Evolutionary game research on the psychological choice of online shopping of fresh agricultural products based on dynamic simulation model

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Abstract

This article conducts a dynamic simulation on new agricultural product networks’ psychological selection based on the evolutionary game theory. Aiming at the characteristics of fresh agricultural products, the article analyses the dynamic evolution process of consumers’ strategic choice psychological state in the model. The research results show that the new agricultural products platform and the seller’s strategic choice for the quality of the product are closely related to the output ratio of the input to the quality of the product. The users of fresh agricultural products are organically related through various network information behaviours, forming a networking group with a particular topological structure relationship.

Keywords: fresh agricultural products, online shopping psychology, dynamic simulation model, quality investment, evolutionary game

AMS 2010 codes: 91A80

1 Introduction

The prices of certain fresh agricultural products have fluctuated sharply in recent years. At the same time, some agricultural products are facing the dilemma of oversupply. The large fluctuations in the prices of fresh agricultural products seem to be caused by the imbalance between the supply and demand of these products [1]. When policymakers overestimate the actual market demand in the future, they will increase their production, and this can lead to an oversupply of agricultural products. When policymakers underestimate the future market demand, they will reduce their production, and this can cause the supply of agricultural products to fall short of demand, which would in turn lead to a sharp increase in the prices of agricultural products. Retailers are in a dominant position in the agricultural product supply chain, and suppliers often arrange production according to the retailers’ orders. Behavioural economics research shows that decision-makers exercise psychological selection that influences the behaviours of buyers of fresh products, which leads to deviations in retailers’ estimates of market demand. The imbalance between the supply and demand of agricultural products is mainly due to

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the errors of retailers in estimating market demand. Therefore, it is more realistic to study how a retailer’s psychological expectations of online shopping for fresh and live products affect the retailer’s decision-making [2]. This experiment will consider the psychological selection behaviour of fresh product buyers of fresh agricultural product retailers. The strategy adopted in this paper involves studying the evolutionary game process of agricultural product quality investment between the supplier group and the retailer group, solving the evolutionary equilibrium strategy and analysing the impact of a balanced strategy on the psychological expectation and evolution of fresh product online shopping.

2 Basic assumptions and model establishment

Assume that \( q \) is the actual market demand and obeys the normal distribution \( N(\mu, \sigma^2) \). Let the probability density function be expressed as \( f(x) > 0 \). The cumulative distribution function is \( F(x) \). Assume that the retailer’s prediction of product demand has an impact on the psychological selection behaviours of buyers of fresh and live products [3]. When we make demand forecasts, we will be more convinced of the impact of retail prices and quality investments on demand. Retailers’ psychological expectations of online shopping for fresh products tend to be overestimated and over-precise. The expected market demand function considering the psychological expectations of online shopping for fresh and live products is:

\[
q_r = a[a - bp + \beta(I_s + I_r)] + (1 - a)q
\]  

\( a - bp + \beta(I_s + I_r) \) represents the market demand expected by the retailer’s psychology, which, in other words, is the market demand that retailers think can be generated under a specific price and quality investment. \( I_s, I_r \in [0, 1] \) represents the quality investment of the supplier and the retailer, respectively. \( \alpha \) represents the retailer’s psychological expectations of online shopping for fresh and live products. The larger the \( \alpha \), the more the retailer believes in retail price and quality investment behaviour on market demand. When \( \alpha = 1 \), it means complete self-confidence. When \( \alpha = 0 \), it means entirely rational. In addition, when \( a = bp + \beta(I_s + I_r) \) is much greater (less than) \( q \). When \( \alpha \to 1 \), the decision-maker will overestimate the market demand [4]. The decision result may deviate far from the optimal value.

During the order period, the retailer orders fresh agricultural products from the supplier according to market demand, and the supplier arranges production according to the retailer’s order quantity. Assume that the retailer can only order once and does not allow replenishment [5]. The production cost of fresh agricultural products per supplier is \( c_s \). The wholesale price of a retailer’s unit of fresh agricultural products is \( w \). The retail market price of a unit of fresh agricultural products is \( p \). The expected revenue of the supplier and the retailer are, respectively

\[
\pi_s = (\omega - c_s)q
\]

\[
\pi_r = (p - \omega)q_r - p\int_0^{q_r} F(x)dx
\]

The supplier’s quality investment includes the careful maintenance of various growth links such as fertilisation, weeding and pesticide application to fresh agricultural products [6]. The quality investment of the retailer includes the decoration and design of the storage room; the freezing, anti-corrosion and meticulous storage of fresh agricultural products; and the preservation of freshness during transportation.

At this time, the two groups of suppliers and retailers make quality investment decisions. The corresponding benefits are as follows:

1. If both the supplier and the retailer choose not to invest in the quality of agricultural products, their benefits are \( \pi_s, \pi_r \), respectively, where \( \pi_s > 0, \pi_r > 0 \).

2. If both suppliers and retailers choose a quality investment, the quality of agricultural products will be significantly improved at this time, and the market demand will also increase. At this time, their income
is \((1 + \delta_s)\pi_s - c_1q, (1 + \delta_r)\pi_r - c_2q_r\), respectively, where \(\delta_s (\delta_r > 0)\) is the output ratio of the supplier’s choice of agricultural product quality investment. This means that the increase in the supplier’s unit investment quality leads to an increase in its income. \(\delta_r (\delta_r > 0)\) selects the output ratio of the agricultural product quality investment for the retailer. This means that the increase in the retailer’s unit quality investment leads to the increase in its income. \(c_1 (c_1 > 0)\) is the supplier’s unit product quality investment cost, and \(c_2 (c_2 > 0)\) is the retailer’s unit product quality investment cost.

3. When the supplier chooses quality investment, and the retailer does not choose a quality investment, the supplier’s income is \((1 + \delta_s)\pi_s - c_1q\), and the retailer’s income is \(T_r (T_r > \pi_r)\).

4. When the supplier does not choose a quality investment, and the retailer chooses a quality investment, the quality of agricultural products can also be improved. The market demand will increase with the increase of its quality investment [7]. In summary, we establish a game payout matrix (Table 1).

| Supplier Behaviour | Retailer | The retailer does not proceed |
|--------------------|----------|-------------------------------|
| Get on             | \((1 + \delta_s)\pi_s - c_1q, (1 + \delta_r)\pi_r - c_2q_r\) | \((1 + \delta_s)\pi_s - c_1q, T_r\) |
| Not proceed        | \(T_r, (1 + \delta_r)\pi_r - c_2q_r\)                          | \(\pi_s, \pi_r\) |

### Table 1 Payment matrix for suppliers and retailers

#### 3 Evolutionary game analysis of quality investment in agricultural product supply chain

#### 3.1 Balance point of the evolution process

Assuming that the proportion of the new agricultural product supplier group \(A_1\) that chooses the quality investment strategy is \(x (x \in [0, 1])\), the proportion that does not choose is \((1 - x)\). The proportion that does not choose is \((1 - x)\). The adaptability of the supplier choosing the quality investment strategy is \(u_{1s} = y\left[(1 + \delta_s)\pi_s - c_1q\right] + (1 - y)\left[(1 + \delta_r)\pi_r - c_1q\right]\). Then the average fitness is \(\bar{\pi}_1 = xu_{1s} + (1 - x)u_{1n}\). According to the Malthusian equation, the number of quality investment strategies selected by the fresh agricultural product supplier \(A1\) is equal to its fitness \(u_{1s}\) minus the average fitness \(\bar{\pi}_1\). After finishing, we need to copy the dynamic equation:

\[
x = x(u_{1s} - \bar{\pi}_1) = x(1-x)[\delta_s\pi_s - c_1q - y(T_s - \pi_s)]
\]

Similarly, the dynamic replication equation of retailer \(A_2\) is expressed as:

\[
y = y(u_{2s} - \bar{\pi}_2) = y(1-y)[\delta_r\pi_r - c_2q_r - y(T_r - \pi_r)]
\]

So, we can get one two-dimensional dynamic system \((I)\):

\[
\begin{align*}
\frac{dx}{dt} &= x(1-x)[\delta_s\pi_s - c_1q - y(T_s - \pi_s)] \\
\frac{dy}{dt} &= y(1-y)[\delta_r\pi_r - c_2q_r - y(T_r - \pi_r)]
\end{align*}
\]

To facilitate the calculation, we determine

\[
\begin{align*}
x_0 &= \frac{\delta_s\pi_s - c_2q_r}{T_r - \pi_r}, \quad y_0 = \frac{\delta_r\pi_r - c_1q}{T_s - \pi_s}, \\
\delta_s^1 &= \frac{c_1q}{\pi_s}, \quad \delta_r^2 = \frac{T_s - \pi_s + c_1q}{\pi_s}, \quad \delta_s^1 = \frac{c_2q_r}{\pi_r}, \quad \delta_r^2 = \frac{T_r - \pi_r + c_2q_r}{\pi_r}
\end{align*}
\]

**Proposition 1.** The balance point of the system \((I)\) composed of fresh agricultural product supplier \(A_1\) and retailer \(A_2\) is \((0,0), (0,1), (1,0), (1,1)\), when \(\delta_s^1 < \delta_s < \delta_s^2, \delta_r^1 < \delta_r < \delta_r^2\), \((x_0,y_0)\) is also the equilibrium point of the system \((I)\).
3.2 Stability analysis of the equilibrium point

**Proposition 2.** According to the judgement method of the evolutionary stability strategy, we calculate the value of the trace and determinant of the Jacobian matrix $J$ at each equilibrium point and its local stability.

3.3 Analysis of evolution results

The evolutionary phases of the evolutionary game process of supplier $A_1$ and retailer $A_2$ in the five situations are shown in Figure 1. Figure 1 shows the following analysis results:

1. In this scenario, the quality investment output of the supplier and the retailer is smaller than that of $\delta_s, \delta_r, \ 0 < \delta_s < \delta_1^s, 0 < \delta_r < \delta_1^r$. But they have paid the investment cost for this, as shown in Figure 1a and 1b. At this time, $(0,0)$ is an evolutionary stable point, whereas $(0,1)$ is a saddle point and an unstable point [8]. Suppliers and retailers not choosing quality investment in agricultural products is an evolutionary and stable strategy [9].

2. In this scenario, the retailer’s income from choosing quality investment is far less than the investment cost it pays and will not enable the retailer to choose a quality investment. The ‘free rider’ behaviour of the supplier cannot be implemented. As shown in Figure 1c, $(1,0)$ is an evolutionary stable point, $(0,0)$ and $(0,1)$ are saddle points and $(1,1)$ is an unstable point. Suppliers choose a quality investment, while retailers do not choose an evolutionary and stable strategy [10].

3. In this scenario, the quality investment–output ratio of the two parties is $\delta_1^s < \delta_s < \delta_2^s, \delta_1^r < \delta_r < \delta_2^r$. At this time, the income is smaller than the income $T_s, T_r$ obtained by choosing quality investment from the other party and taking a ‘free rider’ behaviour. As shown in Figure 1d, $(0,1)$ and $(0,1)$ are evolutionary stable points, and $(1,1)$ are unstable points and $(x_D, x_D)$ is a saddle point. The supplier chooses quality investment, while the retailer does not choose a quality investment, or the supplier does not choose a quality investment. Retailers choose quality investment to constitute the evolutionary stability strategy of the system [11].
4. Under this scenario, suppliers’ and retailers’ quality investment–output ratio in the agricultural product supply chain is substantial, as shown in Figure 1. Both suppliers and retailers choose quality investment as the system’s evolutionary and stable strategy.

Market demand means that retailers overestimate the actual market demand. With the increase of the psychological expectations of retailers for online shopping of fresh and live products, the actual market demand expected by retailers will increase. Therefore, retailers choose quality investments to increase their returns. While rational suppliers can more accurately grasp market demand, they will choose not to invest in quality.

3.4 The influence of parameter changes on the stable equilibrium result of the system evolution game

In summary, it can be seen that when the agricultural product quality investment–output ratios of the supplier and the retailer are \( \delta_1 < \delta_s < \delta_2 \), \( \delta_1 < \delta_r < \delta_2 \), respectively, as shown in Figure 1(d). Organised

\[
S_I = \frac{1}{2} [xD + (1 - yD)] = \frac{1}{2} \left[ \frac{\delta_r \pi_r - c_2 q_r}{T_r - \pi} + \frac{T_r - (1 - \delta_s) \pi_s - c_1 q}{T_s - \pi} \right]
\]

(8)

After the above analysis, proposition 3 can be obtained.

**Proposition 3.** Influences of the retailer’s psychological expectation level \( \alpha \) of online shopping for fresh and live products on the equilibrium and stability of system evolution are the following: (1) At the time \( q > a - bp + \beta (I_s + I_r) \), as the retailer’s psychological expectation level of online shopping for new and live products increases, the system is more inclined to the evolutionary stability strategy of the supplier choosing a quality investment and the retailer not choosing a quality investment. (2) At the time \( q \leq a - bp + \beta (I_s + I_r) \), as the retailer’s psychological expectation level of online shopping for new and live products increases, the system is more inclined to the evolutionary stable strategy of the supplier not choosing a quality investment and the retailer choosing a quality investment.

**Proposition 4.** When a retailer has psychological expectations of online shopping for fresh and live products, the effect of ‘free-riding’ behaviour on the equilibrium and stability of system evolution is as follows:

1. The more significant the revenue \( T_s \) obtained by the supplier from the ‘free-riding’ behaviour, the more the system is inclined to the evolutionary and stable strategy that the supplier does not choose a quality investment and the retailer chooses quality investment.

2. The more significant the revenue \( T_r \) obtained by the retailer from the ‘free-riding’ behaviour, the more the system tends to be the evolutionary stability strategy of the supplier choosing a quality investment and the retailer not choosing a quality investment.
The article calculates the partial derivatives of $S_I$ concerning $T_s$, $T_r$, respectively, and obtains that $S_I$ is an increasing function of $T_s$, and that it is a decreasing function of $T_r$. Therefore, as the supplier’s ‘free rider’ behaviour gains $T_s$ increases, the system’s probability will converge to the equilibrium point $(0, 1)$. The two parties’ evolutionary stability strategy is more inclined to suppliers not choosing a quality investment and retailers choosing a quality investment [13]. As the retailer’s ‘free-riding’ behaviour $T_r$ increases, the system’s probability will converge to the equilibrium point $(1, 0)$. The evolutionary stability strategy of the two parties is more inclined to the supplier’s choice of quality investment and the retailer’s choice to not opt for a quality investment. It shows that when a retailer has psychological expectations of online shopping for fresh and live products. Let us suppose that a supply chain member’s ‘free-riding’ behaviour gains a lot from the quality investment of the other party. In that case, the enthusiasm of the supply chain member in choosing a quality investment will be significantly weakened.

4 Conclusion

This experiment studies the evolution strategies of the two groups of suppliers and retailers regarding the quality investment decisions of fresh agricultural products when the retailer in the new agricultural product supply chain has the psychological selection behavior of fresh product buyers. When the quality investment–output ratio is constantly changing, the system’s multiple evolutionary and stable strategies are obtained. The research results show that the psychological expectation level of retailers’ online shopping of fresh and live products has a significant impact on the evolution and stability of the quality investment in fresh and live agricultural products by suppliers and retailers. In addition, factors such as the quality investment–output ratio of the two parties, the cost of both parties’ choice of quality investment and ‘free-riding’ behaviour also impact the evolution strategies of the two groups in the supply chain.

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