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Pricing of Two-Echelon Supply Chain under Retail Competition

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Abstract: The pricing decision of a two-echelon supply chain is considered in this paper. Two pricing models are established in the case of competition and non-competition. The optimal pricing strategy of the supplier and the retailer are obtained. The conditions of the formation of competition and the influence of competition on the supply chain are analyzed. The results show that the difference in operating efficiency and market share of retailers play an important role in the formation and impact of competition. Smaller differences in operating efficiency and market share make it easier for retailers to compete, but weaken the profits of the supply chain. When the market share difference is large and the operating efficiency difference of retailers is small, competition is beneficial to the supply chain, the supplier and strong retailers.

1. Introduction

With the rapid development of economy, nowadays suppliers often sell their products through multiple retailers. There are many forms of competition among retailers, such as products, price, quantity, service, inventory level, channel selection, etc.

Many scholars have discussed the influence of retailer competition on enterprise operation in the supply chain. Bernstein et al. studied whether a manufacturer should open a direct-sale experience store when the retailer sells the products of two competing manufacturers simultaneously [1]. Ingene and Parry studied the influence of Cournot competition behaviors of two retailers on product sales channels [2]. Perdikaki et al. studied the service decision timing of competitive retailers [3]. Tsay and Agrawal established models of sales effort level when retailers adopt price and service competition under the competitive environment of e-commerce and traditional sales channels [4]. Wang and Gerchak discussed the performance of a supply chain consisting of a manufacturer and two retailers in the case of different inventory levels on product shelves [5]. Wu et al. pointed out that in a supply chain consisting of a single supplier and multiple retailers, the degree of competition among retailers has a negative impact on the profits of each member in the supply chain [6]. Yang et al. discussed the manufacturer's optimal pricing and retailer's ordering decisions when duopoly retailers take different competitive behaviors (Cournot, Collusion and Stackelberg) [7].

Price competition is an important tool when different retailers sell the same products. This paper intends to solve several basic problems of retailers' price competition: (1) under what conditions can competition be formed? (2) What impact does the introduction of competition have on the supply chain and the decision-making of supply chain members? (3) Does competition necessarily benefit all members?

2. Model Description

2.1 Non-Competion Model

In the case of no competition, consider a secondary supply chain consisting of a supplier (S) and a monopolistic e-retailer (R). A supplier produces a product and sells it to a retailer, who has the entire market share. The supplier is the leader of the supply chain, and the retailer is the follower. The supplier first decides the wholesale price to maximize its own profit. The retailer then decides on retail prices to maximize its profit.

The problem of the supplier and the retailer is described as

$$\max_{w} \Pi = \left(w-c\right)q$$
$$s.t. \max_{p} \pi = \left(p-w-c_0\right)q,$$

where w and c are the supplier's wholesale price and marginal production cost respectively; p is the retail price of the retailer; c_0 is the operating cost of the retailer, which reflects the operating efficiency of the operator. Market demand q satisfies

$$q = A - bp. \qquad (1)$$

where A is the potential market size, b is the price elasticity coefficient and reflects the impact of retailer's pricing on its own demand.

2.2 Competition Model

In the competitive case, a two-echelon supply chain consists of one supplier (S) and two retailers (R_1 and R_2). Two retailers are of the same type and can be either e-retailers or traditional retailers. They compete in the same market. Their operational efficiency may be different. Their market shares may also differ. After the supplier decides the wholesale price, both the retailers simultaneously decide their retail prices to maximize their respective profits.

The demands of the two retailers are

$$\begin{aligned} q_1 &= kA - bp_1 + yp_2 \\ q_2 &= (1-k)A - bp_2 + yp_1 \end{aligned}, \qquad (2)$$

where k and $1-k$ are the market shares of retailers R_1 and R_2 respectively. p_i is the retail price of the retailer R_i (i=1,2), y is the cross price elasticity coefficient, which indicates the impact of retailer R_i's pricing on the demand for competitor R_{3-i}. According to the literature [8],suppose $b > y$,which means the retailer's pricing has a greater impact on its own demand than on the demand of competitors.

The profit of upstream supplier is

$$\Pi^C = (w^C - c)(q_1 + q_2), \qquad (3)$$

where w^C is the wholesale price of the supplier in competition case.

The profits of the two retailers are

$$\pi_1 = (p_1 - w^C - c_1)q_1, \quad \pi_2 = (p_2 - w^C - c_2)q_2 \tag{4}$$

where p_i is the retail price of the retailer R_i, c_i is the marginal operating cost of the retailer R_i, and higher marginal operating cost means lower operational efficiency. Without loss of generality, assume $c_1 \le c_2$, that is, the operational efficiency of the retailer R_1 is not lower than that of the retailer R_2.

3. Conditions for Optimal Decision Making and Market Competition

By the backward recursive method, the optimal pricing of the supplier and the retailer when there is no competition can be obtained as follows.

Proposition 1 When $b(c+c_0) < A$, the supplier's optimal wholesale price is $w = \frac{A+b(c-c_0)}{2b}$, the retailer's optimal retail price is $p = \frac{3A+b(c+c_0)}{4b}$. Correspondingly, the optimal demand is $q = \frac{A-b(c+c_0)}{4}$, the optimal profit of the supplier is $\Pi = \frac{(A-b(c+c_0))^2}{8b}$, the optimal profit of the retailer is $\pi = \frac{(A-b(c+c_0))^2}{16b}$.

Proof:Given the wholesale price of the supplier, substituting the demand function in Eq. (1) into the profit function of the retailer yields

$$\pi = (p-w-c_0)(A-bp).$$

The first order condition is $\frac{d\pi}{dp} = A - bp - (p-w-c_0) = 0$. Thus, the only stable point is $p = \frac{A+b(w+c_0)}{2b}$. From Eq. (1), it can be obtained

$$q = \frac{A-b(w+c_0)}{2}. \tag{5}$$

Substituting Eq.(5) into the profit function of the supplier yields the first order condition $\frac{d\Pi}{dw} = \frac{A-b(2w-c+c_0)}{2} = 0.$

Hence, the optimal wholesale price is $w = \frac{A+b(c-c_0)}{2b}$, followed by the optimal price, the optimal demand and the optimal profits of supply chain members.

Similar to the proof of proposition 1, the optimal prices of the supplier and the retailers in the competitive case is as follows.

Proposition 2 For simplicity, denote

$T_1 = \left[(8b-4y)k-(2b-3y)\right]A-\left(4b^2-2by-2y^2\right)c+\left(2b^2+3by-y^2\right)c_2-\left(6b^2+by-3y^2\right)c_1$ and

$T_2 = \left[(6b-y)-(8b-4y)k\right]A-\left(4b^2-2by-2y^2\right)c+\left(2b^2+3by-y^2\right)c_1-\left(6b^2+by-3y^2\right)c_2$.

When $(b-y)(2c+c_1+c_2) < A, T_1 > 0$ and $T_2 > 0$, the optimal wholesale price of the supplier is $w^C = \dfrac{A+(b-y)(2c-c_1-c_2)}{4(b-y)}$. The optimal retail price of the retailer R_1 is

$$p_1 = \frac{(2b^2+5by-4y^2)A}{4(b-y)(4b^2-y^2)} + \frac{kA}{2b+y} + \frac{bc}{2(2b-y)} + \frac{(6b-y)bc_1-(2b-3y)bc_2}{4(4b^2-y^2)};$$

The optimal retail price of the retailer R_2 is

$$p_2 = \frac{(2b^2+5by-4y^2)A}{4(b-y)(4b^2-y^2)} + \frac{(1-k)A}{2b+y} + \frac{bc}{2(2b-y)} + \frac{(6b-y)bc_2-(2b-3y)bc_1}{4(4b^2-y^2)}.$$

Correspondingly,the optimal demand of the retailer R_i is $q_i = bT_i$. The optimal profit of the supplier is $\Pi^C = \dfrac{b(A-(b-y)(2c-c_1-c_2))^2}{8(2b-y)(b-y)}$, the optimal profit of the retailer R_i is $\pi_i = \dfrac{bT_i^2}{16(4b^2-y^2)^2}$.

Proof:Given the wholesale price of the supplier, substituting the demands in Eq. (2) into the retailers' profits yields

$$\pi_1 = (p_1 - w^C - c_1)(kA - bp_1 + yp_2),$$

$$\pi_2 = (p_2 - w^C - c_2)((1-k)A - bp_2 + yp_1).$$

The first order condition can deduce that

$$\frac{d\pi_1}{dp_1} = kA + \left(w^C - 2p_1 + c_1\right)b + yp_2 = 0 \qquad (6)$$

and

$$\frac{d\pi_2}{dp_2} = (1-k)A + \left(w^C - 2p_2 + c_1\right)b + yp_1 = 0 \qquad (7)$$

Solving Eqs. (6) and (7) yields $p_1 = \dfrac{(2bk-ky+y)A + 2b^2\left(w^C+c_1\right) + by\left(w^C+c_2\right)}{4b^2-y^2}$ and $p_2 = \dfrac{(2bk-ky-2b)A - 2b^2\left(w^C+c_2\right) - by\left(w^C+c_1\right)}{4b^2-y^2}$, which is followed by

$$q_1 = \frac{\left((2bk-ky+y)A - (2b^2-y^2)\left(w^C+c_1\right) + by\left(w^C+c_2\right)\right)b}{4b^2-y^2}$$

and

$$q_2 = -\frac{\left((2bk-ky-2b)A + \left(2b^2-y^2\right)\left(w^C+c_2\right) - by\left(w^C+c_1\right)\right)b}{4b^2-y^2}.$$

Substituting the above q_1 and q_2 into Eq. (3) yields the following first condition

$$\frac{d\Pi^C}{dw^C} = \frac{\left(A+(b-y)(2c-c_1-c_2) - 4(b-y)w^C\right)b}{2b-y} = 0,$$

which induces the optimal wholesale price and followed by the optimal prices, the optimal demands and the optimal profits of supply chain members.

The condition $A-(b-y)(2c+c_1+c_2)>0$ is equivalent to $w^C - c > 0$, which ensures that the supplier's profit margin is positive. The condition $T_i > 0$ is equivalent to $p_i - w^C - c_i > 0$ and $q_i > 0$,that is, the retailer's margin profit and demand are both positive, which means that competition can be formed.

It can be seen from Proposition 2 that the retailers' market shares and operating efficiencies play an important role in the formation of equilibrium. The following analyses the specific conditions of competition formation according to the market shares and operating efficiencies of retailers is analyzed in the following.

Corollary 1 Suppose $c_1 \le c_2$, $A > \max\{(b-y)(2c+c_1+c_2),(b+y)(c_2-c_1)\}$.

(1) If $(2b+y)(b-y)(2c+c_1+c_2)+(2b-3y)A < 2(2b-y)(b+y)(c_2-c_1)$,then competition between retailers can certainly take place for all $k \in (0,1)$;

(2) If $(2b+y)(b-y)(2c+c_1+c_2)+(2b-3y)A \ge 2(2b-y)(b+y)(c_2-c_1)$,then competition between retailers can certainly take place only when $k \in (k_3, k_4)$,where

$$k_1 = \frac{(2b-3y)A+(2b+y)(b-y)(2c+c_1+c_2)-2(2b-y)(b+y)(c_2-c_1)}{4(2b-y)A}$$

and

$$k_2 = \frac{(6b-y)A-(2b+y)(b-y)(2c+c_1+c_2)-2(2b-y)(b+y)(c_2-c_1)}{4(2b-y)A}.$$

Proof:From Proposition 1, it can be obtained that $T_1 > 0$ if and only if $k > k_1$,and $T_2 > 0$ if and only if $k < k_2$.

It is easy to verify that

$$k_2 - k_1 = \frac{(2b+y)(A-(b-y)(2c+c_1+c_2))}{2(2b-y)A} > 0$$

and

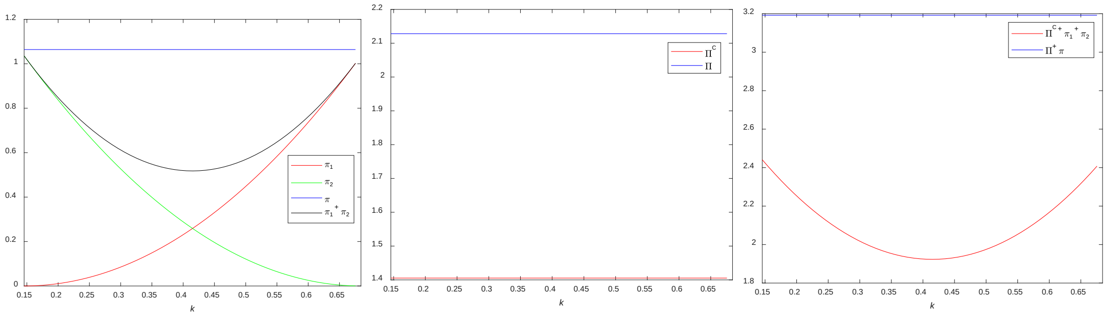
$$k_2 + k_1 = 1 - \frac{(b+y)(c_2-c_1)}{A}.$$

Therefore, if $A \le (b-y)(2c+c_1+c_2)$,then $k_2 \le k_1$,so there is no competition. If $A \le (b+y)(c_2-c_1)$,then $k_2 + k_1 \le 0$,so there is also no competition. Otherwise, we have $A > \max\{(b-y)(2c+c_1+c_2),(b+y)(c_2-c_1)\}$. In this case, if $(2b+y)(b-y)(2c+c_1+c_2) < 2(2b-y)(b+y)(c_2-c_1)-(2b-3y)A$,then $k_1 < 0 < k_2$ because of $2(2b-y)(b+y)(c_2-c_1)-(2b-3y)A < (6b-y)A-2(2b-y)(b+y)(c_2-c_1)$ .Thus, $k_2 > 1$. If $(2b+y)(b-y)(2c+c_1+c_2) \ge 2(2b-y)(b+y)(c_2-c_1)-(2b-3y)A$,then $0 \le k_1 < k_2 < 1$.

Corollary 1 shows that market competition is possible only when the total cost of the supply chain and the difference in operating efficiency between the two retailers are not sufficiently large. When the operating efficiency gap between two retailers is big, market competition can be formed regardless of their market share. When the operating efficiency gap between two retailers is small, the market competition can only be formed when the market share gap between them is also small.

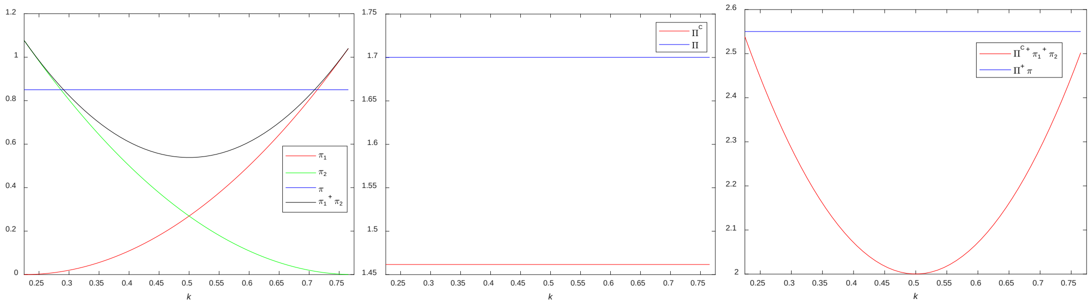
4. Impact of Competition

In this section, some numerical examples will be used to analyze the impact of the introduction of competition on the entire supply chain and its members. Suppose $c = 0.6, b = 1.2,$?$y = 0.5$. According to the differences of potential market capacity and operational efficiency, some analysis results can be obtained in the following (as seen Figures 1-4).



a-1 a-2 a-3

(a) $A = 5, c_0 = 0.2, c_1 = 0.2, c_2 = 0.7$

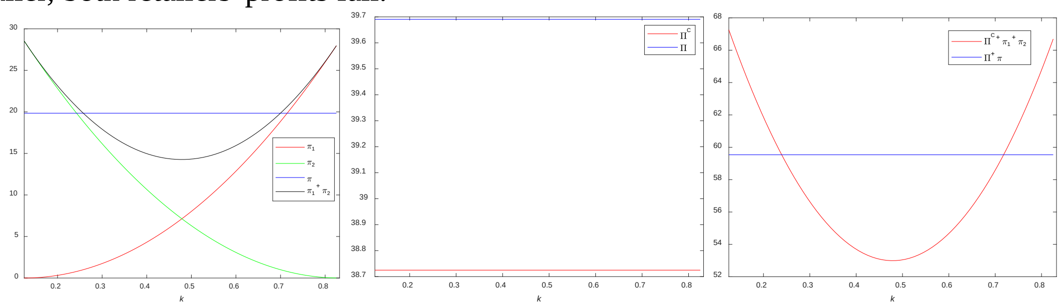


b-1 b-2 b-3

(b) $A = 5, c_0 = 0.4, c_1 = 0.4, c_2 = 0.4$

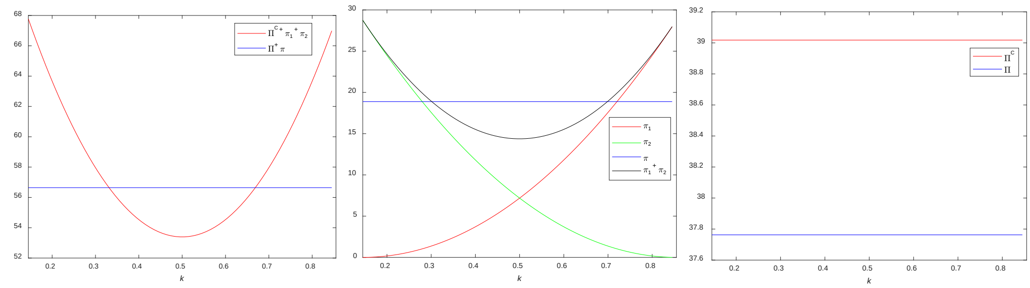
Fig.1 Impact of Competition on Profits When Potential Market Capacity is Small

Figure 1 shows the impact of the introduction of competition on the supply chain and the profits of supply chain members when the potential market capacity is small. The introduction of competition reduces the profits of the entire supply chain and the supplier. Whether the retailers decrease their profit depends on the difference in operating efficiency. When the operating efficiency of the two retailers is different, their profits have been reduced due to the introduction of competition. When the operating efficiency is the same and the market share gap is large, the introduction of competition increases the profits of strong retailer (retailer with a large market share) and reduces the profits of weak retailer (retailer with a small market share). When the market share gap is smaller, both retailers' profits fall.



a-1 a-2 a-3

(a) $A = 20, c_0 = 0.2, c_1 = 0.2, c_2 = 0.7$

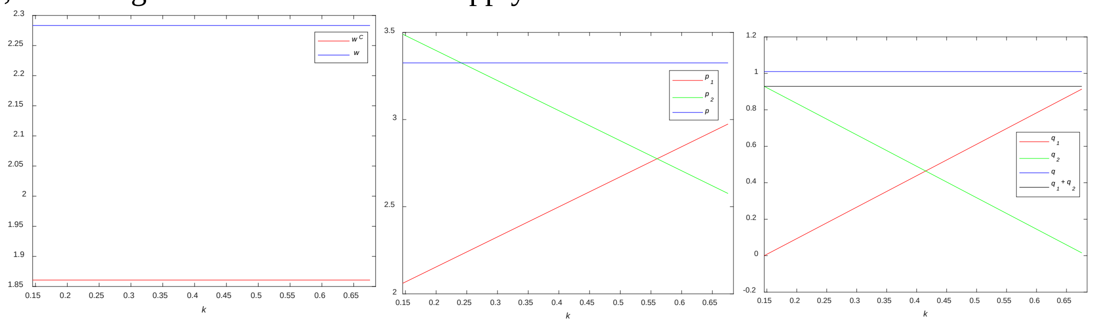


b-1 b-2 b-3

(b) $A = 20, c_0 = 0.4, c_1 = 0.4, c_2 = 0.4$

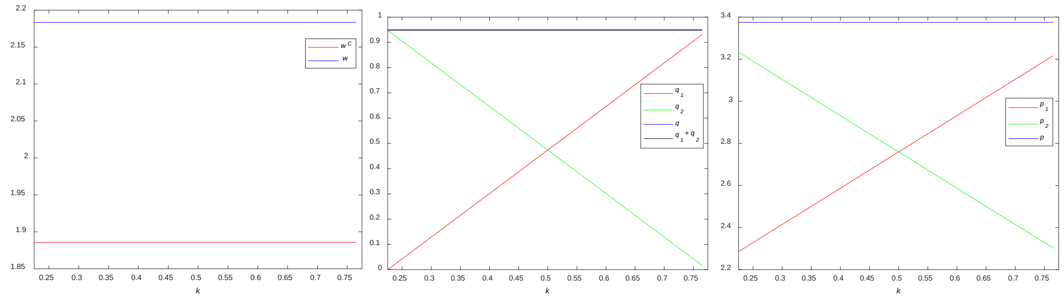
Fig.2 Impact of Competition on Profits When Potential Market Capacity is Large

Figure 2 shows the impact of competition on the supply chain and the profits of supply chain members when the market potential is large. When the market share gap is large, the profits of the whole supply chain and the strong retailer in the competitive situation are higher than those in the non-competitive situation. When the market share gap is smaller, these profits will decrease. The introduction of competition increases the profits of the supplier when two retailers have the same operating efficiency. This means that when the market potential capacity is large, the operating efficiency of retailers is the same, and the market share gap is large, competition is beneficial to suppliers, the strong retailer and the whole supply chain.



a-1 a-2 a-3

(a) $A = 5, c_0 = 0.2, c_1 = 0.2, c_2 = 0.7$

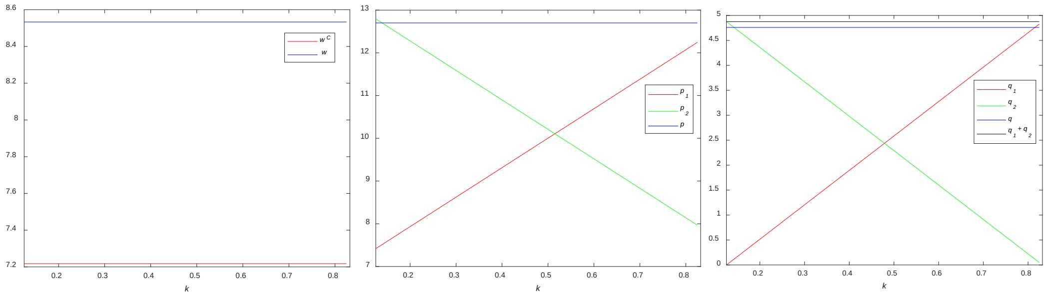


b-1 b-2 b-3

(b) $A = 5, c_0 = 0.4, c_1 = 0.4, c_2 = 0.4$

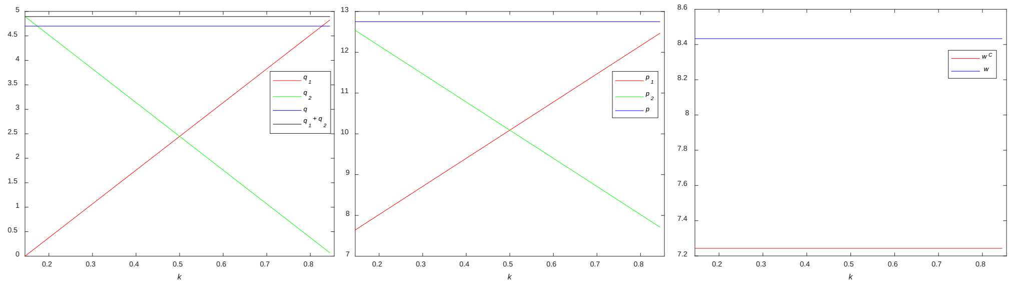
Fig.3 Impact of Competition on Prices and Demands When Potential Market Capacity is Small

Figure 3 shows the impact of competition on the optimal prices and demands when the market potential capacity is small. After introducing competition, the supplier and the retailer with higher efficient operations will lower their prices. The retailer with less efficient operations will raise retail price when it has less market share.



a-1 a-2 a-3

(a) $A=20, c_0=0.2, c_1=0.2, c_2=0.7$



(b) $A=20, c_0=0.4, c_1=0.4, c_2=0.4$

Fig.4 Impact of Competition on Prices and Demands When Potential Market Capacity is Large

Figure 4 shows the impact of competition on the optimal prices and demands when the market potential capacity is large. With the increase of potential market capacity, the price difference between competitive and non-competitive market becomes larger, so does the demand difference.

5. Conclusion

This paper uses game theory to analyze the pricing strategies of upstream suppliers and downstream retailers in a two-echelon supply chain under competitive and non-competitive conditions. The condition of competition formation is discussed and the influence of competition on supply chain is analyzed. The limitation of this paper is that it does not consider the competition between different types of retailers, which is the next research direction.

Acknowledgments

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