Cooperative Production Behavior of Fresh Agricultural Product Suppliers under Regional Product Standardization Construction

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Received 13 December 2021; Revised 10 February 2022; Accepted 1 March 2022; Published 11 April 2022

Abstract

From the perspective of regional product standardization construction, the evolutionary game models of standardized collaborative production of fresh agricultural product suppliers with or without government participation were built respectively, and the stability of the main strategy choice was discussed. The results show that when the standardization of regional fresh agricultural product is low and the participants’ willingness to cooperate is high, the government can choose not to participate in the guidance, but if the government participates in the guidance but does not participate properly, it will have a reverse inhibition effect. When the standardization degree of regional fresh agricultural product is high, the government must effectively guide and regulate, regardless of the initial will of the participants. When government participation is effective, standardized production subsidies can promote the choice of collaborative strategies, while revenue-sharing mechanism and cost-sharing mechanism have little effect.

1. Introduction

Under the background of consumption upgrading and market competition, the development of agricultural industrialization has become an important way to accelerate the development of China’s rural economy and realize the strategy of rural revitalization, and standardization is an important symbol of industrialization. In recent years, more and more landmark associations have cooperated with retailers such as “Jingdong Fresh” and “Hema Fresh” to realize the development of agricultural industrialization, and the high-standard fresh agricultural products created are also favored by consumers. More and more regions have begun to formulate production standards for fresh agricultural products and take the road of industrialization, such as “Dongtai Watermelon” and “Yangcheng Lake Hairy Crab”, which are quite effective.

However, the standardization of most fresh agricultural products in China is still relatively low at present, which is mainly affected by the “small farmers” production mode. From the perspective of standardized production, the small-scale agricultural production economic model is difficult to bear the cost of standardized production (technology introduction, equipment purchase, professional staffing, etc.) and thus cannot realize the development of agricultural industrialization, resulting in the fresh agricultural product industry still staying in the small-scale agricultural economic model, which is a vicious circle. From the perspective of product standardization, fresh agricultural products with different quality, specification, and packaging have different requirements for cold chain logistics, which cannot carry out unified standardized logistics operation, reduce the efficiency of cold chain logistics, increase the cost of cold chain logistics, and cannot obtain the scale effect of industrial agglomeration. Under the background that logistics has already become the “third-party profit source” of industrial industry, cold chain logistics cannot fully meet the basic preservation and transportation needs, which undoubtedly restricts the further industrialization of fresh agricultural products.

In the process of China’s modernization, small-scale peasant economy has always been regarded as the object of
transformation, so as to continuously promote agricultural development [1]. Agricultural organization is regarded as the only way for "small-scale peasant economy" to connect the development of modern agriculture [2]. Under the dual influence of market and policy, many agricultural industrialization organization modes have emerged, such as "company + farmer," "company + farmer cooperative + farmer," "company + family farm," and many scholars have conducted in-depth research on the problems under different development modes [3–7]. However, under the influence of changes in world conditions, national conditions, and agricultural conditions, such as the increase in the risk of international trade in agricultural products, the accelerated transformation of the domestic food consumption structure, and the continuous increase in the requirements for high-quality agricultural development, the above-mentioned agricultural industry development model shows problems such as insufficient cooperation with agriculture, insufficient effect of leading agriculture, and insufficient comprehensive competitiveness [8]. The root cause is that in the above-mentioned agricultural industrialization development model, the main body of fresh agricultural product supply has a low degree of organization, resulting in low autonomy, weak voice, and high dependence on the company.

So how should we break the "small peasant economy" situation, improve the standardization of fresh agricultural products, and promote the development of industrialization? Referring to the definition of synergy and the elaboration of synergistic effect in literature [9], the horizontal collaborative production behavior of fresh agricultural product suppliers can break individual boundaries, integrate resources and allocate them rationally, expand the scale of fresh agricultural product production, jointly introduce standardized production equipment, promote the formation of regional product standardization, and finally realize the industrialization of fresh agricultural product.

Based on this, the main research questions of this study are as follows: (1) what impact does the degree of regional standardization have on the collaborative production behavior of fresh agricultural product suppliers? (2) How should the government guide the suppliers of fresh agricultural product to carry out highly standardized collaborative production behaviors?

In order to answer the above questions, from the perspective of regional standardization construction, we will first build an evolutionary game model of fresh agricultural product supply entities without government participation and explore the decision-making law of collaborative behavior of fresh agricultural product supply entities. Then, an evolutionary game is constructed with government participation and the role of the government is explored in the collaborative process.

The rest of the study is organized as follows: in Section 2, we present the literature review. In Section 3, we make basic assumptions and notation. Section 4 and Section 5 construct the evolutionary game model without government participation and government participation, respectively. Section 6 presents the numerical examples. We conclude this study in Section 7.

2. Literature Review

In this section, we will briefly review the relevant literature based on two streams of research: high-quality development of fresh agricultural product industry and cooperative behavior analysis based on the evolutionary game.

There are many studies on the high-quality development of the fresh agricultural product industry. Generally speaking, scholars have studied and explored it from three perspectives. The first angle is to improve the quality of fresh agricultural products. He et al. [10] conducted a literature review on quality and operational management issues in fresh agricultural product supply chains from four aspects: storage issues, distribution issues, marketing issues, and food traceability and safety issues, providing researchers with a starting point for research. Lin et al. [11] have designed supply chain contracts together with food safety mechanisms that can greatly improve food safety, consumer confidence, and food supply chain profits. Yu et al. [12] studied the impact of government subsidies on food safety. Wang et al. [13] found that the consumption form of online shopping of agricultural products can promote the development of agriculture from high-speed growth to high-quality development. The second angle is the standardization of fresh agricultural products. As the carrier of scientific and technological achievements, standardization can promote the specialization of agricultural production, promote the rational utilization of natural resources, improve competitiveness and sustainable development, and ensure the quality and safety of agricultural products [14]. Yu [15] believed that agricultural standardization can not only ensure quality, reduce production and transaction costs, and form economies of scale but also correct the negative externalities of production and realize the sustainable utilization of resources and the sustainable development of agriculture. Geng and Li [16] believed that standardization can achieve economies of scale, and based on the microdata of mutton sheep scale farms (households), it is confirmed that the economies of scale effect under the standardized breeding mode in the park are significantly better than the family breeding mode, which can improve agricultural productivity. The research of Wang et al. [17] has proved that agricultural technical standards have significantly promoted the promotion of international competitiveness of agriculture. Ma et al. [18] took apple planting as an example, and the study showed that improving apple growers’ awareness of standardized production and the degree of organization of fruit farmers can solve the dilemma of quality and safety. Based on the empirical test of 771 fruit farmers in Hebei, Jiangsu, and Jiangxi provinces, Chen et al. [19] confirmed that standardized production can inhibit the occurrence of "lemon market" in the process of regional public brand of agricultural products and effectively improve farmers’ income and promote the process of agricultural modernization. Yu et al. [20] studied the impact of standardized label certification on retailer behavior and found that when two suppliers adopted an asymmetric
certification strategy, retailers tended to purchase products with organic labels. The third angle is how to promote the industrialization of fresh agricultural products. Zhang et al. [21] believed that the leading enterprises of agricultural industrialization are the most important driving bodies for the development of agricultural industrialization. From the perspective of network organization, Deng and Li [22] suggested that the high-quality development of grain industrialization should be guided by improving the main body of the network. Zhou [1] believed that the economic effect in the development of rural industrialization needs to be closely combined with the ability of self-development. In order to promote the development of fishery industrialization, Sheng et al. [23] proposed a development mechanism of “internal and external linkage and trinity” of policies, driving forces, and paths.

Next, we review literature related to collaborative behavior analysis based on the evolutionary game. There is a lot of research in this area, and it is widely used, especially in the application of collaborative innovation problems. Xu et al. [24], Su et al. [25], Zhou and Ren [26], Hou and Li [27] used evolutionary game models to study collaborative innovation in military-civilian integration, collaborative innovation between enterprises and universities, collaborative innovation in low-carbon technologies, and collaborative innovation in the Internet of Things industry. In addition, some scholars have used evolutionary game models to study issues such as project and organization collaboration (Liu et al. [28], Chen et al. [29], Sun et al. [30]), supply chain collaboration (Qu et al. [31], Long et al. [32]), information collaboration (Yang et al. [33], Zhang et al. [34]), and collaborative supervision and governance (Lei et al. [35], Zhang et al. [36]).

It can be seen from the above literature that, on the one hand, synergistic factors have not been considered in the current research on the high-quality development of the fresh agricultural product industry. On the other hand, although the application of evolutionary games is very extensive, few people have used it to study the collaborative behavior of fresh agricultural product suppliers, and there is no literature focusing on the impact of regional standardization on collaborative decision-making. This study noticed the above deficiencies and carried out research, hoping to provide some guidance for the development of the fresh agricultural product industry.

### 3. Basic Assumptions and Symbol Description

It is assumed that there are only two fresh agricultural product suppliers A and B of the same type in a certain region (such as two fresh agricultural product growers and two fresh agricultural product manufacturers), and they have two strategy choices: standardized collaborative production and nonstandardized collaborative production. The probabilities of coordinated and uncoordinated strategy set are \( (x, 1 - x) \) and \( (y, 1 - y) \), respectively.

1. When both of them choose uncoordinated strategy, they produce independently, the output is \( Q_1 \) and \( Q_2 \), the unit production cost is \( C_1 \) and \( C_2 \), and the price of fresh agricultural product is \( p \). At this time, the regional product standardization degree is 0.

2. Consumers are more interested in high-standardized and high-quality fresh agricultural products, so it is assumed that consumers have a certain consumption preference \( \mu \) for standardized fresh agricultural products.

3. When both of them choose the cooperative strategy, the scale effect of cooperative production can be obtained. Producing the same quantity of fresh agricultural products \( (Q_1, Q_2) \) can reduce the production cost with a ratio of \( \varnothing \). The standardized collaborative production behavior of fresh agricultural product suppliers can bring about the homogenization of the quality and the unification of the specifications of fresh agricultural products in the region. At this time, the standardization degree of fresh agricultural products in the region is \( \theta \). The unit cost paid by the supplier of fresh agricultural product for product standardization is \( 1/2C\theta^2 \) (including the cost of mechanical equipment, production technology, precooling and fresh-keeping equipment, packaging technology, etc.).

4. When the two parties cooperate, the cost paid for the standardization of fresh agricultural products is shared between them in proportion \( \beta \), and the benefits from standardization are shared in proportion \( \alpha \).

5. When one party chooses the collaborative strategy and the other party chooses the uncollaborative strategy, although one party carries out standardized production, it cannot reach a unified standard. At this time, the standardization degree of fresh agricultural products in the region is 0.

### 4. Strategy Stability Analysis without Government Participation

According to the assumptions, we can get the payment matrix of fresh agricultural product suppliers without government participation, as listed in Table 1. It is assumed that the benefits of participating in cooperation are greater than the benefits obtained when choosing a noncooperative strategy.

According to the relevant theory of evolutionary game and the algorithm of expected return, we can get the expected return and average return of fresh agricultural product supplier A as follows:
cultural product supplier B’s collaborative strategy is as follows:

\[
\begin{align*}
E\pi_{A1}^x &= y\alpha\mu\theta(Q_1 + Q_2) - (1 - \varnothing)C_1Q_1 + pQ_1 - \beta y \frac{1}{2} C\theta^2 (Q_1 + Q_2) - (1 - y) \frac{1}{2} C\theta^2 Q_1, \\
E\pi_{A1}^{1-x} &= pQ_1 - C_1Q_1, \\
E\pi_{A1} &= xE\pi_{A1}^x + (1 - x)E\pi_{A1}^{1-x}.
\end{align*}
\]

Then, the replication dynamic equation of fresh agricultural product supplier A’s collaborative strategy is as follows:

\[
F_1(x) = \frac{dx}{dt} = (1 - x)\left[y\alpha\mu\theta(Q_1 + Q_2) - (1 - \varnothing)C_1Q_1 + pQ_1 - \beta y \frac{1}{2} C\theta^2 (Q_1 + Q_2) - (1 - y) \frac{1}{2} C\theta^2 Q_1\right].
\]

Similarly, the expected income and average income of fresh agricultural product supplier B can be obtained as follows:

\[
\begin{align*}
E\pi_{B1}^x &= x(1 - \alpha)\mu\theta(Q_1 + Q_2) - (1 - \varnothing)xC_2Q_2 + pQ_2 - (1 - \beta)x \frac{1}{2} C\theta^2 (Q_1 + Q_2) - (1 - x) \frac{1}{2} C\theta^2 Q_2, \\
E\pi_{B1}^{1-y} &= pQ_2 - C_2Q_2, \\
E\pi_{B1} &= yE\pi_{B1}^x + (1 - y)E\pi_{B1}^{1-y}.
\end{align*}
\]

Then, the replication dynamic equation of fresh agricultural product supplier B’s collaborative strategy is as follows:

\[
F_1(y) = \frac{dy}{dt} = (1 - y)\left[x(1 - \alpha)\mu\theta(Q_1 + Q_2) + \varnothing xC_2Q_2 - (1 - \beta)x \frac{1}{2} C\theta^2 (Q_1 + Q_2) - (1 - x) \frac{1}{2} C\theta^2 Q_2\right].
\]

**Proposition 1.** When \( y > y^*_1 \), the stable strategy of fresh agricultural product supplier A is to participate in collaboration; when \( y < y^*_1 \), the stable strategy of fresh agricultural product supplier A is uncoordinated; when \( y = y^*_1 \), the stable strategy of fresh agricultural product supplier A cannot be determined, where \( y^*_1 = 1/2C\theta^2Q_1/\alpha\mu\theta(Q_1 + Q_2) + \varnothing C_1Q_1 - \beta 1/2C\theta^2(Q_1 + Q_2) + 1/2C\theta^2Q_1 \).

**Proof.**

\[
N(y) = y\alpha\mu\theta(Q_1 + Q_2) + \varnothing y C_1Q_1 - \beta y 1/2C\theta^2 (Q_1 + Q_2) - (1 - y) 1/2C\theta^2 Q_1.
\]
Complexity

\[
\frac{\partial N(y)}{\partial y} = a\mu \theta (Q_1 + Q_2) + C_{1i} Q_i, \quad \text{(5)}
\]
\[-\beta \frac{1}{2} C h^2 (Q_1 + Q_2) + \frac{1}{2} C h^2 Q_1 > 0.
\]

Therefore, \(N(y)\) is the increasing function of \(y\). When \(y > y^*_1\), \(N(y) > 0\), \(F_1(x)|_{x=1} = 0\), \(F_1^*(x)|_{x=1} = 0\), \(x = 1\) is stable, that is, the stable strategy of fresh agricultural product supplier A is coordination; when \(y < y^*_1\), \(N(y) < 0\), \(F_1(x)|_{x=0} = 0\), \(F_1^*(x)|_{x=0} = 0\), \(x = 0\) is stable, the stable strategy of fresh agricultural product A is uncoordinated; when \(y = y^*_1\), \(N(y) = 0\), \(F_1(x) = 0\), \(F_1^*(x) = 0\), the stability strategy cannot be determined.

\section*{Proposition 2.}
When \(x > x^*_1\), the stable strategy of fresh agricultural product supplier B is synergy; when \(x < x^*_1\), the stable strategy of fresh agricultural product supplier B is uncoordinated; when \(z = x^*_1\), the stability strategy of fresh agricultural product supplier B cannot be determined, where \(x^*_1 = \frac{1}{1 - \beta} (Q_1 + Q_2) + C_{1i} Q_i - \frac{1}{2} C h^2 (Q_1 + Q_2) + \frac{1}{2} C h^2 Q_2\).

\section*{Proof.}
\(N(x) = x(1 - \alpha) \mu \theta (Q_1 + Q_2) + C x C_2 Q_2 - (1 - \beta) x 1/2 C h^2 (Q_1 + Q_2) - (1 - \beta) 1/2 C h^2 Q_2\)
\[
\frac{\partial N(x)}{\partial x} = (1 - \alpha) \mu \theta (Q_1 + Q_2) + C x C_2 Q_2 - (1 - \beta) \frac{1}{2} C h^2 (Q_1 + Q_2) + \frac{1}{2} C h^2 Q_2 > 0.
\]

Therefore, \(N(x)\) is the increasing function of \(x\). When \(x > x^*_1\), \(N(x) > 0\), \(F_1(y)|_{y=1} = 0\), \(F_1^*(y)|_{y=1} < 0\), \(y = 1\) is stable, that is, the stable strategy of fresh agricultural product supplier A is coordination; when \(x < x^*_1\), \(N(x) < 0\), \(F_1(y)|_{y=0} = 0\), \(F_1^*(y)|_{y=0} < 0\), \(y = 0\) is stable, that is, the stable strategy of fresh agricultural product supplier A is uncoordinated; when \(x = x^*_1\), \(N(x) = 0\), \(F_1(y) = 0\), \(F_1^*(y) = 0\), the stability strategy cannot be determined.

\section*{Inference 1.}
The choice of cooperative strategy among the suppliers of fresh agricultural product is mutually reinforcing. When the cooperative probability of one side is higher, the possibility of the other side is also higher.

\section*{Proposition 3.}
There are two stable points in the game system of standardized collaborative production of fresh agricultural product suppliers without government participation, which are \((0, 0)\) and \((1, 1)\), respectively. The final game result depends on the initial state of the participants.

\section*{Proof.}
Let \(F_1(x) = 0\) and \(F_1(y) = 0\), then we can get five local equilibrium points: \((0, 0), (0, 1), (1, 0), (C(1, 1), D(x^*_2, x^*_2))\), where \(x^*_2 = \frac{1}{1 - \beta} 1/2 C h^2 Q_2 / (1 - \alpha) \mu \theta (Q_1 + Q_2) + C x C_2 Q_2 - (1 - \beta) 1/2 C h^2 (Q_1 + Q_2) + 1/2 C h^2 Q_2\) and \(y^*_2 = 1/2 C h^2 Q_1 / \mu \theta (Q_1 + Q_2) + C x C_1 Q_1 - \frac{1}{2} C h^2 (Q_1 + Q_2) + 1/2 C h^2 Q_1\).

And, according to formulas (2) and (4), the Jacobian matrix \(J_1\) of the two-dimensional dynamic system \(I\) is as follows:
\[
J_1 = \begin{bmatrix}
\frac{\partial F_1(x)}{\partial x} & \frac{\partial F_1(y)}{\partial x} \\
\frac{\partial F_1(x)}{\partial y} & \frac{\partial F_1(y)}{\partial y}
\end{bmatrix} = \begin{bmatrix}
\alpha_1 & \alpha_2 \\
\alpha_3 & \alpha_4
\end{bmatrix},
\]
where \(\alpha_1 = (1 - 2x) [y (1 - \mu \theta (Q_1 + Q_2) + C x C_2 Q_2 - (1 - \beta) 1/2 C h^2 (Q_1 + Q_2) - (1 - y) 1/2 C h^2 Q_1] + \alpha_2 = x (1 - x) [y \theta (Q_1 + Q_2) + C x C_1 Q_1 - \frac{1}{2} C h^2 (Q_1 + Q_2) + 1/2 C h^2 Q_1], \alpha_3 = y (1 - y) [1 - \alpha] \mu \theta (Q_1 + Q_2) + C x C_2 Q_2 - (1 - \beta) 1/2 C h^2 (Q_1 + Q_2) + 1/2 C h^2 Q_2, \alpha_4 = (1 - 2y) [x (1 - \alpha) \mu \theta (Q_1 + Q_2) + C x C_2 Q_2 - (1 - \beta) x 1/2 C h^2 (Q_1 + Q_2) - (1 - 1/2 C h^2 Q_2).

According to Jacobian matrix local stability analysis method, the stability of five points is analyzed and the results are listed in Table 2.

It can be seen that there are two stable points in the game system of standardized collaborative production of fresh agricultural product suppliers, namely, \((0, 0)\) and \((1, 1)\). The phase diagram of system evolution is shown in Figure 1.

\section*{5. Stability Analysis of System Strategy with Government Participation}

Government synergy factors are introduced into the model, assuming that the government participates in synergy mainly through three means. First, the standard \(\theta\) of fresh agricultural products is formulated in the region. When the suppliers of fresh agricultural product choose standardized collaborative production, they must meet the standards formulated by the government, so as to complete the standardization construction of regional fresh agricultural products. When one supplier of fresh agricultural product participates in collaboration, while the other party does not, the noncooperative party will get free-riding income \(U\) from the cooperative party. The second is to give standardized production cost subsidy \(a\). The third is to impose a penalty of \(F\) on those who enjoy “free-rider” benefits in nonstandard production.

According to the assumed conditions, the payment matrix of fresh agricultural product suppliers can be obtained, as listed in Table 3.

The expected income and average income of fresh agricultural product supplier A are as follows:
Eπx A2 \alpha\mu\theta Q_1 + Q_2 - \frac{1}{2}(C - a)\bar{\theta}^2 (Q_1 + Q_2),
\begin{align*}
-&(1 - y) \frac{1}{2} C\bar{\theta}^2 Q_1 - U,
\end{align*}
E\pi_{A2}^{x-y} = pQ_1 - C_1 Q_1 + pQ_2 - C_2 Q_2 - \frac{1}{2} C\bar{\theta}^2 Q_2 - U,
E\pi_{A2} = xE\pi_{A2}^{x-y} + (1 - x)E\pi_{A2}^{1-x}.
\end{align*}

Then, the replication dynamic equation of fresh agricultural product supplier A’s collaborative strategy is as follows:

\begin{align*}
F_2(x) = \frac{dx}{dt} = x(1 - x) \left[ y_2 \mu\bar{\theta}(Q_1 + Q_2) + C_1 Q_1 + \beta 1/2 (C - a)\bar{\theta}^2 (Q_1 + Q_2) + \frac{1}{2} C\bar{\theta}^2 Q_1 - U + F \right].
\end{align*}

Similarly, the expected income and average income of fresh agricultural product supplier B can be obtained as follows:
\[
\begin{align*}
E_{n_2} &= x(1-a)μ\bar{Q}_1 + Q_2 - (1-\varnothing x)C_2Q_2 + pQ_2 - x(1-\beta)\frac{1}{2} (C-a)\bar{Q} (Q_1 + Q_2) + (1-x)\mu\bar{Q}_2 - (1-x)\frac{1}{2} C\bar{Q}^2 Q_2 - U, \\
E_{n_2} &= pQ_2 - C_2Q_2 + xU - F, \\
E_{n_2} &= yE_{n_2} + (1-y)E_{n_2}.
\end{align*}
\]

(9)

Then, the replication dynamic equation of fresh agricultural product supplier B’s collaborative strategy is as follows:

\[
F_2(y) = \frac{dy}{dt} = y(1-y)\left[ x(1-a)μ\bar{Q}_1 + Q_2 + \varnothing xC_2Q_2 - x(1-\beta)\frac{1}{2} (C-a)\bar{Q} (Q_1 + Q_2) + (1-x)\mu\bar{Q}_2 - (1-x)\frac{1}{2} C\bar{Q}^2 Q_2 - U + F \right].
\]

(10)

According to formulas (8) and (10), the two-dimensional dynamic system II can be obtained, and the Jacobian matrix \( J_2 \) is as follows:

\[
J_2 = \begin{bmatrix}
\frac{\partial F_2(x)}{\partial x} & \frac{\partial F_2(x)}{\partial y} \\
\frac{\partial F_2(y)}{\partial x} & \frac{\partial F_2(y)}{\partial y}
\end{bmatrix} = \begin{bmatrix}
b_{11} & b_{12} \\
b_{21} & b_{22}
\end{bmatrix}.
\]

(11)

Let \( F_2(x) = 0 \) and \( F_2(y) = 0 \), then we can get five local equilibrium points: \( O_2 \), \( A_2 \), \( B_2 \), \( C_2 \), \( D_2 \), and \( E_2 \):

\[
y_2^* = \frac{U - F - μ\bar{Q}_1 + 1/2C\bar{Q}^2 Q_1}{αμ\bar{Q}_1 + \varnothing C_1Q_1 - β1/2(C-a)\bar{Q}^2 (Q_1 + Q_2) - μ\bar{Q}Q_1 + 1/2C\bar{Q}^2 Q_1}, \\
x_2^* = \frac{U - F - μ\bar{Q}_2 + 1/2C\bar{Q}^2 Q_2}{(1-α)μ\bar{Q}_1 + \varnothing C_2Q_2 - (1-β)1/2(C-a)\bar{Q}^2 (Q_1 + Q_2) - μ\bar{Q}_2 + 1/2C\bar{Q}^2 Q_2}.
\]

(12)

The stability of five points is analyzed, and the results are listed in Table 4.

\( O_2 \) is the stable point of the dynamic system when the conditions \( μ\bar{Q}_1 - 1/2C\bar{Q}^2 Q_1 - U + F < 0 \) and \( μ\bar{Q}_2 - 1/2C\bar{Q}^2 Q_2 - U + F < 0 \) are satisfied; when the conditions \( αμ\bar{Q}_1 + \varnothing C_1Q_1 - β1/2(C-a)\bar{Q}^2 (Q_1 + Q_2) - U + F > 0 \) and \( (1-α)μ\bar{Q}_1 + \varnothing C_2Q_2 - (1-β)1/2(C-a)\bar{Q}^2 (Q_1 + Q_2) - μ\bar{Q}_2 + 1/2C\bar{Q}^2 Q_2 \) are satisfied, \( C_2 \) is the stable point of the system.

**Inference 2.** Condition one: when \( U - F > αμ\bar{Q}_1 + \varnothing C_1Q_1 - β1/2(C-a)\bar{Q}^2 (Q_1 + Q_2) \) and \( U - F (1-α)μ\bar{Q}_1 + \varnothing C_2Q_2 - (1-β)1/2(C-a)\bar{Q}^2 (Q_1 + Q_2) \) are satisfied, \( C_2 \) is the stable point of the system.
when $\tilde{\theta} Q_1 - 1/2C \tilde{\theta}^2 Q_1 < U - F < \alpha(C - \alpha)\tilde{\theta}^2(Q_1 + Q_2) + \varnothing C_1 Q_1 - \beta(1/2(C - \alpha)\tilde{\theta}^2(Q_1 + Q_2))$ and $\tilde{\theta} Q_2 - 1/2C \tilde{\theta}^2 Q_2 < U - F < (1 - \alpha)\mu\tilde{\theta}(Q_1 + Q_2) + \varnothing C_2 - (1 - \beta)(1/2(C - \alpha)\tilde{\theta}^2(Q_1 + Q_2))$, the stable points of the system are $O_2(0, 0)$ and $C_2(1, 1)$. Condition three: when $U - F < \tilde{\theta} Q_1 - 1/2C \tilde{\theta}^2 Q_1$ and $U - F < \tilde{\theta} Q_2 - 1/2C \tilde{\theta}^2 Q_2$, the stable point of the system is $C_2(1, 1)$.

The evolution phase diagram of game system with government participation in different situations is shown in Figure 2. Figure 2(a) shows the evolution process of the system when condition one is met. At this time, the suppliers of fresh agricultural product tend to choose uncoordinated strategies. Figure 2(b) shows the evolution process of the system when condition two is met. At this time, the suppliers of fresh agricultural product may all choose uncoordinated strategies or collaborative strategies, depending on the initial state. Figure 2(c) shows the evolution process of the system when condition three is met. At this time, the suppliers of fresh agricultural product tend to choose collaborative strategy.

**Inference 3.** Free-rider income is not conducive to the choice of standardized collaborative production strategy of fresh agricultural product suppliers, and the government’s penalty for not implementing standardized production is conducive to the choice of standardized collaborative production strategy of fresh agricultural product suppliers.

### 6. Simulation Analysis

In order to show more intuitively and clearly the influence of key parameters on the stability strategy of evolutionary game players, the evolution trajectory of dynamic game system is numerically simulated by using Matlab software. According to the basic assumptions and realistic basis, the relevant parameters are initially assigned as follows: $\varnothing = 0.3$, $Q_1 = 200$, $Q_2 = 250$, $C_1 = 5$, $C_1 = 4.5$, $\alpha = \beta = 0.5$, $\mu = 1$, $\theta = 1$, and $C = 2$.

Firstly, the stability of the equilibrium point of the system is verified without government participation. Assuming that the initial states of fresh agricultural product suppliers are $(0.5, 0.5)$ and $(0.4, 0.4)$, respectively, the evolution process of the system is shown in Figure 3(a). It can be found that the stable point of the system is $(1, 1)$ when the initial state of fresh agricultural product supplier is 0.5, and $(0, 0)$ when the initial cooperative probability is reduced to 0.4. Figure 3(b) shows that the stable point of the system is $(1, 1)$ when the initial cooperative probability of fresh agricultural product supplier A is 0.4 and that of fresh agricultural product supplier B is 0.5. Figure 3(c) shows the stable point $(1, 1)$ of the system when the initial cooperative probability of fresh agricultural product supplier A is 0.5 and that of fresh agricultural product supplier B is 0.4. It can be seen that the evolution direction of the system is coordinated/uncoordinated when the initial collaboration probability of participants is high and is (uncoordinated, uncoordinated) when the initial collaboration probability of participants is low. However, when the cooperative probability of one participant is low, the promotion of the cooperative probability of the other participant will promote its choice of cooperative strategy, that is, the cooperative strategy choice of fresh agricultural product suppliers is mutually reinforcing.

Secondly, the stability of the equilibrium point of the system is verified with government participation. Let $a = 1$, $\bar{\theta} = 1, U = 450$, and $F = 30$, then condition 1 in Inference 2 is satisfied. Assuming that the initial state of fresh agricultural product supplier is $(0.5, 0.5)$, the evolution process of the system is shown in Figure 4(a). It can be found that the stable points of the system are $(0, 0)$ when the initial cooperative probabilities are 0.5, respectively. Let $a = 1$, $\bar{\theta} = 1, U = 450$, and $F = 150$, then the second condition in Inference 2 is met and it is assumed that the initial states of fresh agricultural product suppliers are $(0.5, 0.5)$ and $(0.8, 0.8)$, respectively, and the evolution process of the system is shown in Figure 4(b). It can be found that the stable point of the system is $(0, 0)$ when the initial cooperative probability of participants is 0.5 and is $(1, 1)$ when the initial cooperative probability is 0.5, respectively. It can be seen that with the participation of the government, the supplier of fresh agricultural product will tend to choose uncoordinated strategy when the free-riding income obtained from the other party’s standardized production is still large after deducting the government penalty. On the contrary, they will tend to choose the cooperative strategy.

Thirdly, the influence of government participation is explored on the system evolution results. When $\theta = \bar{\theta} = 1$, it is assumed that the initial cooperative probability of participants is 0.5, and the evolution process and results of the system under the conditions of no government participation and government participation are compared. As shown in Figure 5, x and y represent the evolution path of agent strategy without government participation and x1 and y1 represent the evolution path of agent strategy with

### Table 4: Stability analysis of local equilibrium point of system with government participation.

| Local equilibrium point | $tr_{L_2}$ | $det_{L_2}$ | Stability     |
|-------------------------|------------|-------------|---------------|
| $O_2 (0, 0)$            | $U$        | $+$         | ESS when conditions are met |
| $A_2 (0, 1)$            | $+$        | $U$         | Unstable/saddle point |
| $B_2 (1, 0)$            | $+$        | $U$         | Unstable/saddle point |
| $C_2 (1, 1)$            | $U$        | $+$         | ESS when conditions are met |
| $D_2 (x_2, y_2)$       | $0$        |             | Saddle point    |
government participation. And, Figure 5(a) shows the evolution process of the system without government participation and with government participation meeting condition one; Figure 5(b) shows the evolution process of the system without government participation and with government participation meeting condition two; Figure 5(c) shows the evolution process of the system without government participation and with government participation meeting condition three. By comparison, it can be found that under the same initial cooperative probability, only when the third condition is met, the government participation can positively promote the evolution of the system to the (1, 1) direction. That is to say, when the government participates, it is necessary to effectively control the free-rider behavior and increase the punishment; otherwise, the government participation will inhibit the standardized collaborative production behavior of fresh agricultural product suppliers.

Let $\theta = \bar{\theta} = 2$, then it is assumed that the initial cooperative probability of the subjects in the system without government participation and the system with government participation is both (0.5, 0.5). Comparing the evolution process of the system with or without government participation and satisfying condition three, it is represented by
Figure 4: Evolution process of game system with government participation.

Figure 5: Influence of government participation on the evolution results of game system.
lines $x$ and $y$ and lines $x_1$ and $y_1$, respectively, as shown in Figure 6. It can be seen from the figure that when the standardization of fresh agricultural products is improved, the evolution direction of the system without government participation is $(0,0)$, and that of the system with government participation is $(1,1)$. From this, it can be concluded that when the degree of standardization is higher, it is more necessary for the government to participate in coordination, guidance, and encouragement.

Finally, the influence of other parameters on the system evolution results is explored with the effective participation of the government.

(1) **Standardized Cost Subsidy.** Take $\overline{\theta} = 2$ and $a = (0.2, 1, 1.8)$, respectively, with the effective participation of the government, assuming that the initial cooperative probability of subjects is $(0.5, 0.5)$, and the process of system evolution is shown in Figure 7. With the increase of the government standardized cost subsidy, fresh agricultural product suppliers are evolving in the $(1,1)$ direction faster, that is, the government standardized cost subsidy is conducive to promoting fresh agricultural product suppliers to choose standardized collaborative production strategies.

(2) **Benefit Sharing Coefficient and Cost-Sharing Coefficient.** Keeping other parameters unchanged, take $\alpha = 0.5$, $\beta = (0.2, 0.5, 0.8)$, and $\alpha = (0.2, 0.5, 0.8)$, $\beta = 0.5$, respectively. The evolution process of the system is shown in Figure 8. It can be seen from the figure that when the profit-sharing coefficient is constant, with the increase of the cost-sharing coefficient, the evolution rate of the subject in the
direction of 1 becomes slower; when the cost-sharing coefficient is constant, with the increase of the profit-sharing coefficient, the evolution rate of the subject in the direction of 1 becomes faster, but the overall evolution direction remains unchanged. That is, with the effective participation of the government, the revenue-sharing mechanism and cost-sharing mechanism have little influence on the strategy selection results of the fresh agricultural product suppliers.

7. Conclusion

Taking the regional product standardization construction as the goal, this study constructs the evolutionary game model of collaborative production of fresh agricultural product suppliers, explores the decision-making rules of standardized collaborative production behavior of fresh agricultural product suppliers, and finally finds the following conclusions:

1. When the standardization degree of regional fresh agricultural products is low, the cost for standardization of fresh agricultural products suppliers is low, and the choice of cooperative strategy of fresh agricultural product suppliers without government participation is only related to the initial intention. However, when the government participates, it is necessary to strictly supervise the free-riding behavior; otherwise, government participation will inhibit the choice of standardized collaborative production strategy of fresh agricultural products.

2. When the standardization degree of regional fresh agricultural products is high, the cost for standardization is high, and the suppliers of fresh agricultural product are unwilling to actively participate in standardized collaborative production without government participation. Only when the government enforces high standards and does a good job in supervising and punishing free-riding behaviors, the suppliers of fresh agricultural product will be willing to participate in standardized collaborative production.

3. With the government’s effective participation, it can effectively supervise and punish the free-riding behavior, and the standardized cost subsidy is conducive to promoting the supplier of fresh agricultural product to choose the standardized collaborative production strategy. At this time, the profit-sharing coefficient and cost-sharing coefficient have little influence on the selection of standardized collaborative production strategy of fresh agricultural product suppliers.

There are several limitations in the study, which may be worth further exploration. First of all, this study does not consider the scale and individual attributes of fresh agricultural product suppliers. In fact, fresh agricultural product suppliers of different scales and attributes have different risk tolerance and willingness to cooperate. Secondly, the formulation and measurement of the standardization degree of fresh agricultural products are also an issue worthy of further discussion.
Data Availability

The [DATA TYPE] data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (no. 72103178), Jiangsu Social Science Key Fund Project (no. 20GLA002), and Jiangsu Postgraduate Innovation Plan (no. SJKY19_2519).

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