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Coordinating Dual-Channel Supply Chain Under Price Mechanism With Production Cost Disruption

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Abstract

This paper studies a two-stage dual-channel supply chain consisting of one manufacturer and one traditional retailer. The manufacturer has its own online channel when he sells the product to the offline retailer. There exists a Stackelberg game between the manufacturer and the offline retailer, in which the manufacturer is the leader and the retailer is the follower. The manufacturer abandons the pricing right in the online channel and adopts the marketing strategy which the online retail price is equal to the offline one. When the supply chain is in a static (undisrupted) condition, it can obtain Pareto improvement and eventually be coordinated by a two-part-tariff contract with a one-time transfer payment. When disruptions make the manufacturer's unit production cost change, we can obtain the retail price, the production quantity and the total supply chain profit under different disruption levels in the centralized supply chain. Then, we find that there are some certain robustness both in the manufacturer's production quantity and in the offline retail price. When the supply chain is decentralized, we can coordinate the supply chain by changing the wholesale price according to different disruption levels. Finally, some numerical examples are presented to illustrate the results.

Key words: Disruption; Price mechanism; Two-part-tariff contract; Coordination

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INTRODUCTION

Large retail companies setting online channels, such as SuNing in China, are committed to promoting the "Online2Offline" mode, which is the new marketing mode and sets the same retail price in online and offline channels. Many large retail giants besides SuNing have also started building e-stores dedicated to attract consumers which set the same online and offline price. On the other hand, electric retail giant such as Tmall also begins to build offline experience shop. Although price mechanism is faced with some problems in practice, it has become a trend to coordinate dual-channel supply chain with the development of electronic commerce.

With the development of society and economy, E-commerce has become an important mode for manufacturers to do their business. Self-built electronic channel and traditional channel form dual-channel supply chain under E-commerce. Several studies have examined dual-channel supply chains. Rhee and Park (2000) study a hybrid channel design problem, assuming that price sensitive segment and service sensitive segment are two consumer segments. Chiang et al. (2003) examine a price-competition game in a dual-channel supply chain, the supply chain can be coordinated by some supply chain contracts such as the wholesale price contract, the buyback contract, the revenue-sharing contract, the two-part-tariff strategy and other supply chain contracts. Ryan et al. (2013) consider a dual-channel supply chain in which a manufacturer sells a single product to end-users through both an offline retail channel and a manufacturer-

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owned direct online channel，and proposes an improved revenue-sharing contract and gain/loss sharing contract to coordinate the supply chain.

Disruptions have a deep effect on the operation of supply chain. Natural disasters such as earthquakes, tsunamis and landslides, public health emergencies which include SARS, H7N9, and man-made emergencies such as terrorist attacks affect the operation of the stable supply chain. To cope with the supply chain's disruptions has become a very valuable issue for companies around the world. Qi et al. (2004) first introduce the idea of disruption management in supply chain management. In their paper, they consider deviation costs. If the demand exceeds the original production quantity, underage cost can happen. Based on disruptive management, many researchers have extended their studies in various scenarios in the supply chain. Huang et al. (2006) investigate how to coordinate a dyadic supply chain when the retailer faces an exponential demand function. The major differences in those studies lie in that the market demand functions used are different. Xu (2006) studies a kind of supply chain coordination problem when the production cost function is a convex one. Lei (2012) uses a linear contract to handle supply chain coordination in asymmetric information when demand and cost disruptions happen. As to the researches of multi-retailer supply chain, Xiao et al. (2005, 2007, 2008) study how to coordinate a supply chain with one manufacturer and two competing retailers when demands and costs are disrupted. Huang et al. (2012) consider the disruption management in a dual-channel supply chain under demand disruptions. Huang et al. (2013) also study a pricing and production problem in a dual-channel supply chain when production costs are disrupted in the centralized and decentralized dual-channel supply chain.

These related studies generally consider the difference between centralized and decentralized decision-making. There are few researchers in the field that examine a particular contract under the coordination of disruption management in dual-channel supply chain. The same situation is true for studies in exploring equal-price marketing model in dual-channel supply chain. In this paper, we examine the price mechanism in the marketing model, the feasibility of coordinating a dual-channel supply chain with two-part-tariff contract, the decision in dual-channel supply chain when cost disruption occurs, and the mechanism design to coordinate the supply chain with two-part-tariff contract. Finally, some numerical examples are shown to illustrate the related results.

1. BASIC MODEL

There exist one manufacturer and one offline retailer in a two-stage supply chain. The manufacturer orders its product from both offline channel and online retail channel. The retail price is the same both in the online channel and offline channel.

1.1 Notation

The notation used for the model is shown in Table 1.

Table1
Notation and Parameters for the Problems

Value	Description	Test values
a	Total market demand	2000
θ	Demand proportion of online channel	0.4
b_1	Price coefficient in the online channel	10
b_1	Price coefficient in the offline channel	20
p	Unit sale price in O2O channel	Decision variable
c_m	Unit manufacturing cost	10
c_r	Unit offline channel sales cost	6
c_d	Unit online channel sales cost	4
Δc_m	Unit production cost disruption	12,8,4,0,-2,-6,-10
k_1	Marginal costs when production plan increases	5
k_2	Marginal costs when production plan decreases	5
p	Unit sale price in O2O channel after disruption	Decision variable
w	The wholesale price of offline channel	Decision variable

1.2 The Basic Model

We build a demand function considering both online channel and offline channel：

$$\begin{cases} q_1 = \theta a - b_1 p \\ q_2 = (1-\theta)a - b_2 p \end{cases}. \quad (1)$$

The profit function is derived by the following equation:

$$\Pi = (p - c_m - c_d)(\theta a - b_1 p) + (p - c_m - c_r)[(1-\theta)a - b_2 p]. \quad (2)$$

We obtain the optimal solution by solving the first-order condition, i.e., $\partial \Pi / \partial p = 0$ .Thus, the optimal sales price, the production quantities and the total profit of the dual-channel supply chain are

$$\bar{p} = \frac{a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r}{2(b_1 + b_2)}$$, and

$$\begin{cases} \bar{q}_1 = \theta a - \dfrac{b_1[a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r]}{2(b_1 + b_2)} \\ \bar{q}_2 = (1-\theta)a - \dfrac{b_2[a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r]}{2(b_1 + b_2)} \end{cases},$$

$$\bar{\Pi} = \frac{(a + b_1 c_d - b_2 c_r)^2}{4(b_1 + b_2)} + \frac{[b_1(c_m + c_d) - a](c_m + c_r)}{2} + \frac{(b_2 - b_1)(c_m + c_r)^2}{4} + a\theta(c_r - c_d),$$

respectively.

2. COORDINATION OF SUPPLY CHAIN UNDER A STABLE STATE

In the dual-channel compensation mechanism, the manufacturer is the leader of this game and can decide the wholesale price and transfer payment. The offline retailer decides to order product quantity and set the sale price in the supply chain. Based on the Stackelberg game theory, the retailer's profit function can be written as.

$$\pi_r = (p - w - c_r)[(1-\theta)a - b_2 p] - T. \quad (3)$$

The response function of the optimal retail price is

$$p = \frac{(1-\theta)a + b_2(c_r + w)}{2b_2}$$

the wholesale price is

$$w^* = \frac{a + b_1(c_d - c_r)}{(b_1 + b_2)} + c_m - \frac{(1-\theta)a}{b_2},$$

the retail price is

$$p^* = \frac{a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r}{2(b_1 + b_2)} = \overline{p},$$

the profit of the retailer is

$$\pi_r^* = \frac{(b_2^2 c_m - ab_2 - 2ab_1 + b_2^2 c_r + b_1 b_2 c_m + 2\theta ab_1 + 2\theta ab_2 + ab_1 b_2 c_m)^2}{4b_2(b_1 + b_2)^2} - T$$

and the profit of the manufacturer is

$$\pi_d^* = \frac{[(b_1 + b_2)c_m + (b_1 + 2b_2)c_d - b_2 c_r - a](b_1^2 c_m + ab_1 + b_1 b_2 c_m + b_1^2 c_d + b_1 b_2 c_r - 2\theta ab_1 - 2\theta ab_2)}{4(b_1 + b_2)^2}$$
$$- \frac{[2a(\theta - 1)(b_1 + b_2) + b_2(a + b_1 c_m + b_2 c_m + b_2 c_r + ab_1 c_m)](\theta ab_1 - ab_1 + \theta ab_2 - b_1 b_2 c_r + b_1 b_2 c_d)}{2b_2(b_1 + b_2)^2} + T,$$

respectively.

The total profit of the supply chain is $\Pi^* = (\pi_d^* + \pi_r^*) = \overline{\Pi}$.

Lemma 1. *If a dual-channel supply chain faces a demand function shown in Equation (1), the participants' profits in the equal-price supply chain can achieve Pareto improvement and the total profit of the supply chain can be maximized by the two-part-tariff pricing contract* (w,T):

$w^* = \frac{a + b_1(c_d - c_r)}{(b_1 + b_2)} + c_m - \frac{(1-\theta)a}{b_2}$, and

$$T^* \in [\frac{[b_2^2(c_m + c_r) - ab_2 - 2ab_1 + b_1 b_2(c_m + c_d) + 2\theta ab_1 + 2\theta ab_2]^2}{4(b_1 + b_2)^2(b_1 + 2b_2)},$$
$$\frac{(2b_1 + 3b_2)[b_2^2(c_m + c_r) - ab_2 - 2ab_1 + b_1 b_2(c_m + c_d) + 2\theta ab_1 + 2\theta ab_2]^2}{4(b_1 + b_2)^2(b_1 + 2b_2)^2}]$$

Proof.

In the independent decision-making state without contracts, the profit function of the offline retailer is

$$\pi_r = (p - w - c_r)[(1-\theta)a - b_2 p] - T.$$

The optimal price response function is

$$p = \frac{w + c_r}{2} + \frac{(1-\theta)a}{2b_2}.$$

The manufacturer's profit function is

$$\pi_d = [\frac{(1-\theta)a + wb_2}{2b_2} - c_m - c_d][\theta a - b_1 \frac{(1-\theta)a + wb_2}{2b_2}] + (w - c_m)[\frac{(1-\theta)a - wb_2}{2}] + T.$$

The optimal wholesale price is

$$w^0 = \frac{b_2(c_m + c_d - c_r) - (1-\theta)a}{b_2} - \frac{b_2(c_m + 2c_d - c_r) - 3a + 2\mu a}{b_1 + 2b_2}.$$

Therefore, the retailer's profit in the dual-channel supply chain is

$$\pi_r^0 = \frac{(b_2^2 c_m - ab_2 - 2ab_1 + b_2^2 c_r + b_1 b_2 c_m + 2\theta ab_1 + 2\theta ab_2 + ab_1 b_2 c_m)^2}{4b_2(b_1 + 2b_2)^2} < \pi_r^*.$$

The difference of the retailer's profit between π^*_r and π^0_r is

$$\pi_r^* - \pi_r^0 = \frac{(2b_1 + 3b_2)[b_2^2(c_m + c_r) - ab_2 - 2ab_1 + b_1 b_2(c_m + c_d) + 2\theta ab_1 + 2\theta ab_2]^2}{4(b_1 + b_2)^2(b_1 + 2b_2)^2} - T.$$

The profit of the manufacturer is

$$\pi_d^0 = \frac{(6a + b_1 c_m + 2b_1 c_d - b_1 c_r - 4\theta a)^2}{16(b_1 + 2b_2)} - \frac{a(c_m + c_r)}{4} + \frac{b_1(3c_m^2 - c_r^2 + 4c_m c_d + 2c_m c_r + 4c_d c_r)}{16} + \frac{b_2(c_m + c_r)^2}{8} - \frac{a^2(1-\theta)^2}{b_2} - \frac{\theta a(c_m + c_d - c_r)}{2}.$$

The difference of the manufacturer's profit between π^*_d and π^0_d is

$$\pi_d^* - \pi_d^0 = \frac{-[b_2^2(c_m + c_r) - ab_2 - 2ab_1 + b_1 b_2(c_m + c_d) + 2\theta ab_1 + 2\theta ab_2]^2}{4(b_1 + b_2)^2(b_1 + 2b_2)} + T.$$

In order to achieve Pareto improvement, the profits of the manufacturer and the retailer should satisfy

$$\begin{cases} \pi_d^* - \pi_d^0 \ge 0 \\ \pi_r^* - \pi_r^0 \ge 0 \end{cases}.$$

Therefore, the range of the one-time transfer payment is

$$T^* \in [\frac{[b_2^2(c_m + c_r) - ab_2 - 2ab_1 + b_1 b_2(c_m + c_d) + 2\theta ab_1 + 2\theta ab_2]^2}{4(b_1 + b_2)^2(b_1 + 2b_2)},$$
$$\frac{(2b_1 + 3b_2)[b_2^2(c_m + c_r) - ab_2 - 2ab_1 + b_1 b_2(c_m + c_d) + 2\theta ab_1 + 2\theta ab_2]^2}{4(b_1 + b_2)^2(b_1 + 2b_2)^2}]$$

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3. CENTRALIZED DECISION AFTER COST DISRUPTION

Centralized decision-making in the supply chain is to study the overall optimal supply chain pricing and production plan in an integrated way. Then, some unexpected events occur, which leads to some changes in the manufacturer's production cost after the manufacturer arranges production plan according to market forecast in stable state. In the disruption model, the demand functions of the supply chain are

$$\begin{cases} \tilde{q}_1 = \theta a - b_1 \tilde{p} \\ \tilde{q}_2 = (1-\theta)a - b_2 \tilde{p} \end{cases} . \quad (4)$$

As the result of the disruption, the manufacturer needs to increase the production plan when $\tilde{q}_1 + \tilde{q}_2 > q_1^* + q_2^*$, and needs to reduce the production quantity when $\tilde{q}_1 + \tilde{q}_2 < q_1^* + q_2^*$. We assume that there is a central decision-maker who seeks to maximize the total supply chain profit after the uncertainty is resolved. The new expression for the supply chain profit function is derived from the following equations

$$\tilde{\Pi} = (\tilde{p} - c_m - c_d - \Delta c_m)(\theta a - b_1 \tilde{p}) + (\tilde{p} - c_m - c_r - \Delta c_m)[(1-\theta)a - b_2 \tilde{p}] \\ - k_1(\tilde{q}_1 + \tilde{q}_2 - q_1^* - q_2^*)^+ - k_2(q_1^* + q_2^* - \tilde{q}_1 - \tilde{q}_2)^+ \quad (5)$$

in which $(x)^+ = \max\{x, 0\}$.

In Equation (5), the third term on the right side of the equation is the cost associated with the increase of production quantity and the fourth term is the cost associated with the decrease of production quantity.

If $\tilde{q}_d + \tilde{q}_r \geq q_d^* + q_r^*$, the total profit of the supply chain can be rewritten as:

$$\tilde{\Pi}_1 = (\tilde{p} - c_m - c_d - \Delta c_m)(\theta a - b_1 \tilde{p}) + (\tilde{p} - c_m - c_r - \Delta c_m) \\ [(1-\theta)a - b_2 \tilde{p}] - k_1[a - (b_1 + b_2)\tilde{p} - q_1^* - q_2^*] . \quad (6)$$

If $\tilde{q}_d + \tilde{q}_r \leq q_d^* + q_r^*$, the total profit of the supply chain can be rewritten as:

$$\tilde{\Pi}_2 = (\tilde{p} - c_m - c_d - \Delta c_m)(\theta a - b_1 \tilde{p}) + (\tilde{p} - c_m - c_r - \Delta c_m) \\ [(1-\theta)a - b_2 \tilde{p}] - k_2[q_1^* + q_2^* - a + (b_1 + b_2)\tilde{p}] . \quad (7)$$

Lemma 2. *Suppose that* $\tilde{\Pi}$ *in Equation (5) is maximized by* $(\tilde{q}_1^*, \tilde{q}_2^*)$. *Then,* $\tilde{q}_1^* + \tilde{q}_2^* \leq q_1^* + q_2^*$ *if* $\Delta c_m > 0$, *and* $\tilde{q}_1^* + \tilde{q}_2^* \geq q_1^* + q_2^*$ *if* $\Delta c_m < 0$.

Proof. Recall the baseline case that $\bar{Q} = q_1^* + q_2^* = (a - c_m)/2 - (b_1 c_d + b_2 c_r)/2$. Inserting the value into Equation (1), we obtain that $\tilde{\Pi}(\tilde{Q})$ is maximized at $\tilde{Q} = \bar{Q}$ when $\Delta c_m = 0$.

Consider the equation $\tilde{\Pi}(\bar{Q}) = \Pi^* - \Delta c_m \bar{Q}$. Suppose that $\Delta c_m > 0$ and $\tilde{q}_1^* + \tilde{q}_2^* > q_1^* + q_2^*$. Then,

$$\tilde{\Pi}(\tilde{Q}^*) = \tilde{\Pi}(\tilde{Q}) - \Delta c_m \tilde{Q} - k_1(\tilde{Q} - \bar{Q}) \leq \Pi^* - \Delta c_m \tilde{Q} - k_1(\tilde{Q} - \bar{Q}) < \tilde{\Pi}(\bar{Q}) .$$

This contradicts the assumption that $\tilde{\Pi}(\tilde{Q})$ is maximized at $\bar{Q}$. Therefore, we must have $\tilde{q}_1^* + \tilde{q}_2^* \leq q_1^* + q_2^*$ when $\Delta c_m > 0$. Similarly, we get $\tilde{q}_1^* + \tilde{q}_2^* \geq q_1^* + q_2^*$ when $\Delta c_m < 0$.

When the disruption suddenly happens and makes the unit production cost increase, i.e., $\Delta c_m > 0$, we obtain that

$$\tilde{\Pi}_1 = (\tilde{p} - c_m - c_d - \Delta c_m)(\theta a - b_1 \tilde{p}) + (\tilde{p} - c_m - c_r - \Delta c_m) \\ [(1-\theta)a - b_2 \tilde{p}] - k_1[a - (b_1 + b_2)\tilde{p} - q_1^* - q_2^*] \\ \text{s.t.}\ \tilde{q}_1^* + \tilde{q}_2^* \geq q_1^* + q_2^* \quad (8)$$

There are two cases in the supply chain, which are shown as follows:

Case1: $\Delta c_m \leq -k_1$

$$\tilde{p}_1^* = \frac{a + b_1 c_d + b_2 c_r}{2(b_1 + b_2)} + \frac{c_m + \Delta c_m + k_1}{2}$$, and

$$\begin{cases} \tilde{q}_{11}^* = \theta a - \dfrac{b_1[a + (c_m + \Delta c_m + k_1)(b_1 + b_2) + b_1 c_d + b_2 c_r]}{2(b_1 + b_2)} \\ \tilde{q}_{21}^* = (1-\theta)a - \dfrac{b_2[a + (c_m + \Delta c_m + k_1)(b_1 + b_2) + b_1 c_d + b_2 c_r]}{2(b_1 + b_2)} \end{cases} .$$

Case2: $-k_1 < \Delta c_m < 0$

$$\tilde{p}_2^* = p^* = \frac{a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r}{2(b_1 + b_2)}$$, and

$$\begin{cases} \tilde{q}_{12}^* = q_1^* = \theta a - \dfrac{b_1[a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r]}{2(b_1 + b_2)} \\ \tilde{q}_{22}^* = q_2^* = (1-\theta)a - \dfrac{b_2[a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r]}{2(b_1 + b_2)} \end{cases} .$$

When the disruption suddenly happens and makes the unit production cost decrease, i.e., $\Delta c_m < 0$, we obtain that

$$\tilde{\Pi}_2 = (\tilde{p} - c_m - c_d - \Delta c_m)(\theta a - b_1 \tilde{p}) + (\tilde{p} - c_m - c_r - \Delta c_m) \\ [(1-\theta)a - b_2 \tilde{p}] - k_2[q_1^* + q_2^* - a + (b_1 + b_2)\tilde{p}] . \\ \text{s.t.}\ \tilde{q}_1^* + \tilde{q}_2^* \leq q_1^* + q_2^* \quad (9)$$

There are also two cases in the supply chain, which are shown as follows:

Case3: $0 < \Delta c_m < k_2$

Similar to case 2, we get

$$\tilde{p}_3^* = \tilde{p}^* = \frac{a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r}{2(b_1 + b_2)}$$, and

$$\begin{cases} \tilde{q}_{13}^* = \tilde{q}_1^* = \theta a - \dfrac{b_1[a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r]}{2(b_1 + b_2)} \\ \tilde{q}_{23}^* = \tilde{q}_2^* = (1-\theta)a - \dfrac{b_2[a + (b_1 + b_2)c_m + b_1 c_d + b_2 c_r]}{2(b_1 + b_2)} \end{cases} .$$

Case 4: $\Delta c_m \geq k_2$

Similar to case 1, we get

$$\tilde{p}_4^* = \frac{a + b_1 c_d + b_2 c_r}{2(b_1 + b_2)} + \frac{c_m + \Delta c_m - k_2}{2}$$, and

$$\begin{cases} \tilde{q}_{14}^{*} = \theta a - \dfrac{b_1[a+(c_m+\Delta c_m-k_2)(b_1+b_2)+b_1c_d+b_2c_r]}{2(b_1+b_2)} \\ \tilde{q}_{24}^{*} = (1-\theta)a - \dfrac{b_2[a+(c_m+\Delta c_m-k_2)(b_1+b_2)+b_1c_d+b_2c_r]}{2(b_1+b_2)} \end{cases}.$$

Theorem 1. *Suppose that a dual-channel supply chain faces a demand function shown in Equation (1) and the revenue function under the cost disruption is shown in Equation (5). When the production cost disruption occurs, the optimal retail price is*

$$\tilde{p}^{*} = \begin{cases} p^{*} + \dfrac{\Delta c_m + k_1}{2}, if\, \Delta c_m \le -k_1 \\ p^{*}, if -k_1 < \Delta c_m < k_2 \\ p^{*} + \dfrac{\Delta c_m - k_2}{2}, if\, \Delta c_m \ge k_2 \end{cases},$$

the optimal online sales quantity is

$$\tilde{q}_1^{*} = \begin{cases} q_1^{*} - b_1(\dfrac{\Delta c_m + k_1}{2}), if\, \Delta c_m \le -k_1 \\ q_1^{*}, if -k_1 < \Delta c_m < k_2 \\ q_1^{*} - b_1(\dfrac{\Delta c_m - k_2}{2}), if\, \Delta c_m \ge k_2 \end{cases},$$

the optimal offline sales quantity is

$$\tilde{q}_2^{*} = \begin{cases} q_2^{*} - b_2(\dfrac{\Delta c_m + k_1}{2}), if\, \Delta c_m \le -k_1 \\ q_2^{*}, if -k_1 < \Delta c_m < k_2 \\ q_2^{*} - b_2(\dfrac{\Delta c_m - k_2}{2}), if\, \Delta c_m \ge k_2 \end{cases},$$

and the total optimal profit in the supply chain is

$$\tilde{\Pi}^{*} = \begin{cases} \Pi^{*} - \Delta c_m(q_1^{*}+q_2^{*}) + (b_1+b_2)(\dfrac{\Delta c_m + k_1}{2})^2, if\, \Delta c_m \le -k_1 \\ \Pi^{*} - \Delta c_m(q_1^{*}+q_2^{*}), if -k_1 < \Delta c_m < k_2 \\ \Pi^{*} - \Delta c_m(q_1^{*}+q_2^{*}) + (b_1+b_2)(\dfrac{\Delta c_m - k_2}{2})^2, if\, \Delta c_m \ge k_2 \end{cases}.$$

It can be seen in theorem 1, If unexpected events make the unit production cost decrease in the dual channel supply chain, the retail price will increase. If unexpected events make the unit production cost increase in the supply chain, the retail price will decrease. If the disruption makes the production cost reduction greatly, i.e., $\Delta c_m \le -k_1$, manufacturer will increase corresponding production plan, reduce the sales price and increase the online sales quantity, which ,in turn, will make the offline sales quantity increase. If the disruption makes the production cost increase greatly, i.e.,$\Delta c_m \ge k_2$,the manufacturer will reduce corresponding production plan, increase the sales price and decrease the online sales quantity, which, in turn, will make the offline sales quantity decrease. If the deviation of the production cost is relatively small, i.e.,$-k_1<\Delta c_m<k_2$, the manufacturer does not need to adjust production plan and the sales price.

Finally, we would like to know the incremental improvement in the supply chain performance under which there exists production cost disruption. To quantify the performance, we compare our results with the scenario in the decentralized dual-channel supply chain under the-same-retail-price mechanism.

4. DECENTRALIZED DECISION AFTER COST DISRUPTION

In the dual-channel supply chain, double marginal phenomenon happens when supply chain partners only consider their own optimal decisions. The definition of coordination in dual-channel supply chain is that the total profit of a dual-channel supply chain in decentralized decision equals to that in centralized decision. That is to say, for a Stackelberg game, if decentralized decision in a dual-channel supply chain is made according to equal-price mechanism and the coordination mechanism in decentralized decision makes the retail price that the retailer sets, i.e., $\tilde{p}^{WP*}$, equal to the optimal retail price in centralized decision, i.e., $\tilde{p}^{*}$, then the supply chain performance in decentralized decision is the same as that in centralized decision. In order to achieve Pareto improvement, the manufacturer needs to offer a one-time transfer payment $\tilde{T}^{WP}$. The method is consistent with that used in stable state.

When the production cost disruption occurs, the retailer's profit function is

$$\tilde{\pi}_r = (\tilde{p}-\tilde{w})[(1-\theta)a - b_2\tilde{p}] - T. \quad (10)$$

Thus, the response function of the wholesale price and the optimal retail price is

$$\tilde{p} = \frac{(1-\theta)a + \tilde{w}b_2}{2b_2}. \quad (11)$$

For the case 1($\Delta c_m \leqslant -k_1$),

$\tilde{w}_1^{*} = 2p^{*} + \Delta c_m + k_1 - \dfrac{(1-\theta)a}{b_2}$, and

$$\tilde{T}_1^{*} \in [\frac{[b_2^2(c_m+c_r+\Delta c_m+k_1) - ab_2 - 2ab_1 + b_1b_2(c_m+c_r+\Delta c_m+k_1) + 2\theta ab_1 + 2\theta ab_2]^2}{4(b_1+b_2)^2(b_1+2b_2)},$$
$$\frac{(2b_1+3b_2)[b_2^2(c_m+c_r+\Delta c_m+k_1) - ab_2 - 2ab_1 + b_1b_2(c_m+c_r+\Delta c_m+k_1) + 2\theta ab_1 + 2\theta ab_2]^2}{4(b_1+b_2)^2(b_1+2b_2)^2}]$$

Thus, $\tilde{p}_1^{TP*} = \tilde{p}^{*}$, $\tilde{q}_{11}^{TP*} = \tilde{q}_1^{*}$, $\tilde{q}_{21}^{TP*} = \tilde{q}_2^{*}$.

Then, the dual-channel supply chain is coordinated by the two-part-tariff contract $(\tilde{w}_1^{*}, \tilde{T}_1^{*})$.

For the case 2 and case 3 $-k_1<\Delta c_m<k_2$.

$\tilde{w}_2^{*} = \tilde{w}_3^{*} = 2p^{*} - \dfrac{(1-\theta)a}{b_2}$, and

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$$\tilde{T}_2^* \in [\frac{[b_2^2(c_m+c_r+\Delta c_m)-ab_2-2ab_1+b_1b_2(c_m+c_r+\Delta c_m+k_1)+2\theta ab_1+2\theta ab_2]^2}{4(b_1+b_2)^2(b_1+2b_2)},$$

$$\frac{(2b_1+3b_2)[b_2^2(c_m+c_r+\Delta c_m)-ab_2-2ab_1+b_1b_2(c_m+c_r+\Delta c_m)+2\theta ab_1+2\theta ab_2]^2}{4(b_1+b_2)^2(b_1+2b_2)^2}].$$

Thus, $\tilde{p}_2^{TP*}=\tilde{p}_3^{TP*}=\tilde{p}^*$, $\tilde{q}_{12}^{TP*}=\tilde{q}_{13}^{TP*}=\tilde{q}_1^*$, $\tilde{q}_{22}^{TP*}=\tilde{q}_{23}^{TP*}=\tilde{q}_2^*$.

Then, the dual-channel supply chain is coordinated by the two-part-tariff contract $(\tilde{w}_2^*, \tilde{T}_2^*)$.

For the case 4 $\Delta c_m \geq k_2$,

$\tilde{w}_4^*=2p^*+\Delta c_m-k_2-\frac{(1-\theta)a}{b_2}$, and

$$\tilde{T}_4^* \in [\frac{[b_2^2(c_m+c_r+\Delta c_m-k_2)-ab_2-2ab_1+b_1b_2(c_m+c_r+\Delta c_m-k_2)+2\theta ab_1+2\theta ab_2]^2}{4(b_1+b_2)^2(b_1+2b_2)},$$

$$\frac{(2b_1+3b_2)[b_2^2(c_m+c_r+\Delta c_m-k_2)-ab_2-2ab_1+b_1b_2(c_m+c_r+\Delta c_m-k_2)+2\theta ab_1+2\theta ab_2]^2}{4(b_1+b_2)^2(b_1+2b_2)^2}].$$

Thus, $\tilde{p}_4^{TP*}=\tilde{p}^*$, $\tilde{q}_{14}^{TP*}=\tilde{q}_1^*$, $\tilde{q}_{24}^{TP*}=\tilde{q}_2^*$.

Then, the dual-channel supply chain is coordinated by the two-part-tariff contract $(\tilde{w}_4^*, \tilde{T}_4^*)$.

As is shown above, the two-part-tariff contract used above can coordinate the decentralized supply chain when production cost disruption occurs.

5. NUMERICAL EXAMPLES

Let a=2,000 (the market scale of a given product), b_1=10, b_2=20 (the price response factor), θ=0.4 (the online market share), c_m=20 (the unit production cost), c_d=4 (the unit online sales cost), c_r=6 (the unit offline sales cost), k_1=k_2=5 (the unit cost which deviates from the original production plan). Several numerical examples are given to illustrate the results derived in the paper when different production cost disruption happens.

If the manufacturer still uses the original two-part-tariff policy under static state when production cost disruption happens, as that in the Situation I, then the total profits in the decentralized supply chain and those in the centralized decision are shown in Table 2. As is shown in Table 2, the supply chain can be coordinated under the two-part-tariff policy used in this paper when production cost disruption occurs.

Table 2
Parameters Under Decision in the Supply Chain When Production Cost Disruption

Δc_m	Case	$\tilde{p}^*$	$\tilde{p}^{TP*}$	$\tilde{w}^*$	$\tilde{q}_1^*$	$\tilde{q}_2^*$	$\tilde{Q}^*$	$\tilde{\pi}_d$	$\tilde{\pi}_r$	$\tilde{\pi}_d+\tilde{\pi}_r$	$\tilde{\Pi}$
0	2	46	46	32	340	280	620	10840	2240	13080	13080
-10	1	43.5	43.5	27	365	330	695	9428	3465	12893	12893
-6	1	45.5	45.5	31	345	290	635	10608	2465	13073	13073
-2	2	46	46	32	339.2	278.8	618	10808	2230	13038	13038
4	3	46	46	32	341.6	282.4	624	10904	2259	13163	13163
8	4	47.5	47.5	35	328.2	254.8	583	11535	1656	13191	13191
12	4	49.5	49.5	39	309.8	217.2	527	12027	977	13004	13004

CONCLUSION

This paper studies a dual-channel supply chain consisting of one manufacturer and one traditional retailer in which the manufacturer is the leader of the Stackelberg game and sets the same retailer price in the online channel as that in the offline channel. The manufacturer has its own online channel when he sells product to the offline retailer. The optimal retail price and the sale quantities are shown when the supply chain is in static state. Then some unexpected events make production cost change in the supply chain. We design a two-part-tariff contract with a one-time transfer payment to coordinate the supply chain under the production cost disruption. The results are as follows: There exist some certain robustness both in the manufacturer's production quantity and in the offline retail price when the deviation of production cost is relatively small. If the change of production cost is large enough, the manufacturer needs to adjust the corresponding retail price and production quantity according to the two-part-tariff contract we design in this paper. Some numerical examples are also presented.

The disruption management in dual-channel supply chain is a meaningful and interesting field. There are still a lot of questions that need to be studied. For example,

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how to coordinate the dual-channel supply chain when the demand and cost disruption happens simultaneously is a very interesting question.

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