Optimizing Channel Profit in a Retail Dual-channel Supply Chain When Considering Delivery Lead Time

Gan Wan1,2 and Jun Zhang2,3*

1Department of Business Administration, Huashang College, Guangdong University of Finance and Economics, Guangzhou, China
2School of Management and Economics, University of Electronic Science and Technology of China, Chengdu, China
Email: wan_gan@126.com
3Faculty of Business, Kunming Metallurgy College, Kunming, China
Email: zjun434@sina.com.cn

Abstract. With the development of e-commerce, more and more consumers are shopping online, which has led several traditional retailers to redesign their sales strategy to include an online sales channel. Their online and offline channels form dual-channel supply chains. However, consumers have to wait before receiving the products they buy. The time elapsed is called delivery lead time which is an important index in consumer’s channel choice. There are few studies in this new field with studies in dual-channel supply chain being more common. In this paper, a dual-channel supply chain in which there are one manufacturer and one retailer is studied, and the retailer has an online and an offline channel at the same time. The supply chain is considered as a retailer-dominant Stackelberg game. The delivery lead time is introduced into the operation of the supply chain. 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. Finally, the optimal decisions of the supply chain members when the delivery lead time is different are shown using numerical examples.

1. Introduction
Recent years have witnessed the worldwide growth of e-commerce. This trend has vastly changed consumption habits, which in turn has greatly affected the production and operation of manufacturers and retailers. More and more consumers are shopping online, which has led several retailers to redesign their sales strategy to include online sales channels. In doing so, they can expand market share, control channel prices, and ultimately gain more profits. Their online and offline channels form dual-channel supply chains. For example, many well-known retailers sell their products through online and offline channels, which include Bestbuy, Bloomingdales, Wal-Mart, Target, Gome, and Suning, two Chinese companies [1].

To reduce the competition between electronic channels and traditional channels, different manufacturers and retailers around the world try to implement different pricing and channel strategies. Some manufacturers sell different products in different channels. While in China, Suning, a giant retailer, implements an equal retail price for its products in online and offline channels, which completely subverts the entire retail industry in China. Since then, many companies begin to implement such a pricing strategy to reduce channel competition.
However, consumers have to wait before receiving the products they buy. The time elapsed is called delivery lead time, which is an important index in consumer’s channel choice. In this paper, a dual-channel supply chain which is consisted of one manufacturer and one retailer is studied, and the retailer has an online and an offline channel at the same time. The supply chain is considered as a retailer-dominant Stackelberg game. The delivery lead time is introduced into the operation of the supply chain. The impact of the delivery lead time on the operation of the supply chain is analyzed. The two-part tariff contract is used to coordinate the dual-channel supply chain when making the decentralized decision. Finally, the optimal decisions of the supply chain members when the delivery lead time is different are shown using numerical examples.

2. The Assumptions and the Model

This study analyzes a supply chain which is composed of one manufacturer (she) and one retailer (he). The retailer owns both an online channel and a traditional channel. He sells the same short-life cycle product in both channels. The supply chain is considered as a retailer-dominant Stackelberg game. The total market demand is \( d(a > 0) \). The manufacturer sells the product at a wholesale price \( w \). The retailer sells the product in his electronic channel at a retail price \( p_e \), and he sells the product in his traditional channel at a retail price \( p_t \). The market share in the online channel is \( \phi(0 < \phi < 1) \). It is assumed that there is no price competition between the electronic channel and the physical channel. The assumption is the same as that of Baker et al. and Chen et al., that is, \( p_e = p_t = p \) [2-3].

Delivery lead time is referred to as the duration between the time when a consumer places his order on the Internet and the time when he receives the order offline [4]. In general, more customers will buy products online if the delivery lead time the retailer sets is short, and fewer customers will buy products offline in this scenario; in contrast, more customers will buy products offline if the delivery lead time is long, and fewer customers will buy products online in this scenario. The delivery lead time is zero if consumers buy products in physical stores. Thus, delivery lead time plays an important role in consumer channel choices, and it is introduced in this study [5-7]. To analyze the impact of delivery lead time on both the electronic and traditional channels, we suppose that the demand function is written as follows:

\[
\begin{align*}
q_e &= \phi a - (1 - \theta) p - m t \\
q_t &= (1 - \phi) a - (1 - \theta) p + n t
\end{align*}
\]

The delivery lead time sensitivity coefficient in the electronic channel is \( m \) and that in the physical channel is \( n \), where \( m > n > 0 \). In the demand function, if the delivery lead time the retailer offers 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 production cost for the product is \( c_m \), and the unit transportation cost for the product is \( c_t \), which is undertaken by the retailer. The unit delivery cost related to product distribution in the electronic channel is \( \beta t \), where \( \beta > 0 \) and the delivery lead time of the unit product the retailer offers is \( t(t \geq 0) \)[6-8]. Thus, the unit logistics cost of the product in the electronic channel is \( c_e(t) = c_e + \beta t \). For simplicity, it is assumed that other unit costs of the product are zero. The cross-price coefficients are the same both in the electronic channel and in the traditional channel, i.e., \( \theta \), which means that the cross-price effect in the two channels is symmetric (Raju and Roy, 2000; Yue and Liu, 2006) [9-10].

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

\[\pi_e = (p - w - c_e)(q_e + q_t) - \beta q_e \]

The manufacturer profit function is written as

\[\pi_m = (w - c_m)(q_e + q_t)\]

The total profit function of the supply chain is written as
\[ \pi^T = \pi_m + \pi_s = (p - c_m - c_r)(q_r + q_s) - \beta tq_r \]  

(4)

To ensure that there are management implications in the model established earlier, we suppose that the following restrictions are included: (i) \( q_r \geq 0 \); (ii) \( q_s \geq 0 \); (iii) \( p - w c_e + \beta t \); (iv) \( p \geq w c_m \geq 0 \) [11-13]. Condition (iii) ensures that the marginal profit of the retailer in his online and offline channels is no less than zero. Condition (iv) ensures that the marginal profit of the manufacturer is no less than zero and that of the retailer is also no less than zero.

3. Model Solution and Discussion

3.1. Centralized Setting

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

\[ \pi^c = (p - c_m - c_r)[a - 2(1 - \theta)p - (m - n)t] - \beta t[\phi a - (1 - \theta)p - mt] \]  

(5)

Obviously, \( \pi^c \) is a strictly concave function with respect to \( p \). We can obtain the optimal retail price in the supply chain according to the first-order condition. Furthermore, the optimal sales quantity in different channels and the total supply chain profit can be obtained.

The optimal retail price is

\[ p^{c*} = \frac{a - (m - n)t}{4(1 - \theta)} + \frac{2c_m + \beta t + 2c_r}{4} \]  

(6)

The optimal sales quantity in the online channel and that in the offline channel are

\[
q_r^* = \frac{1}{4}[(4\phi - 1)a - (1 - \theta)(2c_m + 2c_r + \beta t) - (3m + n)t] \\
q_s^* = \frac{1}{4}[(3 - 4\phi)a - (1 - \theta)(2c_m + 2c_r + \beta t) + (m + 3n)t] 
\]  

(7)

The total supply chain profit is

\[ \pi^{c*} = (p^{c*} - c_m - c_r)(q_r^* + q_s^*) - \beta tq_r^* \]  

(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 Setting

According to the assumptions in the previous section, the manufacturer and the retailer do business according to their own interests in the decentralized decisions (represented by \( d \)). It is assumed that the retail price the retailer sets is depended on both the wholesale price and the marginal profit of the product, i.e., \( p = w + k \). The decisions are analyzed using the leader-follower game in which the retailer is the price leader. Stage 1: the retailer decides the marginal profit of the product. Stage 2: the manufacturer decides the wholesale price she offers to the retailer [11-12].

In a decentralized setting, the wholesale price set by the manufacturer is obtained with respect to (3). Using the first-order condition, we obtain the response function of the wholesale price with respect to the marginal profit determined by the retailer:

\[ w^{d*} = \frac{1}{4} \left( \frac{a - (m - n)t}{1 - \theta} + 2c_m - 2k \right) \]  

(9)

By substituting (9) into (2), the marginal profit determined by the retailer is obtained according to the first-order condition as

\[ k^{d*} = a - (m - n)t - \frac{2c_m - \beta t - 2c_r}{4(1 - \theta)} \]  

(10)

By substituting (10) into (9), the wholesale price determined by the manufacturer is
Furthermore, we obtain that the retail price set by the retailer is
\[ p_{ret}^{a^*} = \frac{3[a - (m - n)t]}{8(1 - \theta)} + \frac{2c_m + \beta t + 2c_r}{8} \] (12)
Thus, the sales quantities in the online channel and that in the offline channel are
\[
\begin{align*}
q_e^{a^*} &= \frac{1}{8} [(8\phi - 3)a - (1 - \theta)(2c_m + 2c_r + \beta t) - (5m + 3n)r] \\
q_i^{a^*} &= \frac{1}{8} [(5 - 8\phi)a - (1 - \theta)(2c_m + 2c_r + \beta t) + (3m + 5n)r]
\end{align*}
\] (13)
The retailer profit is
\[ \pi_r^{a^*} = \frac{1}{4(1 - \theta)} (q_e^{*} + q_i^{*})^2 - \frac{1}{2} \beta t(q_e^{*} - q_i^{*}) \] (14)
The manufacturer profit is
\[ \pi_m^{a^*} = \frac{1}{8(1 - \theta)} (q_e^{*} + q_i^{*})^2 \] (15)
The total supply chain profit is
\[ \pi_T^{a^*} = \frac{3}{8(1 - \theta)} (q_e^{*} + q_i^{*})^2 - \frac{1}{2} \beta t(q_e^{*} - q_i^{*}) \] (16)

3.3. Comparison
The difference between the total supply chain profit in the centralized decision and that in the decentralized decision is
\[ \Delta \pi = \pi_T^{c^*} - \pi_T^{a^*} = \frac{1}{8(1 - \theta)} (q_e^{*} + q_i^{*})^2 > 0 \] (17)
Equation (17) shows that there is a “double marginalization effect” in the supply chain. A supply chain contract can be used to coordinate the dual-channel supply chain, which will be discussed in the next section.

4. Supply Chain Coordination
According to the definition of supply chain coordination, a dual-channel supply chain is coordinated if the total supply chain profit in the decentralized setting is equal to that in the centralized setting. To coordinate the retailer-dominant dual-channel supply chain, it must make the retail price in the decentralized decision equal to that in the centralized decision. Furthermore, there must be a motive for the supply chain members to participate [13]. 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 retailer-dominant supply chain in this section [14].

Furthermore, each supply chain member in this study acts according to the profit maximization principle of the entire supply chain and implements a two-part tariff contract \( (W, T) \). According to the contract, the manufacturer sells the product at the wholesale price \( w \) and, at the same time, the retailer charges the manufacturer a transfer payment \( T \). Thus, the profit function of each supply chain member is shown as follows.

The manufacturer’s profit function is
\[ \pi_m' = (w - c_m)(q_e + q_i) - T \] (18)
The retailer’s profit function is
\[ \pi_r' = (p - w - c_i)(q_e + q_i) - \beta tq_e + T \] (19)
According to the leader-follower game principle, we obtain the response function of the wholesale price set by the manufacturer with respect to the marginal profit set by the retailer at first. The wholesale price set by the manufacturer is obtained with respect to (18). That is

\[
w' = \frac{1}{4} \left[ \frac{a-(m-n)t}{1-\theta} + 2c_m - 2k' \right]
\]

(20)

According to the equilibrium condition of how to coordinate the supply chain with the two-part tariff contract, we suppose that \( p^\ast = w' + k' = p^c \). The marginal profit determined by the retailer is obtained solving the above equation. The marginal profit is

\[
k^\ast = \frac{\beta t + 2c_r}{2}
\]

(21)

By substituting (21) into (20), we determine that the wholesale price set by the manufacturer is

\[
w^\ast = \frac{1}{4} \left[ \frac{a-(m-n)t}{1-\theta} + 2c_m - \beta t - 2c_r \right]
\]

(22)

The retail price set by the retailer in this scenario is

\[
p^\ast = \frac{a-(m-n)t}{4(1-\theta)} + \frac{2c_m + \beta t + 2c_r}{4}
\]

(23)

Thus, the manufacturer’s profit is

\[
\pi_m^\ast = \frac{1}{2(1-\theta)} (q^\ast_r + q^\ast_c)^2 - T
\]

(24)

The retailer’s profit is

\[
\pi_r^\ast = \frac{\beta t}{2} (q^\ast_r - q^\ast_c) + T
\]

(25)

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:

\[
\begin{align*}
\pi_m^c &\geq \pi_m^d \\
\pi_r^c &\geq \pi_r^d
\end{align*}
\]

According to the above constraints, we obtain that the interval of the transfer payment \( T \) is

\[
T \in \left[ -\frac{1}{4(1-\theta)} (q^\ast_r + q^\ast_c)^2, \frac{3}{8(1-\theta)} (q^\ast_r + q^\ast_c)^2 \right]
\]

(26)

Therefore, the supply chain profit in this study is maximized. It is noted that the retailer will pay the manufacturer the transfer payment if it is less than zero. Numerical examples will be used to show the results obtained in this section.

5. Numerical Examples

Numerical examples are used to show the results obtained in the two previous sections. Parameters in the model are set as follows. The market scale of the product is \( a = 1500 \), and the market share in the online channel is \( \phi = 0.5 \). The cross-price coefficient in the electronic and traditional channels is \( \theta = 0.4 \). The unit product cost of the product is \( c_m = 3 \), and the unit transportation cost of the product is \( c_r = 5 \). The delivery lead time sensitivity coefficient in the electronic channel is \( m = 0.62 \) and that in the traditional channel is \( n = 0.35 \). The sensitivity coefficient of the delivery lead time is \( \beta = 0.25 \). The supply chain members’ decisions including the wholesale price and the retail price and their influences 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 1 and 2, where the transfer payment in the two-part tariff contract after the negotiation between the supply chain members
is $T = 135000$. The difference between table 1 and table 2 lies in whether the supply chain contract is used or not.

**Table 1.** Decisions in the supply chain without the contract.

| $t$ | $p^c$ | $w^d$ | $p^d$ | $\pi_m^d$ | $\pi_r^d$ | $\pi^f$ |
|-----|-------|-------|-------|------------|------------|--------|
| 0   | 629.00| 313.50| 939.50| 115692     | 231385     | 347077 |
| 1   | 628.95| 313.41| 939.36| 115627     | 231254     | 346881 |
| 3   | 628.85| 313.24| 939.09| 115497     | 230995     | 346492 |
| 5   | 628.75| 313.06| 938.81| 115367     | 230736     | 346103 |
| 7   | 628.65| 312.89| 938.54| 115236     | 230479     | 345715 |

**Table 2.** Decisions in the supply chain with the two-part tariff contract.

| $t$ | $w^*$ | $p^*$ | $q^s_*$ | $q^r_*$ | $\pi_m^*$ | $\pi_r^*$ | $\pi^f^*$ |
|-----|-------|-------|---------|---------|------------|------------|-----------|
| 0   | 624.00| 629.00| 372.60  | 372.60  | 327769     | 135000     | 462769    |
| 1   | 623.83| 628.95| 372.01  | 372.98  | 327508     | 135001     | 462509    |
| 3   | 623.48| 628.85| 370.83  | 373.74  | 326987     | 135001     | 461988    |
| 5   | 623.13| 628.75| 369.65  | 374.50  | 326466     | 135003     | 461469    |
| 7   | 622.78| 628.65| 368.47  | 375.26  | 325945     | 135006     | 460951    |

Tables 1 and 2 show that the total profits in the supply chain with the two-part tariff contract are always larger than those without the contract, and the profits of supply chain members 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 manufacturer’s profit and the total supply chain profit decrease when the delivery lead time increases. However, the offline sales quantity and the retailer’s profits in the offline channel 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. It is assumed in this section that the transfer payment the retailer earns in this section occupies more than half of what the manufacturer earns. In reality, why many leading retailers including Wal-mart, Suning and Gome succeed mainly lies in that they have more channel resources. Thus, they have stronger power in negotiation with other manufacturers and suppliers. This is why we set the transfer payment in this section. Additionally, it is noted that there are some differences in the optimal wholesale prices decided by the manufacturer and the optimal retail prices decided by the retailer before and after using the two-part tariff contract. This is due to the parameters set in the model and the complexity of the equations obtained in this research.

6. Conclusions

A dual-channel supply chain which is composed of one manufacturer and one retailer is studied in this paper, in which the retailer owns both online and offline channels and sells a short-life cycle product in both channels. There is no price competition in the different sales channels. The supply chain is considered as a Stackelberg game. We suppose that the retailer is the price leader and the manufacturer is the price follower. The delivery lead time is introduced into the operation of the supply chain, and it is considered as an exogenous variable in this study. In the centralized decision, the optimal retail price undergoes different changes if the delivery sensitivity coefficient in the electronic and traditional channels satisfies different conditions. There exists the “double-marginalization” phenomenon in the supply chain when making decentralized decisions. The two-part tariff contract is used to coordinate the dual-channel supply chain. Numerical examples are given to show the optimal decisions for each supply chain member when the delivery lead time is different.
The research about the operation of the supply chain discussed in this study 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 different sales channels, and there are some new problems worth studying when price competition is taken into account. Furthermore, other factors, including retailer promotion and technology innovation, can be introduced into the supply chain. There are other interesting problems existing in these fields for scholars home and abroad to explore in the future.

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