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Pricing Analysis on a Dual-Channel Supply Chain When Delivery Lead Time is Introduced

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ABSTRACT. With the development of e-commerce, more and more consumers are shopping online, which has led several manufacturers to redesign their sales strategy and open online sales channel. Online and offline channels form the dual-channel supply chain. However, consumers have to wait before receiving the products they bought. The duration between time when a consumer places an order on the Internet and time when he receives what he bought is called the delivery lead time. It is an important index in channel choice of consumers, which is introduced into the operation of the dual-channel supply chain. A dual-channel supply chain consisting of one manufacturer and one retailer is studied in this paper, and the supply chain is considered as a manufacturer Stackelberg game model. The impact of the delivery lead time on the operation of the supply chain is analyzed in this paper. The two-part tariff contract is used to coordinate the supply chain when making the decentralized decision. At last, numerical examples are given to show the optimal decisions in the supply chain when the delivery lead time is different.

KEYWORDS: Delivery lead time, Dual-channel supply chain, Two-part tariff contract

1. Introduction

With the development of e-commerce, more and more consumers are shopping online, which has led several manufacturers to redesign their sales strategy and open an online sales channel. The online and offline channels form dual-channel supply chains. For example, many well-known manufacturers sell their products through online channel, including DELL, IBM, HP, Apple, Nike, Coca-Cola, Budweiser and Campbell's Soup. These companies also sell their products in physical stores around the world.

However, consumers have to wait before receiving the products they bought. The duration between time when a consumer places an order on the Internet and time when he receives what he bought is called the delivery lead time. It is an important index in channel choice of consumers, which is introduced into the operation of dual-channel supply chain.

In this paper, a dual-channel supply chain consisting of one manufacturer and one retailer is studied, and the supply chain is considered as a manufacturer-led Stackelberg game. The delivery lead time is introduced into the demand part of the dual-channel supply chain. Decisions about pricing and sales quantity in the centralized and decentralized supply chain are obtained under optimization theory and game theory. A supply chain contract is used to coordinate the supply chain when making decentralized decision. Finally, optimal decisions in supply chain are shown in numerical examples when the delivery lead time is different.

2. Basic Model

This study analyzed a dual-channel supply chain composed of one manufacturer (she) and one traditional retailer (he), in which the manufacturer sells the same kind of short-life cycle product in her online channel and traditional channel. The supply chain is considered as a manufacturer-led Stackelberg game. The total market demand is $a(a>0)$. The manufacturer sells the product to the retailer at a wholesale price w, and the retailer sells the product at a retail price p_t. The manufacturer sells the product at the retail price p_e in her electronic channel in which the market share is $\phi(0<\phi<1)$. It is assumed that there is no price competition between the electronic channel and the traditional channel in this study. The assumption is the same as that of Baker *et al.* and Chen *et al.*, that is, $p_e = p_t = p$.

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Delivery lead time refers to the duration between the time when a consumer places an order on the Internet and the time when he receives the order offline. Delivery lead time is the total time between when consumers buy products online and when they receive the products offline. The delivery lead time is zero if consumers buy products in physical stores, which plays an important role in consumer channel choices. Thus, delivery lead time is introduced in the demand function. In general, more customers will buy products online if the delivery lead time is shorter, and fewer customers will buy products offline in this scenario; in contrast, more customers will buy products offline if the delivery lead time is longer, and fewer customers will buy products online in this scenario. To analyze the impact of delivery lead time on the electronic and traditional channels, the demand function in this study is written as follows:

$$\begin{cases} q_e = \phi a - (1-\theta_1)p - mt \\ q_t = (1-\phi)a - (1-\theta_2)p + nt \end{cases}. \quad (1)$$

The delivery lead time sensitivity coefficient in the electronic channel is m and that in the traditional channel is n, where $m > n > 0$. In the demand function, if the delivery lead time is increased by one unit, the demand in the electronic channel will decrease by m units, and the demand in the traditional channel will increase by n units. The unit cost of the product in the electronic channel is c_e, which includes the unit production cost and the unit transportation cost. The unit delivery cost related to product distribution is βt, where $\beta > 0$ and the delivery lead time of the unit product is $t(t \geq 0)$. Thus, the unit cost of the product in the electronic channel is $c_e(t) = c_e + \beta t$. The unit transportation cost of the product in the traditional channel is c_t. For simplicity, we assume that other unit costs of products are zero. The cross-price coefficients in the electronic channel and in the traditional channel are θ_1 and θ_2, respectively. Referring to the assumption of Raju and Abhik (2000) and Yue and Liu (2006), we also assume that the cross-price effect is symmetric, that is, $\theta_1 = \theta_2 = \theta$.

According to these assumptions, the retailer profit function is written as

$$\pi_r = (p - w)q_t. \quad (2)$$

The manufacturer profit function is written as

$$\pi_m = (p - c_e - \beta t)q_e + (w - c_t)q_t. \quad (3)$$

The total supply chain profit function is written as

$$\pi_T = \pi_m + \pi_r = (p - c_e - \beta t)q_e + (p - c_t)q_t. \quad (4)$$

To ensure that there are management implications in the model established earlier, the following restrictions are included: (i) $q_e \geq 0$; (ii) $q_t \geq 0$; (iii) $p \geq \max\{c_e + \beta t, c_t\}$; (iv) $p \geq w \geq 0$. Condition (iii) ensures that the marginal profit in both channels is no less than zero. Condition (iv) ensures that the retailer cannot purchase his products in the electronic channel.

3. Decision and Profit Analyses in the Dual-Channel Supply Chain

3.1 Centralized Decisions in the Dual-Channel Supply Chain

According to the assumptions in section 2, the manufacturer, that is, the supply chain leader, decides the retail price and the corresponding sales quantity in the centralized decision (represented by c). The total profit function of the supply chain is written as

$$\pi_c = (p - c_e - \beta t)[\phi a - (1-\theta)p - mt] + (p - c_t)[(1-\phi)a - (1-\theta)p + nt]. \quad (5)$$

Obviously, π_c is a strictly concave function with respect to p. The optimal retail price in the supply chain is obtained using the first-order condition. Furthermore, the optimal sales quantity in different channels and the total profit of the supply chain are also obtained.

The optimal retail price is

$$p_c^* = \frac{a-(m-n)t}{4(1-\theta)} + \frac{c_e + c_t + \beta t}{4}. \quad (6)$$

The optimal sales quantity in different channels is

$$\begin{cases} q_e^* = \dfrac{1}{4}[(4\phi-1)a-(1-\theta)(c_e+c_t+\beta t)-(3m+n)t] \\ q_t^* = \dfrac{1}{4}[(3-4\phi)a-(1-\theta)(c_e+c_t+\beta t)+(m+3n)t] \end{cases}. \quad (7)$$

The total profit of the supply chain is

$$\pi_c^* = (p_c^* - c_e - \beta t)q_e^* + (p_c^* - c_t)q_t^*. \quad (8)$$

The total profit function obtained in this section is complex, and hence, the corresponding result is illustrated using numerical examples in section 5.

3.2 Decentralized Decisions in the Dual-Channel Supply Chain

According to the assumptions in section 2, the manufacturer and traditional retailer do business according to their own interests in the decentralized decisions (represented by d). The decisions are analyzed using the leader-follower game principle.

In decentralized decisions, the retail price determined by the retailer is obtained with respect to (2). Using the first-order condition, we obtain the following retail price:

$$p^{(d)} = \frac{(1-\phi)a + nt}{2(1-\theta)} + \frac{w}{2}. \quad (9)$$

By substituting (9) into (3), the wholesale price determined by the manufacturer is obtained according to the first-order condition as

$$w^{(d)*} = \frac{\phi a - mt}{3(1-\theta)} + \frac{c_e + c_t + \beta t}{3}. \quad (10)$$

By substituting (10) into (9), the retail price determined by the retailer is

$$p^{(d)*} = \frac{(3-2\phi)a + (3n-m)t}{6(1-\theta)} + \frac{c_e + c_t + \beta t}{6}. \quad (11)$$

Thus, the sales quantities in the online and offline channels are

$$\begin{cases} q_e^{(d)*} = \dfrac{1}{6}[(8\phi-3)a-(1-\theta)(c_e+c_t+\beta t)-(5m+3n)t] \\ q_t^{(d)*} = \dfrac{1}{6}[(3-4\phi)a-(1-\theta)(c_e+c_t+\beta t)+(m+3n)t] \end{cases}. \quad (12)$$

The retailer profit is

$$\pi_r^{(d)} = \frac{4}{9(1-\theta)}(q_t^*)^2. \quad (13)$$

The manufacturer profit is

$$\pi_m^{(d)} = (p_c^* - c_e - \beta t + \frac{q_t^*}{3(1-\theta)})(q_e^* - \frac{1}{12}q_t^*) + \frac{11}{12}(p_c^* - c_t - \frac{q_t^*}{3(1-\theta)})q_t^*. \quad (14)$$

The total profit of the supply chain is

$$\pi_T^{(d)} = (p_c^* - c_e - \beta t + \frac{q_t^*}{3(1-\theta)})(q_e^* - \frac{1}{12}q_t^*) + \frac{11}{12}(p_c^* - c_t + \frac{q_t^*}{3(1-\theta)})q_t^*. \quad (15)$$

3.3 Comparison of the Total Profits in Different Decisions

The difference between the total profit of the supply chain in the centralized decision and that in the decentralized decision is

$$\Delta\pi = \pi_c^* - \pi_T^{(d)} = \frac{2}{9(1-\theta)}(q_t^*)^2 > 0 \cdot \qquad (16)$$

Equation (16) shows that there is a "double marginalization effect" in the dual-channel supply chain. A supply chain contract can be used to coordinate the supply chain, which will be discussed in the next section. In addition, it can be seen that the profit margin in this scenario increases in the delivery lead time if the other parameters in the model are fixed. In other words, the difference in the total profit in the two decisions increases when the delivery lead time increases.

4. Coordinating the Dual-Channel Supply Chain

According to the definition of supply chain coordination, a supply chain is coordinated if the total profit of the supply chain in the decentralized decision is equal to that in the centralized decision. To coordinate the manufacturer-led dual-channel supply chain, it is necessary to make the retail price in the decentralized decision equal to that in the centralized decision. Furthermore, there must be a motive for each member in the supply chain to participate. In other words, the profit of each member with the supply chain contract is no less than its profit without the supply chain contract. The two-part tariff contract is used to coordinate the manufacturer-dominant dual-channel supply chain in this section.

In this study, the supply chain members act according to the maximization principle of the entire supply chain and implement a two-part tariff contract, $(W\ ,T\ )$, in which the manufacturer sells the product to the retailer at the wholesale price w and, at the same time, charges the retailer a transfer payment T. Thus, each member's profit function is shown as follows.

The retailer's profit function is

$$\pi_r^{(1)} = (p-w)q_t - T\ . \qquad (17)$$

The manufacturer's profit function is

$$\pi_m^{(1)} = (p-c_e-\beta t)q_e + (w-c_t)q_t + T\ . \qquad (18)$$

The retail price determined by the retailer is obtained with respect to (17). Using the first-order condition, we calculate that the retail price is

$$p^{(1)} = \frac{(1-\phi)a+nt}{2(1-\theta)} + \frac{w}{2} \cdot \qquad (19)$$

The retail price is obtained after solving the corresponding equations in this section, which is equal to that in the previous section, so we make $p^{(1)} = p_c^*$. That is, we make the retail price in the decentralized decision equal to that in the centralized decision. Then, we determine that the wholesale price determined by the manufacturer is

$$w^{(1)*} = \frac{(2\phi-1)a-(m+n)t}{2(1-\theta)} + \frac{c_e+c_t+\beta t}{2} \cdot \qquad (20)$$

The retail price determined by the retailer in this scenario is

$$p^{(1)*} = \frac{a-(m-n)t}{4(1-\theta)} + \frac{c_e+c_t+\beta t}{4} \cdot \qquad (21)$$

Hence, the manufacturer's profit is

$$\pi_m^{(1)*} = (p_c^*-c_e-\beta t)q_e^* + (p_c^*-c_t)q_t^* - \frac{1}{1-\theta}(q_t^*)^2 + T\ \cdot \qquad (22)$$

The retailer's profit is

$$\pi_r^{(1)*} = \frac{1}{1-\theta}(q_t^*)^2 - T \quad . \tag{23}$$

To realize the Pareto improvement of the profit of each supply chain member when using the two-part tariff contract, the profit of each member with the contract must be no less than its profit in the decentralized decision, which means that the profit of each member in this study must satisfy the following constraints:

$$\begin{cases} \pi_m^{(1)*} \geq \pi_m^{(d)} \\ \pi_r^{(1)*} \geq \pi_r^{(d)} \end{cases} .$$

According to the above constraints, we obtain the interval of the transfer payment T . Therefore, the dual-channel supply chain is coordinated. A numerical example will be used to show the results obtained in this section. The interval obtained in this case is

$$T \in \left[\frac{(q_e^* + 2q_t^*)\, q_t^*}{3(1-\theta)} - \frac{1}{12}\pi_c^*, \frac{5}{9(1-\theta)}(q_t^*)^2 \right].$$

5. Numerical Studies

Numerical examples are used to illustrate the results obtained in the previous sections. Parameters in the model are set as follows. The market scale is $a = 1200$, and the market share is $\phi = 0.5$. The cross-price coefficient in the electronic and traditional channels is $\theta = 0.4$. The unit cost of the product in the electronic channel is $c_e = 4$, and the unit transportation cost of the product in the traditional channel is $c_t = 6$. The delivery lead time sensitivity coefficient in the electronic channel is $m = 0.5$ and that in the traditional channel is $n = 0.3$. The sensitivity coefficient of the delivery lead time is $\beta = 0.3$. The decision variables of the supply chain members and their impacts on the supply chain performance are shown in the following tables. Comparisons of supply chain performances with different delivery lead times are illustrated in Table 2, where the transfer payment in the two-part tariff contract is $T = 60000$.

Table 1 Decisions in The Supply Chain without the Contract.

t	p_c^*	$w^{(d)}$	$p^{(d)}$	$\pi_m^{(1)}$	$\pi_r^{(1)}$	π_T
0	502.50	336.67	668.33	198005	66002	264007
2	502.48	336.31	668.66	197221	66272	263493
4	502.47	335.96	668.98	196437	66542	262979
6	502.45	335.60	669.30	195654	66813	262467
8	502.43	335.24	669.62	194871	67085	261956

Table 2 Decisions in The Supply Chain with the Two-Part Tariff Contract.

t	$w^{(1)*}$	$p^{(1)*}$	q_e^*	q_t^*	$\pi_m^{(1)*}$	$\pi_r^{(1)*}$	π_T^*
0	5.00	502.50	298.50	298.50	208504	88504	297008
2	3.97	502.48	297.51	299.11	207517	89111	296628
4	2.93	502.47	296.52	299.72	206530	89721	296251
6	1.90	502.45	295.53	300.33	205544	90330	295874
8	0.87	502.43	294.54	300.94	204557	90941	295498

Tables 1 and 2 show that the total supply chain profits with the two-part tariff contract are always larger than those without the contract, and the profits of the manufacturer and retailer are also improved. Table 2 shows that the wholesale price, the retail price, and the online sales quantity decrease when the delivery lead time increases. The profits of the manufacturer and the total supply chain profit also decrease when the delivery lead time increases. However, the offline sales quantity and the profits of the retailer increase when the delivery lead time increases, which is in accordance with what occurs in real life. The delivery lead time is zero if consumers buy products in physical stores, which is one of the advantages existing in physical stores. Therefore, more consumers will buy products offline if the delivery lead time increases. Additionally, it is noted that there are some differences in the optimal prices determined by the manufacturer and the retailer before and after using the two-part tariff contract. This is mostly related to the parameters set in the model and the complexity of the equations obtained in this research.

6. Conclusion

A dual-channel supply chain consisting of one manufacturer and one retailer is studied in this paper, in which the manufacturer owns online channel and sells products through offline channel. There is no price competition in the supply chain. The supply chain is considered as a Stackelberg game in which the manufacturer is the leader and the retailer is the follower. The delivery lead time is introduced into the operation of the dual-channel supply chain. In the centralized decision, the optimal retail price undergoes different changes if the delivery sensitivity coefficient in the electronic channel and traditional channel satisfies different conditions. The two-part tariff contract is used to coordinate the supply chain when making the decentralized decision. Numerical examples are given to show the optimal decisions in the supply chain when the delivery lead time is different.

The study about the operation of supply chain is a new field, and there are many problems worth exploring in the future. For example, the decision and coordination strategy in the supply chain with stochastic demand are challenging work, and there are few studies related to this field. In general, there exists price competition in the dual-channel supply chain, and there are some new problems worth studying when price competition is taken into account. Furthermore, other factors can be introduced into the supply chain, which include promotion and innovation. There are some other interesting problems existing in consumer’s choice for scholars home and abroad to discuss in the near future.

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