# A Study on Preservation Efforts of Fresh Supply Chain Considering Overconfidence of Suppliers

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***Abstract*—Overconfidence of enterprise decision-makers will affect supply chain returns. In this paper, a game model of fresh product supply chain is constructed, and the effects of complete rationality and overconfidence of supplier on the revenue of fresh product supply chain are compared and analyzed. The results show that the overconfidence coefficient of suppliers will have different effects on the decision-making and profit of both sides, and the existence of overconfidence of suppliers may also have a positive impact on the profit of supply chain.**

***Keywords—fresh-food supply chain; overconfidence; Stackelberg game***

## I. Introduction

In recent years, the fresh food market has developed rapidly, and there are many factors that affect the development of fresh food supply chain. There are more and more uncertain factors caused by the problems of cost, competition with other enterprises, demand uncertainty, information asymmetry, etc. In uncertain environment, human behavior is often difficult to be completely rational, so it is necessary to pay attention to the influence of decision-maker's behavior factors on supply chain decision-making.

At present, the relationship between the enterprise's effort behavior and the efficiency of supply chain operation has become a hot topic in academia. Roels et al. (2010) [1] examined the impact of different contractual arrangements on bilateral efforts and profits under the assumption that bilateral efforts of principals and agents jointly determine the final output of the supply chain. The results show that the fixed wage contract is the best when the output is greatly affected by the agent's effort; When the output is greatly affected by the effort of the client, the fixed wage plus input return contract is the best.; When the two sides work equally, the fixed wage plus revenue sharing contract is the best. Kaya (2011) [2] found that in the case of manufacturers' efforts to influence market demand, quantity discount or the use of revenue sharing and cost sharing contracts can fully coordinate the operation of the supply chain; In the case of suppliers' efforts to influence market demand, only by using revenue sharing and cost sharing contracts at the same time can supply chain operation be coordinated Zhu et al. (2011) [3] studied the problem of demand joint forecasting by manufacturers and retailers, and considered that information sharing is the optimal strategy for supply chain coordination when manufacturers have no forecast effort cost and market demand variance is less than forecast variance. Aus and Buscher (2012) [4] found that, compared with the Stackelberg game model, the cooperative game under the framework of Asymmetric Nash negotiation can motivate both parties to invest more advertising, strive to occupy market share, make the retail price lower, and achieve higher overall profits of the supply chain.

Compared with the general supply chain, fresh food supply chain has its own characteristics. The academic community has made some explorations on its market demand function and deterioration rate characterization. Ghare and Schrader (1963) [5], the early researchers of fresh food inventory, established the differential equation model of perishable product inventory, in which the rate of fresh product corruption was negatively related to time, and started the research of fresh food supply chain. Then many scholars in the market demand and deterioration rate of fresh supply chain research. Under the assumption that the quantity and quality deterioration rate of perishable products meet certain distribution conditions, Qin (2014) [6] established the market demand function depending on price and quality, and explored its pricing strategy. In addition, Rong (2011) [7] considered the temperature and time factors, and based on the Arrhenius equation, designed the expression form of perishable products' deterioration rate. Aung (2014) [8] provides different freshness functions based on temperature and shelf life.

A large number of psychological and behavioral economics studies show that decision makers are not completely rational, and their cognitive biases and behavioral preferences will have a wide range of impacts on social and economic activities [9]. Among them, overconfidence is considered to be the most tested cognitive bias finding. Moore (2008) [10] proposed three types of overconfidence behaviors: overestimation, over positioning and over accuracy. Overestimation and over positioning emphasize that the decision-maker overestimates his own ability, while the third category means that the decision-maker overestimates his own prediction accuracy. Ren (2013) [11] studied the newsvendor model in the presence of overconfidence, and used the third type of overconfidence behavior to describe the behavior characteristics of decision makers, indicating that overconfidence led to the existence of mean bias effect in the newsvendor model. Pu (2014) [12] established a two-stage stackelberg game model to investigate the change of the main body's effort behavior in the supply chain when the supplier only has overconfidence and the supplier also has the characteristics of fair concern behavior. Sandra and Philipp's (2014) [13] research shows that when agents have overconfidence characteristics, their efforts are higher than that of rational people.

The research of this paper is based on the overconfidence of the retailers in the supply chain. Through the construction of the decision-making model of fresh product supply chain, the two-stage fresh product supply chain system composed of fresh supplier and retailer is studied. In this system, considering the overconfidence of retailers in their efforts to keep fresh, the optimal equilibrium strategy of Stackelberg dynamic game is solved. This paper analyzes the influence of the retailer's overconfidence on the decision-making of both sides, and shows the influence of overconfidence on the real fresh product supply chain's main income through a simulation example, in order to provide relevant theoretical guidance for the fresh product supply chain management enterprises.

## II. Model Building

This paper considers a two-level supply chain composed of a retailer and a supplier, in which the retailer is the overconfident decision-maker, while the supplier is completely rational. Referring to Moore's summary of overconfidence, this paper assumes that when retailers are overconfident, they will overestimate the effect of their own preservation efforts. In Stackelberg game, retailers play the leading role and suppliers follow. The two sides cooperate to sell a kind of fresh food without loss of generality, so that the product quantity is 1. The efforts of retailers and suppliers and time determine the quality of products. The final freshness of products is $Q=\left(a_1e_1+a_2e_2\right)q$, where $e_1$, $e_2$ are the retailer's and supplier's efforts to keep fresh, $a_1$, $a_2$ are the fresh keeping effect coefficients of retailers and suppliers, $q=q_0e^{-ht}$ is the freshness of fresh products, $h$ is the decay rate of fresh product, $t$ is the time after the product is produced, $q_0 \in (0,1)$, indicating the freshness of fresh product when it is just produced. Considering that suppliers, as the source of fresh products, often have a more important impact on their quality, so suppliers can affect the freshness of fresh products to a greater extent than retailers, that is, $a_2>a_1$. The cost of fresh keeping efforts of fresh retailers and suppliers is $c\left(e_i\right)=\frac{1}{2}e_i^2,\left(i=1,2\right)$.

Sale price of final product $P=pQ$, $p$ is the benchmark price. The higher the freshness, the higher the price (since the number of products is assumed to be unit 1, $P$ is the income from selling products). Retailers and suppliers distribute the final revenue through revenue sharing mechanism, $wQ$ is the profit sharing amount given by the retailer to the supplier, where $0<w<p$, index $R$, $S$, $SC$ represents retailer, supplier and the whole supply chain respectively, The three benefit functions are respectively

$$p_R=\left(p-w\right)\left(a_1e_1+a_2e_2\right)q_0e^{-ht}-\frac{1}{2}e_1^2 \quad (1)$$

$$p_S=w\left(a_1e_1+a_2e_2\right)q_0e^{-ht}-\frac{1}{2}e_2^2 \quad (2)$$

$$p_{SC}=p\left(a_1e_1+a_2e_2\right)q_0e^{-ht}-\frac{1}{2}e_1^2-\frac{1}{2}e_2^2 \quad (3)$$

Retailer and supplier play Stackelberg game, and the decision-making process of effort investment and profit sharing quota is as follows: first the retailer decide its fresh keeping effort $e_1$ and profit sharing quota $w$, then the supplier decides its fresh keeping effort $e_2$ according to the retailer's decision, then the freshness of the product is achieved and so are the supply chain's profit.

### A. Scenario 1: The Supplier Is Completely Rational

According to the above content, the game can be divided into two stages, and the following game models can be solved by using the inverse induction method:

$$\max_{w,e_1} p_R=\left(p-w\right)\left(a_1e_1+a_2e_2\right)q_0e^{-ht}-\frac{1}{2}e_1^2 \quad (4)$$

$$\text{s.t.} \max_{e_2} p_S=w\left(a_1e_1+a_2e_2\right)q_0e^{-ht}-\frac{1}{2}e_2^2 \quad (5)$$

Hessian matrix from formula (4)

$$\begin{vmatrix} -1 & -a_1q_0e^{-ht} \\ -a_1q_0e^{-ht} & -2a_2^2\left(q_0e^{-ht}\right)^2 \end{vmatrix}=\left(2a_2^2-a_1^2\right)\left(q_0e^{-ht}\right)^2>0$$

Therefore, the model has an optimal solution. The profit sharing quota $w^*$, retailer's fresh keeping effort $e_1^*$ and supplier's fresh keeping effort $e_2^*$ are obtained as follows:

$$w^*=\frac{a_2^2-a_1^2}{2a_2^2-a_1^2}p,\ e_1^*=\frac{a_1a_2^2}{2a_2^2-a_1^2}pq_0e^{-ht},$$

$$e_2^*=\frac{a_2^3-a_1^2a_2}{2a_2^2-a_1^2}pq_0e^{-ht}$$

Therefore, it is concluded that the ratio $h^*$ of bilateral efforts and the final freshness $Q^*$ of the product are respectively.

$$h^* = \frac{e_1^*}{e_2^*} = \frac{a_1 a_2}{a_2^2 - a_1^2}, \quad Q^* = \frac{a_2^4 p}{2a_2^2 - a_1^2}\left(q_0 e^{-ht}\right)^2.$$

By substituting $w^*$, $e_1^*$, $e_2^*$ into formula (1), (2), (3), we can get supplier's income, retailer's income and supply chain's overall income as follows:

$$p_s^* = \frac{a_2^4\left(2a_2^2 - 3a_1^2\right)p^2}{2\left(2a_2^2 - a_1^2\right)^2}\left(q_0 e^{-ht}\right)^2$$

$$p_R^* = \frac{a_2^2\left(a_2^4 + 2a_1^2 a_2^2 - a_1^4\right)p^2}{2\left(2a_2^2 - a_1^2\right)^2}\left(q_0 e^{-ht}\right)^2$$

$$p_{SC}^* = \frac{a_2^2\left(3a_2^4 - a_1^4 - a_1^2 a_2^2\right)p^2}{2\left(2a_2^2 - a_1^2\right)^2}\left(q_0 e^{-ht}\right)^2$$

*B. Scenario 2: Supplier Overconfidence*

When the supplier has the characteristics of overconfidence, it often overestimates its effort effectiveness coefficient, and the expected quality of the final product in the supplier's mind will become

$$Q' = \left[a_1 e_1 + \left(a_2 + b\right)e_2\right]q_0 e^{-ht}$$

where $b$ is the degree of overconfidence of the supplier, The larger the $b$, the higher the supplier's estimation of the effect of their own preservation efforts. As above, the following game models are solved by inverse induction method:

$$\max_{w', e_1'} p_R = \left(p - w'\right)\left(a_1 e_1' + a_2 e_2'\right)q_0 e^{-ht} - \frac{1}{2}e_1'^2 \quad (6)$$

$$\text{s.t.} \max_{e_2'} p_R = w'\left(a_1 e_1' + \left(a_2 + b\right)e_2'\right)q_0 e^{-ht} - \frac{1}{2}e_2'^2 \quad (7)$$

Similarly, the Hessian matrix of equation (6) shows that there is an optimal solution. Therefore, it can be calculated that the profit sharing quota $w'^*$, The retailer's fresh keeping effort $e_1'^*$ and the supplier's fresh keeping effort $e_2'^*$ are respectively:

$$w'^* = \frac{a_2\left(a_2 + b\right) - a_1^2}{2a_2\left(a_2 + b\right) - a_1^2}p, \quad e_1'^* = \frac{a_1 a_2\left(a_2 + b\right)p}{2a_2\left(a_2 + b\right) - a_1^2}q_0 e^{-ht},$$

$$e_2'^* = \frac{\left(a_2 + b\right)\left[a_2\left(a_2 + b\right) - a_1^2\right]}{2a_2\left(a_2 + b\right) - a_1^2}pq_0 e^{-ht}$$

At this time, the final freshness of the product realized due to the overconfidence of the supplier is

$$Q'^* = \left(a_1 e_1 + a_2 e_2\right)q_0 e^{-ht} = \frac{a_2^2\left(a_2 + b\right)^2 p}{2a_2\left(a_2 + b\right) - a_1^2}\left(q_0 e^{-ht}\right)^2,$$

The ratio of bilateral efforts to keep fresh is

$$h'^* = \frac{e_1'^*}{e_2'^*} = \frac{a_1 a_2}{a_2\left(a_2 + b\right) - a_1^2}.$$

By substituting $w'^*$、$e_1'^*$、$e_2'^*$ into formula (1), (2), (3), we can get supplier's income, retailer's income and supply chain's overall income as follows:

$$p_s'^* = \frac{a_2^2\left(a_2 + b\right)^2\left(2a_2^2 + 2a_2 b - 3a_1^2\right)p^2}{2\left[a_2\left(a_2 + b\right) - a_1^2\right]^2}\left(q_0 e^{-ht}\right)^2$$

$$p_R'^* = \frac{a_2^2\left(a_2 + b\right)^2\left(2a_1^2 a_2^2 + 2a_1^2 a_2 b + a_2^4 - a_1^4 - a_2^2 b^2\right)p^2}{2\left[a_2\left(a_2 + b\right) - a_1^2\right]^2}\left(q_0 e^{-ht}\right)^2$$

$$p_{SC}'^* = \frac{a_2^2\left(a_2 + b\right)^2\left(2a_1^2 a_2 b + 3a_2^4 + 2a_2^3 b - a_2^2 b^2 - a_1^4 - a_1^2 a_2^2\right)p^2}{2\left[a_2\left(a_2 + b\right) - a_1^2\right]^2}\left(q_0 e^{-ht}\right)^2$$

## III. MODEL ANALYSIS

Comparing the results of scenarios 1 and 2, the following propositions can be obtained:

Proposition 1: when the supplier is overconfident, the profit sharing quota, the supplier's own efforts to keep fresh and the final freshness of the product will increase, while the proportion of the retailer's efforts to keep fresh and the supplier's efforts to keep fresh will decrease.

- Proof:

$$w'^* - w^* = \frac{ba_1^2 a_2 p}{\left(2a_2^2 - a_1^2\right)\left[2a_2\left(a_2 + b\right) - a_1^2\right]} > 0$$

$$e_1'^* - e_1^* = -\frac{ba_1^3 a_2 p}{\left(2a_2^2 - a_1^2\right)\left[2a_2\left(a_2 + b\right) - a_1^2\right]}q_0 e^{-ht} < 0$$

$$e_2'^* - e_2^* = \frac{b\left(a_1^4 - 2a_1^2 a_2^2 + 2a_2^4 - ba_1^2 a_2 + 2ba_2^3\right)p}{\left(2a_2^2 - a_1^2\right)\left[2a_2\left(a_2 + b\right) - a_1^2\right]}q_0 e^{-ht} > 0$$

$$h'^* - h^* = -\frac{ba_1^3 a_2}{\left(a_2 + b\right)\left(2a_2^2 - a_1^2\right)\left[2a_2\left(a_2 + b\right) - a_1^2\right]} < 0$$

$$Q'^* - Q^* = \frac{ba_1^4 a_2 p}{\left(2a_2^2 - a_1^2\right)\left[2a_2\left(a_2 + b\right) - a_1^2\right]}\left(q_0 e^{-ht}\right)^2 > 0$$

When the supplier is overconfident, it believes that the same efforts to keep fresh will get better results, so it will improve its own fresh keeping efforts. Because of the symmetry of information, the retailer also knows this information and that supplier will increase its investment in fresh keeping. Therefore, according to the free rider theory, retailers will reduce their investment to maximize their own profits. But at the same time, it will also increase the amount of profit distribution to ensure the supplier's profit. As a result, the proportion of suppliers' fresh-keeping efforts increased, and finally the fresh degree of fresh products also increased.

Proposition 2: when the supplier is overconfident, the amount of profit distribution, the supplier's fresh keeping effort, and the final freshness of products increase with respect to the degree of supplier's overconfidence, while the retailer's fresh keeping effort and the ratio of the retailer's effort decrease with respect to the degree of supplier's overconfidence.

- Proof:

$$\frac{\partial w'^{*}}{\partial b}=\frac{a_1^2 a_2 p}{\left[2a_2\left(a_2+b\right)-a_1^2\right]^2}>0$$

$$\frac{\partial e_1'^{*}}{\partial b}=-\frac{a_1^3 a_2 p}{\left[2a_2\left(a_2+b\right)-a_1^2\right]^2}q_0 e^{-ht}<0$$

$$\frac{\partial e_2'^{*}}{\partial b}=\frac{p}{2}q_0 e^{-ht}+\frac{a_1^4 p}{2\left[2a_2\left(a_2+b\right)-a_1^2\right]^2}q_0 e^{-ht}>0$$

$$\frac{\partial h'^{*}}{\partial b}=-\frac{a_1 a_2^2 p}{\left[2a_2\left(a_2+b\right)-a_1^2\right]^2}<0$$

$$\frac{\partial Q'^{*}}{\partial b}=\frac{2a_2^2\left(a_2+b\right)\left(a_2^2-a_1^2+a_2 b\right)p}{\left[2a_2\left(a_2+b\right)-a_1^2\right]^2}\left(q_0 e^{-ht}\right)^2>0$$

Proposition 2 reveals that the main variables of supply chain change with the degree of overconfidence of suppliers.

## IV. Example Simulation

The above mathematical derivation has proved the influence of the degree of supplier's overconfidence on the profit sharing quota, bilateral efforts and ratio of fresh keeping, and the final freshness of products. Due to the complexity of the income expression, it is not easy to directly compare it with the mathematical expression. The following is an example to study the effect of supplier overconfidence on the main body's and the whole supply chain's income. Assuming that the external market price $p=20$, the retailer's fresh keeping effort effect coefficient $a_1=3$, the supplier's fresh keeping effort effect coefficient $a_2=4$, the freshness of fresh products at the first output is $q_0=0.9$, decay rate of fresh products $h=0.005$, time $t\in\left[50,120\right]$. The simulation results are as follows:

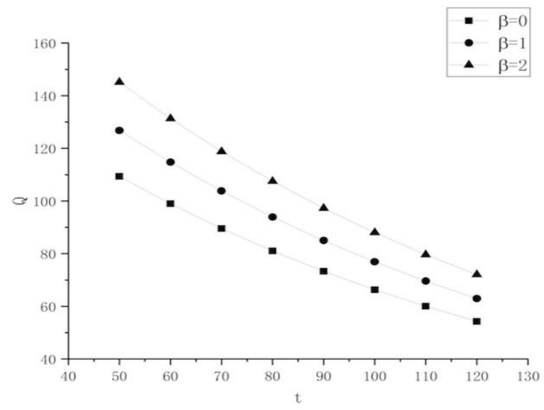


Fig. 1. Product freshness comparison.

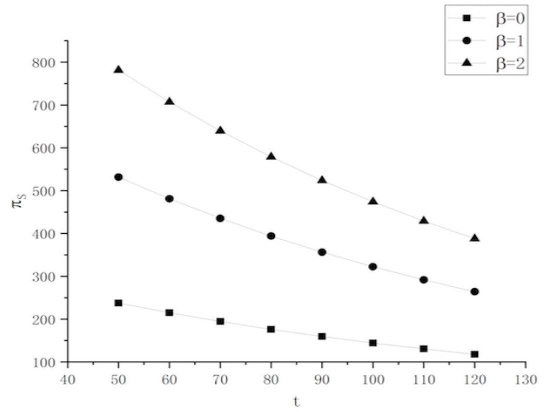


Fig. 2. Supplier revenue comparison.

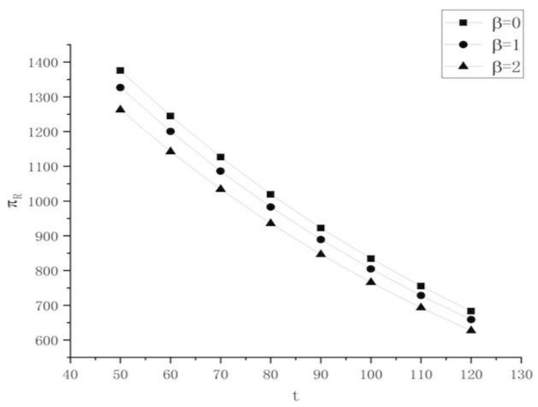


Fig. 3. Retailer revenue comparison.

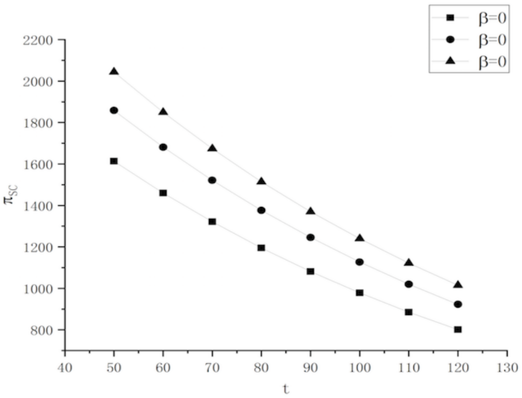


Fig. 4. Supply chain revenue comparison.

From "Fig. 1" to "Fig. 4", it is obvious that with the increase of time, the supplier and retailer's fresh keeping effort are gradually reduced, so the freshness of products is also reduced, and the overall income of supplier, retailer and supply chain are also decreased, which is consistent with the reality. It can be seen by comparing the results of different overconfidence levels of supplier, when the degree of supplier's overconfidence increases, it will damage the retailer's profit, but its own profit has increased, and the increase of its own profit is more than the decrease of the retailer's profit, so the overall profit of the supply chain increases. We can see that the existence of overconfidence is not always bad for the supply chain.

## V. CONCLUSION

In this paper, when we study the supply chain, we set the fresh supplier as the leader and retailer as the follower, and analyze the effect of overconfidence of the supplier on the operation of fresh product supply chain. The results show that: (1) the overconfidence of the supplier leads to the improvement of its effort to keep fresh, which also has a positive impact on its profit. The retailer's efforts to keep fresh will inevitably be reduced, and the joint effect of both sides will make the freshness of products higher than when the supplier is completely rational. (2) In the case of supplier’s overconfidence, the retailer will increase the amount of profit distribution, which will increase the profit of the supplier, and reduce the profit of the retailer. The overall income of supply chain is higher than that of the supplier completely rational under the influence of both sides, which shows that the existence of the supplier's overconfidence is not always unfavorable. In this paper, the influence of freshness and price on demand is not considered. Further research can be carried out around this.

## ACKNOWLEDGMENT

This paper was supported by the Jiangsu province postgraduate research and innovation project, 2018, project number: KYCX18_1328 and National Social Science Foundation of China (Grant No. 16BGL130) and Social Science Foundation of the Higher Education Institutions of Jiangsu Province, China (Grant No. 2017ZDIXM062).

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