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# MOBILE OR FIXED? EVOLUTIONARY GAME BETWEEN FARMERS AND PRECOOLING SERVICE PROVIDERS IN CHINA

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Abstract. *Precooling plays an important role in ensuring the quality of agricultural products. However, farmers in China are not very enthusiastic about precooling. According to the characteristics of precooling in China villages, this paper proposes two precooling modes, fixed and mobile, and then establishes an evolutionary game model of farmers and precooling service providers. We deeply study the impact of relevant factors on the two groups; the results show that with the deepening of vehicle cost and fixed cost, farmers' willingness to precooling decreases. Compared with fixed precooling, farmers are more sensitive to the vehicle cost and fixed cost of mobile precooling; on the contrary, farmers are more tolerant of the operation cost of mobile precooling. There is an inverted U-shaped relationship between farmers' willingness to precool and the precooling fee of mobile precooling.*
**Keywords:** Precooling service, Farmers, Precooling facilities, Evolutionary game

1. **Introduction.** The precooling of agricultural products refers to the use of precooling equipment to quickly remove field heat after harvesting, so as to reduce the temperature of agricultural products to the minimum temperature suitable for transportation and storage. Studies have shown that if agricultural products are not precooled in time, it will accelerate the decay [1]. The longer the precooling delay, the lower the quality of agricultural products [2]. Because it was not precooled in time, the loss of agricultural products in China is as high as 15%, while the proportion of developed countries such as the United States is less than 5% [3]. However, China is a typical small-scale peasant economy, and it is difficult for farmers to afford the cost of purchasing precooling equipment. The precooling service provided by service providers has become an important way to ensure the quality of agricultural products [2].

Scholars have carried out a lot of research on the precooling of agricultural products and the coordinated operation of farmers and service providers. Su et al. pointed out that due to the low technological literacy of Chinese farmers, the application of precooling in agricultural production is relatively late [4]. Hu and Sun found that as more and more farmers choose to sell products through e-commerce, the demand for small-scale and high-frequency precooling services will greatly increase [5]. The studies show that precooling mainly includes two modes: fixed and mobile [2]. Wang et al. investigated the cold chain

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transportation system under the coordinated operation scenario of fixed cold storage and mobile reefer, and designed a hybrid heuristic algorithm based on a genetic algorithm and improved plant growth simulation algorithm to solve the coordinate operational issues [6]. Ruan et al. found that compared with mobile precooling, fixed precooling has a lower cost, but has a higher precooling delay. However, mobile precooling has the advantages of flexibility and speed, but the purchase cost of mobile precooling equipment is relatively high [7]. Therefore, the choice of precooling model has become an important issue for farmers and service providers.

Whether mobile precooling mode or fixed precooling mode can be adopted by farmers is affected by many factors. Ruan et al. pointed out that the application of a new model in the agricultural field often brings great changes to the original operation mode, and the market price, quality, and market demand of agricultural products will change significantly [2]. Li and Wang developed a fresh food distribution path optimization model for conflicting partnerships between retailers and outsourced cold chain distribution companies under a fixed precooling model by considering farmers' fuzzy needs [8]. If farmers use fixed precooling, the scale of precooling stations will be larger and the cost-of-service provider will increase [1]. Otherwise, if farmers use mobile precooling for precooling, the construction scale of precooling station can be reduced. Meanwhile, more precooling vehicles need to be purchased, and the cost of precooling vehicles will increase accordingly [7]. Therefore, which precooling mode farmers choose is not only the concern of service providers but also the problem studied in this paper.

When the precooling service providers help farmers to carry out precooling, one side's strategy directly affects the income of the other side, which is a game process between the two groups [9]. However, existing studies have well explored similar problems of macroeconomic analysis and scheduling service resources for fulfilling the requests of farmers, but the game process between service providers and farmers was rarely considered [2]. This study focuses on the game process between precooling service providers and farmers, aiming to explore the decision-making mechanism of both. Due to the bounded rationality of farmers and service providers in the game, the players will continuously improve their decisions through learning and imitation [10]. The evolutionary game model is a method that combines game analysis with the dynamic evolution process of groups with bounded rationality [11]. In order to promote the application of precooling in China's agricultural field, this study establishes an evolutionary game model of farmers and service providers and deeply studies the impact of relevant factors on the two groups.

The paper is organized as follows. Section 2 constructs the evolutionary game model of farmers and precooling service providers. Numerical experiments and sensitivity analysis are shown in Section 3. Section 4 concludes the paper.

## 2. Evolutionary Game Model of Farmers and Precooling Service Providers.

2.1. **Problem description.** In the process of the precooling service, farmers first pick agricultural products. After picking, they wait for the arrival of the service provider's vehicle (mobile precooling mode is a precooling vehicle, and fixed precooling mode is a truck) to perform the precooling service. In the mobile mode, a vehicle equipped with special precooling equipment is driven to the farmer for on-site precooling. The service process of the vehicle at the farmer includes product loading and in-vehicle precooling. In the fixed mode, the service process of the truck for the farmer mainly refers to loading. The truck first drives to the farmer's field to collect the products and then transports them back to the precooling warehouse for centralized precooling.

The utilities are different under different modes. The fixed mode has the construction cost of precooling warehouse, but it has relatively low equipment costs and can meet the precooling needs of large quantities. Meanwhile, the fixed mode has the disadvantages of high precooling delay and low utilization rate. On the contrary, the mobile mode has the advantages of flexibility and convenience, and a wide range of applications, but the purchase cost of mobile precooling equipment is relatively high. Meanwhile, the loss of agricultural products on the way and during transportation can be avoided. Consequently, the precooling fee for the mobile mode is higher than the fee for the fixed mode.

2.2. **Assumptions.** To facilitate modeling, we make the following assumptions.

**Assumption 2.1.** *Vehicle cost generation for precooling service providers is $V_i$. Because the cost of precooling vehicle is higher than the cost of the truck, the vehicle costs in the mobile mode and the fixed mode are $V_m$ and $V_f$ ($V_m > V_f$), respectively.*

**Assumption 2.2.** *The precooling operation cost of farmers is $C_i$, and then the precooling operation costs of farmers in mobile mode and fixed mode are $C_m$ and $C_f$, respectively. Note that mobile precooling requires more operation cost for farmers than fixed precooling, i.e., $C_m > C_f$.*

**Assumption 2.3.** *The income brought by the quality of agricultural products is $Q_i$, and then the benefits of the quality in the mobile mode, the fixed mode and the non-precooling mode are $Q_m$, $Q_f$ and $Q_n$, respectively. Note that the quality of agricultural products will be significantly improved after precooling, and the mobile mode is better than the fixed mode for quality improvement, i.e., $Q_m > Q_f > Q_n$.*

**Assumption 2.4.** *The fixed cost invested by the service provider to the precooling facility are $FC_i$, and the fixed cost investment of the mobile mode and the fixed mode are $FC_m$ and $FC_f$, respectively. Note that the fixed cost of the mobile mode is higher than the fixed cost of the fixed mode, i.e., $FC_m > FC_f$.*

**Assumption 2.5.** *The precooling fee charged by the service providers to farmers is $PC_i$. The precooling fee of the mobile mode and the fixed mode is $PC_m$ and $PC_f$, respectively. It is found by investigation that the precooling fee of the mobile mode is higher than the fee of the fixed mode, i.e., $PC_m > PC_f$.*

2.3. **Game payoff matrix.** When a farmer and a service provider engage in game, the benefits of both are different under different strategy scenarios. If farmer and service provider choose precooling strategy and mobile strategy respectively, i.e., (precooling, mobile), they can successfully complete the mobile precooling activities. Farmers get the benefits of product quality improvement due to the mobile precooling service and bear the own operating costs and expenses of the precooling service. The service provider obtains the benefits of the precooling service and bears the fixed cost of the precooling facility. That is, the income obtained by farmers and service providers is $Q_m - C_m - PC_m$ and $PC_m - FC_m - V_m$, respectively. Similarly, if farmers and service providers adopt precooling strategy and fixed precooling strategy, respectively, i.e., (precooling, fixed), then the income of farmers and service providers is $Q_f - C_f - PC_f$ and $PC_f - FC_f - V_f$.

When the farmer does not adopt the precooling strategy and the service provider adopts the mobile strategy (not precooling, mobile), the farmer obtains the quality benefit $Q_n$ of the agricultural products and the service provider pays the fixed cost of the mobile precooling equipment $FC_m$. Similarly, if the farmer adopts the non-precooling strategy and the service provider adopts the fixed precooling strategy, namely (not precooling, fixed), the income of the farmer and the service provider is $Q_n$ and $-FC_f$.

In light of the different benefits of the game players under the above strategy scenarios, the game payoff matrix of farmers and precooling service providers is constructed, as shown in Table 1.

Table 1. Payoff matrix of the evolutionary game model

| Payoff under different strategies | | Precooling service providers: Mobile ($y$) | Precooling service providers: Fixed ($1-y$) |
|---|---|---|---|
| Farmers | Precooling ($x$) | $Q_m - C_m - PC_m$, $PC_m - FC_m - V_m$ | $Q_f - C_f - PC_f$, $PC_f - FC_f - V_f$ |
| | Not precooling ($1-x$) | $Q_n$, $-FC_m$ | $Q_n$, $-FC_f$ |

2.4. **Replicator dynamic equation.** In the process of the game between farmers and service providers, the probability of the farmer implementing the precooling strategy is $x$ $(0 \leq x \leq 1)$, and the probability of not implementing the precooling strategy is $1-x$. Simultaneously, the probability of the precooling service provider choosing mobile facility strategy is $y$ $(0 \leq y \leq 1)$, and the probability of choosing fixed facility strategy is $1-y$. According to Table 1, the expected revenue of farmers choosing precooling strategy is

$$\begin{aligned} F_1 &= (Q_m - C_m - PC_m)y + (Q_f - C_f - PC_f)(1-y) \\ &= (Q_m - Q_f + C_f - C_m + PC_f - PC_m)y + Q_f - C_f - PC_f \end{aligned} \tag{1}$$

The expected revenue of farmers choosing not to precool agricultural products strategy is

$$F_2 = Q_n y + Q_n(1-y) = Q_n \tag{2}$$

The average expected revenue of the two strategies chosen by farmers with the probabilities of $x$ and $1-x$ is

$$\begin{aligned} \bar{F} &= xF_1 + (1-x)F_2 \\ &= (Q_m - Q_f + C_f - C_m + PC_f - PC_m)xy + (Q_f - Q_n - C_f - PC_f)x + Q_n \end{aligned} \tag{3}$$

In the same way, the expected revenue of service providers choosing mobile strategy is

$$S_1 = (PC_m - FC_m - V_m)x - FC_m(1-x) = (PC_m - V_m)x - FC_m \tag{4}$$

The expected revenue of service providers choosing fixed is

$$S_2 = (PC_f - FC_f - V_f)x - FC_f(1-x) = (PC_f - V_f)x - FC_f \tag{5}$$

The average expected revenue of the two strategies chosen by service providers with the probabilities of $y$ and $1-y$ is

$$\begin{aligned} \bar{S} &= yS_1 + (1-y)S_2 \\ &= (PC_m - PC_f + V_f - V_m)xy + (FC_f - FC_m)y + (PC_f - V_f)x - FC_f \end{aligned} \tag{6}$$

According to Malthusian dynamic equation [9], the precooling strategy growth rate of farmers or the mobile strategy growth rate of precooling agricultural products ($dx/dt$ or $dy/dt$) is equal to their expected revenue ($F_1$ or $S_1$) minus the average expected revenue ($\bar{F}$ or $\bar{S}$). Therefore, the replicator dynamic equations of farmers and service providers are shown in Equations (7) and (8), respectively.

$$\frac{dx}{dt} = x(1-x)[(Q_m - Q_f + C_f - C_m + PC_f - PC_m)y + Q_f - Q_n - C_f - PC_f] \tag{7}$$

$$\frac{dy}{dt} = y(1-y)[(PC_m - PC_f + FC_f + V_f - V_m)x + FC_f - FC_m] \tag{8}$$

2.5. **Local stability analysis.** In the above replicator dynamic system, let $\frac{dx}{dt} = 0$, $\frac{dy}{dt} = 0$, then $x_1^* = 0$, $x_2^* = 1$, $y^* = (Q_n - Q_f + C_f + PC_f)/(Q_m - Q_f + C_f - C_m + PC_f - PC_m)$; $y_1^* = 0$, $y_2^* = 1$, $x^* = (FC_f - FC_m)/(PC_m - PC_f + FC_f + V_f - V_m)$; thus, the 5 local equilibrium points are obtained as $(0,0)$, $(0,1)$, $(1,0)$, $(1,1)$ and $(x^*, y^*)$. Simultaneously, the Jacobian matrix $J$ of the replicator dynamic system is obtained according to the replicator dynamic equations (7) and (8).

$$\boldsymbol{J} = \begin{bmatrix} (1-2x)[(Q_m - Q_f + C_f - C_m + PC_f - PC_m)y + Q_f - Q_n - C_f - PC_f] & x(1-x)(Q_m - Q_f + C_f - C_m + PC_f - PC_m) \\ y(1-y)(PC_m - PC_f + FC_f + V_f - V_m) & (1-2y)[(PC_m - PC_f + FC_f + V_f - V_m)x + FC_f - FC_m] \end{bmatrix} \tag{9}$$

According to Jacobian matrix (9), the determinant (Det) and the trace (Tr) of Jacobian matrix are calculated to prepare for the local stability analysis of the system equilibrium points, where

$$\begin{aligned} \text{Det } J = {} & (1-2x)(1-2y)[y(Q_m - Q_f + C_f - C_m + PC_f - PC_m)y + Q_f - Q_n \\ & - C_f - PC_f][(PC_m - PC_f + FC_f + V_f - V_m)x + FC_f - FC_m] \\ & - xy(1-x)(1-y)(Q_m - Q_f + C_f - C_m + PC_f - PC_m)(PC_m - PC_f \\ & + FC_f + V_f - V_m) \end{aligned} \tag{10}$$

$$\begin{aligned} \text{Tr } J = {} & (1-2x)[(Q_m - Q_f + C_f - C_m + PC_f - PC_m)y + Q_f - Q_n - C_f - PC_f] \\ & + (1-2y)[(PC_m - PC_f + FC_f + V_f - V_m)x + FC_f - FC_m] \end{aligned} \tag{11}$$

According to the local stability analysis method of Jacobian matrix [9], if and only if the equilibrium point satisfies Det $J > 0$ and Tr $J < 0$, it is the ESS. Therefore, the 5 local equilibrium points are respectively brought into Equations (10) and (11) for local stability analysis, where the Tr $J$ of the equilibrium point $(x^*, y^*)$ is equal to 0, so the equilibrium point $(x^*, y^*)$ is not the ESS of the system in the interval $[0, 1]$. On this basis, a thorough classified discussion about the logical relations among the model parameters is given and the ESS of the system under the following eight different situations was obtained.

Situation 1: When $(Q_m - Q_n) - (C_m + PC_m) < 0$, $(Q_f - Q_n) - (C_f + PC_f) > 0$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m) < 0$ and $FC_f - FC_m < 0$ are established, the ESS of the system is $(1,0)$.

Situation 2: When $(Q_m - Q_n) - (C_m + PC_m) < 0$, $(Q_f - Q_n) - (C_f + PC_f) < 0$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m) < 0$ and $FC_f - FC_m < 0$ are established, the ESS of the system is $(0,0)$.

Situation 3: When $(Q_m - Q_n) - (C_m + PC_m) < 0$, $(Q_f - Q_n) - (C_f + PC_f) < 0$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m) > 0$ and $FC_f - FC_m < 0$ are all established, the ESS of the system is $(0,0)$.

Situation 4: When $(Q_m - Q_n) - (C_m + PC_m) > 0$, $(Q_f - Q_n) - (C_f + PC_f) < 0$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m) > 0$ and $FC_f - FC_m < 0$ are established, the ESS of the system is $(1,1)$ or $(0,0)$.

Situation 5: When $(Q_m - Q_n) - (C_m + PC_m) > 0$, $(Q_f - Q_n) - (C_f + PC_f) > 0$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m) > 0$ and $FC_f - FC_m < 0$ are established, the ESS of the system is $(1,1)$.

Situation 6: When $(Q_m - Q_n) - (C_m + PC_m) < 0$, $(Q_f - Q_n) - (C_f + PC_f) > 0$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m) > 0$ and $FC_f - FC_m < 0$ are established, the ESS of the system is none.

Situation 7: When $(Q_m - Q_n) - (C_m + PC_m) > 0$, $(Q_f - Q_n) - (C_f + PC_f) < 0$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m) < 0$ and $FC_f - FC_m < 0$ are established, the ESS of the system is $(0,0)$.

Situation 8: When $(Q_m - Q_n) - (C_m + PC_m) > 0$, $(Q_f - Q_n) - (C_f + PC_f) > 0$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m) < 0$ and $FC_f - FC_m < 0$ are established, the ESS of the system is $(1,0)$.

Thus, it can be seen that the relationship among $(Q_m - Q_n) - (C_m + PC_m)$, $(Q_f - Q_n) - (C_f + PC_f)$, $(PC_m - PC_f) + (FC_f - FC_m) + (V_f - V_m)$, $FC_f - FC_m$ determines the final ESS of the system. The detailed analysis is shown in Table 2.

TABLE 2. Analysis of equilibrium points

| | Situation 1 | | | Situation 2 | | | Situation 3 | | | Situation 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $(x, y)$ | Det $J$ | Tr $J$ | Stability | Det $J$ | Tr $J$ | Stability | Det $J$ | Tr $J$ | Stability | Det $J$ | Tr $J$ | Stability |
| $(0, 0)$ | − | Uncertain | Saddle point | + | − | ESS | + | − | ESS | + | − | ESS |
| $(1, 0)$ | + | − | ESS | − | Uncertain | Saddle point | + | + | Instability | + | + | Instability |
| $(1, 1)$ | + | + | Instability | + | + | Instability | − | Uncertain | Saddle point | + | − | ESS |
| $(0, 1)$ | − | Uncertain | Saddle point | − | Uncertain | Saddle point | − | Uncertain | Saddle point | + | + | Instability |
| $(x^*, y^*)$ | Uncertain | 0 | Saddle point | Uncertain | 0 | Saddle point | Uncertain | 0 | Saddle point | − | 0 | Saddle point |
| | Situation 5 | | | Situation 6 | | | Situation 7 | | | Situation 8 | | |
| $(x, y)$ | Det $J$ | Tr $J$ | Stability | Det $J$ | Tr $J$ | Stability | Det $J$ | Tr $J$ | Stability | Det $J$ | Tr $J$ | Stability |
| $(0, 0)$ | − | Uncertain | Saddle point | − | Uncertain | Saddle point | + | − | ESS | − | Uncertain | Saddle point |
| $(1, 0)$ | − | Uncertain | Saddle point | − | Uncertain | Saddle point | − | Uncertain | Saddle point | + | − | ESS |
| $(1, 1)$ | + | − | ESS | − | Uncertain | Saddle point | − | Uncertain | Saddle point | − | Uncertain | Saddle point |
| $(0, 1)$ | + | + | Instability | − | Uncertain | Saddle point | + | + | Instability | + | + | Instability |
| $(x^*, y^*)$ | Uncertain | 0 | Saddle point | Uncertain | 0 | Saddle point | Uncertain | 0 | Saddle point | − | 0 | Saddle point |

## 3. Numerical Experiments.

**3.1. Numerical example.** In order to visually analyze the influence of various factors on the strategies of farmers and service providers, this section is based on the assumptions proposed in Section 2 and the actual situation, after consulting experts in the fields of agricultural operation management (combined with the actual investigation of an apple producing area in Shaanxi Province, China), and referring to the method proposed by [12] to set the following numerical examples. Vehicle cost $V_m = 150$, $V_f = 100$; farmer's precooling operation cost $C_m = 80$, $C_f = 20$; profits on quality of agricultural products $Q_m = 1000$, $Q_f = 800$, $Q_n = 50$; precooling fixed cost $FC_m = 150$, $FC_f = 100$; precooling fee $PC_m = 400$, $PC_f = 290$. The dynamic evolution process of game strategy is simulated by MATLAB.

Since the above ESS (in Section 2) of evolutionary game model has two possibilities in Situation 4: $(0, 0)$ and $(1, 1)$, in order to analyze the influence of different factors on the behavior of game players more accurately, a numerical experiment is carried out with the idea of control variables based on the case of Situation 4. Each group of numerical examples is tested 100 times to ensure the generality of the results.

**3.2. The impact of vehicle cost $V_i$ on evolution.** As shown in Figure 1, the abscissa represents time, different rectangular coordinate systems represent different values of the corresponding factors, and the ordinate represents the evolution paths of $x$ and $y$ (the same below). In mobile mode, as $V_m$ increases, $x$ and $y$ converge to 1. when $V_m = 250$, $x$ and $y$ converge to 0. In fixed mode, the increase of $V_f$ will cause $x$ and $y$ always converge to 1. This shows that with the increase of $V_i$, farmers' willingness to precooling decreases. Compared with the fixed mode, farmers are more sensitive to the $V_m$. In addition, when the $V_m$ is high, service providers are reluctant to adopt the mobile precooling mode.

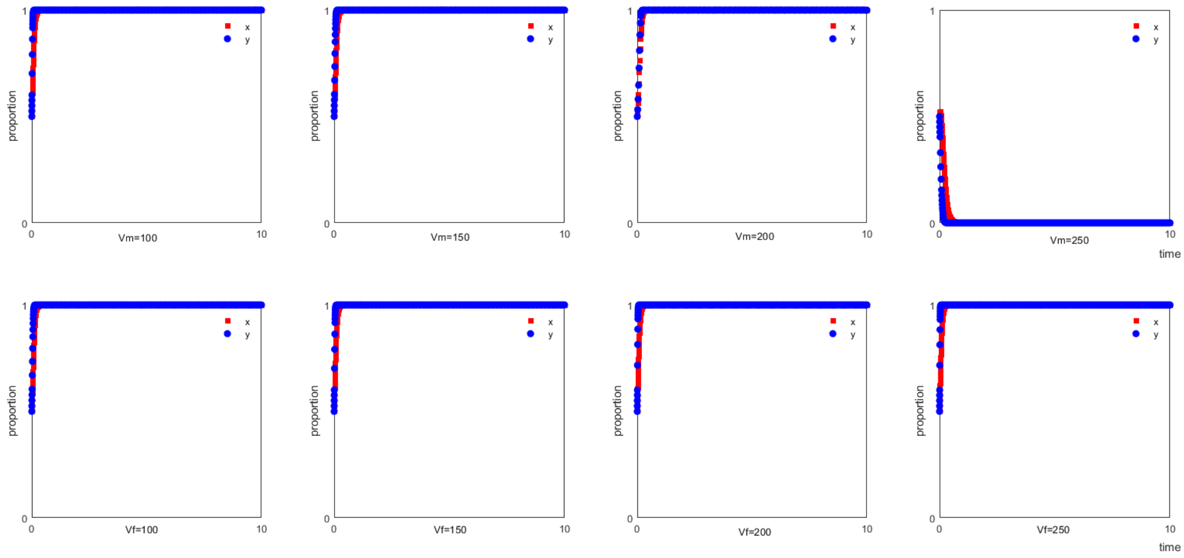


FIGURE 1. Influence of $V_i$ on evolution

3.3. **The impact of precooling fixed cost $FC_i$ on evolution.** Figure 2 depicts the influence of the service providers' precooling fixed cost $FC_i$ on the game evolution path. In mobile mode, the increase of $FC_m$ can lead to the convergence of $x$ and $y$ from 1 ($FC_m$ = 100, 150) to 0 ($FC_m$ = 200, 250). In fixed mode, as the increase of $FC_f$ from 100 to 250, $x$ and $y$ always converge to 1. This shows that with the increase of $FC_m$, farmers' willingness to precool decreases. It can be explained that the service provider generally transfers the increase of fixed cost to farmers by increasing the precooling cost. Compared with the fixed precooling mode, farmers are more sensitive to $FC_m$.

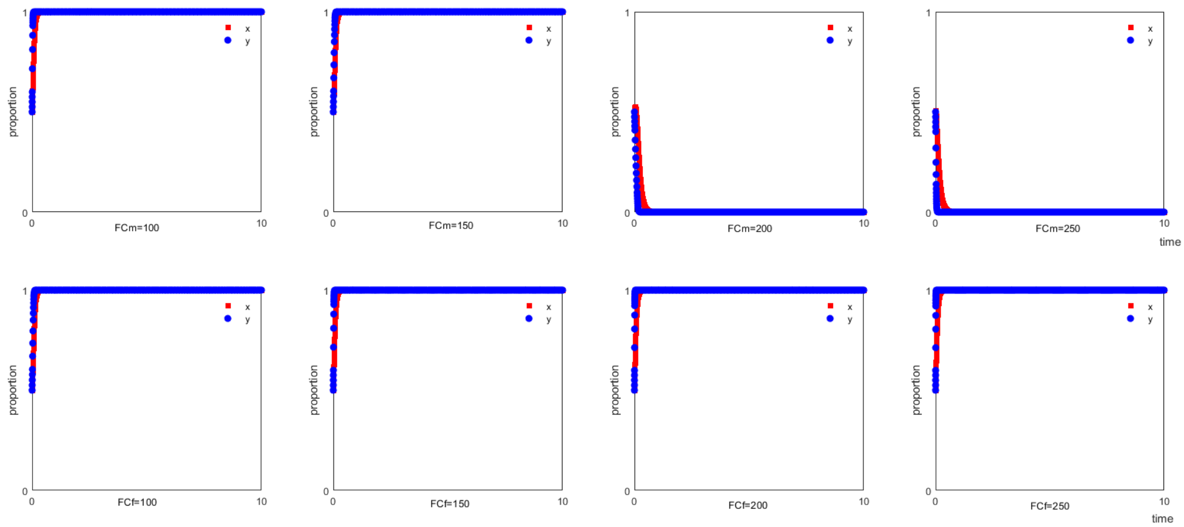


FIGURE 2. Influence of $FC_i$ on evolution

3.4. **The impact of farmer's precooling operation cost $C_i$ on evolution.** As shown in Figure 3, in mobile mode, when farmer's precooling operation cost $C_m$ = 20, 40, 60, 80, $x$ and $y$ converge to 1. In fixed mode, when $C_f$ = 20, 40, 60, 80, $x$ and $y$ converge to 0. This result shows that since the precooling effect of mobile precooling is higher than that of fixed-mode precooling, farmers are more tolerant of $C_m$ than $C_f$.

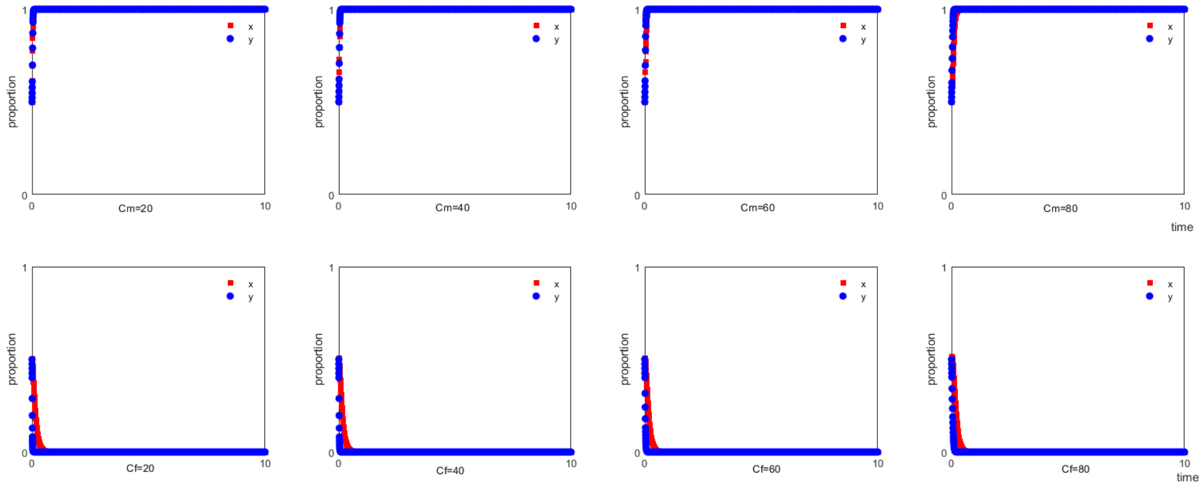

FIGURE 3. Influence of $C_i$ on evolution

3.5. **The impact of precooling fee $PC_i$ on evolution.** As shown in Figure 4, in mobile mode, when $PC_m = 300$, 400, $x$ and $y$ converge to 1; when $PC_m = 200$, 500, $x$ and $y$ converge to 0. In fixed mode, when $PC_f = 200$, 300, 400, 500, $x$ and $y$ converge to 1. This is because when $PC_m$ is low, the farmers' willingness to pre-cool increases, but the service provider is reluctant to provide the service because of the low profit. When $PC_m$ is high, the farmers' willingness to precool will be very low. That is, the precooling willingness of farmers and $PC_m$ showed an inverted U-shaped relationship.

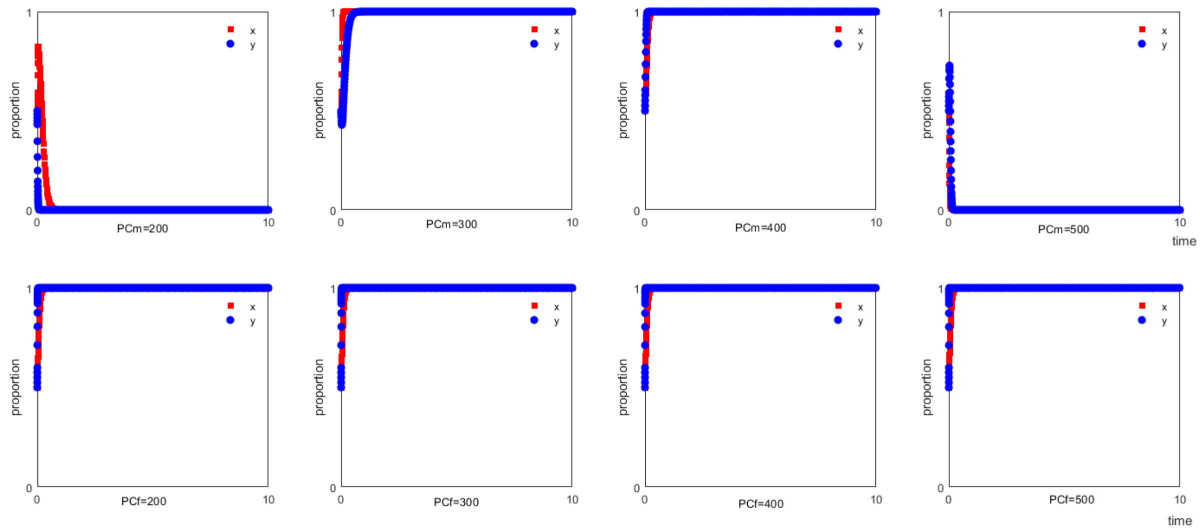

FIGURE 4. Influence of $PC_i$ on evolution

4. **Conclusions.** Precooling of agricultural products plays an important role in ensuring product quality. This study therefore establishes an evolutionary game model between precooling service providers and farmers. From the perspective of market environment and subject interaction, the factors affecting the cooperation of game subjects are proposed, and the influence mechanism of each factor on the strategy selection of game subjects is revealed. What this study finds can provide theoretical guidance for service providers to participate in the farmers' precooling service. Despite this study has made some contributions, some limitations still exist that can be further explored, such as testing the findings

of this study by empirical methods and improving the interaction mechanisms between service providers and farmers by network theory.

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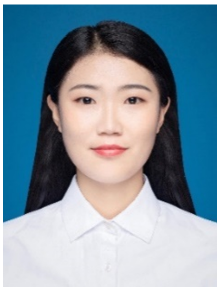

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