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Retail Enterprise Corporate Social Responsibility and Freshness Preservation in Fresh Agricultural Products Supply Chains

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Abstract: A fresh agricultural products supply chain composed of a manufacturing enterprise (ME), a retail enterprise (RE), and a logistics company (LC) is considered. When logistics freshness-preservation effort affects both the RE's pricing decision and the market value of fresh agricultural products, Stackelberg game models are developed for two scenarios: one in which the RE does not implement Corporate Social Responsibility (CSR), and another in which the RE implements CSR. The equilibrium changes in wholesale price, order quantity, freshness-preservation effort, and member profits are then analyzed. The results show that, after the RE implements CSR, a higher degree of CSR engagement promotes increases in order quantity and logistics freshness-preservation effort, thereby improving consumer surplus. Meanwhile, CSR implementation increases the profits of the ME and the LC, but reduces the RE's pure economic profit. Furthermore, when consumer surplus is incorporated into the RE's objective function, the RE's Corporate Social Responsibility-oriented payoff increases with the degree of CSR engagement, and the overall payoff of the supply chain is also improved. These findings indicate that moderate CSR implementation helps enhance the operational performance of the fresh agricultural products supply chain, while the RE should maintain a reasonable balance among economic profit, consumer welfare, and preservation investment.

Keywords: Fresh Agricultural Products Supply Chain; Corporate Social Responsibility; Freshness-preservation Effort; Stackelberg Game; Consumer Surplus.

1. Introduction

Fresh agricultural products are characterized by perishability, high preservation requirements, and strong timeliness in circulation. Their market value is jointly affected by production supply, retail ordering decisions, and logistics freshness-preservation effort. With the development of cold-chain logistics and fresh retail formats, consumers have placed higher demands on product freshness, quality stability, and consumption experience. Consequently, the operational objective of fresh agricultural products supply chains has gradually extended from single economic-profit maximization to consumer welfare and comprehensive supply chain payoff. Therefore, how to form reasonable decisions on wholesale price, order quantity, and freshness-preservation effort has become an important issue in fresh agricultural products supply chain management.

Existing studies on fresh agricultural products supply chains mainly focus on logistics preservation, product loss, and supply chain operational decisions. [1] considered quantity loss during transportation and quality loss in the retail process, and studied pricing, coordination, and loss-control decisions in a fresh agricultural products supply chain under strategic consumers. Related studies suggest that logistics freshness-preservation effort is an important factor affecting the operational performance of fresh agricultural products supply chains. However, most existing analyses concentrate on economic returns and loss control, leaving room for further discussion on how consumer surplus changes after the RE implements CSR(Corporate Social Responsibility).

Meanwhile, corporate social responsibility has gradually become an important topic in supply chain decision-making research. Recent studies usually understand CSR as a firm's concern for consumer welfare, social welfare, or overall supply chain performance in addition to pursuing its own profit. [2] introduced consumer welfare into a socially responsible distribution system and analyzed the effects of CSR behavior on supply chain coordination and profit allocation. [3] studied CSR decision-making in supply chains from the perspective of external policy factors, showing that CSR behavior affects pricing and revenue distribution among supply chain members. [4] further indicated that CSR and fairness concerns may increase consumer surplus, retailer profit, and system profit, but may also harm the dominant firm's payoff. Thus, CSR is not merely a moral expression; it is an important factor that changes supply chain members' decision objectives and profit structures.

From the perspective of consumer surplus, the RE occupies a key position connecting the production side and the consumption side. Its CSR behavior is more likely to affect consumer welfare through price, order quantity, and service level. [5] incorporated consumer surplus into the supply chain CSR analytical framework and compared the effects of CSR implementation by different members, pointing out that retailers, because they are closer to the consumer market, have certain advantages in implementing CSR and improving consumer surplus and social welfare. [6] also noted that firms in a supply chain may simultaneously pursue profit and consumer surplus, and that such a dual-purpose objective affects the retailer's product introduction and quality strategies. These studies provide a theoretical basis for characterizing RE Corporate Social Responsibility from the perspective of consumer surplus in this paper.

Based on the above, this study introduces consumer surplus to characterize RE Corporate Social Responsibility in a fresh

agricultural products supply chain composed of a manufacturing enterprise, a retail enterprise, and a logistics enterprise. It analyzes the influence mechanism of CSR on wholesale price, order quantity, freshness-preservation effort, and member payoffs, with the aim of providing references for fresh agricultural products the RE to implement CSR reasonably and optimize logistics preservation investment.

2. Problem Description and Model Assumptions

2.1. Problem Description

This paper considers a three-tier supply chain composed of a large fresh agricultural manufacturing enterprise, a retail enterprise, and a logistics company, and analyzes the operational decisions and payoff changes of all members within a single selling cycle. Information is assumed to be symmetric, and all three types of firms are risk-neutral and rational decision makers. The ME is located upstream in the supply chain and has the first-mover pricing right. It first determines the wholesale price w of fresh agricultural products. The RE then determines the order quantity Q according to the wholesale price and market demand. The LC determines the freshness-preservation effort level K according to the RE's service requirements and provides transportation and preservation services.

Before the selling cycle begins, the ME and the RE sign a procurement contract. The ME determines the wholesale price w according to cost conditions and payoff objectives, and the RE determines the order quantity Q accordingly and purchases logistics preservation services from the LC. After the ME completes supply, the LC carries out transportation, refrigeration, and quality maintenance according to the agreed freshness-preservation effort level K, and finally delivers the products to the sales terminal or consumers. After the selling season ends, the RE obtains sales revenue and makes corresponding payments to the ME and the LC.

Whether the RE incorporates consumer surplus into its objective function is used as the criterion for CSR implementation. The supply chain structure is shown in Figure 1.

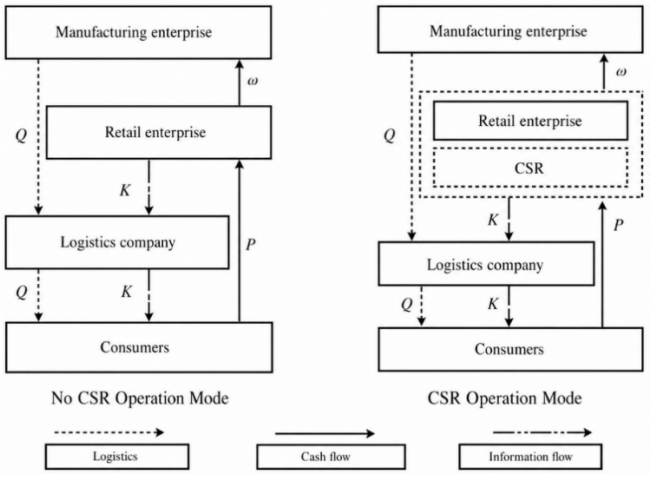

Figure 1. Structure of the fresh agricultural products supply chain system

2.2. Basic Assumptions and Notations

Before constructing the decision model of the fresh agricultural products supply chain, the following basic assumptions and notations are introduced.

(1) The production cost of the ME is $C(Q) = CQ$, where Q is the order quantity of fresh agricultural products, C is the unit input cost, and $C > 0$.

(2) The RE does not separately consider other operating costs, and its decision objective depends on whether it implements CSR. Without CSR, the RE aims only to maximize its own economic profit. With CSR, the RE incorporates consumer surplus into its objective function, thereby forming a decision objective that balances economic profit and consumer welfare.

(3)Consumer surplus, denoted by SR, is used to measure the net welfare obtained by consumers from purchasing fresh agricultural products. Let θ represent the degree of CSR engagement of the RE, where $0<\theta<1$. A larger value of θ indicates that the RE places greater emphasis on consumer welfare in its operational decisions. Accordingly, θSR represents the level of consumer surplus incorporated into the RE's objective function, reflecting the extent to which the RE fulfills its corporate social responsibility.

$$SR = \int_0^Q [(a-bx+tk)-(a-bQ+tk)] = \frac{1}{2}bQ^2$$

where b ($b>0$) denotes the sensitivity of market demand to the retail price.

(4) Improving the level of logistics preservation services usually requires more equipment, technology, and managerial resources. Therefore, logistics service cost is assumed to be related to the freshness-preservation effort level K and to follow a quadratic increasing form, namely

$$C(K) = \frac{1}{2}\lambda K^2$$

where K denotes the LC's freshness-preservation effort level, and λ denotes the preservation effort cost coefficient. A larger λ indicates a higher marginal cost for the LC to improve its freshness-preservation effort. Let μ denote the unit charge coefficient for logistics service level; then $K\mu$ represents the logistics service fee per unit of fresh agricultural products. Similar assumptions can be found in Yu (2017).

Assume that the retail price function of fresh agricultural products is $P=a-bQ+tK$. Here, a ($a>0$) denotes the choke price, namely the price level above which consumers no longer purchase the product. The parameter t ($t>0$) denotes the coefficient measuring the effect of freshness-preservation effort on retail price and market value.

The main variables and their meanings are shown in Table 1.

Table 1. Notation

Variable	Meaning
w	Wholesale price of fresh agricultural products
Q	RE's order quantity
K	LC's freshness-preservation effort level
π^m	Profit of ME
π^r	Profit of RE
π^l	Profit of LC
π_{sr}	RE's Corporate Social Responsibility-oriented objective payoff

Note: Subscript N denotes the scenario without CSR, subscript C denotes the scenario with CSR, and superscript * denotes the equilibrium optimal value.

3. Model Construction and Analysis

3.1. No-CSR Scenario

In the No-CSR scenario, the ME, the RE, and the LC all make independent decisions with the objective of maximizing their own profits. The ME first determines the wholesale price w of fresh agricultural products, the RE then determines the order quantity Q, and the LC further chooses the freshness-preservation effort level K. This forms a three-tier Stackelberg game structure. At this time, the ME's profit consists of sales revenue minus production cost, and its profit function is as follows:

$$\pi_N^m=wQ-CQ$$

The RE's profit consists of product sales revenue minus procurement cost and logistics service cost, and its profit function is as follows:

$$\pi_N^r=PQ-wQ-K\mu Q$$

The LC's profit consists of logistics service revenue minus preservation effort cost, and its profit function is as follows:

$$\pi_N^l=K\mu q-\frac{1}{2}\lambda K^2$$

Based on the above game relationship, the supply chain decision model in the No-CSR scenario can be expressed as

$$\max_w(\pi_N^m)=wQ-CQ$$
$$s.t.\begin{cases}\max_K(\pi_N^r)=PQ-wQ-K\mu Q\\ \max_K(\pi_N^l)=K\mu q-\frac{1}{2}\lambda K^2\end{cases}$$

Solving the above model by backward induction yields the following result.

Theorem 1. In the No-CSR scenario, when $t<\frac{b\lambda+\mu^2}{\mu}$, all supply chain members can obtain non-negative profits, and the equilibrium decisions are as follows:

(1) The equilibrium values of the wholesale price of fresh agricultural products, the RE's order quantity, and the LC's freshness-preservation effort level are respectively:

$$w_N^*=\frac{a+C}{2},$$
$$Q_N^*=\frac{\lambda(a-C)}{4(b\lambda+\mu^2-\mu t)},K_N^*=\frac{\mu(a-C)}{4(b\lambda+\mu^2-\mu t)},SR_N^*=\frac{b\lambda^2(a-C)^2}{32(b\lambda+\mu^2-\mu t)^2}.$$

(2) The equilibrium profits of the ME, the RE, and the LC are respectively:

$$\pi_N^{m*}=\frac{\lambda(a-C)^2}{8(b\lambda+\mu^2-\mu t)},\pi_N^{r*}=\frac{\lambda(a-C)^2}{16(b\lambda+\mu^2-\mu t)},\pi_N^{l*}=\frac{\lambda\mu^2(a-C)^2}{32(b\lambda+\mu^2-\mu t)^2}.$$

3.2. CSR Scenario

In the CSR scenario, the ME still makes decisions with the objective of maximizing its own economic profit. The RE, however, no longer pursues only pure economic profit maximization, but incorporates consumer surplus into its objective function and makes decisions according to the maximization of CSR-oriented objective payoff. At this time, the ME's profit function is as follows:

$$\pi_C^m=wQ-CQ$$

The RE's pure economic profit consists of product sales revenue minus procurement cost and logistics service cost, and its function is as follows:

$$\pi_C^r=PQ-wQ-K\mu Q$$

The RE's Corporate Social Responsibility-oriented objective payoff consists of pure economic profit and a weighted consumer-surplus term, and its function is as follows:

$$\pi_{sr}=\pi_C^r+\theta SR$$

$$SR=\frac{1}{2}bQ^2$$

The LC's profit consists of logistics service revenue minus preservation effort cost, and its function is as follows:

$$\pi_C^l=K\mu q-\frac{1}{2}\lambda K^2$$

Based on the above game relationship, the supply chain decision model in the RE Corporate Social Responsibility scenario can be expressed as

$$\max_w(\pi_C^m)=wQ-CQ$$
$$s.t.\begin{cases}\max_Q(\pi_{sr})=PQ-wQ-K\mu Q+\theta SR\\ \max_K(\pi_C^l)=K\mu q-\frac{1}{2}\lambda K^2\end{cases}$$

Solving the above model by backward induction yields the following result.

Theorem 2. In the RE Corporate Social Responsibility scenario, when $t<\frac{(2-\theta)b\lambda+2\mu^2}{2\mu}$, all supply chain members can obtain non-negative profits, and the equilibrium decisions are as follows:

(1) The equilibrium values of the wholesale price of fresh agricultural products, the RE's order quantity, and the LC's freshness-preservation effort level are respectively:

$$w_C^*=\frac{a+C}{2}$$
$$Q_C^*=\frac{\lambda(a-C)}{2((2-\theta)b\lambda+2\mu^2-2\mu t)},K_C^*=\frac{\mu(a-C)}{2((2-\theta)b\lambda+2\mu^2-2\mu t)},SR_C^*=\frac{b\lambda^2(a-C)^2}{8((2-\theta)b\lambda+2\mu^2-2\mu t)^2}.$$

(2) The equilibrium profits of the ME, the RE, and the LC are respectively:

$$\pi_C^{m*}=\frac{\lambda(a-C)^2}{4((2-\theta)b\lambda+2\mu^2-2\mu t)},\pi_{sr}^*=\frac{\lambda(a-C)^2}{8((2-\theta)b\lambda+2\mu^2-2\mu t)},\pi_C^{l*}=\frac{\lambda\mu^2(a-C)^2}{8((2-\theta)b\lambda+2\mu^2-2\mu t)^2}.$$

(3) The RE's pure economic profit is:

$$\pi_C^{r*}=\frac{\lambda(a-C)^2(b\lambda+\mu^2-\mu t-\theta b\lambda)}{4((2-\theta)b\lambda+2\mu^2-2\mu t)^2}.$$

4. Scenario Comparison

By comparing the equilibrium results in the No-CSR and CSR scenarios, the following propositions can be obtained.

Proposition 1. A higher degree of CSR engagement leads to increases in both the order quantity and the freshness-preservation effort level, namely

$$\frac{\partial Q_C^*}{\partial\theta}>0,\frac{\partial K_C^*}{\partial\theta}>0.$$

Proposition 1 indicates that, in the RE Corporate Social Responsibility scenario, a higher degree of CSR engagement leads to higher optimal order quantity and logistics freshness-preservation effort. This suggests that CSR is not merely a soft constraint related to corporate image, but affects actual supply chain operations through the RE's ordering decision. As the degree of CSR engagement increases, the RE pays more attention to consumer welfare and market supply, and therefore tends to expand order quantity and encourage the LC to improve its freshness-preservation effort level.

Proposition 2. RE CSR implementation can improve consumer surplus, namely

$$SR_C^*>SR_N^*,\frac{\partial SR_C^*}{\partial\theta}>0.$$

Proposition 2 indicates that, compared with the No-CSR scenario, RE Corporate Social Responsibility implementation

can significantly improve consumer surplus, and consumer surplus increases with the degree of CSR engagement. This suggests that CSR behavior improves consumer welfare by expanding order quantity and enhancing freshness-preservation effort, reflecting the welfare-enhancing effect of the RE CSR implementation.

Proposition 3. RE Corporate Social Responsibility implementation can increase the profits of the ME and the LC, but reduces the RE's pure economic profit, namely

$$\pi_C^{m*} > \pi_N^{m*}, \pi_C^{l*} > \pi_N^{l*}, \pi_C^{r*}, \pi_C^{r*} < \pi_N^{r*}.$$

Proposition 3 indicates that, after the RE implements CSR, the equilibrium profits of the ME and the LC increase, whereas the RE's pure economic profit decreases. The reason is that the CSR orientation prompts the RE to expand order scale and increase market supply, thereby increasing the payoffs of the upstream ME and the LC. However, the RE needs to give up part of its economic profit in the process of improving consumer welfare, and its pure economic profit is therefore compressed.

Proposition 4. The RE's Corporate Social Responsibility-oriented objective payoff increases with the degree of CSR engagement, namely

$$\frac{\partial \pi_{sr}^*}{\partial \theta} > 0$$

Proposition 4 indicates that although CSR implementation compresses the RE's pure economic profit, once consumer surplus is incorporated into its objective function, the RE's Corporate Social Responsibility-oriented objective payoff increases with the degree of CSR engagement. This suggests that CSR behavior should not be evaluated only from the perspective of short-term economic profit, but should be judged from the perspective of comprehensive payoff after the firm's objective function is expanded.

Proposition 5. RE Corporate Social Responsibility implementation can improve the comprehensive payoff of the supply chain; from the perspective of pure economic profit, the magnitude of economic-profit improvement first increases and then decreases with θ, namely

$$\pi_C^* > \pi_N^*;$$

$$\text{when } \theta < \overline{\theta}, \pi_{sr}^* > \pi_N^*;$$

$$\text{when } \theta > \overline{\theta}, \pi_{sr}^* < \pi_N^*.$$

$$\overline{\theta} = \frac{4(b\lambda+\mu^2-\mu t)[2(b\lambda+\mu^2-\mu t)+\mu^2]}{b\lambda[6(b\lambda+\mu^2-\mu t)+\mu^2]}.$$

Proposition 5 indicates that, from the perspective of comprehensive supply chain payoff, the RE Corporate Social Responsibility implementation can improve system-level operational outcomes, suggesting that CSR behavior helps enhance the overall performance of the fresh agricultural products supply chain. However, from the perspective of pure economic profit, the economic benefit brought by CSR has boundaries. When the degree of CSR engagement is relatively low, the RE can maintain good economic performance while considering consumer welfare. When the degree of CSR engagement exceeds a certain level, the consumer-welfare orientation may expand the RE's profit concession, causing its ordering decision to deviate from the objective of pure economic-profit maximization and thereby compressing the economic profit space.

5. Numerical Simulation Analysis

To further verify the above propositions, this paper examines the effects of the degree of CSR engagement θ on equilibrium decisions and member payoffs under different values of the price-impact coefficient of freshness-preservation effort t. The numerical simulation results are as follows. For convenience, the parameters are set as shown in Table 2.

Table 2. System Parameter Assignment

a	C	b	λ	μ	t
10	2	1	3	1	0.8

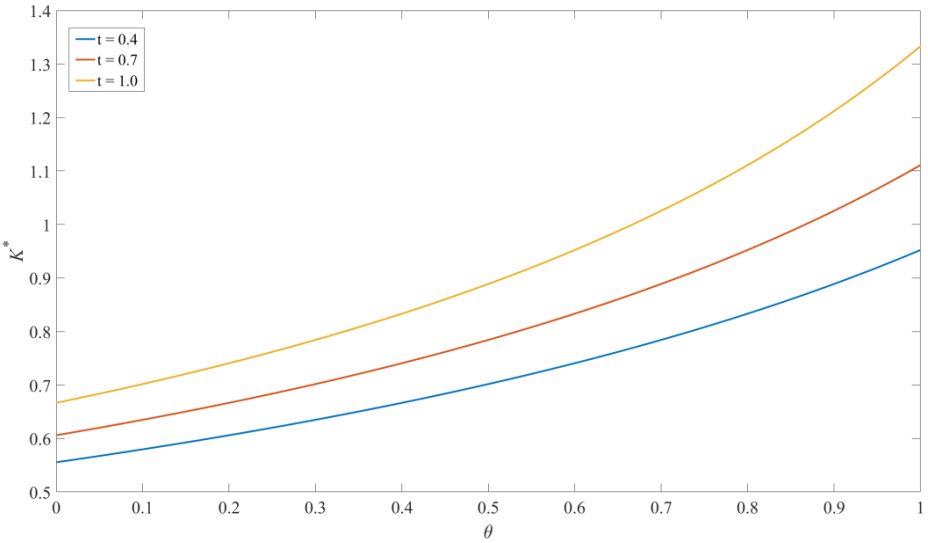

Figure 2. Effect of the degree of CSR engagement on optimal freshness-preservation effort under different price-impact coefficients of preservation effort

Figures 2 and 3 show that, under different values of the price-impact coefficient of freshness-preservation effort t, both the optimal freshness-preservation effort K^* and the optimal order quantity Q^* exhibit a continuously increasing trend as the RE's degree of CSR engagement θ rises. Moreover, the larger t is, the higher the overall curve level and the more pronounced the growth. This indicates that, when freshness-preservation effort can be more effectively converted into retail price and market value, RE Corporate Social Responsibility implementation further strengthens the motivation to expand order quantity and improve preservation service level, thereby promoting simultaneous increases in

logistics preservation investment and market supply.

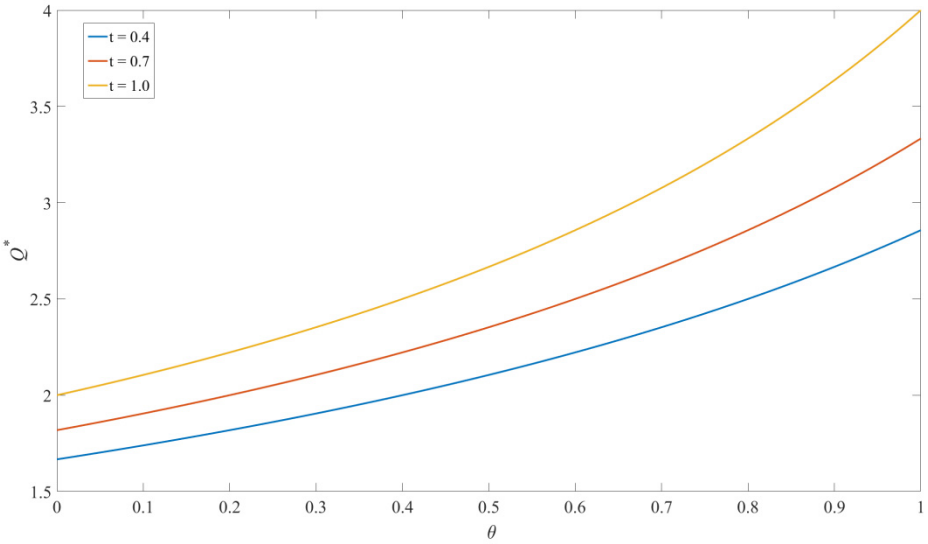

Figure 3. Effect of the degree of CSR engagement on order quantity under different price-impact coefficients of preservation effort

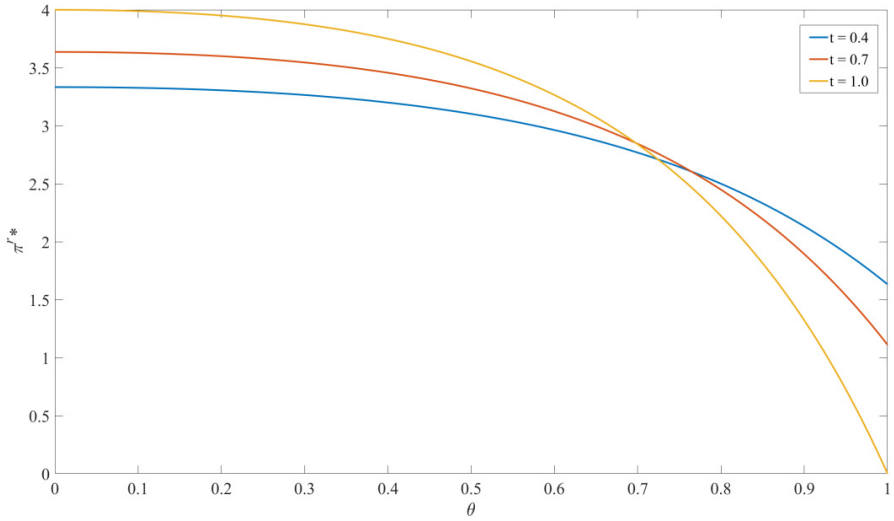

Figure 4. Effect of the degree of CSR engagement on the RE's pure economic profit under different price-impact coefficients of preservation effort

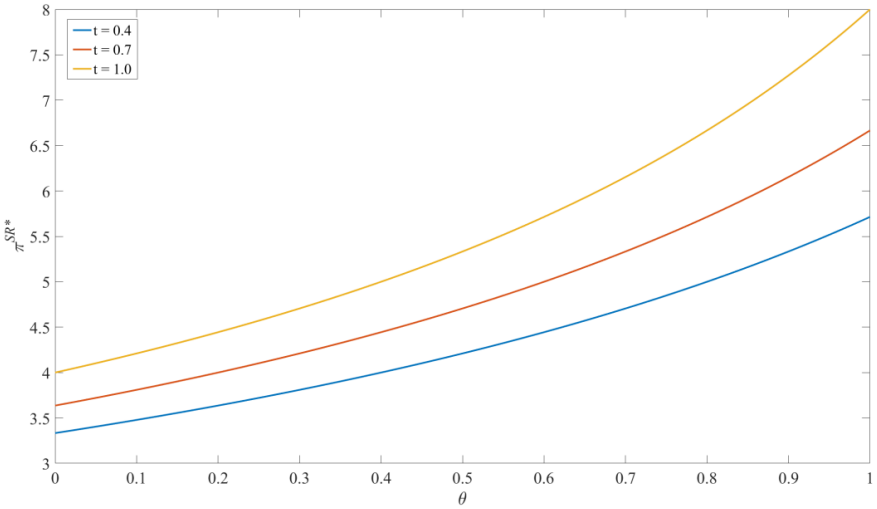

Figure 5. Effect of the degree of CSR engagement on the RE's Corporate Social Responsibility-oriented objective payoff under different price-impact coefficients of preservation effort

Figures 4 and 5 show clear differences in how the RE's pure economic profit and CSR-oriented objective payoff change with θ. Figure 4 shows that the RE's pure economic profit continuously decreases as θ increases, and the decline becomes more pronounced when t is larger, indicating that CSR implementation leads the RE to transfer more payoff to the improvement of consumer welfare. Figure 5 shows that, after consumer surplus is incorporated into the objective

function, the RE's Corporate Social Responsibility-oriented objective payoff continuously increases with θ, and a higher t further raises the level of the objective payoff. Therefore, CSR has a dual effect on the RE: from the perspective of pure economic profit, CSR causes certain profit compression; from the perspective of the objective payoff including consumer surplus, CSR improves comprehensive objective performance.

6. Conclusion

This paper constructs a Stackelberg game model for a fresh agricultural products supply chain composed of a ME, a RE, and an LC, centering on whether the RE incorporates consumer surplus into its decision objective. It then compares the equilibrium decisions and member payoffs under the two scenarios. The results show that, after the RE implements CSR, a higher degree of CSR engagement increases order quantity and logistics freshness-preservation effort, and consumer surplus is also improved. This result indicates that CSR is not limited to corporate image, but affects actual supply chain operations through ordering decisions and preservation investment.

Furthermore, RE Corporate Social Responsibility implementation can increase the profits of the ME and the LC, but reduces the RE's pure economic profit. Once consumer surplus is incorporated into the RE's objective function, its CSR-oriented objective payoff increases with the degree of CSR engagement. Meanwhile, CSR can improve the comprehensive payoff of the supply chain, although the improvement in pure economic profit has certain boundaries. Therefore, when implementing CSR, the RE should avoid pursuing welfare maximization alone while ignoring its own profitability, and should maintain a dynamic balance among consumer welfare, preservation service investment, and corporate economic returns.

Overall, moderate CSR implementation helps improve the operational performance of the fresh agricultural products supply chain and can enhance logistics service level and consumer welfare. In terms of managerial practice, the RE should determine the intensity of CSR investment according to product preservation value, demand price sensitivity, and logistics cost conditions. The ME and the LC should also promote a more stable distribution of supply chain payoffs among members through reasonable wholesale pricing, service charging, and preservation investment arrangements.

Acknowledgments

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