farm sustainability–A literature review. Journal of Economic Surveys, 35(4), 1118-1144.

[12] Jing, L., Peng, X., Li, J., Wang, J., & Jiang, S. (2018). A decision approach with multiple interactive qualitative objectives for product conceptual schemes based on noncooperative-cooperative game theory. Advanced Engineering Informatics, 38, 581-592.

[13] Slime, M., El Kamli, M., & Ould Khal, A. (2024). Analyzing cooperative game theory solutions: Core and Shapley value in cartesian product of two sets. Frontiers in Applied Mathematics and Statistics, 10, 1332352.

[14] Parlar, M., Sharafali, M., & Goh, M. (2019). Optimal control and cooperative game theory based analysis of a by-product synergy system. Journal of cleaner production, 233, 731-742.

[15] Patel, P. (2021). Modelling Cooperation, Competition, and Equilibrium: The Enduring Relevance of Game Theory in Shaping Economic Realities. Social Science Chronicle, 1, 1-19.

[16] Parikh, J., Śledziński, J. D., Gök, Ś. Z. A., Özcan, İ., & Weber, G. W. (2025). Balancing cooperation and competition in game theory for business. In Operations Research (pp. 130-156). CRC Press.

[17] Patare, S., & Venkataraman, S. V. (2023). Strategies in supply chain competition: A game theoretic approach. Computers & Industrial Engineering, 180, 109242.

[18] Telser, L. G. (2017). Competition, collusion, and game theory. Routledge.

[19] Gupta, S. K., & Mishra, V. K. (2025). Sustainable competition and cooperation: a game-theoretical analysis of substitutable green products. International Journal of System Assurance Engineering and Management, 16(1), 234-253.

[20] Li, M., Nguyen, B., Yu, X., & Han, Y. (2018). Competition vs. collaboration: a four set game theory–innovation, collaboration, imitation, and'do nothing'. International Journal of Technology Management, 76(3-4), 285-315.

[21] Lefeng Cheng,Xin Wei,Manling Li,Can Tan,Meng Yin,Teng Shen & Tao Zou. (2024). Integrating Evolutionary Game-Theoretical Methods and Deep Reinforcement Learning for Adaptive Strategy Optimization in User-Side Electricity Markets: A Comprehensive Review. Mathematics,12(20),3241-3241.

[22] Pang Jinbo,Deng Lingfei & Wang Gangyi. (2017). An evolutionarily stable strategy and the critical point of hog futures trading entities based on replicator dynamic theory: 2006-2015 data for China's 22 provinces. PloS one,12(2),e0172009.

[23] Qiang Wang,Nanrong He & Xiaojie Chen. (2018). Replicator dynamics for public goods game with resource allocation in large populations. Applied Mathematics and Computation,328,162-170.