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DECISION-MAKING RESEARCH ON THE SUPPLY CHAIN COORDINATION OF MULTI-MANUFACTURERS AND SINGLE-RETAILERS

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Abstract. *Intending to solve the coordination problem between multi-manufacturers and single-retailers, this paper constructed a retailer-led, multi-manufacturer-following supply chain model, using Stackelberg game theory to discuss the profit of the cooperating parties and the supply chain in decentralized and centralized decision-making. We used the Shapley value method and the same profit growth rate method to make a coordinated comparison. The research showed that the dominant retailers choose the same profit growth rate method to be more beneficial to themselves. In contrast, the subordinate manufacturers choose the Shapley value method as more useful to themselves.*
Keywords: Retailer-led, Multi-manufacturer, Homogeneous products, Shapley value, The same profit growth rate

1. **Introduction.** Supply chain coordination is an essential concept in today's competitive business, and is particularly important in [1]. Supply chain coordination management is an effective management, and has become a research hotspot in supply chain-related fields [2]. Regarding supply chain coordination, the subjects and methods used by various scholars differ. Many scholars use the commitment-based revenue sharing and punishment model to coordinate the supply chain coordination where two members face random demand [3-6]. [7] effectively coordinated the supply chain through volume discounts, and [8] used revenue and cost-sharing to achieve coordination among supply chain members. [9,10] studied the benefit-sharing coordination mechanism of two-level supply chains to create a win-win situation. [11] not only extended the coordination to the three-level supply, but also deduced the coordination conditions of the two supply chain structures.

Most of the above studies are dominated by manufacturers. Even if retailers are dominant, exiting studies focus primarily on single-manufacturer-to-single-retailer or single-manufacturer-to-multi-retailer coordination. For example, [12] achieved the coordination of a single manufacturer and a single retailer through an optimal production rate. [13] and [14] achieved supply chain coordination among single manufacturers (suppliers) and multiple retailers, respectively. Even if there are literature studies on supply chain coordination between numerous manufacturers and a single retailer, there are generally only two manu-

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facturers involved. [15] constructed a supply chain model of a retailer, a supplier, and a manufacturer, and achieved supply chain coordination through Pareto improvement. [16] extended Model 4 to the case of single-retailer-to-multi-manufacturers procurement, exploring delivery supply chain coordination for future quotes and hedging issues.

For the coordination of multiple manufacturers and a single retailer, [17] found that the retailer should choose m orders with the lowest wholesale price among n manufacturers, $2 \leq m \leq n$, but this does not consider the relationship between the profits of the parties in the cooperation and the number of manufacturers, nor does it feel the homogenization of products among manufacturers. At this stage, it is relatively common for multiple manufacturers to sell products to consumers through a single retailer, due to the dominant position of retailers, and manufacturers can only obtain retained profits. As a result, the stability of the supply chain is affected. Therefore, the decision-making and coordination problem of the $n:1$ supply chain dominated by retailers has become a real problem that members of the supply chain face. Based on previous research results, this paper considered the research of strategic choices and development countermeasures of the relationship between the profits of all parties in the $n:1$ supply chain and the number of manufacturers, the homogeneity of products among multiple manufacturers, and the comparison of manufacturers under various coordination mechanisms. The Shapley value method and the same profit growth rate method were chosen for supply chain coordination; both ways resulted in increased profits for manufacturers and retailers compared to the decentralized decision. How exactly to choose is also the question that needs to be explored in this paper to provide a new approach and reference for supply chain coordination mechanism.

The rest of this paper is organized as follows. We perform the model description in the second part and conform to the assumptions. In the third section, the decentralized decision-making scenario is explored. The fourth section focuses on the analysis of the centralized decision scenario; it concludes that manufacturers are motivated to participate in the coordination of centralized decisions only if they obtain no less profit than when the decisions are decentralized. In the fifth section, the supply chain coordination mechanism is completed using the Shapley value method and the same profit growth rate method. In the sixth section, numerical arithmetic examples are used to derive the precision of the conclusions in the text. Finally, in the seventh section, we conclude and propose directions for future research.

2. Model Description and Symbolic Assumptions.

This paper mainly considered the $n:1$ ($n \geq 1$) supply chain coordination between multiple manufacturers and a single retailer under asymmetric information; that is, it was assumed that n manufacturers are selling homogeneous products to consumers through retailers. The model structure is shown in Figure 1.

The transaction price between the manufacturer and the retailer will directly affect the retail price set by the retailer for the consumer, affecting the market demand. The

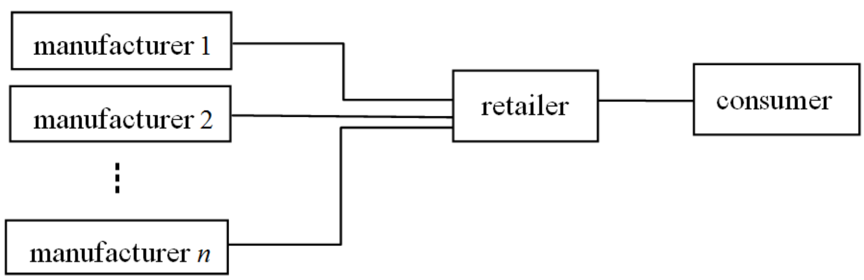

FIGURE 1. $n:1$ supply chain model

market demand further affects the benefits of each member of the supply chain. For ease of analysis, assume that the manufacturer's unit production cost is c_M, the wholesale price to retailers is ω, n is the number of manufacturers ($n \geq 1$), q_i is the quantity supplied by manufacturer i to the retailer, $Q = \sum_{i=1}^{n} q_i$ indicates total supply, π_{Mi} is the profit for the manufacturer i; p is the retail price of the product sold by the retailer, and $p = a - b \cdot Q$ assumes that the retailer can sell all products at a specific price, where a, b are constants greater than zero, c_R is the unit cost of goods sold by the retailer, and g is the unit profit. At this point, the unit profit, wholesale price, and retail price satisfy $p = \omega + g$. π_R is the retailer's profit and π is the whole profit of the total supply chain system. For the convenience of the research, it was assumed that there is no essential difference between the manufacturers' products, and retailer R is fair and non-discriminatory to manufacturer i.

According to the assumptions, the respective profit expressions of the manufacturer and the retailer can be obtained:

$$\begin{aligned} \pi_{Mi} &= (\omega - c_M)q_i = (p - g - c_M)q_i = (a - bQ - g - c_M)q_i \\ &= \left(a - b\sum_{i=1}^{n} q_i - g - c_M\right) q_i \end{aligned} \tag{1}$$

$$\pi_R = (p - \omega - c_R)Q = (g - c_R)Q \tag{2}$$

To compare the effect of cooperation and non-cooperation, this paper analyzed the profit situation in the case of decentralized and centralized decision-making, respectively.

3. **Decentralized Decision-Making.** Assuming that a single retailer is the leader of the Stackelberg game, multiple manufacturers are followers. Their goals are to maximize their profits to play a non-cooperative game, the decision order is: the retailer first decides its unit profit level g, and the manufacturer decides the supply quantity q_i based on the decision of the retailer. According to the reverse induction method (It means that there is a sequence of actions of the players in the game, and the players who act later can observe the previous steps.), the first-order condition of q_i in Formula (1) can be obtained:

$$q_i = \frac{a - g - c_M}{(n+1)b} \tag{3}$$

The retailer's total supply to the manufacturer is then

$$Q = \sum_{i=1}^{n} q_i = \frac{n(a - g - c_M)}{(n+1)b} \tag{4}$$

Substitute Equation (4) into Equation (2) and obtain from the first-order condition of g:

$$g = \frac{a - c_M + c_R}{2} \tag{5}$$

Substituting Equation (5) into Equation (3), the optimal supply quantity from manufacturer i to the retailer is

$$q_i^* = \frac{a - c_M - c_R}{2(n+1)b} \tag{6}$$

Then, the optimal decision for total sales volume, retail price, and wholesale price obtained from $Q = \sum_{i=1}^{n} q_i$, $p = a - b \cdot Q$, and $\omega = p - g$ are as follows:

$$Q^* = \frac{n(a - c_M - c_R)}{2(n+1)b} \tag{7}$$

$$p^* = \frac{2a + n(a + c_M + c_R)}{2(n+1)} \tag{8}$$

$$\omega^* = \frac{a + (2n+1)c_M - c_R}{2(n+1)} \tag{9}$$

Substitute Equations (6)-(9) into Equations (1) and (2) to obtain the optimal profits of manufacturers, retailers, and supply chains:

$$\begin{aligned} \pi_{Mi}^* &= \frac{(a - c_M - c_R)^2}{4b(n+1)^2}, \quad \pi_M^* = \sum_{i=1}^{n} \pi_{Mi}^* = \frac{n(a - c_M - c_R)^2}{4b(n+1)^2} \\ \pi_R^* &= \frac{n(a - c_M - c_R)^2}{4b(n+1)}, \quad \pi^* = \pi_M^* + \pi_R^* = \frac{(n^2+2n)(a - c_M - c_R)^2}{4b(n+1)^2} \end{aligned} \tag{10}$$

4. **Centralized Decision-Making.** If both parties can play cooperative games with the goal of maximizing the total profit of the supply chain, the wholesale price of the manufacturer to the retailer is the production cost c_M, and then the expression of the total profit of the supply chain is

$$\pi = (p - c_M - c_R)Q = (a - bQ - c_M - c_R)Q \tag{11}$$

Substitute $Q = \sum_{i=1}^{n} q_i$ into Equation (11). Since it has been assumed that there is no essential difference between the products of the manufacturers, and the retailer R is fair and non-discriminatory to manufacturer i, the first-order condition of q_i in Equation (11) can be obtained:

$$q_i^{**} = \frac{a - c_M - c_R}{2bn} \tag{12}$$

Then, the equilibrium result under centralized decision-making can be obtained:

$$Q^{**} = \frac{a - c_M - c_R}{2b} \tag{13}$$

$$p^{**} = \frac{a + c_M + c_R}{2} \tag{14}$$

$$\pi_{Mi}^{**} = 0, \quad \pi_R^{**} = \pi^{**} = \frac{(a - c_M - c_R)^2}{4b} \tag{15}$$

Property 4.1. *Whether it is a decentralized or centralized decision-making situation, the dominant retailer, at best, leaves the manufacturer with retained profits. With decentralizing decision-making, the sum of the multi-manufacturer profits is only $\frac{1}{n+1}$ of the retailer's profit. When decision-making is centralized, the gain of the supply chain is concentrated in the retailers, and the total profit of the supply chain is higher than that under decentralized decision-making.*

Proof: Comparing manufacturers, retailers, and supply chain profits

$$\Delta\pi_{Mi} = \pi_{Mi}^{**} - \pi_{Mi}^* = -\frac{(a - c_M - c_R)^2}{4b(n+1)^2} < 0$$

$$\Delta\pi_R = \pi_R^{**} - \pi_R^* = \frac{(a - c_M - c_R)^2}{4b(n+1)} > 0$$

$$\Delta\pi = \pi^{**} - \pi^* = \frac{(a - c_M - c_R)^2}{4b(n+1)^2} > 0$$

From Equations (10) and (15), the following inferences can be obtained.

Inference 4.1. *In the case of decentralized decision-making, as the number of manufacturers n increases, the retailer's profit increases, and the manufacturer's profit decreases.*

Inference 4.2. *The larger the number n of manufacturers, the closer the total profit of the supply chain under decentralized decision-making is to the profit of centralized decision-making.*

Since retailers are the leaders and manufacturers are followers, if the supply chain is to be stable, it is necessary to ensure reasonable profits for the supply chain members. Only when the manufacturer makes a centralized decision and obtains no less than the profit when a decentralized decision is made, can he actively participate in the centralization. The coordination of decision-making, therefore, requires a reasonable profit distribution mechanism.

5. **Coordination Mechanism of an $n : 1$ Supply Chain.** The role of the coordination mechanism is not only to make the profits of both manufacturers and retailers higher than before coordination, but also to be quantified and easy to operate. In the following, a research method from [18] is used for reference, the Shapley value method and the same profit growth rate method are used to distribute the profits of the supply chain system in centralized decision-making separately, and we study the applicable conditions of different distribution mechanisms.

5.1. **Shapley value method coordination mechanism.** When n members are engaged in a non-confrontational economic activity, the increase in the number of members participating in the action will not only not cause a decrease in benefits, but will increase the benefits, and the cooperation of all n members will bring the most significant overall benefits. In terms of benefit distribution, the Shapley value method can be used for distribution based on the contribution made by each member to the alliance.

In the Shapley value method, the profit distribution of each enterprise under cooperation I is recorded as $\phi(v) = [\phi_1(v), \phi_2(v), \ldots, \phi_n(v)]$ and among them $\phi_i(v)$ represents the distribution amount obtained by the i-th enterprise under cooperation I.

$$\phi_i(v) = \sum_{s \in s_i} w(|s|)[v(s) - v(s \backslash i)], \quad i = 1, 2, \ldots, n, \quad w(|s|) = \frac{(n - |s|!)(|s| - 1)!}{n!}$$

where s_i is all subsets of member i contained in set I, $|s|$ is the number of elements in subset s, $w(|s|)$ is the weighting factor, $v(s)$ is the benefit of subset s, $v(s \backslash i)$ is the number of elements removed from subset s's benefits after member i, and n is the number of elements in set I.

For the convenience of analysis, M is used to represent all manufacturers, and R is used to represent retailers. The calculation process of the Shapley value of manufacturers is shown in Table 1.

Table 1. Manufacturer Shapley value assignment calculation

s	M	$M \cup R$
$v(s)$	π_M^*	π^{**}
$v(s \backslash 1)$	0	π_R^*
$v(s) - v(s \backslash 1)$	π_M^*	$\pi^{**} - \pi_R^*$
$\|s\|$	1	2
$w(\|s\|)$	0.5	0.5
$w(\|s\|)[v(s) - v(s \backslash 1)]$	$\frac{\pi_M^*}{2}$	$\frac{\pi^{**} - \pi_R^*}{2}$

Adding up the data in the last row of Table 1, the profit distribution of the manufacturer is

$$\phi_M(v) = \frac{\pi^{**} + \pi_M^* - \pi_R^*}{2} = \frac{(2n+1)(a - c_M - c_R)^2}{8b(n+1)^2} \tag{16}$$

Similarly, the profit distribution of the retailer can be obtained as

$$\phi_R(v) = \frac{\pi^{**} + \pi_R^* - \pi_M^*}{2} = \frac{(2n^2+2n+1)(a - c_M - c_R)^2}{8b(n+1)^2} \tag{17}$$

Compared with the decentralized decision-making situation, it can be concluded that

$$\phi_M(v) - \pi_M^* = \frac{\pi^{**} + \pi_M^* - \pi_R^*}{2} - \pi_M^* = \frac{\pi^{**} - (\pi_M^* + \pi_R^*)}{2} = \frac{(a - c_M - c_R)^2}{8b(n+1)^2} > 0 \quad (18)$$

$$\phi_R(v) - \pi_R^* = \frac{\pi^{**} + \pi_R^* - \pi_M^*}{2} - \pi_R^* = \frac{\pi^{**} - (\pi_M^* + \pi_R^*)}{2} = \frac{(a - c_M - c_R)^2}{8b(n+1)^2} > 0 \quad (19)$$

Property 5.1. *By distributing the cooperative profits of manufacturers and retailers through the Shapley value method, the profits of all parties are higher than that under decentralized decision-making, and the higher amount is* $\frac{(a-c_M-c_R)^2}{8b(n+1)^2}$.

Therefore, before cooperation, if the manufacturer and the retailer reach a consensus on using the Shapley value method to distribute the cooperation profits, all parties will be motivated to collaborate to achieve a win-win improvement compared with independent decision-making.

5.2. **Coordination mechanism of the same profit growth rate.** To compare the applicability of different coordination mechanisms, we used the same profit growth rate method to distribute profits in centralized decision-making. Assuming that the profit growth rate under centralized decision-making is more decentralized than that of decentralized decision-making, r, we can obtain from $\frac{\pi^{**}}{\pi^*} = 1 + r$:

$$r = \frac{\pi^{**}}{\pi^*} - 1 = \frac{\frac{(a-c_M-c_R)^2}{4b}}{\frac{(n^2+2n)(a-c_M-c_R)^2}{4b(n+1)^2}} - 1 = \frac{1}{n(n+2)}$$

Then, under centralized decision-making, the profits distributed to manufacturers and retailers according to the same profit growth rate are

$$\Pi_M = (1+r)\pi_M^* = \frac{(n+1)^2}{n(n+2)} \cdot \frac{n(a - c_M - c_R)^2}{4b(n+1)^2} = \frac{(a - c_M - c_R)^2}{4b(n+2)} \quad (20)$$

$$\Pi_R = (1+r)\pi_R^* = \frac{(n+1)^2}{n(n+2)} \cdot \frac{n(a - c_M - c_R)^2}{4b(n+1)} = \frac{(n+1)(a - c_M - c_R)^2}{4b(n+2)} \quad (21)$$

The added value of profits in the case of more decentralized decision-making is

$$\Pi_M - \pi_M^* = \frac{(a - c_M - c_R)^2}{4b(n+2)} - \frac{n(a - c_M - c_R)^2}{4b(n+1)^2} = \frac{(a - c_M - c_R)^2}{4b(n+1)^2(n+2)} \quad (22)$$

$$\Pi_R - \pi_R^* = \frac{(n+1)(a - c_M - c_R)^2}{4b(n+2)} - \frac{n(a - c_M - c_R)^2}{4b(n+1)} = \frac{(a - c_M - c_R)^2}{4b(n+1)(n+2)} \quad (23)$$

Property 5.2. *Use the same profit growth rate to distribute the profits of centralized decision-making based on the earnings of decentralized, so that the earnings of manufacturers and retailers are increased in the same proportion; therefore,* $\Pi_M > \pi_M^*$, $\Pi_R > \pi_R^*$ *and* $\Pi_R > \Pi_M$.

5.3. **Profit comparison under different strategies.** The analysis of the above two coordination mechanisms shows that, whether using the Shapley value method or the same profit growth rate method to distribute the profits in centralized decision-making, the retailer's profit is always more significant than the sum of the profits of the manufacturers. Comparing the profits of manufacturers and retailers under the two allocation mechanisms, the following properties are obtained.

Property 5.3. $\Pi_R > \phi_R(v) > \phi_M(v) > \Pi_M$.

Proof: Compare the following results obtained from the above two allocation mechanisms.

$$\phi_M(v) - \Pi_M = \frac{(n+1)(a-c_M-c_R)^2}{8(n+2)(n+1)^2 b} > 0, \text{ which is } \phi_M(v) > \Pi_M$$

$$\Pi_R - \phi_R(v) = \frac{n(a-c_M-c_R)^2}{8(n+2)(n+1)^2 b} > 0, \text{ which is } \Pi_R > \phi_R(v)$$

It can be seen that although both coordination mechanisms can make the profits of manufacturers and retailer higher than that of non-cooperation, there are still differences in the size of the profits obtained by each party with different coordination methods. It is more beneficial for the manufacturer to use the Shapley value method, while it is more beneficial for the retailer to use the same profit growth rate method.

Calculated from $\phi_R(v)$, $\phi_M(v)$, Π_R, Π_M out of (16), (17), (20), (21), the profit added value $\frac{(a-c_M-c_R)^2}{8b(n+1)^2}$ of both parties when the Shapley value method is used in Formulas (18) and (19), and the profit added value $\frac{(a-c_M-c_R)^2}{4b(n+1)^2(n+2)}$ of the manufacturer and value $\frac{(a-c_M-c_R)^2}{4b(n+1)(n+2)}$ of the retailer when the same profit growth rate method is used in Formulas (22) and (23), give the following inference.

Inference 5.1. *In the above two coordination mechanisms, the changing trend of the profits of retailers and manufacturers with the number of manufacturers n is the same as that in decentralized decision-making; when reconciling using the Shapley method, the increase in profit is precisely the same for both parties and decreases with the increase in the number of manufacturers n. When using the same profit growth rate method for coordination, with the increase of manufacturers n, the added value of both parties' profits shows a decreasing trend, and the added value of the manufacturer's profit decreases faster.*

According to the assumptions of this paper, the retailer is the dominant enterprise in the supply chain system, so the retailer will tend to choose the same profit growth rate method for profit distribution. The profit obtained by the manufacturer is also more extensive than that in the non-cooperative game.

6. **Numerical Example.** Suppose $a = 2.5$, $b = 0.1$, $c_M = 0.35$, $c_R = 0.15$ and $n = 9$, and let the retailer be the dominant enterprise. The calculation results are shown in Table 2, and the results in Table 2 further verify the correctness of Property 4.1.

Table 2. Equilibrium results and comparison of decentralized decision-making and centralized decision-making

	Decentralized decision-making	Centralized decision-making	Balanced contrast
Manufacturer's profit	$\pi_M^* = 0.9$	$\pi_M^{**} = 0$	$\pi_M^{**} < \pi_M^*$
Retailer's profit	$\pi_R^* = 9$	$\pi_R^{**} = 10$	$\pi_R^{**} > \pi_R^*$
Supply chain profit	$\pi^* = 9.9$	$\pi^{**} = 10$	$\pi^{**} > \pi^*$

We choose the cell phone as a representative product category to conduct the numerical study. A data report from STATISTA shows that the manufacturing cost of the iPhone is in the range of $[0.16, 0.35]$ [19], and we choose $c_M = 0.35$ [20]. It shows that the cost of the retailer accounts for 35%-60% of the manufacturing cost, and we assume that $c_R = 0.15$. To ensure the positive value of the retailer price, we assume that $a = 2.5$ and $b = 0.1$ [21]. Without loss of generality, we also assume that $n = 9$ to represent the realistic scenario.

In decentralized and centralized decision-making, two coordination methods are used to distribute profits. The profits of manufacturers and retailers are shown in Table 3. When the retailer is the leading enterprise, the relationship between the profit size is consistent with Properties 5.1 and 5.2's conclusions.

It can be seen from Table 3 that the distribution of the cooperative profits of manufacturers and retailers through the Shapley value method and the same profit growth

TABLE 3. Comparison of profits under different situations

	Decentralized decision-making	Shapley value method	Profit growth rate	Balanced contrast
Manufacturer's profit	$\pi_M^* = 0.9$	$\phi_M(v) = 0.95$	$\Pi_M = 0.909$	$\phi_M(v) > \pi_M^*$, $\Pi_M > \pi_M^*$
Retailer's profit	$\pi_R^* = 9$	$\phi_R(v) = 9.05$	$\Pi_R = 9.09$	$\phi_R(v) > \pi_R^*$, $\Pi_R > \pi_R^*$

rate method can make the profits of all parties higher than that of decentralized decision-making. When the retailer is the dominant enterprise, it is most beneficial for the retailer to choose the profit growth rate method for distribution. When using the same profit growth rate method for distribution, the difference between the manufacturer's profit and the distributed decision-making profit is 0.009; the difference between the retailer's profit and the decentralized decision-making profit is 0.09. Obviously, using the same profit growth rate to distribute the profits of centralized decision-making based on the profits of decentralized decision-making, the results are $\frac{0.009}{0.909}$, $\frac{0.09}{9.09}$ respectively, and the profits of the manufacturers and retailer increased in the same proportion.

7. **Conclusion.** Based on game theory, this paper studies the coordination of an $n : 1$ supply chain composed of multiple manufacturers and a single retailer under the condition of complete information. Through comparing decentralized decision-making in non-cooperative games and centralized decision-making in cooperative games, we found that supply chain collaboration is an effective way for supply chain members to win together. For the coordination of multi-manufacturer homogeneous $n : 1$ supply chains under the condition of complete information, under the premise of a linear demand function, this paper used the Shapley value method and the same profit growth rate method. Distributing profits using the Shapley value method enables manufacturers and retailers to obtain the same profit increment; however, using the same profit growth rate method for distribution, the profits of both parties will be increased in the same proportion, and the profit gap will be further enlarged. No matter which coordination mechanism is adopted, as the number of manufacturers increases, the manufacturers' profits decrease and the retailers' profits increase. The coordination mechanism depends on the dominant position and bargaining power supply chain members. To maintain the stability of the entire supply chain, retailers should not choose too many manufacturers of homogeneous products for supply, and should make appropriate concessions to manufacturers. Manufacturers should also seek opportunities to form supply chains with more downstream companies, for example, supply chain coordination between supermarkets selling fresh milk, yogurt, and manufacturers; supply chain coordination between hotels requiring disposable consumables and manufacturers, etc. This provides a decision-making reference for the selection of $n : 1$ supply chain coordination strategies and cooperation objects in reality. This paper studied a supply chain system composed of homogeneous multi-manufacturers and a single retailer under complete information. In fact, the situation is usually more complicated, and dealing with asymmetric information, multi-layer supply chains, and multiple upstream enterprises with non-homogeneous synergy needs further study.

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