Research on Decision and Coordination Model of Fresh Products Supply Chain with Quality and Price

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Abstract. With the adding emphasis on the fresh products quality, the competition among suppliers has been expanded from pure price competition to the competition of the quality and price of fresh products. By introducing the price impact coefficient and the influence coefficient of quality of two variables, this paper analyzes the game equilibrium of a supply chain respectively in the centralized, decentralized and coordination decision-making model. Through numerical analysis, the paper analyzes the retailers, manufacturers and the change of each decision variable value of the supply chain. The results indicate that the price of sales and the quality of fresh food are related to the variables in the three different decision-making model, and when the revenue sharing coefficient and cost coefficient are in a rational range, after revenue sharing cost sharing contract is coordinated, retailers must pay fixed costs to compensate for manufacturers. The whole supply chain profit is greater than the decentralized decision-making gains after the coordination.

Keywords. Price and quality competition, Supply chain decision-making and coordination.

1. Introduction

With the development of commodity economy, consumers not only take commodity price ratio into consideration, but also pursue the quality. Vegetables, fruits, flesh, aquatic products and processed products of bread, cooked food as well as other fresh food, such kind food has easy deteriorated, freshness time varying, and quality-demand influenced characteristics. Consumers pay more attention to the food quality when they compare the prices. Therefore, both the price and its own quality are considered in the sale process, during which is the dual competition of price and quality at the same time.

In recent years, many scholars have studied the impact of competitive factors such as price and quality on the profitability of supply chain and the coordination effect of shared contract in supply chain. Clements et al. [1] studied the characteristics of agricultural supply chains and analyzed their impact on supply chain procurement and quality. Cai et al. [2] hypothesized that the deterioration of fresh produce would reduce the number of products and reduce the quality of the product at the same time, and proposed a higher survival rate and quality through the fresh effort of the supplier to bring the fresh produce to the retailer's stock. The problem of optimization and coordination of supply chain of fresh agricultural products was studied. Saadany et al. [3] examines how to coordinate the number of orders to maximize the supply chain's local revenue and minimize the cost. Simatu et al. [4] argued that the goal of aligning all members of the supply chain and finally getting a supply chain overall goal is supply chain coordination.
Chen et al. [5] used empirical research to examine the impact of two factors on consumer choice on car brands and negotiated prices. Harish and Ralph [6] studied the importance of supply chain coordination in the supply chain consisting of a supplier and a retailer. El and Kim [7] studied the role of revenue sharing contracts and wholesale price contracts in supply chain quality management under horizontal competition.

It is necessary to research the decision and coordination model of the supply chain from the perspectives of prices and quality of fresh agricultural products. Former research can't satisfy the market need anymore. Proper assumption towards market need will contribute to deduce the profits of supply chain model. Finally, the improvement of model is verified by the theoretical deduction and data experiment.

2. Model Assumptions
Assuming a supply chain model consisting of the two retailers and a supplier, two retailers are faced with the same market, and when consumers choose retailers to purchase fresh food, they will consider fresh food sales prices and products quality. Assuming that retailers are able to keep up with the freshness of fresh food, thus they need to pay a certain product quality cost to retain freshness.

Thus, the following assumptions are made in this thesis: (1) as supply chain members, retailers’ and suppliers’ decisions based on the principle of maximum expected revenue are complete rational; (2) market demand is connected with sales price and product quality, there is price and quality competition between retailers, regardless of sales marketing strategy, the market demand is the linear demand; (3) freshness preservation quality marginal cost function is the strict convex function increasing with the freshness of the quality, which has the second derivative.

3. Model Establishment and Solution
Market demand is D, retailers’ sales price is Pᵢ, quality effort level is Qᵢ, cost of agriculture production is C. The retailer’s cost of product quality is Cᵢ = \frac{1}{2}aQᵢ (α > 1), α is retail quality effort coefficient. Two retailers’ demand is expressed as

\begin{align*}
D₁ &= D - Pᵢ + βP₂ + Qᵢ - γQ₂, \\
D₂ &= D - Pᵢ + βP₁ + Q₂ - γQ₁,
\end{align*}

for which the impact coefficient of fresh food prices is β (0 < β < 1), for the product quality impact coefficient is γ (0 < γ < 1), if P₁ = P₂ = 0, D₁ = D₂ = D.

3.1. Centralized Decision Model
In the supply chain centralized decision-making model, retailers and suppliers do not consider their own interests, and aim to maximize overall interests of the supply chain, the supply chain revenue is:

\[\Pi_c = (D - P₁ + βP₂ + Q₁ - γQ₂)(P₁ - C) + (D - P₂ + βP₁ + Q₂ - γQ₁)(P₂ - C) - \frac{1}{2}α(Q₁^2 + Q₂^2)\]  \hspace{1cm} (1)

Two retailers and the supplier, as members of supply chain, maximized supply chain revenue, make variables Pᵢ and Qᵢ the first-order-partial-derivative to zero, it follows:

\[Pᵢ^c = P₂^c = \frac{Dα + C[(1-β)α - (1-γ)γ]}{2α(1-β) - (1-γ)γ}\]

and

\[Q₁^c = Q₂^c = \frac{(1-γ)[D - C(1-β)]}{2α(1-β) - (1-γ)γ}\]
Variables $P_i$ and $Q_i$ is the unique optimal solution of equation (1). Due to the actual meaning of supply chain, the optimal profit in the centralized decision model of supply chain can be deduced:

$$\Pi^C = \frac{a[D-(1-\beta)C]}{2a(1-\beta)-(1-\gamma)}.$$  

3.2. Decentralized Decision Model

In the supply chain decentralized decision model, both retailers and suppliers consider to maximize their own interests exclusively, regardless of the overall and the other interests, the game theory can be obtained in the order of decision: the supplier set out fresh food wholesale price, the two retailers then make the optimal product sales price and the optimal product quality decision based on the price of wholesale, and finally the supplier makes the final wholesale price decision on this basis. This game model belongs to the Stackelberg game, supplier is the game leader, two retailers are partners, and the inverse induction method can be used to find the equilibrium solution. So the interests of the two retailers and suppliers are:

$$\begin{align*}
\Pi_{R1}^D &= (P_1 - \omega)(D - P_1 + \beta P_2 + Q_1 - \gamma Q_1) - \frac{1}{2} a Q_1^2 \\
\Pi_{R2}^D &= (P_2 - \omega)(D - P_2 + \beta P_1 + Q_2 - \gamma Q_2) - \frac{1}{2} a Q_2^2 \\
\Pi_C^D &= (\omega - C)\left[(D - P_1 + \beta P_2 + Q_1 - \gamma Q_1) + (D - P_2 + \beta P_1 + Q_2 - \gamma Q_2)\right]
\end{align*}$$

$\omega$ refers to the wholesale price of the supplier. As retailers maximize their own interests, take the first-order-derivative of $\Pi_{Ri}^D$ equals to zero with the respect of $P_i, Q_i$, it follows:

$$\begin{align*}
P_i^* &= P_i^{o^D} = \frac{D \alpha + \omega (\alpha + \gamma - 1)}{(2-\beta) \alpha - (1-\gamma)} \\
Q_i^* &= Q_i^{o^D} = \frac{D - \omega (1-\beta)}{(2-\beta) \alpha - (1-\gamma)}
\end{align*}$$

The optimal benefits of retailer, supplier and supply chain are:

$$\begin{align*}
\Pi_{Ri}^{o^*} &= \frac{\alpha (2\alpha - 1) \left[D - C (1-\beta)\right]^{2}}{8(2-\beta) \alpha - (1-\gamma)^{2}} \\
\Pi_S^{o^*} &= \frac{\alpha \left[D - C (1-\beta)\right]^{2}}{2(1-\beta) (2-\beta) \alpha - (1-\gamma)^{2}} \\
\Pi_C^{o^*} &= \frac{\alpha \left[D - C (1-\beta)\right]^{2} \left[2\alpha (3-2\beta) - 3 + 2\gamma + \beta\right]}{4(1-\beta) (2-\beta) \alpha - (1-\gamma)^{2}}
\end{align*}$$

3.3. Coordinated Decision Model

In the decentralized-decision-making model, under the influence of the "double marginal" effect, the decision-making model can’t be consistent with the centralized-decision-making model, so that the optimal income cannot reach the optimal level of centralized decision-making model. Given that retailers increase sales and product quality, suppliers reduce their wholesale prices, while to compensate for the lower wholesale prices and higher product quality brought about by the loss of the interests of the supply
chain members, the income sharing contract can be adopted, that is, retailers transfer the portion of the income to the supplier (revenue sharing factor η), and the cost (supply quality effort coefficient λ) of the supplier to increase the quality of the fresh produce to increase sales. At this point the retailers and suppliers of their respective interests are:

\[
\begin{aligned}
\Pi_{i1}^r &= (\eta P_i - \omega)D_i - \frac{1}{2} \theta \sigma Q_i^r \\
\Pi_{i2}^r &= (\eta P_i - \omega)D_i - \frac{1}{2} \theta \sigma Q_i^s
\end{aligned}
\]

\[
\Pi_i = \left[ (1-\eta) P_i + \omega - C \right] D_i + \left[ (1-\eta) P_i + \omega - C \right] D_i - \frac{1}{2} (1-\theta) \alpha (Q_i^r + Q_i^s)
\]

Make the first-order-partial-derivative in regard to of the equation (2) and make it to zero, then it follows:

\[
\begin{aligned}
P_i^r &= P_i^s = \frac{D \gamma \alpha + \omega (\theta \alpha + \eta \gamma - \eta)}{2 \eta \theta (2-\beta) \alpha - \eta (1-\gamma)} \\
Q_i^r &= Q_i^s = \frac{\theta D + \beta \omega - \omega}{2 \theta (2-\beta) \alpha - \eta (1-\gamma)}
\end{aligned}
\]

By calculating the Hessian matrix composed of second partial derivative of the equation (2) with respect to P, Q, the result is \( \Delta_1 = -2\eta \theta < 0 \) and \( \Delta_2 = 2\eta \beta \theta - \eta \gamma^2 > 0 \), which \( \Delta_1, \Delta_2 \) is first and second order principle minor determinant of Hessian matrix, the negative definite matrix, \( \Pi_i \) is a strictly concave function of \( P_i, Q_i \).

In the case of a, let the profit of coordinated-decision-making model equals to that of the centralized-decision-making model, it must meet the following: \( P_i^c = P_i^r = P_i^s, Q_i^r = Q_i^s = Q_i^c \), and it follows:

\[
\theta = \frac{(1-\beta)}{(1-\gamma)} \eta, \quad \omega^f = \eta \left[ C + \alpha \beta (D + C \beta - C) - (1-\beta) \right], \quad \text{so as to get the best interests of retailers and suppliers}
\]

above, we have discussed the comparison between optimal sales price decision and the optimal quality effort under different decision-making. To demonstrate the validity of the supply chain model, the following is an example.

4. Numerical Calculation and Result Analysis

Through the numerical analysis, this paper discusses the impact of the price influence coefficient \( \beta \) and the product quality influence coefficient \( \gamma \) on the sales price, the level of quality effort and the benefits of the supply chain members. At the same time, it also discusses the influence of the revenue sharing coefficient \( \eta \) on the benefits of the supply chain members. Assuming the cost of fresh food to be \( C=20 \) etai quality effort coefficient to be \( \alpha = 2.5 \), market demand to be \( D=25 \).
(1) Through the price influence coefficient is continuously uniformly varying, the comparison of the optimal selling price, the best quality and the overall interests of the optimal effort level are studied under centralized-decision-making and decentralized-decision-making model, and the analysis results are shown in figure 1.

As shown in the figure, when the product quality influence coefficient $\gamma = 0.5$ is fixed, the optimal value of the selling price, the fresh food quality and the whole income of supply chain add as product price influence coefficient $\beta$ increases under the centralized-decision-model or the decentralized-decision-model. The retailer's selling price in centralized-decision-model is lower than the retailer's selling price under the decentralized decision-making model, and figure 1a illustrates the above analysis. The optimal value of fresh food quality, especially the concentration of product quality under centralized-decision-making model, is more pronounced, and figure 2b also validates the analysis. Figure 2c shows that the overall benefit of supply chain in the focus-decision-making model is greater than the supply chain revenue under the unfocus-decision-making model.

(2) Through product quality influence coefficient is continuously uniformly varying, the optimal selling price, the optimal quality effort level and the overall optimal benefits are compared under the centralized-decision-making model and decentralized-decision-making model. The analysis results are shown in figure 2.

As shown in the figure, when the price influence coefficient $\beta = 0.2$ is fixed, the optimal value of the selling price, the fresh food quality and the whole income of supply chain decrease as the product quality
influence coefficient increases under the centralized-decision-making model or the decentralized-decision-making model. Product quality reduction is more obvious under the centralized decision-making model.

If \( 0 < \beta < \min \left\{ 1, \sqrt{\frac{(1-\gamma)(\alpha+\gamma-1)}{2\alpha}} \right\} \), the retailer’s sales price under the centralized decision-making model was lower than the retailer’s selling price under the decentralized decision-making model, and figure 2a illustrates the above analysis. If \( \beta = \frac{(1-\gamma)^2 + 2\alpha(\gamma-1)}{2\alpha\gamma} \), the product quality level under the centralized decision-making model is equal to the product quality level under the decentralized decision-making model, where there is a critical point, and figure 2b also validates the analysis. Figure 2c shows that the overall benefit of supply chain in the focus-decision-making model is greater than supply chain revenue under the unfocus-decision-making model.

(3) Set the product quality influence coefficient to be \( \gamma = 0.5 \), through income sharing coefficient is continuously uniformly varying, the comparison of the benefits of decentralized decision-making and the benefits of comparative decision-making are studied, and the analysis results shown in figure 3.

Figure 3a shows that the retailer is greater than that of the decentralized decision model when the revenue sharing coefficient changes, and the profitability of the supplier is smaller than that of the decentralized decision model with the increase of the revenue sharing coefficient. If \( \Pi_{R1}^x = \Pi_{R2}^x = 20.16 \times \eta \), \( \Pi_{S}^x = 54 - 40.32 \times \eta \), revenue critical point is \( \eta = 0.5545 \), if \( \eta < 0.5545 \), supplier revenue by coordination is more profitable than that of decentralized decision-making model. If \( \eta > 0.5545 \), the compensation should be used, that is, the retailer pays a fixed fee to the supplier showed in the shadow part of figure 3. The shaded portion of figure 3a corresponds to its upper limit, and the shaded portion of figure 3b corresponds to its lower limit.

![Figure 3. Effect of revenue sharing coefficient on income before and after coordination.](image)

5. Conclusion

(1) Introduce the price impact coefficient and product quality impact coefficient, construct supply chain dynamic game model under different decision-making conditions; (2) Analyze the relevant decision-making questions about the optimal pricing of retailers and the optimal product quality and the overall income of the supply chain; (3) Changes of the price impact coefficient, product quality impact coefficient within a reasonable range is the decision variable changes and the validity of the contract.

The results show that: 1) the overall revenue of the supply chain is larger than that of the decentralized decision-making model under the centralized decision-making model; 2) the sales price and the product quality are related to the size and price influence coefficient and the product quality influence coefficient
under the centralized-decision-making model and decentralized-decision-making model; 3) through the coordination of revenue sharing cost sharing contract, the retailer and supplier gain the revenues when revenue sharing factor is in reasonable range. When the revenue sharing factor goes out of range, the retailer must compensate the supplier, that is, to pay a fixed fee. The scope of this fee is related to the revenue sharing factor, and the revenue sharing factor is related to the price impact coefficient and the product quality impact coefficient.

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