Supply Chain Coordination of Fresh Products E-Commerce Under Evolutionary Game

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Abstract—From the perspective of moral hazard, this paper proposes the evolutionary game model of decision-making of e-commerce retailers and their suppliers in the fresh products e-commerce supply chain coordination. This paper analyzes the impact of food perishability, the total demand, and the input cost on supplier decision-making and the effect of the market price and the input cost on the stability of the fresh commodities supply chain. The numerical simulation conducted by Python/MATLAB shows the relation between the above factors and the resulting evolutionary stability strategy when the parameters of the factors are changed.

Keywords-moral hazard; fresh products e-commerce supply chain; evolutionary game; evolutionarily stable strategy

1 INTRODUCTION

In recent years, with the continuous improvement of people's living standards and consumption concepts, more and more consumers choose to buy fresh products. Therefore the consumption of fresh products is increasing year by year. According to the data from the National Bureau of Statistics, the consumption of main fresh products of Chinese residents has reached 3.1 trillion tons in 2019 and maintained a positive growth year by year. With the rise of e-commerce platforms as a novel and convenient channel, the fresh products e-commerce industry develops rapidly. It is reported by iResearch that the proportion of fresh online retail is yearly soaring, accounting for 14.6% of the total fresh retail when the total fresh retail reaches 5.0395 trillion yuan in 2020. Shopping online blocks real access to products as a result consumers fail to effectively judge the quality of products. Consumers have to depend on the online introduction such as pictures and descriptions. However, even if online retailers truthfully report the quality of fresh products, fresh products are still facing damage during transportation. Low-quality transportation services corrupt the evaluation of consumers when they receive products, thus preventing their desire to buy again. Therefore, ensuring that the suppliers can provide high-quality transportation services plays an important role in the healthy development of the fresh products e-commerce supply chain.

In recent years, many scholars have studied coordination in the fresh products supply chain. Gu[1] studied that the optimal quality improvement efforts and fresh-keeping efforts are distorted in a decentralized environment, and it is impossible to judge whether suppliers adopt high-quality transportation services for fresh products following the requirements. Liu[2] discussed the information sharing in the fresh agricultural products e-commerce supply chain and put forward the influence of information sharing under different demand information and freshness elasticity

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on equilibrium decision-making. Zheng [3] analyzed supply chain coordination from the perspective of fresh-keeping efforts and found that there was a positive correlation between supply chain profits and consumers' sensitivity to freshness. At the same time, a cost-and-benefit-sharing contract was proposed to coordinate participants' benefit of the supply chain.

At the same time, some scholars have studied the impact of providing value-added services on the overall revenue of the supply chain in the e-commerce environment. Yang Lei and others[4] proposed that consumers' demand for fresh products depends on the effort level of suppliers, and fresh e-commerce companies carry out the optimal pricing strategy based on the supplier's strategy. Based on considering the fresh-keeping efforts, Liu Molin[5] considered the coordination under the fresh products e-commerce that provides value-added services and proposed that the various elasticity of the freshness and the various elasticity of demand for services will change the results of coordination.

As for the application of the evolutionary game in the study of the fresh supply chain, Xu Minli et al[6] analyzed the "free rider" behavior between food suppliers and manufacturers in the process of quality input and output. This paper showed the evolutionary stable equilibrium of the decision-making of both parties of the supply chain under the regulation of the government. Liu and Wang[7], based on the evolutionary game, studied the investment in preservation efforts of logistics outsourcing for the fresh supply chain and illustrated the impact of investment in preservation efforts of fresh enterprises and logistics enterprises on product quality.

Both parties can get externalities from the efforts of another party. The fresh products suppliers provide great fresh-keeping efforts so that the fresh products e-commerce retailers can improve their profits even if they do not carry out value-added services. But the retailers have incentives to provide value-added services if the products are of high quality, to obtain more profits. Additionally, value-added services offered by the e-commerce retailers also promote consumers to buy more fresh products, bringing profit growth to suppliers even if they do not make efforts. However, the moral hazard may arise, because, under the situation, the suppliers are reluctant to provide high fresh-keeping efforts. The main reasons are that greater fresh-keeping efforts mean higher costs and the efforts made by the suppliers cannot be supervised by the e-commerce retailers. Based on the observation, this paper establishes the evolutionary game model considering the value-added service decision of the e-commerce retailers and the fresh-keeping efforts of the suppliers under moral hazard. The evolutionary equilibrium derived from the model provides novel insights for improving the quality of fresh products in the supply chain of fresh products in reality.

2 MODEL ASSUMPTION

This paper considers a two-level fresh products e-commerce supply chain system, whose game subjects are the fresh products e-commerce retailers and the fresh products, suppliers. The fresh products e-commerce retailers are responsible for the sales and promotion of fresh products. The price of fresh products in the market is fixed. The strategies of the fresh products e-commerce retailers and the suppliers jointly affect consumer demand. The retailers sell their fresh products through the platform and stimulate people's demand for fresh products through high value-added services such as advertising and publicity. The retails should evaluate the benefit of investing high value-added services and decide whether or not to do. The fresh products suppliers, responsible for transporting fresh products to customers, should adopt special storage and transportation methods for fresh products. If the suppliers adopt better fresh-keeping technology, they will achieve a higher product fresh-keeping rate in exchange for higher expenditure. The suppliers can reject high fresh-keeping technology. The fresh products e-commerce retailers and the suppliers are assumed to be limited rational. Each time, one representer is chosen from each group as a fresh products e-commerce retailer or a supplier to play a game. To maintain their interests both need to constantly update their strategy until the two parties reach an equilibrium.

2.1 Assumption 1

Both the fresh products e-commerce retailers and the suppliers of the fresh product have two strategies: high input (H) and low input (L). For the retails, high input means the careful inspection of fresh products to ensure their quality from the place of origin, and the input on the advertisement to improve people's awareness of fresh products and to increase demand. For the suppliers, high input refers to the use of more protective packages and cartons with temperature and humidity control or other equipment to improve the shelf life of fresh products. The suppliers are unable to observe the actual quality of the goods in the process of storage and transportation, there will be two kinds of situations, which are divided into high transport quality and low transport quality, and the probabilities of the two situations are various with the degree of efforts made by the suppliers. The probability of high-quality results under the high input is p_S^H. The probability of high-quality results under the low input is p_S^L. And there are only two results, so the probability of low quality is $p_F^i = 1 - p_S^i$. The cost of low input is zero for both the retails and the suppliers while the cost of high input is c_1 for the suppliers and c_2 for the retailers .

2.2 Assumption 2

The consumer demand d is also affected by the decision-making of the retailers and the fresh-keeping quality of the suppliers, $d = g(f^j, q^l), j \in (H, L), l \in (S, F)$.

At the same time, two parties are complementary in strategy, the increase of one party has a higher marginal utility when another party is better, that is $(d_S^H - d_F^H) - (d_S^L - d_F^L) > 0$.

2.3 Assumption 3

The profit function of the suppliers is $U = d_l^j - c_1^i, i \in (H, L), j \in (H, L), l \in (S, F)$. There is a positive correlation between the income of the suppliers and consumer demand. The profit function of the retailers is $V = md_l^j - c_2^j, j \in (H, L), l \in (S, F)$.

The notations used with their explanation are shown in Table 1.

Table 1 Model parameters and symbols

parameters	Explanation
$e^i, i \in \{H, L\}$	The level of input provided by logistics suppliers can be divided into high input and low input.
$q^l, l \in \{S, F\}$	Suppliers will have the result of two kinds of damage rates when supplying fresh agricultural products. q^S means low damage ratio, q^F means high damage ratio

p_l^i	When the logistics supplier choose i, the probability of the result l of the goods loss rate
$f^j, j \in \{H, L\}$	The level of value-added services provided by e-commerce can be divided into high input and low input
$c_k^i, k \in (1,2)$	The cost of player k when choosing strategy i,1 means logistics supplier, 2 means e-commerce
$c_k^j, k \in (1,2)$	The cost of player k when choosing strategy j,1 means logistics supplier, 2 means e-commerce
d_l^j	consumer demand when e-commerce chooses strategy i and the damage rate of the goods is l
$w(d)$	The income of logistics suppliers is related to consumer demand
m	The price of fresh goods
U_j^i	Revenue of logistics suppliers when e-commerce chooses strategy i and logistics supplier chooses strategy j
V_j^i	Revenue of e-commerce when e-commerce chooses strategy i and logistics supplier chooses strategy j

3 INCOME MATRIX OF FRESH E-COMMERCE AND FRESH SUPPLIERS

According to the assumptions, both the fresh products e-commerce retailers and the fresh product suppliers have two strategies, that is that both parties can decide to make great or little efforts of promoting consumers' demand for fresh products. The specific results are as follows:

If both parties do not want to increase demand, they choose low input together. Because there is no investment, so the cost is 0.

If only the retailers choose high input to ensure that consumers increase their demand for fresh products through advertisements or other publicity channels but the suppliers do not lift their efforts, suppliers will reap additional benefits from "hitchhiking" due to increased demand.

If only the suppliers choose high input to ensure the quality of fresh products in the process of storage and transportation, the retailers will get additional benefits because of the increase in demand.

If the retailers and the suppliers select high input together, in this two-level system, the retailers achieve the higher demand through publicity promotion, and the suppliers ensure the freshness of the products through high-quality transportation. Both parties will benefit from positive effects brought by themselves and each other.

According to the above description, the income matrix of the evolutionary game model between the retailers and the suppliers is obtained, as shown in Table 2.

Table 2 Income matrix of fresh e-commerce and fresh suppliers

		e-commerce	
		High	**Low**
Fresh suppliers	**High**	$U_H^H = p_S^H d_S^H + p_F^H d_F^H - c_1$ $\boldsymbol{V_H^H = m(p_S^H d_S^H + p_F^H d_F^H) - c_2}$	$U_L^H = p_S^H d_S^L + p_F^H d_F^L - c_1$ $\boldsymbol{V_L^H = m(p_S^H d_S^L + p_F^H d_F^L)}$
	Low	$U_H^L = p_S^L d_S^H + p_F^L d_F^H$ $\boldsymbol{V_H^L = m(p_S^L d_S^H + p_F^L d_F^H) - c_2}$	$U_L^L = p_S^L d_S^L + p_F^L d_F^L$ $\boldsymbol{V_L^L = m(p_S^L d_S^L + p_F^L d_F^L)}$

4 ANALYSIS OF GAME MODEL BETWEEN FRESH E-COMMERCE AND FRESH SUPPLIERS

4.1 The equilibrium point in the Evolutionary Game Model

For the suppliers, the fitness value of choosing the high fresh-keeping investment strategy is calculated by (1).

$$\mu_1^H = y(p_S^H d_S^H + p_F^H d_F^H - c_1) + (1-y)(p_S^H d_S^L + p_F^H d_F^L - c_1) \quad (1)$$

The fitness value of choosing the low fresh-keeping investment strategy is calculated by (2).

$$\mu_1^L = y(p_S^L d_S^H + p_F^L d_F^H) + (1-y)(p_S^L d_S^L + p_F^L d_F^L) \quad (2)$$

The expected fitness value of logistics suppliers is calculated by (3).

$$\overline{\mu}_1 = x\mu_1^H + (1-x)\mu_1^L \quad (3)$$

Similarly, the fitness value of fresh e-commerce to choose a high value-added service investment strategy is calculated by (4).

$$\mu_2^H = x(m(p_S^H d_S^H + p_F^H d_F^H) - c_2) + (1-x)(m(p_S^L d_S^H + p_F^L d_F^H) - c_2) \quad (4)$$

The fitness value of e-commerce choosing low value-added service investment strategy is calculated by (5)

$$\mu_2^L = xm(p_S^H d_S^L + p_F^H d_F^L) + (1-x)m(p_S^L d_S^L + p_F^L d_F^L) \quad (5)$$

The expected fitness value of e-commerce is calculated by (6).

$$\overline{\mu}_2 = y\mu_2^H + (1-y)\mu_2^L \quad (6)$$

According to the Malthusian Equation, the growth rate of the suppliers choosing high input is expressed by the fitness value μ_1^H of the suppliers choosing high input strategy minus the corresponding average fitness $\overline{\mu}_1$. The time is expressed by t, the replication dynamic equation can be obtained by (7).

$$\dot{x}=\frac{dx}{dt}=x(\mu_1^H-\overline{\mu}_1)=x(1-x)[(p_S^H-p_S^L)(y(d_S^H-d_F^H)+(1-y)(d_S^L-d_F^L))-c_1] \quad (7)$$

Similarly, the replication dynamic equation of e-commerce is shown as (8)

$$\dot{y}=\frac{dy}{dt}=(\mu_2^H-\overline{\mu}_2)=y(1-y)m(xp_S^H+(1-x)p_S^L)(d_S^H-d_F^H-d_S^L+d_F^L)+m(d_F^H-d_F^L)-c_2 \quad (8)$$

The two-dimensional dynamic system is formulated by (9)

$$\begin{cases} f(x,y)=\frac{dx}{dt} \\ g(x,y)=\frac{dy}{dt} \end{cases} \quad (9)$$

where $N=d_S^H-d_F^H-d_S^L+d_F^L$ and $P=p_S^H-p_S^L$.

When $\frac{dx}{dt}=0$ and $\frac{dy}{dt}=0$, the solution of (x,y) are $(0,0),(0,1),(1,0),(1,1)$, and obviously these are the local equilibrium points of the system.

4.2 Stability Analysis and Evolutionary Stability Strategy of Evolutionary equilibrium

The four local equilibrium points derived from the replication dynamic equations are not necessarily the evolutionary stability strategy of the system. Thus, according to the method proposed by Friedman, the stability of the local equilibrium points should be tested by analyzing the local stability of the Jacobian matrix of the system. Then, the equilibrium points of evolutionary stability can be obtained.

The Jacobian matrix of the game model between the suppliers and the retailers of the fresh products e-commerce supply chain under moral hazard is

$$J=\begin{bmatrix} \frac{\partial f(x,y)}{\partial x} & \frac{\partial f(x,y)}{\partial y} \\ \frac{\partial g(x,y)}{\partial x} & \frac{\partial g(x,y)}{\partial y} \end{bmatrix}=\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \quad (10)$$

Where $a_{11}=(1-2x)[P(y(d_S^H-d_F^H)+(1-y)(d_S^L-d_F^L))-c_1]$, $a_{12}=x(1-x)PN$, $a_{21}=y(1-y)mPN$, $a_{22}=(1-2y)[m(xp_S^H+(1-x)p_S^L)N+m(d_F^H-d_F^L)-c_2]$.

The Expression of trJ and $det\,J$ of the matrix J are $trJ=a_{11}+a_{22}$ and $det\,J=a_{11}a_{22}-a_{21}a_{12}$. The four equilibration points evaluated in the previous section were substituted into trJ and $det\,J$, and the results are shown in Table 3.

Table 3 trJ and $det\,J$, of the equilibrium point

	trJ	$det\,J$
(0,0)	$P(d_S^L-d_F^L)-c_1+mp_S^LN+m(d_F^H-d_F^L)-c_2$	$[P(d_S^L-d_F^L)-c_1][mp_S^LN+m(d_F^H-d_F^L)-c_2]$
(0,1)	$P(d_S^H-d_F^H)-c_1-(mp_S^LN+m(d_F^H-d_F^L)-c_2)$	$[P(d_S^H-d_F^H)-c_1][-(mp_S^LN+m(d_F^H-d_F^L)-c_2)]$

(1,0)	$-(P(d_S^L - d_F^L) - c_1) + mp_S^H N + m(d_F^H - d_F^L) - c_2$	$[-(P(d_S^L - d_F^L) - c_1)][mp_S^H N + m(d_F^H - d_F^L) - c_2]$
(1,1)	$-(P(d_S^H - d_F^H) - c_1) - (mp_S^H N + m(d_F^H - d_F^L) - c_2)$	$[P(d_S^H - d_F^H) - c_1][mp_S^H N + m(d_F^H - d_F^L) - c_2]$

Where $\alpha = P(d_S^L - d_F^L)$, $\beta = P(d_S^H - d_F^H)$, $\gamma = c_2 - m(d_F^H - d_F^L)$, $\eta = mp_S^L N$, $\delta = mp_S^H N$.

$p_S^H > p_S^L$ and $N > 0$ can be drawn from the assumptions, so we can figure out $\beta > \alpha$ and $\delta > \eta$.

So the Proposition 1 can be derived as follows.

Proposition 1: The evolutionarily stable strategy (*ESS*) of the system is (L, L) in the following case:

$$\beta > c_1 > \alpha, \gamma > \delta > \eta \quad (11)$$

$$c_1 > \beta > \alpha, \delta > \gamma > \eta \quad (12)$$

$$c_1 > \beta > \alpha, \gamma > \delta > \eta \quad (13)$$

Proof: By substituting the condition into Jacobian matrix J , and the symbols of trJ and $detJ$ of each local equilibrium point were obtained to verify the stability of the local equilibrium point. The analysis results are shown in Table 4.

Table 4 Local Stability Analysis of each case in Proposition 1

Condition	**Equilibrium Point**	trJ	$\det J$	**Local stability**
$\beta > c_1 > \alpha$ $\gamma > \delta > \eta$	(0,0)	−	+	*ESS*
	(0,1)	+	+	
	(1,0)		−	
	(1,1)		−	
$c_1 > \beta > \alpha$ $\delta > \gamma > \eta$	(0,0)	−	+	*ESS*
	(0,1)		−	
	(1,0)	+	+	
	(1,1)		−	
$c_1 > \beta > \alpha$ $\gamma > \delta > \eta$	(0,0)	−	+	*ESS*
	(0,1)		−	
	(1,0)		−	
	(1,1)	+	+	

To verify the local stability of the point, only the positive and negative signs of $\mathrm{tr}J$ and $\det J$ need to be verified. When $\det J$ is negative, it means that this point is a saddle point. When $\det J$ is positive and $\mathrm{tr}J$ is negative, this point is unstable.

According to Proposition 1, similarly, when the parameters are other, Proposition 2-5 can be verified.

Proposition 2: When the case is $c_1 > \beta > \alpha, \delta > \eta > \gamma$, the evolutionary stability strategy ESS of the system is (L, H).

Proposition 3: When the case is $\beta > \alpha > c_1, \gamma > \delta > \eta$, the evolutionary stability strategy ESS of the system is (H, L).

Proposition 4: The evolutionarily stable strategy (ESS) of the system is (H, H) in the following case:

$$\beta > c_1 > \alpha, \delta > \eta > \gamma \quad (14)$$

$$\beta > \alpha > c_1, \delta > \gamma > \eta \quad (15)$$

$$\beta > \alpha > c_1, \delta > \eta > \gamma \quad (16)$$

Proposition 5: When the case is $\beta > c_1 > \alpha, \delta > \gamma > \eta$, the evolutionary stability strategy ESS of the system is (L, L) and (H, H).

4.3 Analysis of evolution results

Based on the above analysis of the local stability of equilibrium points under different conditions, the strategy evolution processes of the fresh products e-commerce retailers and the fresh products suppliers under different conditions can be obtained. The result analysis and phase diagram of the evolutionary game that promotes the joint choice of input of both parties are given.

In all the cases mentioned in Proposition 4, *ESS* is (1,1). When the case $\delta > \eta > \gamma$ is satisfied, (0,1) is the saddle point. Similarly, When the case $\beta > \alpha > c_1$ is satisfied, (1,0) is the saddle point. When both cases $\beta > c_1 > \alpha$ and $\delta > \gamma > \eta$ are satisfied, (0,0) is a saddle point and other points are unstable. Therefore, the corresponding phase diagrams of the three cases in Proposition 4 are shown in Fig. 1-3, respectively.

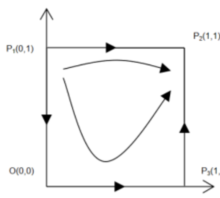

Figure 1. Phase diagram of the case (14)

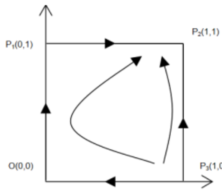

Figure 2. Phase diagram of the case (15)

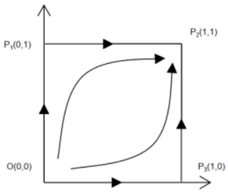

Figure 3. Phase diagram of the case (16)

In Proposition 5, there are two stable equilibrium points. When the supply chain is in the state, every party may get both the better result, and the worse consequence. Therefore, in this case, there is no such guarantee that the fresh products e-commerce supply chain will develop in a good direction.

5 CONCLUSION

Based on the analysis of the decision evolution of the retailers and the suppliers in the fresh e-commerce products supply chain, this paper demonstrates the changed utility of two parties under different decisions made by the retailers and suppliers. The analysis results point out that only when both parties jointly select high input, the overall profit of the whole supply chain is optimal. What's more, because the income of the retailers (the suppliers) is not only affected by their own decisions but also the suppliers' (the retailers), once one party finds the utility of high input is lower than the one of low input, and the party tends not to invest, another parties even though they select the high input at the beginning will transfer to low input. It makes the supply chain move in a relatively poor direction.

To lead to the healthy development of the industry, the parties can manipulate the parameters of the factors to meet the situations illustrated in Proposition 5. Because under the situations where both parties of the supply chain have incentives to invest and the benefit brought by the "hitchhike" is less than the benefit when both parties conduct high input together, the retailers and the suppliers of fresh products e-commerce supply chain have the same motivation of the high input, resulting in a win-win balance.

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