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PRICING DECISIONS AND CHANNEL COORDINATION OF FRESH PRODUCE SUPPLY CHAIN UNDER MULTI-TRANSPORTATION MODES

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Abstract. *The two-stage fresh produce supply chain consists of one supplier and one retailer where fresh produce's price depends on the freshness, and the optimal decisions and channel coordination are investigated with long distance transportation under multi-transportation modes. The retailer determines the optimal ordering quantity and optimal retailing price according to the mode of transportation and the risk of market uncertainty, while the supplier subsequently sets the optimal wholesale price based on the Stackelberg game. Further analysis shows that the transportation mode is affected by supply chain structure and the demand price elasticity. The government subsidy in rail transport increases the trade and profit volume of both parties of the supply chain in rail. Meanwhile, the different contracts can be adopted to coordinate the decentralized supply chain with different transport modes.*
Keywords: Fresh produce supply chain, Multi-transportation modes, Price elasticity, Government subsidy

1. **Introduction.** Shipping is the primary mode of transport of international exports, and about 90% products are transported by shipping. In 2013 China proposed the Silk Road Economic Belt and the 21st Century Maritime Silk Road national strategy, and this policy is accelerating the railway transport exports and developed the land Silk Road economic zone while maintaining existing seaborne exports. In fact, the integration and development of international supply chain are very important in the implementation of the OBOR (One Belt One Road) strategy. Interestingly, regional fresh produces are often transported to the market through long distance transportation, such as through China's "south food north luck" process and China's vegetable exports to Europe and other countries. Meanwhile, freshness affects the random life cycle and the demand of fresh produces. In the marine export mode, the export of fresh produces is restricted by many factors, such as difficulties in preservation and long-time transportation. Such factors increase the possibility of losing products in the transport process and therefore hinder the export of fresh produces. However, with the development of railway transportation and the implementation of the OBOR policy, the export of fresh produces through railways has gained various advantages, especially for the western region of China. Furthermore, with the OBOR policy, China has encouraged exportation through railways and has provided some government subsidies or tax concessions for goods exported through railways. Furthermore, in the inland international trade, the railway transport has significant advantages compared to maritime transport and strongly influences the economic development of the central and western regions and foreign export. This paper tries to investigate the optimization of decision-making and transportation channel selection against the background of the OBOR policy, and coordinates the whole supply chain or the retail end

of the retailers based on the long-distance transport of fresh produces through different transportation modes.

Previous studies have focused on the fresh produce supply chain and relevant operations research. Xiao et al. [8] studied the decision of fresh produce supply chain under long-distance transportation from the cost insurance and freight (CIF) business model and developed the retailers' ordering and sales decisions under considering the market uncertainty and the loss from long-distance transportation. Then, Lin et al. [3] examined the three-level supply chain of fresh agricultural products, and introduced inventory factors to optimize the expected profit of supply chains and the profit of the members under the decentralized system with revenue-sharing contracts. These authors discovered that the optimal expected profit decreases as the price elasticity of the demand increases. Lin et al. [4] constructed models related to freshness and loss ratios based on transportation time and subsequently proposed revenue-sharing contracts, and these contracts improved the coordination of the three-level fresh agricultural product supply chain. In addition, Wang and Dan [5] investigated the consumer time-varying preference depended on price and freshness. The ordering policy of fresh agricultural products was proposed by Chen and Dan [6] to control the loss of fresh agricultural products in the circulation process. With efficient coordination, the unit loss of distributors with low effort was found to be smaller than that of the retailers alone with high effort while obtaining a higher unit gross profit. This information was also provided by a reference for the suppliers and retailers to preserve the cost sharing of fresh products. Xiao et al. [7] utilized consumer choice behavior to analyze pricing strategies of fresh products with multi-quality levels. They proposed that the effect of the "separation" strategy on the improvement of income is more prevalent when the customer is small or when the product supply is large. Moreover, Cai et al. [9] focused on the fresh-product supply chain with long-distance transport and thoroughly optimized the profits of suppliers and retailers when the cost of preservation efforts and transportation losses are considered. Recently, Soto-Silva et al. [1] focused on the coordination problems in fresh produce supply chains under the control of consumption using the newsboy model and the related theory of inventory deterioration.

In another view, Sun et al. [10] applied the demand of the exponential function to discuss the benefit-sharing and the interest-sharing contracts affected by effort-dependent demand. The paper also analyzed the influence of price elasticity in a three-stage supply chain benefit-sharing contract, and found that the benefit-sharing contract based on incentive and penalty coefficients can coordinate the supply chain when efforts promote the demand. Lin et al. [13] analyzed the optimal decision-making behaviors of risk-averse retailers and suppliers under the centralized and decentralized supply chain systems. Chaab and Rasti-Barzoki [11] evaluated the channel coordination effects of cooperative advertising launched by manufacturers and retailers together. Zhang and Liu [19] investigate the effect of pricing and ordering in group buying, and consider the joint decision and channel coordination in competing markets if retailers provide the emergency procurement to meet all stochastic demands.

In contrast with the abovementioned, this paper will examine the optimal decision of fresh produces with long-distance transportation under the uncertainty demand and different transportation modes, and the variable price elasticity is related to the sale time. Meanwhile, this paper will also thoroughly analyze the choice of product transport channels, and discuss the effect of government subsidies on rail transport and the channel coordination under decentralized system.

2. Assumptions and Denotations.

For the single period two-stage fresh produce supply chain consists of one supplier and one retailer, this paper considers the optimal purchasing and sales decisions of the retailers who face the market uncertainty and chooses the transport mode for the long-distance transport of fresh products.

Assumption 2.1. *Generally, the wholesale price w_i of suppliers covers the CIF, and for the non-negative of the profit. Therefore, $w_i > \frac{\theta_i^2}{2}$, where θ_i is the freshness of the product.*

The retailer purchases fresh produces with quantities of q_i and decides the transportation mode according to the supplier's CIF wholesale price w_i, while the supplier sets different CIF wholesale prices for different transit-times and pays for the freights. Then, the retailer sets the retail price p_i according to the market uncertainty ε and the actual arrival quantities subsequently. Considering that $t = 0$ is the time at which the product is loaded on the vehicle or ship, the fresh produce reaches the selling market after transit time $t = t_i$. The product starts to perish at a significant rate. The perishability leads to deterioration and obsolescence, and both of them can occur during the transportation. The deterioration lessens the quality of the product, especially its freshness, and obsolescence reduces the surviving quantity. This paper models two types of perishability by the following two-dependent indices: the function $\theta_i = \theta(t_i)$ of time t_i is as the freshness of the product, and the function $1 - \varphi(t_i)$ of time t_i is decreasing in t_i and defined over $[0, 1]$ as the index on the surviving quantity of the product at the time t_i. Suppose that q units of the product are loaded, the surviving quantity becomes $[1 - \varphi(t_i)]q$ after a period of time t_i.

The product freshness affects market demand, which indicates that the higher the freshness degree is, the greater product demands are in the market. Meanwhile, the difference in price elasticity of selling and loss in transit with respect to different times of transport also affects the procurement of the retailer. Existing literature such as Xiao et al. [7,8,18] and Cai et al. [17] used the exponential function to model quantity decreases and the quality decline of fresh product without considering the variable price elasticity, which has a strong impact on decisions. The product's market demands depend on its freshness level θ_i and the retailer's retail price p_i with the following multiplicative functional-form: $D(p_i, \theta_i) = k\theta_i p_i^{-f(T-t_i)}\varepsilon$, where k is the scaling factor that measures the potential market size and T is the deadline of product selling period, $f(T - t_i)$ is the price elasticity of selling after t_i of transportation which is a variable with t_i, and ε is a random variable that reflects the fluctuations of the market demand. Let $g(x)$ and $G(x)$ denote the PDF and CDF of ε, respectively. Without loss of generality, we assume $E(\varepsilon) = 1$. Focusing on price-sensitive products, we also assume that the price elasticity meets $f(T - t_i) > 1$.

Assumption 2.2. *Suppose the demand function satisfies the following conditions: (1) θ_i is decreasing in t_i, with $\theta_i > 0$ for any given t_i; (2) ε has an increasing generalized failure rate (IGFR), and $\lim_{x\to\infty} x[1 - G(x)] = 0$; (3) $f(T - t_i)$ increases with t_i, with $f(T - t_i) > 1$ for given t_i and meets $\left[\frac{f(T-t_i)-1}{f(T-t_i)}\right]^{f(T-t_i)} < \frac{f(T-t_i)}{2f(T-t_i)-1}$.*

Generally, the demand function effectively depicts the influence of demand on the market uncertainty, freshness, and price elasticity. We assume that the salvage value of any product left unsold is zero, and we do not consider any cost except for the transport freight and procurement cost. According to the background of "OBOR", we assume fresh produce exports only through shipping ($i = 1$) or rail transport ($i = 2$), and the retailer only chooses one means of transport for the export.

Assumption 2.3. *We assume that t_e is the time of the highest price elasticity, and the retailer can gain more profits by low price promotion. For the simplicity, this paper does not consider the time after t_e.*

Assumption 2.4. *To simplify our analysis with no loss of generality, we assume that all the information (e.g., production cost, and transportation period) is common knowledge to both parties, and both decision makers are risk neutral. As a result, both parties' objectives are geared toward maximizing their expected profits.*

Assumption 2.5. *Suppose that* $h(x) = \frac{xg(x)}{1-G(x)}$ *increases with respect to* x *and* $\lim_{x\to\infty} x[1-G(x)] = 0$.

This paper establishes the cost of transportation as $\frac{\theta_i^2}{2}q_i$, referring to the relative cost function description of Li et al. [15] and the hypothesis. The paper researches the optimal decisions in both centralized and decentralized modes as follows.

3. Optimal Decisions of Shipping Transportation.

In this section, we investigate the optimal decisions of shipping transportation under both centralized and decentralized systems. Fresh produce is sold in the long distance market through shipping, and we assume that the transportation time is t_1 and it meets $0 < t_1 < t_e$.

3.1. Optimal decisions of shipping transportation under the centralized system.

The retailers and suppliers are holistic in the centralized system, and as a whole they aim to maximize the expected profits. The expected profit of the centralized supply chain is

$$\pi_1^c\left(p_1^c, q_1^c\right) = p_1^c E\left\{\min\left(D(p_1^c), [1-\varphi(t_1)]q_1^c\right)\right\} - \frac{q_1^c}{2}\theta_1^2. \tag{1}$$

Following Petruzzi and Dada [16], we defined a "stocking factor" as z_1 that satisfies: $z_1 = [1-\varphi(t_1)]q_1^c / k\theta_1 {p_1^c}^{-f(T-t_1)}$, based on which the decision variable (p_1^c, q_1^c) can be transformed to (q_1^c, z_1). Substituting z_1 into Equation (1), the expected profit function is transformed to

$$\pi_1^c(q_1^c, z_1) = [k\theta_1 z_1]^{\frac{1}{f(T-t_1)}} \left\{[1-\varphi(t_1)]q_1^c\right\}^{1-\frac{1}{f(T-t_1)}} E\left\{\min\left(\frac{\varepsilon}{z_1}, 1\right)\right\} - \frac{q_1^c}{2}\theta_1^2. \tag{2}$$

Lemma 3.1. *For the centralized supply chain, the optimal stocking factor is determined by*

$$[f(T-t_1)-1]\int_0^{z_1} xg(x)dx = z_1[1-G(z_1)]. \tag{3}$$

According to the assumption that $h(x) = xg(x)/[1-G(x)]$ is increasing with respect to x, and $\lim_{x\to\infty} x[1-G(x)] = 0$, then the optimal stocking factor z_1^* is unique. Without considering the limit of the suppliers' capacity, the centralized mode's optimal purchasing quantity is

$$q_1^{c^*} = k\theta_1 z_1^* \left[\frac{1-G\left(z_1^*\right)}{\frac{\theta_1^2}{2}}\right]^{f(T-t_1)} [1-\varphi(t_1)]^{f(T-t_1)-1}. \tag{4}$$

Therefore, the optimal retail price is

$$p_1^{c^*} = \frac{\frac{\theta_1^2}{2}}{[1-G(z_1^*)][1-\varphi(t_1)]}, \tag{5}$$

which implies that the optimal retail price of the centralized system is proportional to the unit cost of transportation. Substituting (4) and (5) into (2), we can get the optimal expected profit as Equation (6),

$$\pi_1^{c^*} = \frac{k\theta_1 z_1^*[1-G(z_1^*)]}{f(T-t_1)-1}\left[\frac{[1-G(z_1^*)][1-\varphi(t_1)]}{\frac{\theta_1^2}{2}}\right]^{f(T-t_1)-1}. \tag{6}$$

3.2. **Optimal decisions of shipping transportation under decentralized system.** In the decentralized system, all members aim to the maximization of their own expected profits, the supplier is the leader and the retailer is her follower. The sequence of events is expressed as follows. The supplier determines the CIF wholesale price w_1 according to the transportation mode required by the retailer and the destination. Then the retailer will decide on his procurement quantity q_R^1 and retail price p_R^1 based on the wholesale price and product freshness. Using the shipping transportation, the retailers' expected profit function is as follows.

$$\pi_R^1 = p_R^1 E\left[\min\left\{D(p_R^1), [1-\varphi(t_1)]q_R^1\right\}\right] - w_1 q_R^1. \tag{7}$$

Similar to the centralized system, we introduce the "stocking factor" as z_1': $z_1' = [1-\varphi(t_1)]q_R^1/k\theta_1 {p_R^1}^{1-f(T-t_1)}$, and then the expected profit function of retailer is transformed to

$$\pi_R^1(z_1', q_R^1) = [k\theta_1 z_1']^{\frac{1}{f(T-t_1)}}\left\{[1-\varphi(t_1)]q_R^1\right\}^{1-\frac{1}{f(T-t_1)}} \min\left[\frac{\varepsilon}{z_1'}, 1\right] - w_1 q_R^1. \tag{8}$$

Lemma 3.2. *With shipping the optimal stocking factor under the decentralized system is equal to that of the centralized system, and it is expressed as* $[f(T-t_1)-1]\int_0^{z_1} xg(x)dx = z_1[1-G(z_1)]$.

Thus, the optimal expected profit of retailer is transformed into

$$\pi_R^1(z_1^*, q_R^1) = [k\theta_1 z_1^*]^{\frac{1}{f(T-t_1)}}\left\{[1-\varphi(t_1)]q_R^1\right\}^{1-\frac{1}{f(T-t_1)}} \left[\frac{f(T-t_1)}{f(T-t_1)-1}[1-G(z_1^*)]\right] - w_1 q_R^1. \tag{9}$$

Under the centralized system, we can demonstrate that the expected profit is concave with the procurement quantity q_R^1. The optimal procurement quantity ${q_R^1}^*$ of the retailer with shipping transportation under the decentralized system can be expressed by

$${q_R^1}^* = k\theta_1 z_1^* \left[\frac{1-G(z_1^*)}{w_1}\right]^{f(T-t_1)} [1-\varphi(t_1)]^{f(T-t_1)-1}. \tag{10}$$

Meanwhile, we can find the optimal retail price as follows:

$${p_R^1}^* = \frac{w_1}{[1-G(z_1^*)][1-\varphi(t_1)]}. \tag{11}$$

Equation (11) shows that the optimal retail price ${p_R^1}^*$ is proportional to the wholesale price of the supplier and is greater than $p_1^{c^*}$ due to $w_1 > \frac{\theta_1^2}{2}$. According to the negative correlation between the retail price and the procurement quantity, we can summarize that the decentralized decision can decrease the quantity that will increase the upstream suppliers' inventory pressure. Substituting (10) and (11) into (9), the retailer's optimal expected profit ${\pi_R^1}^*$ can be expressed as follows:

$${\pi_R^1}^* = \frac{k\theta_1 z_1^* w_1 \left[\frac{1-G(z_1^*)}{w_1}\right]^{f(T-t_1)} [1-\varphi(t_1)]^{f(T-t_1)-1}}{f(T-t_1)-1}. \tag{12}$$

According to the Stackelberg game theory, the supplier's profit under the decentralized system is

$$\pi_S^1 = \left(w_1 - \frac{\theta_1^2}{2}\right){q_R^1}^*. \tag{13}$$

Lemma 3.3. *With shipping transportation under the decentralized system, the wholesale price* w_1 *satisfies* $\frac{\theta_1^2}{2} < w_1 < \left[\frac{f(T-t_1)+1}{f(T-t_1)-1}\right]\frac{\theta_1^2}{2}$, *and the optimal wholesale price* w_1^* *is*

$$w_1^* = \left[\frac{f(T-t_1)}{f(T-t_1)-1}\right]\frac{\theta_1^2}{2}. \tag{14}$$

Substituting (14) into (12) and (13) respectively, the optimal profit of the supplier ${\pi_S^1}^*$ and the retailer ${\pi_R^1}^*$ are as follows:

$$ {\pi_R^1}^* = \frac{k\theta_1 z_1^*[1-G(z_1^*)]^{f(T-t_1)}}{f(T-t_1)-1}\left\{\frac{[f(T-t_1)-1][1-\varphi(t_1)]}{f(T-t_1)\frac{\theta_1^2}{2}}\right\}^{f(T-t_1)-1}, \tag{15} $$

and

$$ {\pi_S^1}^* = \frac{k\theta_1 z_1^*[1-G(z_1^*)]^{f(T-t_1)}}{f(T-t_1)}\left\{\frac{[f(T-t_1)-1][1-\varphi(t_1)]}{f(T-t_1)\frac{\theta_1^2}{2}}\right\}^{f(T-t_1)-1}. \tag{16} $$

Accordingly, the optimal profit of the overall supply chain under decentralized system is as

$$ {\pi_{S+R}^1}^* = \frac{[2f(T-t_1)-1]k\theta_1 z_1^*[1-G(z_1^*)]^{f(T-t_1)}}{f(T-t_1)[f(T-t_1)-1]}\left\{\frac{[f(T-t_1)-1][1-\varphi(t_1)]}{f(T-t_1)\frac{\theta_1^2}{2}}\right\}^{f(T-t_1)-1}. \tag{17} $$

4. **Optimal Decisions of Rail Transportation.** In this section, we will investigate the optimal decisions of the rail transportation under both centralized and decentralized systems. Of course, the fresh produces exported through the rail transportation possess many advantages, especially with regard to transportation time. Under the background of the OBOR policy, the government has encouraged the product export by the rail transportation. The government will provide participants with subsidies for several special products. We assume that the time of rail transportation is t_2 and it satisfies $t_2 < t_1 < t_e$.

4.1. **Optimal decisions of rail transportation without government subsidies.** In this section, we will investigate the optimal decision of rail transportation under both centralized and decentralized systems, and meanwhile, the government subsidies factors are considered in these decisions.

4.1.1. *Optimal decisions of rail transportation under the centralized system.* The expected profit function with rail transportation under the centralized system is

$$ \pi_2^c = p_2^c E\left\{\min(D(p_2^c),[1-\varphi(t_2)]q_2^c)\right\} - \frac{q_2^c}{2}\theta_2^2. \tag{18} $$

We define z_2 as the "stocking factor" under rail transportation, and this factor satisfies with

$$ z_2 = [1-\varphi(t_2)]q_2^c / k\theta_2 {p_2^c}^{-f(T-t_2)}. \tag{19} $$

Lemma 4.1. *The optimal stocking factor of the rail transportation under the centralized system is determined by*

$$ [f(T-t_2)-1]\int_0^{z_2} xg(x)dx = z_2[1-G(z_2)]. \tag{20} $$

Accordingly, $h(x) = xg(x)/[1-G(x)]$ *increases with* x *and* $\lim_{x\to\infty} x[1-G(x)] = 0$*, and then the optimal stocking factor* z_2^* *is unique.*

According to Lemma 4.1, we can get the expected profit of centralized system is

$$ \pi_{2|z_1^*}^c = [k\theta_2 z_2^*]^{\frac{1}{f(T-t_2)}}\left\{[1-\varphi(t_2)]q_2^c\right\}^{1-\frac{1}{f(T-t_2)}}\left[\frac{f(T-t_2)}{f(T-t_2)-1}[1-G(z_2^*)]\right] - \frac{q_2^c}{2}\theta_2^2. \tag{21} $$

It is easy that we can determine that the profit $\pi_{2|z_1^*}^c$ is concave with the procurement quantity q_2^c with the rail transportation. Thus, the optimal quantity is

$$ {q_2^c}^* = k\theta_2 z_2^*\left[\frac{1-G(z_2^*)}{\frac{\theta_2^2}{2}}\right]^{f(T-t_2)}[1-\varphi(t_2)]^{f(T-t_2)-1}. \tag{22} $$

Accordingly, the optimal retail price with rail transportation under the centralized system without government subsidy is

$$p_2^{c^*} = \frac{\frac{\theta_2^2}{2}}{[1 - G(z_2^*)][1 - \varphi(t_2)]}. \tag{23}$$

Substituting (22) and (23) into (21), the optimal expected profit is expressed as Equation (24)

$$\pi_2^{c^*} = \frac{\frac{\theta_2^2}{2}}{f(T - t_2) - 1} \left[k\theta_2 z_2^* \left[\frac{1 - G(z_2^*)}{\frac{\theta_2^2}{2}} \right]^{f(T-t_2)} [1 - \varphi(t_2)]^{f(T-t_2)-1} \right]. \tag{24}$$

4.1.2. *Optimal decisions of rail transportation under the decentralized system.* Under the decentralized system, the retailer's expected profit with rail transportation is

$$\pi_R^2 = p_R^2 E \left[\min \left\{ D\left(p_R^2\right), [1 - \varphi(t_2)] q_R^2 \right\} \right] - w_2 q_R^2. \tag{25}$$

Similarly, we define that the "stocking factor" of the decentralized system is

$$z_2' = [1 - \varphi(t_2)] q_R^2 / k\theta_2 {p_R^2}^{2 - f(T-t_2)}.$$

Lemma 4.2. *The optimal stocking factor under the decentralized system is equal to that under the centralized system with the rail transportation. It is unique under the condition that $h(x) = xg(x)/[1 - G(x)]$ increases with x and $\lim_{x \to \infty} x[1 - G(x)] = 0$.*

Therefore, we can summarize that the optimal stocking factor is not affected by the supply chain structure and the supplier's wholesale price is regardless of the transportation mode used; the optimal stocking factor is determined by the price elasticity of the selling point and market uncertainty. Referring to the previous processing method, the optimal procurement quantity and the retailer's selling price are respectively expressed as follows:

$$ {q_R^2}^* = k\theta_2 z_2^* \left[\frac{1 - G(z_2^*)}{w_2} \right]^{f(T-t_2)} [1 - \varphi(t_2)]^{f(T-t_2)-1} \text{ and } {p_R^2}^* = \frac{w_2}{[1 - G(z_2^*)][1 - \varphi(t_2)]}.$$

Thus, the optimal expected profit of retailer is:

$$ {\pi_R^2}^* = \frac{k\theta_2 z_2^* w_2 \left[\frac{1 - G(z_2^*)}{w_2} \right]^{f(T-t_2)} [1 - \varphi(t_2)]^{f(T-t_2)-1}}{f(T - t_2) - 1}. \tag{26}$$

According to the Stackelberg game theory, the supplier's profit with the rail transportation under the decentralized system is expressed by

$$\pi_S^2 = \left(w_2 - \frac{\theta_2^2}{2} \right) {q_R^2}^*. \tag{27}$$

Lemma 4.3. *With the railway transport under the decentralized system, the wholesale price w_2 satisfies $\frac{\theta_2^2}{2} < w_2 < \left[\frac{f(T-t_2)+1}{f(T-t_2)-1} \right] \frac{\theta_2^2}{2}$, and the optimal wholesale price w_2^* is expressed as follows:*

$$w_2^* = \left[\frac{f(T - t_2)}{f(T - t_2) - 1} \right] \frac{\theta_2^2}{2}. \tag{28}$$

Thus, the optimal profit of supplier ${\pi_S^2}^*$ and retailer ${\pi_R^2}^*$ is gained as follows.

$$ {\pi_S^2}^* = \frac{k\theta_2 z_2^* [1 - G(z_2^*)]^{f(T-t_2)}}{f(T - t_2)} \left\{ \frac{[f(T - t_2) - 1][1 - \varphi(t_2)]}{f(T - t_2) \frac{\theta_2^2}{2}} \right\}^{f(T-t_2)-1}, \tag{29}$$

and

$$ {\pi_R^2}^* = \frac{k\theta_2 z_2^* [1 - G(z_2^*)]^{f(T-t_2)}}{f(T - t_2) - 1} \left\{ \frac{[f(T - t_2) - 1][1 - \varphi(t_2)]}{f(T - t_2) \frac{\theta_2^2}{2}} \right\}^{f(T-t_2)-1}. \tag{30}$$

Accordingly, the optimal profit of the overall supply chain with the rail transportation under the decentralized system without government subsidy is expressed as Equation (31):

$$\pi_{R+S}^{2}{}^{*} = \frac{[2f(T-t_2)-1]k\theta_2 z_2^*[1-G(z_2^*)]^{f(T-t_2)}}{f(T-t_2)[f(T-t_2)-1]} \left\{ \frac{[f(T-t_2)-1][1-\varphi(t_2)]}{f(T-t_2)\frac{\theta_2^2}{2}} \right\}^{f(T-t_2)-1}. \tag{31}$$

The structure of supply chain will affect the optimal procurement quantity regardless of whether the rail or shipping transportation is used without the government subsidy. We find that the optimal procurement quantity under the decentralized system is smaller than that under the centralized system and that the retail price presents the opposite nature. Meanwhile, considering that all members seek to maximize their profits in the decentralized system, the supplier's wholesale price is greater than the unit cost of the freight, which consequently decreases the procurement quantity and increases the capital occupancy rate and risk of the retailer.

Proposition 4.1. *Under the centralized system, the shipping transportation is more suitable for the product if*

$$\frac{\theta_2}{\theta_1} < \frac{\int_0^{z_1^*} xg(x)dx \left[\frac{[1-\varphi(t_1)][1-G(z_1^*)]}{\frac{\theta_1^2}{2}}\right]^{f(T-t_1)-1}}{\int_0^{z_2^*} xg(x)dx \left[\frac{[1-\varphi(t_2)][1-G(z_2^*)]}{\frac{\theta_2^2}{2}}\right]^{f(T-t_2)-1}},$$

while the railway is more appropriate if

$$\frac{\theta_2}{\theta_1} > \frac{\int_0^{z_1^*} xg(x)dx \left[\frac{[1-\varphi(t_1)][1-G(z_1^*)]}{\frac{\theta_1^2}{2}}\right]^{f(T-t_1)-1}}{\int_0^{z_2^*} xg(x)dx \left[\frac{[1-\varphi(t_2)][1-G(z_2^*)]}{\frac{\theta_2^2}{2}}\right]^{f(T-t_2)-1}}.$$

Meanwhile, under the decentralized system, the retailer should choose shipping transportation if

$$\frac{\theta_2}{\theta_1} < \frac{\left[\frac{[f(T-t_1)-1]}{f(T-t_1)}\right]^{f(T-t_1)-1} \int_0^{z_1^*} xg(x)dx \left[\frac{[1-\varphi(t_1)][1-G(z_1^*)]}{\frac{\theta_1^2}{2}}\right]^{f(T-t_1)-1}}{\left[\frac{[f(T-t_2)-1]}{f(T-t_2)}\right]^{f(T-t_2)-1} \int_0^{z_2^*} xg(x)dx \left[\frac{[1-\varphi(t_2)][1-G(z_2^*)]}{\frac{\theta_2^2}{2}}\right]^{f(T-t_2)-1}},$$

while the railway is more appropriate if

$$\frac{\theta_2}{\theta_1} > \frac{\left[\frac{[f(T-t_1)-1]}{f(T-t_1)}\right]^{f(T-t_1)-1} \int_0^{z_1^*} xg(x)dx \left[\frac{[1-\varphi(t_1)][1-G(z_1^*)]}{\frac{\theta_1^2}{2}}\right]^{f(T-t_1)-1}}{\left[\frac{[f(T-t_2)-1]}{f(T-t_2)}\right]^{f(T-t_2)-1} \int_0^{z_2^*} xg(x)dx \left[\frac{[1-\varphi(t_2)][1-G(z_2^*)]}{\frac{\theta_2^2}{2}}\right]^{f(T-t_2)-1}}.$$

The above proposition shows that the transportation modes should be selected by different products, and the decision-makers should decide according to the nature of the product (e.g., freshness and perishability) and the desired transport time. However, the differences in transport benchmarks under different supply chains resulted from the differences of price elasticity under different transport cycles.

Proposition 4.2. *The structure of supply chain has a strong impact on transit decision of fresh products. For the high price elasticity product defined as* $f(T-t_i) > \frac{e}{e-1}$, *the decentralized system will decrease the proportion of product which is suitable for transport by* *train. For the low price elasticity product defined as* $1 < f(T-t_i) < \frac{e}{e-1}$*, the decentralized system will increase the proportion.*

We further evaluate the optimal decision of members and analyze how the procurement quantity and decision of transportation choice are affected by the supply chain structure. However, participants of the overall supply chain are more concerned about the influence of the supply chain structure on profits.

Proposition 4.3. *The optimal profit of the overall supply chain under the decentralized system is shorter than that under the centralized system if choosing the same transport mode without government subsidy. Therefore, the "double marginalization" exists in the decentralized supply chain.*

4.2. **Optimal decisions of the rail transportation with government subsidy.** Under the OBOR policy, the government provides subsidies to specific products if they are transported using railway transportation. In this paper, we assume that the proportion of the government subsidy is λ. The government provides subsidies for supplier who undertakes the freight cost and risk of transportation.

4.2.1. *Optimal decisions of the rail transportation under centralized mode.* With the government subsidy, the profit function of the centralized system is expressed as follows:

$$\pi_{2\lambda}^c = p_{2\lambda}^c E\left\{\min\left(D(p_{2\lambda}^c), [1-\varphi(t_2)]q_{2\lambda}^c\right)\right\} - \frac{q_{2\lambda}^c}{2}\theta_2^2 + \lambda q_{2\lambda}^c. \tag{32}$$

According to the above lemmas, the optimal stocking factor in this situation is z_2^*. Thus, the optimal quantity can be expressed as

$$q_{2\lambda}^{c\ *} = k\theta_2 z_2^* \left[\frac{1-G(z_2^*)}{\frac{\theta_2^2}{2}-\lambda}\right]^{f(T-t_2)} [1-\varphi(t_2)]^{f(T-t_2)-1}. \tag{33}$$

Meanwhile, the optimal retail price is presented as $p_{2\lambda}^{c\ *} = \frac{\frac{\theta_2^2}{2}-\lambda}{[1-G(z_2^*)][1-\varphi(t_2)]}$, and the optimal profit under the centralized system $\pi_{2\lambda}^{c\ *}$ is expressed as Equation (34):

$$\pi_{2\lambda}^{c\ *} = \frac{\frac{\theta_2^2}{2}-\lambda}{f(T-t_2)-1}\left[k\theta_2 z_2^* \left[\frac{1-G(z_2^*)}{\frac{\theta_2^2}{2}-\lambda}\right]^{f(T-t_2)} [1-\varphi(t_2)]^{f(T-t_2)-1}\right]. \tag{34}$$

4.2.2. *Optimal decisions of rail transportation under decentralized mode.* Under the decentralized system, we suppose that only the supplier acquires the subsidy, and can gain the following formula about the optimal procurement quantity $q_{2\lambda}^{R\ *}$, the optimal price $p_{2\lambda}^{R\ *}$ and the wholesale w_2^λ.

$$q_{2\lambda}^{R\ *} = k\theta_2 z_2^* \left[\frac{1-G(z_2^*)}{w_2^\lambda}\right]^{f(T-t_2)} [1-\varphi(t_2)]^{f(T-t_2)-1} \text{ and } p_{2\lambda}^{R\ *} = \frac{w_2^\lambda}{[1-G(z_2^*)][1-\varphi(t_2)]}.$$

The government subsidy acquired by the supplier decreases the cost of transportation and reduces supplier's CIF wholesale price, and improves the railway freight volume, so the supplier will reset the CIF wholesale price decision when subsidy is acquired. The profit function of supplier with government subsidy is expressed by Equation (35)

$$\pi_s^\lambda = \left(w_\lambda - \frac{\theta_2^2}{2} + \lambda\right) q_R^{2\ *}. \tag{35}$$

Following the above mentioned methods, the optimal CIF wholesale price in this situation is determined as follows:

$$w_\lambda^{\ *} = \left[\frac{f(T-t_2)}{f(T-t_2)-1}\right]\left[\frac{\theta_2^2}{2}-\lambda\right]. \tag{36}$$

According to the optimal results, the optimal profit is expressed as follows:

$$\pi_s^{\lambda *} = \frac{k\theta_2 z_2^*[1-G(z_2^*)]^{f(T-t_2)}}{f(T-t_2)} \left\{ \frac{[f(T-t_2)-1][1-\varphi(t_2)]}{f(T-t_2)\left[\frac{\theta_2^2}{2}-\lambda\right]} \right\}^{f(T-t_2)-1}, \tag{37}$$

$$\pi_R^{\lambda *} = \frac{k\theta_2 z_2^*[1-G(z_2^*)]^{f(T-t_2)}}{f(T-t_2)-1} \left\{ \frac{[f(T-t_2)-1][1-\varphi(t_2)]}{f(T-t_2)\left[\frac{\theta_2^2}{2}-\lambda\right]} \right\}^{f(T-t_2)-1}. \tag{38}$$

The total optimal profit with a government subsidy is expressed by Equation (39):

$$\pi_{R+S}^{\lambda}{}^* = \frac{[2f(T-t_2)-1]k\theta_2 z_2^*[1-G(z_2^*)]^{f(T-t_2)}}{f(T-t_2)[f(T-t_2)-1]} \left\{ \frac{[f(T-t_2)-1][1-\varphi(t_2)]}{f(T-t_2)\left[\frac{\theta_2^2}{2}-\lambda\right]} \right\}^{f(T-t_2)-1}. \tag{39}$$

With a government subsidy ($\frac{\theta_2^2}{2} > \lambda$), the subsidy can effectively decrease the wholesale price and improve the procurement quantity; on the other hand, it can improve the profit gained by the member. Accordingly, we find that "double marginalization" also exists in the decentralized system. The question is raised on whether the previous shipping should be altered by rail transportation when the product can obtain the government subsidy under the rail transportation.

Proposition 4.4. *With the rail transportation for the product export, we obtain the government subsidy as λ_0, which satisfies $\lambda_0 < \frac{\theta_2^2}{2}$, and the decision-maker will face a problem whether the transportation decision should be reenacted. If the freshness of the initial sale meets the condition as follows:*

$$A\frac{\int_0^{z_1^*} xg(x)dx\left[\frac{[1-\varphi(t_1)][1-G(z_1^*)]}{\frac{\theta_1^2}{2}}\right]^{f(T-t_1)-1}}{\int_0^{z_2^*} xg(x)dx\left[\frac{[1-\varphi(t_2)][1-G(z_2^*)]}{\frac{\theta_2^2}{2}-\lambda_0}\right]^{f(T-t_2)-1}} < \frac{\theta_2}{\theta_1} < A\frac{\int_0^{z_1^*} xg(x)dx\left[\frac{[1-\varphi(t_1)][1-G(z_1^*)]}{\frac{\theta_1^2}{2}}\right]^{f(T-t_1)-1}}{\int_0^{z_2^*} xg(x)dx\left[\frac{[1-\varphi(t_2)][1-G(z_2^*)]}{\frac{\theta_2^2}{2}}\right]^{f(T-t_2)-1}},$$

where $A = \frac{\left[\frac{[f(T-t_1)-1]}{f(T-t_1)}\right]^{f(T-t_1)-1}}{\left[\frac{[f(T-t_2)-1]}{f(T-t_2)}\right]^{f(T-t_2)-1}}$. Decision-makers should change the previous shipping into the rail transportation. Detailed proof can be seen in Proposition 4.1.

Proposition 4.4 shows that the government subsidy as a method of macroeconomic control can change the previous transportation pattern and adjust the freight volume between shipping and train. With the increase in government subsidy, more types of products will change the transportation mode from the shipping to railway. Under real-life practice, when China government carries out the OBOR policy, the subsidy is used as a method of adjustment and control to increase the freight volume of train. Policies such as tariff incentives can increase the "quantity" and "type" of rail transportation export to improve economic development, especially in inland areas, and solve overcapacity problems for fresh produces.

5. **Supply Chain Channel Coordination.** Double marginalization exists in all decentralized systems, and it is the key problem for managers and scholars of how to alleviate the double marginalization in decentralized system with the coordination mechanisms. In this section, we will focus on the channel coordination problems with different transportation modes, and design a contract for each party in the supply chain to increase the overall supply chain profit and the procurement quantity.

5.1. **The channel coordination of supply chain with shipping transportation.** We coordinate the decentralized system under the shipping transportation by using a revenue-sharing contract. This contract can effectively improve the profit of each party and supply chain procurement quantity when the proportion of revenue-sharing ρ satisfies certain conditions.

Proposition 5.1. *The revenue-sharing contract is applied to coordinating the decentralized supply chain under shipping. The contract can effectively improve all members under the decentralized system if the proportion ρ satisfies* $\left[\frac{[f(T-t_1)-1]}{f(T-t_1)}\right]^{f(T-t_1)} < \rho < 1-\left[\frac{[f(T-t_1)-1]}{f(T-t_1)}\right]^{f(T-t_1)-1}$.

5.2. **The channel coordination of supply chains with rail transportation.** According to the practices in OBOR strategy, the franchise contract is applied to coordinating the decentralized supply chain under the rail transportation without a government subsidy. That is, the retailer places an order to the supplier who delivers a product to the retailer without a wholesale price charging the franchise fee with the certain proportion of ϕ according to the retailer income in an optimized amount, and sells the product at an optimized price under the centralized supply chain.

Proposition 5.2. *The franchise contract is applied to coordinating the decentralized supply chain with rail transportation without government subsidy. If the proportion satisfies* $\frac{f(T-t_2)-1}{f(T-t_2)}\left\{1+\frac{1}{f(T-t_2)}\left[\frac{[f(T-t_2)-1]}{f(T-t_2)}\right]^{f(T-t_2)-1}\right\} < \phi < 1-\frac{1}{f(T-t_2)}\left[\frac{[f(T-t_2)-1]}{f(T-t_2)}\right]^{f(T-t_2)-1}$, *the contract can achieve the coordination.*

6. **Numerical Examples.** In this section, we provide different parameters to compare the different transportation modes. We have selected 7 transportation routes to verify the results: (1) Shanghai-Vietnam; (2) Shanghai-Burma; (3) Shanghai-Thailand; (4) Shanghai-Turkey; (5) Shanghai-Saudi Arabia; (6) Shanghai-Netherlands; (7) Shanghai-German. Similar to Wang et al. [5], we assume that the freshness θ_i meets $\theta_i = \theta\left[1-\left(\frac{t_i}{T}\right)^2\right]$, where the θ presents the sensitivity coefficient with transportation.

The results of the same product in shipping for decentralized supply chain and centralized supply chain are presented in Table 1. The parameters are set as $k = 1000$, $\varepsilon \sim U(0,\mu)$, and we assume that the market uncertainty is constant, which means $\mu = 100$.

Table 1. Optimized results under shipping transportation

	$\varphi(t_1)$	$f(T-t_1)$	$p_1^{c^*}$	$q_1^{c^*}$	$\pi_1^{c^*}$	$p_R^{1\,*}$	$q_R^{1\,*}$	$w_1{}^*$	$\pi_R^{1\,*}$	$\pi_S^{1\,*}$	$\pi_{S+R}^{1\quad *}$
①	0.16	2.10	13.91	87.81	331.06	26.56	22.58	7.92	162.56	85.15	247.7
②	0.19	2.60	10.99	37.94	93.79	17.85	10.74	6.43	43.13	26.54	69.67
③	0.20	2.70	10.36	33.85	75.79	16.45	9.71	6.05	34.52	21.73	56.25
④	0.23	3.00	9.46	20.69	37.69	14.19	6.13	5.46	16.75	11.17	27.92
⑤	0.24	3.10	9.13	18.00	30.48	13.48	5.38	5.25	13.45	9.11	22.57
⑥	0.25	3.30	8.16	15.54	22.13	11.71	4.72	4.70	9.65	6.72	16.37
⑦	0.28	3.70	6.39	14.22	13.92	8.76	4.43	3.62	5.94	4.34	10.28

(The time (day) for each route: (1):12; (2):15; (3):17; (4):19; (5):20; (6):23; (7):29)

The results of the same product under rail transportation without a government subsidy for both decentralized and centralized supply chains are shown in Table 2.

The tables show the optimized results for the same product in the same risk. Firstly, we find that regardless of transportation mode, the profit in the decentralized supply chain

TABLE 2. Optimized results under rail transportation

	$\varphi(t_2)$	$f(T-t_2)$	$p_2^{c^*}$	$q_2^{c^*}$	$\pi_2^{c^*}$	$p_R^{2\,*}$	$q_R^{2\,*}$	$w_2{}^*$	$\pi_R^{2\,*}$	$\pi_S^{2\,*}$	$\pi_{S+R}^{2\;\;*}$
①	0.12	1.50	25.44	212.01	1898.55	76.32	40.80	13.43	1096.13	365.38	1461.5
②	0.13	1.70	19.77	159.21	1014.44	48.02	35.23	10.83	545.11	224.46	769.56
③	0.14	1.85	17.30	124.54	650.22	37.66	29.54	9.66	335.72	154.25	489.96
④	0.16	2.10	14.69	80.51	320.46	28.04	20.71	8.36	157.35	82.42	239.77
⑤	0.17	2.20	13.95	67.33	243.58	25.57	17.74	7.96	117.69	64.20	181.89
⑥	0.18	2.52	11.54	41.67	112.06	19.14	11.66	6.78	51.96	31.34	83.31
⑦	0.19	2.60	10.99	37.94	93.79	17.85	10.74	6.43	43.13	26.54	69.67

(The time (day) for each route: (1):3; (2):4; (3):5; (4):7; (5):8; (6):13; (7):15)

is smaller than that in the centralized supply chain in the same transportation mode. Secondly, under the same risk, the profit in the railway transportation is better than that in the sea transportation. Lastly, the optimal wholesale price for the supplier is not affected by the market uncertainty and increases as time decreases.

7. **Conclusions.** This paper considers the OBOR strategy in determining the optimal decisions of the price and order quantity as well as the transportation channel selection under different circumstances. Under the centralized system, the optimal order quantity and the optimal retail price of different modes of transportation are obtained. Furthermore, different modes of transportation are applied to different products. Moreover, the decisions can be made according to the freshness of products determined. Under the decentralized system, the optimal retail quantity and the optimal retail price of the terminal retailer were obtained. Furthermore, the optimal wholesale price is gained according to the Stackelberg game model, and the channel selection conditions under the decentralized mode are expressed. Meanwhile, we further verify the existence of the "double marginal effect" under the decentralized supply chain under the same transportation mode. Against the background of the OBOR strategy, several products with rail transport obtain government subsidies. Moreover, the government subsidies optimize the procurement volume and profit of rail transport; however, they can also change transportation modes of other products. Factors such as the "quantity" and "classification" of rail transportation further optimize the supply chain. However, considering that the amount of government subsidies is usually small, the optimization of government subsidies for supply chains is limited; thus, this paper further uses internal contracts to coordinate the decentralized supply chain and adopts a profit-sharing contract to achieve supply chain coordination under shipping transportation, and the franchise contract can be adopted to optimize the decentralized supply chain under rail transportation. Once decision variables satisfy the appropriate conditions, the contract can achieve its respective conditions of supply chain coordination.

However, this paper does not provide a detailed description of the transportation cost under long-distance transport and the impact of uncertain demands on a supply chain, which provides a direction for future research.

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