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Collaborative Preservation Strategy of Agricultural Product Suppliers and Retailers: An Evolutionary Game and Simulation Analysis

Abstract. *Agricultural products incur a large losses and their quality and freshness are significantly reduced, which is easy to cause consumers to refrain from purchasing. Therefore, aiming at the problems of short shelf life and damage of agricultural products in the current agricultural supply chain under the background of the digital era, an evolutionary game model is built between its suppliers and retailers to analyze whether suppliers carry out cold chain distribution and whether retailers apply intelligent preservation technology, and analyze the evolution and stability strategy in the system, and explore the key factors affecting the evolution trend and evolution and stability strategy of the dynamic system. The simulation analysis using MATLAB shows that: 1) whether agricultural product suppliers carry out cold chain distribution is affected by transportation cost, fresh-keeping effort cost coefficient and fresh-keeping effort elasticity coefficient; 2) the unit cost of intelligent preservation technology and the sensitivity coefficient of intelligent preservation technology to potential demand are the key factors for retailers to choose and apply intelligent preservation technology.*

Keywords: *agricultural products supply chain, Evolutionary game, freshness preservation strategy, cold chain distribution, intelligent preservation technology.*

JEL Classification: C73, Q12.

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1. Introduction

China is a large agricultural country. How to realize the comprehensive revitalization of the countryside has always been the focus of the Chinese government. In 2024, the No. 1 document of the central government proposed to focus on suppliers, adhere to promoting agriculture through industry, quality and green, develop smart agriculture, and narrow the "digital divide" between urban and rural areas. The agricultural products industry is an important part of rural revitalization, driving the increase of rural residents' income and rural economic development. In 2023, Per capita disposable income of rural residents in China reached 21690 Yuan, an increase of 7.7% over last year. In addition, the import and export amount of agricultural products in China reached 333.03 billion US dollars, an increase of 0.04% over the previous period. Among them, the export value was US $98.93 billion, an increase of 0.9%, the import value was US $234.11 billion, a decrease of 0.3%, and the added value of the agricultural product processing industry increased by 5.5%, accounting for 1.96% of the GDP; The added value of agriculture and its related products will increase by 0.15% of GDP. Although the output of agricultural products and farmers' income are increasing, the loss of agricultural products is still large. The survey report on the construction of the “First Kilometre” of agricultural products circulation shows that the postpartum loss rates of grain, potatoes, fruits and vegetables in China are 7% -11%, 15% -20%, 15% -20% and 20%-25%, respectively, which are far higher than the average level of developed countries. This not only causes serious waste of resources, but also affects the increase of farmers' income.

At the same time, with the rapid development of science and technology and the Internet, consumers' living standards have improved significantly. They pay more attention to the quality and freshness of agricultural products and have a good understanding of the freshness of products (Al-Amin et al., 2023). The freshness will decrease with time, making it more difficult for consumers to obtain high freshness and high quality goods in the agricultural supply chain (Qin et al., 2014). Especially the circulation losses that occur during transportation (Fang et al., 2020), it can be managed through preservation activities, which involve pre-cooling at the production site, temporary storage in the cold storage, and cold chain transportation (Tomislav and Ratko, 2023). Many links, such as pre-storage fresh-keeping, low-temperature delivery and fresh-keeping technology (Bardhan et al., 2025), need to consume a lot of costs, but for farmers, there will be losses, which should require the joint efforts of multiple parties in the supply chain. Therefore, participants in the product supply chain apply relevant technologies to improve their freshness level, such as intelligent packaging system (Chen et al., 2020) and UV Technology. The agricultural product supply chain (Wang et al., 2022) is composed of farmers, suppliers, logistics service providers, retailers and consumers, which is the main bridge connecting farmers and consumers. It includes multiple links such as "planting, breeding, purchasing, processing, transportation, storage, sales and service". Therefore, for the preservation of agricultural products, all node enterprises in the supply chain should actively participate. In addition to the manufacturers' efforts to improve the freshness of products through the establishment of cold storage, suppliers and retailers can make preservation decisions for different sales modes, such as retail mode, dual channel mode and o2o mode (Yang and Tang, 2019), so as to effectively reduce the loss of agricultural products. Yonghui supermarket and other large supermarkets actively invest in fresh-keeping technology, so as to improve customers' purchase desire and improve the profits of enterprises in the whole supply chain.

Therefore, aiming at the preservation strategy in the supply chain of agricultural products, this paper constructs an evolutionary game model between suppliers and retailers, and explores the key factors that influence whether suppliers provide cold chain delivery and whether retailers apply intelligent preservation technology. Whether the collaborative preservation of suppliers and retailers can increase the freshness of agricultural products and the market demand of consumers, what is the impact of the profits of supply chain enterprises, and whether the preservation strategy of the supply chain can be optimized? This provides a certain reference value for the selection of preservation strategy of agricultural products supply chain.

2. Literature review

By exploring the previous research on preservation in the supply chain, it is found that the existing research results mainly focus on the preservation strategy and the cost of preservation efforts. In terms of preservation strategies, most scholars mainly study the impact of preservation efforts on products and the main body of preservation strategies. The market demand for agricultural products is affected by random variables such as retail prices and product freshness (Ma et al., 2019). Li (2018) considered the impact of product freshness and price on demand, and suppliers tried to maintain the freshness of agricultural products. Herbon (2016) believes that product freshness also has an impact on prices, and profits are strongly affected by the volatility of consumers' sensitivity to freshness. Anshika and Abhinav (2024) explored the impact of deterioration of perishable products on carbon emissions. Therefore, product preservation effort (Tsao, 2015) was necessary, it could reduce waste, spoilage, and loss of product value and give retailers more time to sell their products, improve sales and increase profits.

At the same time, some scholars have studied the impact of different fresh-keeping strategy subjects on the supply chain. Liu et al. (2024) elaborated that preservation efforts can be invested by suppliers, while retailers provide value-added services. Zhang et al. (2020) used the grey number to identify the freshness of agricultural produce and concluded that farmers and retailers would eventually adopt fresh-keeping strategies to keep them fresh. Due to the perishable nature of agricultural products, the damage rate of agricultural products during transportation is high. Therefore, suppliers consider providing cold chain distribution during transportation. At the same time, cold chain logistics service providers (Liu et al., 2022) are developing rapidly and gradually towards intelligent logistics (Gao et al., 2023). Therefore, suppliers can choose their own cold chain distribution or choose logistics service providers. Third-party logistics service providers have a certain advantage in fresh-keeping costs. And its high corruption rate in the circulation process leads to risks in cold chain logistics (Liu and Wang, 2020). Different fresh-keeping strategies have different selection subjects and different impact on profits. Agricultural products with higher freshness have a greater impact on consumer satisfaction, and the prices of retailers will also change. Liu et al. (2020) proposed that all members of the supply chain should cooperate seamlessly in preservation, so as to deliver with the desired freshness.

In terms of fresh-keeping costs, enterprises in the supply chain will incur corresponding fresh-keeping costs when adopting fresh-keeping strategies. Chen et al. (2017) set a certain preservation cost according to the expected long-term average profit, Wang et al. (2020) believed that retailers need to pay a high cost of preservation efforts. Therefore, in order to improve the fresh-keeping level of products and maximize the profits of the whole supply chain, we should consider sharing the fresh-keeping cost (Song and He, 2019).

In conclusion, many scholars at home and abroad have made in-depth research on the preservation of agricultural products from different directions, and the existing research results provide an important reference for this paper. Nevertheless, research on the evolutionary game of different players in the supply chain is still relatively small, and it is mostly carried out from the preservation strategies of enterprises, agricultural producers and third-party logistics service providers. Secondly, most of them analyze the decision-making interaction process of members in the supply chain from the static perspective, The level of information sharing among the main bodies in the supply chain (Nazifa and Ramachandran, 2019) and synergy effect (He, 2024) are low, so evolutionary game method (Ji and Xu, 2024) (Hu et al., 2023) and inventory management (Freile et al., 2020) (Pekarcikova et al., 2024) are often used, but the research on how to promote the preservation of agricultural products supply chain by using the dynamic game method is scarce. Therefore, from the perspective of dynamic evolutionary game theory, this paper constructs an evolutionary game model between agricultural product suppliers and retailers, and introduces the cold chain distribution behavior of suppliers and retailers' intelligent fresh-keeping technology to improve the fresh-keeping level of agricultural product supply chain, so as to maintain the fresh taste of agricultural products, so as to achieve the overall optimal profit of the supply chain.

3. Model establishment and symbol description

This paper considers the establishment of an evolutionary game model consisting of a supplier and a retailer, in which the supplier provides fresh products and sells the products to consumers through the retailer. Therefore, in order to meet the order demand of the retailer and reduce their consumption, the supplier considers the distribution of agricultural products to the retailer through the cold chain. Therefore, the supplier considers the cold chain distribution as its fresh-keeping strategy. At the same time, in order to attract and retain customers and improve the fresh-keeping level of agricultural products, the retailer considers the application of intelligent fresh-keeping technology as its fresh-keeping strategy, and studies the fresh-keeping strategy between the supplier and the retailer and its impact on the profits of the agricultural product supply chain. The supplier is responsible for providing fresh products and making decisions on the wholesale price w and unit transportation cost of fresh products ci (i=1,2), The unit cost of cold chain distribution c2>the unit cost of ordinary distribution c1. The retailer is responsible for determining the retail price p of fresh products, and its unit cost of intelligent fresh-keeping technology is c_b.

Preservation can delay the deterioration of freshness and increase demand. Therefore, the potential market demand a is introduced, and let the demand $D = a - bq + \beta e$, where a is the potential market demand, P is the retail price of fresh agricultural products, e is the level of fresh-keeping efforts for the overall decision-making of the supply chain, $b>0$ is the elasticity coefficient of consumers' price, and $\beta > 0$ is the elasticity coefficient of consumers' fresh-keeping efforts.

In order to facilitate the description, the explanation of symbols in the model is shown in Table 1.

Table 1. Parameters symbols and descriptions

Symbol	Descriptions	Symbol	Descriptions
w	wholesale price	p	retail price
e	Preservation effort level	b	Price elasticity coefficient
D	market demand	Π_m	Supplier profit function
a	market potential	Π_r	Retailer profit function
k	Input cost coefficient of preservation effort	c_b	Unit cost of intelligent preservation technology
c1	General distribution unit cost	c_m	Unit production cost of product
c2	Unit cost of cold chain distribution	β	Elasticity coefficient of consumers' efforts to keep fresh

Source: Authors' own creation.

This paper mainly considers four strategies for the selection of suppliers and retailers in the fresh supply chain. The four situations are (ordinary distribution, without the application of intelligent preservation technology) strategy (NN); (general distribution, application of intelligent preservation technology) strategy (NS); (cold chain distribution, without application of intelligent preservation technology) strategy (SN); (cold chain distribution, application of intelligent preservation technology) (SS). Therefore, the profit functions of the four strategies can be obtained, as shown in Table 2.

Table 2. Profit function of four strategies

Strategy combination	Π_m	Π_r
SS	$(w-c_m-c2)(a-bp+\beta e)-\frac{ke^2}{2}$	$(p-w-c_b)(a-bp+\beta e)$
SN	$(w-c_m-c2)(a-bp+\beta e)-\frac{ke^2}{2}$	$(p-w)(a-bp+\beta e)$
NS	$(w-c_m-c1)(a-bp+\beta e)-\frac{ke^2}{2}$	$(p-w-c_b)(a-bp+\beta e)$
NN	$(w-c_m-c1)(a-bp+\beta e)-\frac{ke^2}{2}$	$(p-w)(a-bp+\beta e)$

Source: Authors' own creation.

According to the profit functions of the four strategies in Table 2, the corresponding p, w, e and their profit function equilibrium solutions can be obtained, so as to carry out evolutionary game analysis between suppliers and retailers. In view of whether suppliers provide cold chain distribution and whether retailers apply intelligent preservation technology to play games, so as to select their maximum profit preservation strategy.

4. Evolutionary game analysis

According to the evolutionary game analysis of the equilibrium solution of the profit function obtained in Table 2, this paper may wish to assume that the proportion of suppliers providing cold chain distribution strategy is x ($0<x<1$), then the proportion of suppliers not providing cold chain distribution strategy is $1-x$. At the same time, assuming that the proportion of retailers applying intelligent preservation technology strategy is y ($0<y<1$), the proportion of retailers not applying intelligent preservation technology strategy is $1-y$. Therefore, we can get the game matrix between suppliers and retailers, as shown in Table 3.

Table 3. Game matrix between suppliers and retailers

supplier	retailer	
	Application of intelligent preservation technology (y)S	**No application of intelligent preservation technology (1-y)N**
Cold chain distribution (xS	$\pi_m^{SS}=\frac{k(bc_m+bc_b+bc2-a)^2}{2(4kb-\beta^2)}$ $\pi_r^{SS}=\frac{k^2b(bc_m+bc2+bc_b-a)^2}{(4kb-\beta^2)^2}$	$\pi_m^{SN}=\frac{k(bc_m+bc2-a)^2}{2(4kb-\beta^2)}$ $\pi_r^{SD}=\frac{k^2b(bc_m+bc2-a)^2}{(4kb-\beta^2)^2}$
General distribution (1-x)N	$\pi_m^{NS}=\frac{k(bc_m+bc1+bc_b-a)^2}{2(4kb-\beta^2)}$ $\pi_r^{NS}=\frac{k(bc_m+bc1+bc_b-a)^2}{(4kb-\beta^2)^2}$	$\pi_m^{NN}=\frac{k(bc_m+bc1-a)^2}{2(4kb-\beta^2)}$ $\pi_r^{NN}=\frac{k^2b(bc_m+bc1-a)^2}{(4kb-\beta^2)^2}$

Source: Authors' own creation.

Therefore, the supplier's revenue from "providing cold chain distribution" and "providing ordinary distribution" is Π_{11} and Π_{12}, and the average expected revenue is Π_1.

$$\Pi_{11} = y\Pi_m^{SS} + (1-y)\Pi_m^{SN} = \frac{ky(bc_m+bc_b+bc2-a)^2+(1-y)k(bc_m+bc2-a)^2}{2(4kb-\beta^2)} \quad (1)$$

$$\Pi_{12} = y\Pi_m^{NS} + (1-y)\Pi_m^{NN} = \frac{ky(bc_m+bc1+bc_b-a)^2}{2(4kb-\beta^2)} + \frac{(1-y)(bc_m+bc1-a)^2}{8b} \quad (2)$$

$$\Pi_1 = x\Pi_{11} + (1-x)\Pi_{12} \quad (3)$$

The replication dynamic equation selected by the supplier is:

$$F(x) = \frac{dx}{dt} = x(\Pi_{11} - \Pi_1) = x(1-x)[\frac{kb(c2-c1)(bc1-2a+bc2+2bc_m+2bc_by}{2(4kb-\beta^2)}] \quad (4)$$

At the same time, the retailer's revenue from "applying intelligent preservation technology" and "not applying intelligent preservation technology" is Π_{21} and Π_{22}, and the average expected revenue is Π_2.

$$\Pi_{21} = x\Pi_r^{SS} + (1-x)\Pi_r^{NS}$$

$$= \frac{xk^2b(bc_m + bc2 + bc_b - a)^2 + (1-x)k^2b(bc_m + bc1 + bc_b - a)^2}{(4kb-\beta^2)^2} \quad (5)$$

$$\Pi_{22} = x\Pi_r^{SN} + (1-x)\Pi_r^{NN} = \frac{xk^2b(bc_m + bc2 - a)^2}{(4kb-\beta^2)^2} + \frac{(1-x)k^2b(bc_m + bc1 - a)^2}{(4kb-\beta^2)^2} \quad (6)$$

$$\Pi_2 = y\Pi_{21} + (1-y)\Pi_{22} \quad (7)$$

The replication dynamic equation selected by the retailer is

$$F(y) = \frac{dy}{dt} = y(\Pi_{21} - \Pi_2) = y(1-y)\left[\frac{k^2b^2c_b(2bc1 - 2a + bc_b + 2bm - 2bc1x + 2bc2x)}{(4kb-\beta^2)^2}\right] \quad (8)$$

The replication dynamic equation *F(x)* selected by the supplier and the replication dynamic equation *F(y)* selected by the retailer can be obtained (x*, y*). When *F(x)* and *F(y)* are both 0, we can get:

$$x^* = \frac{2bc1 - 2a + bc_b + 2bc_m}{2b(c1-c2)}$$

$$y^* = \frac{2a - bc1 - bc2 - 2bc_m}{2bc_b}$$

From this, we can know that there are five equilibrium points of the system, which are (0,0), (0,1), (1,0), (1,1), $(\frac{2bc1-2a+bc_b+2bc_m}{2b(c1-c2)}, \frac{2a-bc1-bc2-2bc_m}{2bc_b})$,both x* and y * belong to [0,1].

Then, we calculate the partial derivative of the replication dynamic equation of suppliers choosing "cold chain distribution" and retailers choosing "Application of intelligent preservation technology":

$$\frac{\partial F(x)}{\partial x}=\frac{(1-2x)kb(c2-c1)(bc1-2a+bc2+2bc_m+2bc_by)}{2(4kb-\beta^2)} \tag{9}$$

$$\frac{\partial F(y)}{\partial y}=\frac{(1-2y)k^2b^2c_b(2bc1-2a+bc_b+2bc_m-2bc1x+2bc2x)}{(4kb-\beta^2)^2} \tag{10}$$

When $x=\frac{2bc1-2a+bc_b+2bc_m}{2b(c1-c2)}$, *F(y)=0*, the choice of retailers does not change with time; when $x<\frac{2bc1-2a+bc_b+2bc_m}{2b(c1-c2)}$, let *F(y)=0*, *y=0* and *y=1* be the two stable states of retailer selection strategy. When y=0, ∂F(y)/∂y>0, retailers choose not to apply intelligent preservation technology. On the contrary, when $x>\frac{2bc1-2a+bc_b+2bc_m}{2b(c1-c2)}$, *y=1*, ∂F(y)/∂y>0, intelligent preservation technology is applied in retail.

When $y=\frac{2a-bc1-bc2-2bc_m}{2bc_b}$, *F(x)=0*, When $y<\frac{2a-bc1-bc2-2bc_m}{2bc_b}$, let *F(x)=0, x=0* and *x=1* be the two stable states of supplier strategy selection. When x=0, ∂F(x)/∂x>0, then the supplier chooses not to provide cold chain delivery. On the contrary, when $y>\frac{2a-bc1-bc2-2bc_m}{2bc_b}$, *x=1*, then ∂F(x)/∂x>0, the supplier chooses to provide cold chain distribution.

The equilibrium point obtained by copying the dynamic equation described in Xu et al. (2024) is not necessarily a stable strategy for system evolution. Therefore, the stability of the equilibrium point of the differential system is obtained through the local stability analysis of the Jacobian matrix (J) proposed by Friedman (1991). The Jacobian matrix in the supply chain is:

$$J=\begin{bmatrix}\frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y}\\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y}\end{bmatrix}=\begin{bmatrix}a11 & a12\\ a21 & a22\end{bmatrix} \tag{11}$$

The local equilibrium point is introduced into the Jacobian matrix, and *det(J)* and *tr(J)* are obtained to search for the evolutionary stability point (ESS) of the system. Therefore, this paper sets the evolutionary stability strategy equilibrium point ESS which meets the following two conditions:

- Determinant of Jacobian matrix: $det\ J=a11a22-a12a21>0$;
- The trace of Jacobian matrix: $tr\ J=a11+a22<0$.

We can obtain *a11*, *a12, a21* and *a22* separately as follows.

$$a11=\frac{(1-2x)kb(c2-c1)(bc1-2a+bc2+2bc_m+2bc_by)}{2(4kb-\beta^2)} \tag{12}$$

$$a12=\frac{x(1-x)b^2c_bk(c2-c1)}{4kb-\beta^2} \tag{13}$$

$$a21=\frac{(1-2y)k^2b^2c_b(2bc1-2a+bc_b+2bc_m-2bc1x+2bc2x)}{(4kb-\beta^2)^2} \tag{14}$$

$$a22 = \frac{y(1-y)2b^3k^2c_b(c2-c1)}{(4kb-\beta^2)^2} \tag{15}$$

Therefore, the determinant and trace of the mapping matrix of the five replication dynamic equilibrium points and their expressions are shown in Table 4.

Table 4. Determinant and trace of equilibrium points

ESS	det J	TrJ
(0,0)	$\frac{k^3b^3c_b(c2-c1)(bc1-2a+bc2+2bc_m)(2bc1-2a+bc_b+}{2(4kb-\beta^2)^3}$	$\frac{kb(c2-c1)(bc1-2a+bc2+2bc_m)}{2(4kb-\beta^2)} + \frac{k^2b^2c_b(2bc1-2a+bc_b+2bc_m)}{(4kb-\beta^2)^2}$
(0,1)	$\frac{-k^3b^3c_b(c2-c1)(bc1-2a+bc2+2bc_m+2bc_b)}{2(4kb-\beta^2)^3}(2bc1-2a+bc_b+2bc_m)$	$\frac{kb(c2-c1)(bc1-2a+bc2+2bc_m+2bc}{2(4kb-\beta^2)}$ $\frac{k^2b^2c_b(2bc1-2a+bc_b+2bc_m)}{(4kb-\beta^2)^2}$
(1,0)	$\frac{-k^3b^3c_b(c2-c1)(bc1-2a+bc2+2bc_m)}{2(4kb-\beta^2)^3}(2bc2-2a+bc_b+2bc_m)$	$\frac{-kb(c2-c1)(bc1-2a+bc2+2bc_m)}{2(4kb-\beta^2)} + \frac{k^2b^2c_b(2bc2-2a+bc_b+2bc_m)}{(4kb-\beta^2)^2}$
(1,1)	$\frac{k^3b^3c_b(c2-c1)(bc1-2a+bc2+2bc_m+2bc_b)}{2(4kb-\beta^2)^3}(2bc2-2a+bc_b+2bc_m)$	$\frac{-kb(c2-c1)(bc1-2a+bc2+2bc_m+2}{2(4kb-\beta^2)}$ $\frac{k^2b^2c_b(2bc2-2a+bc_b+2bc_m)}{(4kb-\beta^2)^2}$
(x^*,y^*)	$\frac{bk^3(2a-2bc2-2bc_b-2bc_m)(2bc1-2a+bc_b+2bc_m)}{16(4kb-\beta^2)^3}[(2a-bc1-bc2-2bc_m)(2bc_b-2a+bc1+bc2+2bc_m)]$	0

Source: Authors' own creation.

From Table 4, we can know the determinant and trace of these five equilibrium points, so as to conduct stability analysis and get table 5.

Table 5. Stability analysis of evolutionary game

ESS	det J	tr J	Stable condition
(0,0)	+	-	$4kb-\beta^2>0$; $bc1-2a+bc2+2bc_m<0$; $2bc1-2a+bc_b+2bc_m<0$
(1,0)	+	Indeterminacy	$4kb-\beta^2>0$;$bc1-2a+bc2+2bc_m>0$; $2bc2-2a+bc_b+2bc_m>0$
(0,1)	+	-	$4kb-\beta^2<0$; $bc1-2a+bc2+2bc_m+2bc_b>0$; $2bc1-2a+bc_b+2bc_m>0$
(1,1)	+	-	$4kb-\beta^2>0$; $bc1-2a+bc2+2bc_m+2bc_b>0$; $2bc2-2a+bc_b+2bc_m>0$
(x^*,y^*)	Indeterminacy	0	Non-existent

Source: Authors' own creation.

Because when the equilibrium point is (x*, y*), trJ is always 0, and the stability condition cannot be determined at this time, so it is always unstable. If the determinant of (1, 0) equilibrium point is greater than 0, then $4kb-\beta^2>0$;$bc1-2a+bc2+2bc_m>0$; $2bc2-2a+bc_b+2bc_m<0$, and because c2>c1, the condition $2bc1 - 2a + bc_b + 2bc_m < 0$ does not exist, while *a11<0, a22>0*, At this time, if *detJ <0*, the trace may be negative or positive, so the stability condition cannot be determined at this point, and there is no stable state. It can be seen from Table 4 that the three equilibrium points (0,0), (0,1) and (1,1) have stable states, but have stable conditions, assuming that a, c_m, b and β are constants, and the evolutionary stability strategy of the dynamic system depends on k, c_1, c_2, and c_b. Therefore, numerical simulation analysis can be carried out.

5. Simulation analysis

5.1 Simulation Analysis of Evolutionary Game Equilibrium Points

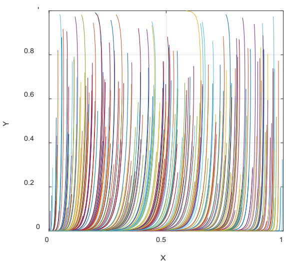
This paper constructs an evolutionary game model between agricultural product suppliers and retailers, mainly discusses the choice of fresh-keeping strategies between them, and uses MATLAB for simulation analysis. Because there are only three equilibrium points in stable state, namely (0,0), (0,1), (1,1), the relevant parameters are adjusted according to the stability conditions of the three equilibrium points, and the impact on their evolutionary strategies is analyzed.

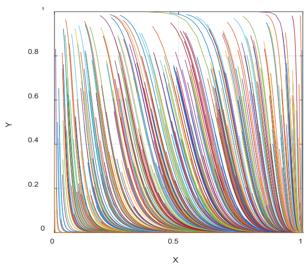
First, set the basic parameters of the stabilization strategy (ESS) to (0,0), and simulate and analyze other possible ESS strategies by adjusting them according to the documented conditions. Because the conditions of these four equilibrium points may be unique, while there are many other equilibrium conditions, and because of space constraints, they will not be verified one by one. Each balance only lists one condition, and the same restriction applies to the other conditions. Therefore, 200 groups of initial probabilities are randomly selected to observe the evolution trajectory of the participating entities. Therefore, the parameter settings and results are as follows.

The initial value of the parameter are a=300, b=1.2, c_m=100, β=1.5, k=0.6, c_b= 160, c1=30, c2=100, At this time, $4kb - \beta^2 > 0$; $bc1 - 2a + bc2 + 2bc_m = -204 < 0$; $2bc1 - 2a + bc_b + 2bc_m = -48 < 0$. At this time, the unit cost of the ordinary distribution provided by suppliers is much lower than that of the cold chain distribution. Therefore, for suppliers, choosing ordinary distribution costs less and makes more profits. Retailers tend not to apply intelligent preservation technology, while suppliers tend to provide ordinary distribution. Therefore, the strategic choice between the supplier and the retailer is (ordinary distribution, without the application of intelligent preservation technology), which is the strategic equilibrium point of the evolutionary game, as shown in Figure 1(a).

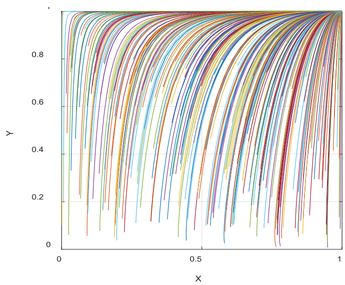
The initial value of the parameter are a=300, b=1.2, c_m=100, β=1.5, k=0.4, c_b= 150, c1=80, c2=100. At this time, $4kb - \beta^2 = -0.33 < 0$; $bc1 - 2a + bc2 + 2bc_m + 2bc_b = 228 > 0$; $2bc1 - 2a + bc_b + 2bc_m = 18 > 0$, the input cost coefficient of the supplier's fresh-keeping efforts is low, so the supplier chooses ordinary distribution, but the unit cost of ordinary distribution increases compared with before, and the unit cost of the retailer's application of intelligent fresh-keeping level will be reduced. The retailer chooses to apply intelligent fresh-keeping technology, so th

e strategy choice between the supplier and the retailer is (ordinary distribution, appl ication of intelligent fresh-keeping technology). At this time, (0, 1) is the ESS strate gy equilibrium point of the evolutionary game, as shown in Figure 1(b).
The initial value of the parameter are a=300, b=1.2, cm=100, β=1.5, k=0.6, cb=160, c1=80, c2=90. At this time, $4kb-\beta^2>0$; $bc1-2a+bc2+2bc_m+2bc_b=168>0$; $2bc2-2a+bc_b+2bc_m=18>0$, the supplier's input cost coefficient of fresh-keeping efforts is high, and the unit cost of ordinary distribution and cold chain distribution is not much different, so the supplier chooses cold chain distribution. At this time, the retailer's unit cost of applying intelligent fresh-keeping technology is low, so retailers apply intelligent fresh-keeping technology, when the unit cost of ordinary distribution increases, and the gap between the unit cost of ordinary distribution and that of cold chain distribution is gradually diminishing; in addition, the higher the input cost coefficient of suppliers' fresh-keeping efforts, the supplier gradually tends to the cold chain distribution strategy. Therefore, the strategy choice between the supplier and the retailer is (cold chain distribution, application of intelligent preservation technology). At this time, (1,1) is the ESS strategy equilibrium point of the evolutionary game, as shown in Figure 1(c).





(a) **(b)**



(c)

Figure 1. Evolutionary equilibrium

Source: Authors' own creation.

5.2 Analysis of factors influencing evolutionary game equilibrium

Further simulation analysis is carried out according to the evolutionary strategy (1,1) and the profit function of suppliers and retailers. It can be known that the evolutionary game result is related to parameters such as a, c_m, b, β,k and c_b. It is hypothesized that a, c_m and b are constant, and that the evolutionary stability strategy of the dynamic system depends on k, β,c1, c2 and c_b. Thus, the impact of fresh-keeping effort cost coefficient k, fresh-keeping effort elasticity coefficient β, application intelligent fresh-keeping unit cost c_b, ordinary distribution unit cost c1 and cold chain distribution unit cost c2 on fresh-keeping strategies of suppliers and retailers in the fresh supply chain are analyzed.

(1) The influence of the the unit cost of ordinary distribution c1 and the unit cost of the cold chain distribution c2 on the evolution results.

Assuming (c1, c2) values are (80,90), (30,90), (30,50) and (80,85), it can be seen from Figure 2 that other parameter values are unchanged, and only the unit cost of ordinary distribution and cold chain distribution is changed. Moreover, when the distribution cost of cold chain logistics is greater than 70, and the difference between the unit cost and ordinary distribution is larger, the faster the supplier evolves to the cold chain distribution strategy. For retailers, the difference between the unit cost of cold chain distribution and ordinary distribution is small, the supplier provides cold chain logistics, which can improve the level of fresh-keeping efforts of agricultural products, and the unit cost of intelligent fresh-keeping technology can be appropriately reduced. The reduction of the unit cost of intelligent fresh-keeping technology makes retailers gradually tend to apply intelligent fresh-keeping technology strategy.

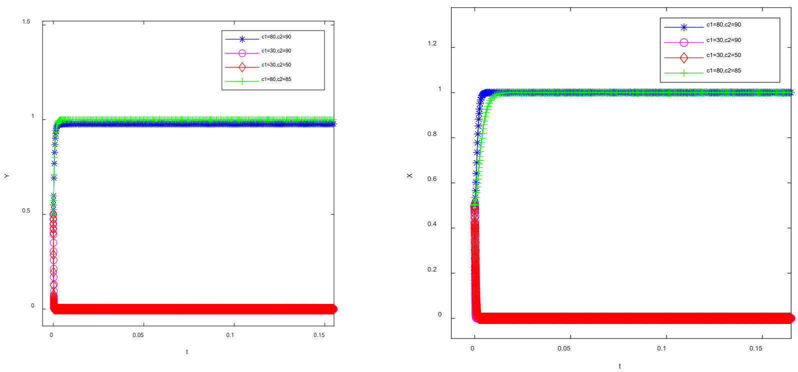


Figure 2. The influence of different c1 and c2 on the evolution strategy of suppliers and retailers (Note: a=300, b=1.2, c_m=100, c_b=160, k=0.6, β=1.5)
Source: Authors' own creation.

(2) Effects of unit cost k and elasticity coefficient β of preservation effort on Strategy Evolution

Suppose β is 1.5 and 1.2, while k is 0.6 and 0.2, respectively. the evolution of strategies between suppliers and retailers can be obtained as shown in Figure 3. It can be seen from Figure 3 that when other parameters remain unchanged, the unit cost of fresh-keeping effort is changed. Because the unit cost of fresh-keeping effort is related to the size of β, the ratio of β^2/k is used to determine whether the supplier will invest in fresh-keeping effort strategy. When the ratio is smaller, the supplier will gradually evolve from a ordinary distribution to a cold chain distribution strategy. At this time, the critical value of the supplier's strategy change is 4.8. When the ratio is less than 4.8, suppliers tend to choose cold chain distribution, when the ratio is greater than 4.8, suppliers prefer normal distribution. For retailers, the smaller the ratio, the faster it will evolveto the strategy of applying intelligent preservation technology.

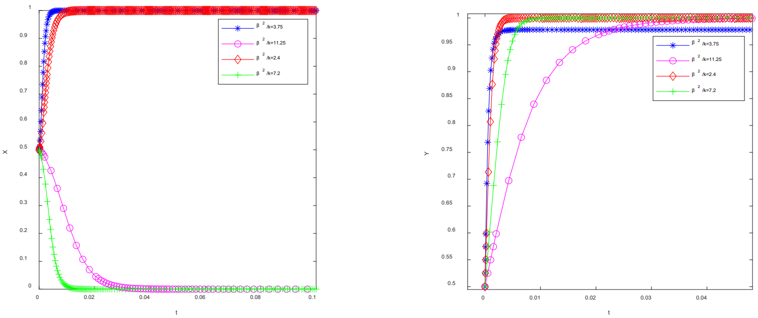


Figure 3. The influence of different *k* and β on the evolution strategy of suppliers and retailers (Note: *a*=300, b=1.2, c_m=100, c_b=160, c1=80, c2=90)
Source: Authors' own creation.

(3) Influence of unit cost of intelligent preservation technology on Strategy Evolution

Assuming that the unit cost of intelligent preservation technology c_b is assigned as 160, 120, 100 and 200 respectively, the numerical simulation results of the impact of the unit cost of intelligent preservation technology on the decision-making of agricultural product suppliers and retailers are shown in Figure 4. It can be seen from Figure 4, an increase in the unit cost of intelligent preservation technology c_b leads supplier will gradually tend to the cold chain distribution strategy over time. For retailers, the higher the unit cost of intelligent preservation technology, the less likely the retailer will tend to apply intelligent preservation technology, and the critical value of the retailer's strategy change is between c_b<140. When c_b is greater than the critical value, the retailer will apply intelligent preservation technology.

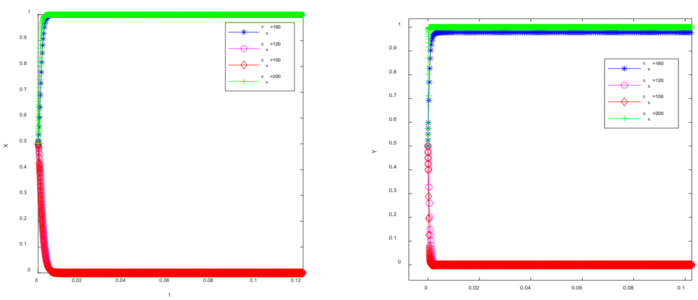


Figure 4. Influence of unit cost CB of different AI technologies on Strategy Evolution
(Note: *a*=300, b=1.2, c_m=100, k=0.6, β=1.5, c1=80, c2=90)
Source: Authors' own creation.

（4）The influence of price elasticity coefficient b on Strategy Evolution

It is hypothesized that other parameters unchanged, and the values of b are 1.2 and 1 respectively. The simulation results of the probability of the supplier selecting cold chain distribution and retail application of intelligent preservation technology are shown in Figure 5. At this time, when $b > \frac{2a}{2c1+c_b+2c_m}$, with the increase of b, suppliers tend to evolve the cold chain distribution strategy. At the same time, retailers also tend to evolve the strategy of applying intelligent preservation technology. From this, we can know that the critical point of the evolution game strategy transformation is b>1.16. Therefore, the strategy choice between suppliers and retailers is (cold chain distribution, applying intelligent preservation technology).

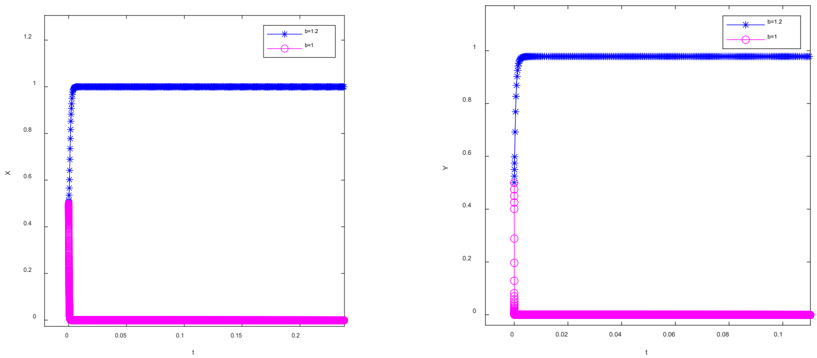


Figure 5. impact of different price elasticity coefficients B on Strategy Evolution（Note : a=300，c_m=100,c_b=160, k=0.6,β=1.5,c1=80,c2=90）

Source: Authors' own creation.

However, if b does not change and $b<\beta^2/4k$, then the supplier will choose ordinary distribution and the retailer's strategy will also change. Therefore, we can know that the value of b is related to c1, c2 and c_b. Assuming that in addition to b, these three parameters also change accordingly, we can get the influence of b and c1, c2 and c_b on the evolution strategy, as shown in Figure 6. It can be seen from Figure 6 that when b is larger, the cost of intelligent preservation technology is smaller, and the cost of cold chain distribution is smaller. Suppliers choose cold chain distribution, and retailers choose intelligent preservation technology. But if b is smaller, and the unit cost of intelligent preservation technology is larger, retailers will accelerate the application of intelligent preservation technology, and suppliers will also accelerate the provision of cold chain distribution.

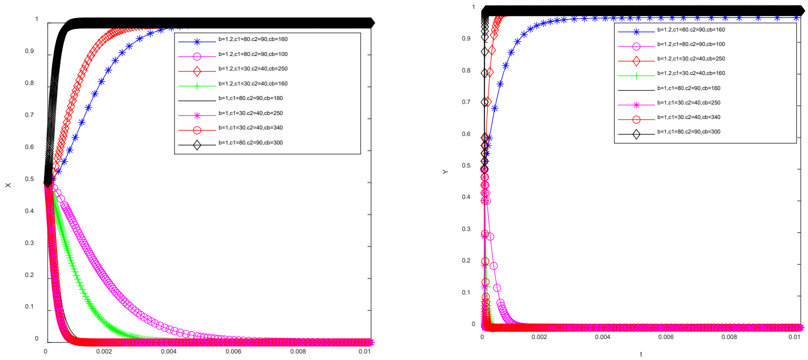


Figure 6. The influence of different b, c1, c2 and c_b on Strategy Evolution

(Note: a=300, c_m=100, c_b=160, k=0.6, β=1.5)

Source: Authors' own creation.

6. Conclusions

In this paper, the evolutionary game model of agricultural products preservation strategy between suppliers and retailers is constructed, and the evolutionary stability strategy of whether suppliers choose cold chain distribution and whether retailers apply intelligent preservation technology is classified and discussed. The formation process and influencing factors of the evolutionary game system stability strategy of agricultural products suppliers and retailers are discussed by numerical simulation:

1) There are five equilibrium points of the evolutionary strategy of the evolutionary game, but only three equilibrium points (0,0), (0,1), and (1,1) satisfy the stable state condition that the determinant is greater than 0 and the trace is less than 0. Therefore, the evolution strategy of the system is related to the unit cost of ordinary distribution, the unit cost of cold chain distribution, the coefficient of fresh-keeping effort cost and the unit cost of intelligent fresh-keeping technology. It is certain that the unit cost of ordinary distribution is lower than the unit cost of cold chain distribution. The smaller the gap between the unit cost of ordinary distribution and the unit cost of cold chain distribution, the more suppliers tend to cold chain distribution, and the difference is within a certain range, the supplier will choose cold chain distribution. When the cold chain distribution cost is greater than a certain value, the retailer will choose to apply intelligent fresh-keeping technology.

2) Under the balanced conditions of cold chain logistics provided by suppliers, when retailers apply intelligent preservation technology, the fresh-keeping efforts of the fresh supply chain are the highest. Therefore, agricultural product suppliers and retailers can cooperate to keep fresh, thereby enabling consumers to buy newer and higher quality agricultural products, and the profits of the whole supply chain will also be maximized.

3) Through numerical simulation, it can be seen that the smaller the ratio between the unit cost K of fresh-keeping effort investment and the elasticity

coefficient β of fresh-keeping effort, the more suppliers tend to use the cold chain distribution strategy. Moreover, the price elasticity coefficient also has an impact on the evolution strategy. When the price elasticity coefficient b is larger, it shows that the price elasticity coefficient has a greater impact on demand. The more suppliers tend to choose cold chain distribution, the more retailers tend to use intelligent fresh-keeping technology. So as to improve the fresh-keeping level of agricultural products, improve consumer demand, so the profit of the supply chain is optimal.

In this paper, there are still some deficiencies, so the research of this paper can be further extended: first, this paper only focuses on the evolutionary game between suppliers and retailers. In the future, we can further consider the government's technology subsidies for suppliers and retailers and conduct a tripartite game. Secondly, this paper has not considered the introduction of fresh-keeping ability into decision variables, and the impact of fresh-keeping ability on the estimation deviation of potential demand can be further considered in the future. Furthermore, this paper discusses the impact of preservation strategy on demand and further considers the role of intelligent preservation technology in production management, inventory management and logistics management. Finally, this paper only considers the fresh-keeping measures taken by suppliers and retailers, without considering whether producers or farmers adopt fresh-keeping strategies, which can be further taken into account in the future.

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References

[1] Al-Amin, M.K., Akbar, A.S., Rahman, A.K., et al. (2023), *Advertising and pricing strategies of an inventory model with product freshness-related demand and expiration date-related deterioration*. *Alexandria Engineering Journal*, 73, 353-375.

[2] Ankita, A., Khanna, A. (2024), *Integrating Environmental Impact and Digital Marketing Strategies for Deteriorating Items with Preservation Technology Investment*. *Process Integration and Optimization for Sustainability*, 8(4), 1131-1148.

[3] Bardhan, S., Modak, I., Giri, C.B. (2025), *A multi-period inventory model with price, time and service level dependent demand under preservation technology investment*. *European Journal of Industrial Engineering*, 19(1), 18-44.

[4] Cao, G.M., Zhao, X.X., Gao, H.H., Tang, M.C. (2023), *A game theory analysis of intelligent transformation and sales mode choice of the logistics service provider*. *Advances in Production Engineering & Management*, 18(3), 327-344.

[5] Chen, J., Dong, M., Chen, F.F. (2017), *Joint decisions of shipment consolidation and dynamic pricing of food supply chains*. *Robotics and Computer Integrated Manufacturing*, 43, 135-147.

[6] Chen, S., Brahma, S., Mackay, J., Cao, C., (2020), *Aliakbarian, B. The role of smart packaging system in food supply chain*. *Journal of food science*, 85, 517-525.

[7] Fang, X., Wang, R., Yuan, F.J., Gong, Y., Cai, J.R., Wang, Y.L. (2020), *Modelling and Simulation of Fresh-Product Supply Chain Considering Random Circulation Losses*. *Int. Journal of Simulation Modelling*, 19(1), 169-177.

[8] Freile, A.J., Mula, J., Campuzano-Bolarin, F. (2020), *Integrating Inventory and Transport Capacity Planning in a Food Supply Chain*. *International Journal of Simulation Modelling*, 19(3), 434-445.

[9] Friedman, D. (1991), *Evolutionary game in economics*. *Econometrica*, 59(3), 637-666.

[10] He, S.H. (2024), *Coordination of Production Planning in Multi-Echelon Supply Chains: a Simulation Approach*. *International Journal of Simulation Modelling,* 23(3), 728-739.

[11] Herbon, A. (2016), *Optimal piecewise-constant price under heterogeneous sensitivity to product freshnes. International Journal of Production Research*, 54(2), 365-385.

[12] Hu, H., Zhu, W., Li, Y., Zhou, J. (2023), *A Four-dimensional Evolutionary Game Analysis of Quality Cheating Behavior in Traditional Chinese Medicine Supply Chain*. *Economic Computation and Economic Cybernetics Studies and Research*, 57(3), 151-172.

[13] Li, R.H., Teng, Jinn-Tsair. (2018), *Pricing and lot-sizing decisions for perishable goods when demand depends on selling price, reference price, product freshness, and displayed stocks*. *European Journal of Operational Research*, 270(3), 1099-1108.

[14] Liu, C., Chen, W.D., Zhou, Q., et al. (2020), *Modelling dynamic freshness-keeping effort over a finite time horizon in a two-echelon online fresh product supply chain*. *European Journal of Operational Research*, 293(2), 511-528.

[15] Liu, C., Lv, J.Y., Hou, P., et al. (2023), *Disclosing products freshness level as a non-contractible quality: Optimal logistics service contracts in the fresh products supply chain*. *European Journal of Operational Research*, 307(3), 1085-1102.

[16] Liu, M., Dan, B., Guan, Z., et al.（2023), *Information sharing in an e-tailing supply chain for fresh produce with supplier encroachment*. *International Transactions in Operational Research*, 31(5), 3494-3530.

[17] Liu, P., Wang, S. (2020), *Evolutionary Game Analysis of Cold Chain Logistics Outsourcing of Fresh Food Enterprises with Operating Risks*. *IEEE Access*, 8, 127094-127103.

[18] Ma, X., Wang, S., Islam, M.S., et al. (2019), *Coordinating three-echelon fresh agricultural products supply chain considering freshness-keeping effort with asymmetric information. Applied Mathematical Modelling*, 67, 337-356.

[19] Nazifa, T.H., Ramachandran, K.K. (2019), *Information sharing in supply chain management: A case study between the cooperative partners in manufacturing industry*. *Journal of System and Management Sciences,* 9(2), 19-47.

[20] Pekarcikova, M., Trebuna, P., Matiscsak, M., et al. (2024), *Inventory Management Supported by Tecnomatix Plant Simulation Tool*. *Int. Journal of Simulation Modelling,* 23(3), 251-262.

[21] Qin, Y., Wang, J., Wei, C. (2014), *Joint pricing and inventory control for fresh produce and foods with quality and physical quantity deteriorating simultaneously*. *International Journal of Production Economics*, 152, 42-48.

[22] Song, Z.L., He, S.W., (2019), *Contract coordination of new fresh produce three-layer supply chain*. *Industrial Management & Data Systems*, 119(1), 148-169.

[23] Tomislav, P., Ratko, S. (2023), *Optimizing vehicle utilization in the cold chain: Literature review*. *Transportation Research Procedia*, 73, 167-176.

[24] Tsao, Y.C. (2016), *Designing a supply chain network for deteriorating inventory under preservation effort and trade credits*. *International Journal of Production Research*, 54(13), 3837-3851.

[25] Wang, G., Ding, P., Chen, H., et al. (2020), *Green fresh product cost sharing contracts considering freshness-keeping effort*. *Soft Computing*, 24(4), 2671-2691.

[26] Wang, Y.L., Yin, X.M., Zheng, X.Y., Cai, J.R., Fang, X. (2022), *Supply chain coordination contract design: The case of farmer with capital constraints and behavioral preferences*. *Advances in Production Engineering & Management*, 17(2), 219-230.

[27] Xin, J., Wei, X., Rabia, A., Yuan, Y. (2024), *The Influence of Government on Automobile Enterprise`s Production Methods: An Evolutionary Game Based Study*. *Economic Computation and Economic Cybernetics Studies and Research*, 58(4), 223-240.

[28] Xu, W., Xu, S., Liu, D.Y., Awaga, A.L., Rabia, A., Zhang, Y.Y. (2024), *Impact of Fairness Concerns on Resource-Sharing Decisions: A Comparative Analysis Using Evolutionary Game Models in Manufacturing Enterprises*. *Advances in Production Engineering & Management*, 19(2), 223-238.

[29] Yang, L. Tang, R. (2019), *Comparisons of sales modes for a fresh product supply chain with freshness-keeping effort. Transp. Res. Pt. e-Logist. Transportation Research Part E*, 125, 425–448.

[30] Zhang, Q., Zhang, Q.Y., Zhang, Z.C. (2020), *Fresh-keeping Strategy of Agricultural Products Supply Chain Considering Grey Game*. *Journal of Grey System*, 32(3), 1-10.