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SUPPLY CHAIN COORDINATION UNDER CONSIDERING THE DUAL-CHANNEL RETAILER

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Abstract. *In this paper, we make a major contribution by examining supply chain coordination under considering the dual-channel retailer. To end this, we first establish a two-echelon supply chain model which consists of a manufacturer and a dual-channel retailer. We then derive the optimal price decisions under the centralized and decentralized supply chain. We find that there are different optimal price decisions in the different range of customer acceptance of online channel. Subsequently, we compare the price decisions between the centralized and decentralized supply chain. We find that facing a same channel (online channel or offline channel) no matter what range of customer acceptance of online channel is, the sale price under the decentralized supply chain is always higher than that under the centralized supply chain. Lastly, we develop a sales rebate and penalty contract which can perfectly coordinate supply chain and achieve win-win outcome.*
Keywords: Dual-channel retailer, Supply chain coordination, Contract, Price decision

1. **Introduction.** With the rapid development of e-commerce, more and more bricks-and-mortar retailers start to set up the online channel, such as Gome, Carrefour, Suning, Metro and WalMart. Meanwhile, many online retailers also begin to layout offline channel, such as JD.com, Tmall supermarket, Dangdang.com and Jumei.com. Thus, the dual-channel retailer has become an important part of the modern retail industry.

Coordination between the manufacturer and retailer is a very important issue in the field of supply chain management. A properly designed coordination contract cannot only improve the performance of the entire supply chain, but also can lead the manufacturer and retailer to achieve win-win outcome. Therefore, the following question is of great practical importance: Facing the new channel structure, i.e., dual-channel retailer, how the manufacturer designs a suitable contract to achieve supply chain coordination? Currently, the related researches mainly focus on the traditional supply chain structure, i.e., without considering the online channel [1-7]. Though some researches consider the online channel, these researches mainly investigate the coordination under manufacturer's dual-channel mode, i.e., manufacturer distributes her product through her own direct online channel and a bricks-and-mortar retailer simultaneously. For example, Chen et al. find that the quantity discount contract can coordinate the dual-channel supply chain, and make the supply chain members achieve Pareto improvement [8]. David and Adida further consider the multiple retailers under the manufacturer's dual-channel mode, and find that though the quantity discount contract also can improve profits, it cannot achieve complete coordination [9]. To coordinate dual-channel supply chain under the complex situations, many new contracts have been proposed. Cao and Xiong consider the demand disruption, and propose an improved revenue sharing contract and a one-time fee contract respectively [10,11]. Saha et al. consider a closed-loop dual-channel supply chain structure, and design a tripartite discount contract [12].

To the best of our knowledge, vacant previous work has studied the supply chain coordination under considering the dual-channel retailer. To fill this gap, we construct a two-echelon supply chain model consisting of a manufacturer and a dual-channel retailer. Our analysis proceeds in three phases. Firstly, as a benchmark, we begin by analyzing the case of a centralized supply chain and obtain the supply chain's optimal price decision. Secondly, we use game theory to study equilibrium solutions under a decentralized supply chain. Lastly, we compare the price decisions between the centralized and decentralized, and then we propose a sales rebate and penalty contract to achieve supply chain coordination.

The rest of this paper is organized as follows. Section 2 introduces model assumptions and notations. Sections 3 and 4 investigate price decisions under centralized and decentralized supply chains, respectively. Section 5 compares the centralized and decentralized supply chains and proposes a coordinating contract. Section 6 uses numerical studies to illustrate our results. Finally, Section 7 provides concluding remarks and suggests future research.

2. **Model Assumptions and Notations.** We consider a supply chain with a manufacturer (she) and a dual-channel retailer (he). Like most existing studies, we assume that the manufacturer is the leader. The manufacturer produces a single product at cost c per unit and supplies the retailer at a unit wholesale price w, and $w > c$. The dual-channel retailer distributes the product through an offline channel at price p_r and an online channel at price p_e simultaneously. Following [13], we also assume that the consumers are heterogeneous in the valuation of the product, and the consumption value v is uniformly distributed within the consumer population from 0 to 1, with a density of 1. Purchasing from the offline channel, the consumer can physically inspect the product, so the product is worth v. However, the product is worth θv $(0 < \theta < 1)$ when it is obtained from an online channel without detailed physical inspection. θ also represents the customer acceptance of the online channel. Since offline shoppers have to travel to the stores, spending time locating the desired items, waiting in lines to pay, etc., we assume an offline channel's purchase cost b_r is higher than an online channel's purchase cost b_e. This assumption is also used in [14].

We then discuss the dual-channel retailer's demand function. If the consumer would consider buying from the offline channel, at least the consumer surplus is greater than 0, i.e., $v - p_r - b_r \geq 0$. The consumer whose valuation v^r equals $p_r + b_e$ is indifferent to purchase from the offline channel or not at all. Equivalently, only if $\theta v - p_e - b_e \geq 0$, the consumer would consider buying from the online channel. The consumer whose valuation v^e equals $\frac{p_e+b_e}{\theta}$ is indifferent to purchase from the online channel or not at all. If consumer can buy from either channel, the consumer will further compare $v-p_r-b_r$ and $\theta v-p_e-b_e$. For example, a consumer will prefer the offline channel if $v - p_r - b_r > \theta v - p_e - b_e$. The customer whose valuation v^u equals $\frac{p_r+b_r-p_e-b_e}{1-\theta}$ is indifferent between the two channels. We then derive the dual-channel retailer's demand function in the two possible cases.

Case 1 $v^e < v^r$

In this case, we can easily check that $v^e < v^r < v^u$, as shown in Figure 1. If $v^u < 1$, the offline channel's demand Q_r and the online channel's demand Q_e equal $1 - v^u$ and $v^u - v^e$ respectively. If $v^u \geq 1$, $Q_r = 0$ and $Q_e = 1 - v^e$.

Case 2 $v^e > v^r$

In this case, we can easily check that $v^u < v^r < v^e$, as shown in Figure 2. We then can obtain $Q_r = 1 - v^r$ and $Q_e = 0$.

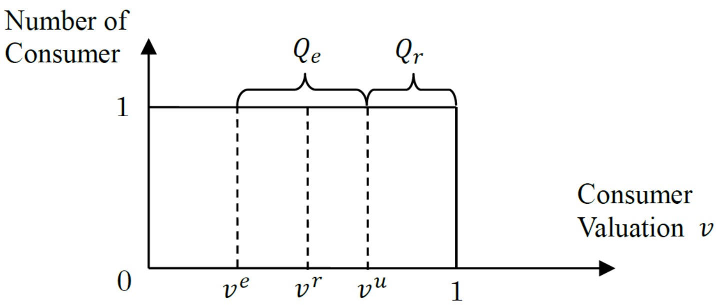

Figure 1. Retailer's demand when $v^e < v^r$

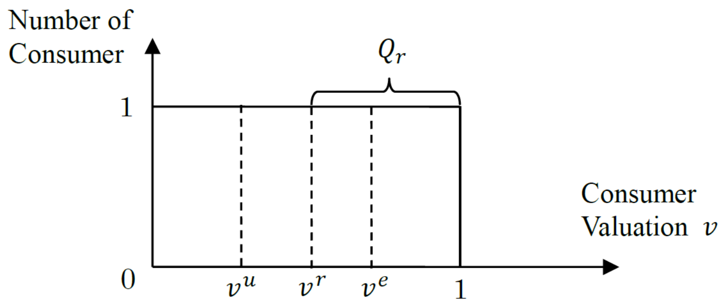

Figure 2. Retailer's demand when $v^e > v^r$

To sum up, the dual-channel retailer's demand function is

$$Q_r = \begin{cases} 0 & \text{if} \quad 1-\theta+p_e+b_e < p_r \leq 1-b_r \\ 1-\dfrac{p_r+b_r-p_e-b_e}{1-\theta} & \text{if} \quad \dfrac{p_e+b_e}{\theta}-b_r \leq p_r \leq 1-\theta+p_e+b_e-b_r \\ 1-p_r-b_r & \text{if} \quad w \leq p_r \leq \dfrac{p_e+b_e}{\theta}-b_r \end{cases} \tag{1}$$

$$Q_e = \begin{cases} 1-\dfrac{p_e+b_e}{\theta} & \text{if} \quad 1-\theta+p_e+b_e < p_r \leq 1-b_r \\ \dfrac{\theta(p_r+b_r)-(p_e-b_e)}{(1-\theta)\theta} & \text{if} \quad \dfrac{p_e+b_e}{\theta}-b_r \leq p_r \leq 1-\theta+p_e+b_e-b_r \\ 0 & \text{if} \quad w \leq p_r \leq \dfrac{p_e+b_e}{\theta}-b_r \end{cases} \tag{2}$$

3. **Centralized Supply Chain.** To establish a performance benchmark, in this section, we analyze the centralized supply chain, where optimal decisions are made to maximize the profit of the entire supply chain. For clarity, we add superscript $()^v$ to the notation. Hence, the supply chain's profit, denoted as Π_s^v, is given by

$$\Pi_s^v(p_r^v, p_e^v) = (p_r^v - c)Q_r^v + (p_e^v - c)Q_e^v \tag{3}$$

From (1) and (2), we know that demand function differs in different intervals. We assume that both channels have positive demands, i.e., $\frac{p_e+b_e}{\theta} - b_r \leq p_r \leq 1-\theta+p_e+b_e-b_r$. The supply chain's profit function is then

$$\Pi_s^v(p_r^v, p_e^v) = (p_r^v - c)\left(1 - \frac{p_r^v + b_r - p_e^v - b_e}{1-\theta}\right) + (p_e^v - c)\frac{\theta(p_r^v + b_r) - (p_e^v + b_e)}{(1-\theta)\theta} \tag{4}$$

Taking the second-order conditions with respect to p_r^v and p_e^v respectively, we have

$$\frac{\partial^2 \Pi_s^v(p_r^v, p_e^v)}{\partial p_r^{v2}} = -\frac{2}{1-\theta}; \quad \frac{\partial^2 \Pi_s^v(p_r^v, p_e^v)}{\partial p_r^v \partial p_e^v} = \frac{2}{1-\theta};$$

$$\frac{\partial^2 \Pi_s^v(p_r^v, p_e^v)}{\partial p_e^{v2}} = -\frac{2}{(1-\theta)\theta}; \quad \frac{\partial^2 \Pi_s^v(p_r^v, p_e^v)}{\partial p_e^v \partial p_r^v} = \frac{2}{1-\theta}$$

Then the Hessian matrix is

$$H(p_r^v, p_e^v) = \begin{bmatrix} -\dfrac{2}{1-\theta} & \dfrac{2}{1-\theta} \\ \dfrac{2}{1-\theta} & -\dfrac{2}{(1-\theta)\theta} \end{bmatrix} \tag{5}$$

It is easy to check that

$$|H_1(p_r^v, p_e^v)| = -\frac{2}{1-\theta} < 0$$

$$|H_2(p_r^v, p_e^v)| = -\frac{4}{(1-\theta)\theta} > 0$$

$$|H_3(p_r^v, p_e^v)| = -\frac{2}{(1-\theta)\theta} < 0$$

Therefore, $H(p_r^v, p_e^v)$ is a negative definite matrix, which implies that $\Pi_s^v(p_r^v, p_e^v)$ is jointly concave in (p_r^v, p_e^v). The unique optimal $(p_r^{v^*}, p_e^{v^*})$ should satisfy the first-order condition. Hence, we can get

$$p_r^{v^*} = \frac{1 - b_r + c}{2} \tag{6}$$

$$p_e^{v^*} = \frac{\theta - b_e + c}{2} \tag{7}$$

This solution satisfies $\frac{p_e+b_e}{\theta} - b_r \le p_r \le 1 - \theta + p_e + b_e - b_r$ only when $\theta \in \left[\frac{b_e+c}{b_r+c}, 1 - b_r + b_e\right]$. When $\theta < \frac{b_e+c}{b_r+c}$, the online channel has no demand. When $\theta > 1 - b_r + b_e$, the offline channel has no demand. Using the similar method, we can get the optimal price decision under these two conditions. In summary, we can have the following proposition.

Proposition 3.1. *The centralized supply chain's profit function Π_s^v is jointly concave in (p_r^v, p_e^v), and the optimal price decisions are summarized in Table 1.*

Table 1. The optimal price decisions under the centralized supply chain

	$\theta < \theta^\alpha$	$\theta^\alpha \le \theta \le \theta^\beta$	$\theta > \theta^\beta$
$p_r^{v^*}$	$\frac{1-b_r+c}{2}$	$\frac{1-b_r+c}{2}$	$\frac{2-\theta+b_e-2b_r+c}{2}$
$p_e^{v^*}$	$\frac{\theta(1+b_r+c)-2b_e}{2}$	$\frac{\theta-b_e+c}{2}$	$\frac{\theta-b_e+c}{2}$

where $\theta^\alpha = \frac{b_e+c}{b_r+c}$ and $\theta^\beta = 1 - b_r + b_e$

4. **Decentralized Supply Chain.** In this section, the manufacturer and the retailer independently decide their price to maximize their own profits. Based on assumption, the manufacturer is leader, so the game sequence is as follows. First, the manufacturer acts the Stackelberg leader and decides the wholesale price. Second, the retailer acts the Stackelberg follower and decides on the sale price. We use backward deduction to solve this game. For clarity, we use superscript $()^d$ to denote this scenario of decentralization.

Similar to the case of supply chain centralization, we also assume that the two channels both have positive demands, i.e., $\frac{p_e+b_e}{\theta} - b_r \le p_r \le 1 - \theta + p_e + b_e - b_r$. Then the profit functions of the manufacturer and the retailer are:

$$\Pi_M^d\left(w^d\right) = \left(w^d - c\right)\left(\frac{\theta - p_e^d - b_e}{\theta}\right) \tag{8}$$

$$\begin{aligned}\Pi_R^d\left(p_r^d, p_e^d\right) &= \left(p_r^d - w^d\right)\left(1 - \frac{p_r^d + b_r - p_e^d - b_e}{1-\theta}\right) \\ &+ \left(p_e^d - w^d\right)\frac{\theta\left(p_r^d + b_r\right) - \left(p_e^d + b_e\right)}{(1-\theta)\,\theta}\end{aligned} \tag{9}$$

To solve the Stackelberg game, we first find the retailer's best response. Similar to proof of Proposition 3.1, we can get that the $\Pi_R^d\left(p_r^d, p_e^d\right)$ is jointly concave in $\left(p_r^d, p_e^d\right)$. Therefore, the best response is

$$p_r^d = \frac{1 - b_r + w^d}{2} \tag{10}$$

$$p_e^d = \frac{\theta - b_e + w^d}{2} \tag{11}$$

Substituting (10) and (11) into (8), the manufacturer's profit can be rewritten as:

$$\Pi_M^d\left(w^d\right) = \left(w^d - c\right)\left(\frac{\theta - b_e - w^d}{2\theta}\right) \tag{12}$$

We can easily check that Π_M^d is concave in w^d. Hence, by using the first-order condition, we can get the optimal wholesale price w^{d^*}, which is

$$w^{d^*} = \frac{\theta - b_e + c}{2} \tag{13}$$

Substituting w^{d^*} into (10) and (11), we can obtain the equilibrium selling price.

$$p_r^{d^*} = \frac{2(1 - b_r) + \theta - b_e + c}{4} \tag{14}$$

$$p_e^{d^*} = \frac{3(\theta - b_e) + c}{4} \tag{15}$$

This solution satisfies $\frac{p_e + b_e}{\theta} - b_r \leq p_r \leq 1 - \theta + p_e + b_e - b_r$ only when

$$\theta \in \left[\frac{-(2b_r - b_e + c - 1) + \sqrt{(2b_r - b_e + c - 1)^2 + 4(b_e + c)}}{2}, 1 - b_r + b_e\right].$$

When $\theta < \frac{-(2b_r - b_e + c - 1) + \sqrt{(2b_r - b_e + c - 1)^2 + 4(b_e + c)}}{2}$, the online channel has no demand. When $\theta > 1 - b_r + b_e$, the offline channel has no demand. Using the similar method, we can get the equilibrium solutions under these two conditions. In summary, we can have the following proposition.

Proposition 4.1. *Under the decentralized supply chain, there exist Stackelberg equilibrium solutions which are summarized in Table 2.*

Table 2. The Stackelberg equilibrium solutions under the decentralized supply chain

	$\theta < \theta^\gamma$	$\theta^\gamma \leq \theta \leq \theta^\beta$	$\theta > \theta^\beta$
$p_r^{d^*}$	$\frac{3(1-b_r)+c}{4}$	$\frac{2(1-b_r)+\theta-b_e+c}{4}$	$\frac{4-\theta+b_e-4b_r+c}{2}$
$p_e^{d^*}$	$\frac{\theta(3+b_r+c)-4b_e}{4}$	$\frac{3(\theta-b_e)+c}{4}$	$\frac{3(\theta-b_e)+c}{4}$
w^{d^*}	$\frac{1-b_r+c}{2}$	$\frac{\theta-b_e+c}{2}$	$\frac{\theta-b_e+c}{2}$
where $\theta^\gamma = \frac{-(2b_r-b_e+c-1)+\sqrt{(2b_r-b_e+c-1)^2+4(b_e+c)}}{2}$			

5. **Supply Chain Coordination.** In this section, our main purpose is to propose a contract for the decentralized supply chain to achieve coordination. To end this, we first compare the optimal decisions of prices between the centralized and decentralized supply chain.

We can check that $\theta^\alpha < \theta^\gamma < \theta^\beta$, so we will compare the price decisions in four intervals, i.e., $\theta < \theta^\alpha$, $\theta^\alpha \le \theta < \theta^\gamma$, $\theta^\gamma \le \theta \le \theta^\beta$, and $\theta > \theta^\beta$. From Propositions 3.1 and 4.1, we can get the following proposition.

Proposition 5.1. *For a same channel (online channel or offline channel), no matter what range of θ is, the sale price under the decentralized supply chain is always higher than that under the centralized supply chain.*

Proposition 5.1 implies that coordination is needed to attain the optimal supply chain's profit. We then develop a sales rebate and penalty contract. Under such a contract, the manufacturer sets up a constant wholesale price w^t and a sales target T for the retailer. If the retail sales are above (below) the target, the manufacturer will offer a unit rebate λ (a unit penalty λ) for each unit above (below) T. Under the coordination contract, the retailer's profits Π_R^t is

$$\Pi_R^t\left(p_r^t, p_e^t, w^t, \lambda, T\right) = \left(p_r^t - w^t\right) Q_r^t + \left(p_e^t - w^t\right) Q_e^t + \lambda\left(Q_r^t + Q_e^t - T\right) \tag{16}$$

Rearranging (16), we have

$$\Pi_R^t\left(p_r^t, p_e^t, w^t, \lambda, T\right) = \left[p_r^t - \left(w^t - \lambda\right)\right] Q_r^t + \left[p_e^t - \left(w^t - \lambda\right)\right] Q_e^t - \lambda T \tag{17}$$

Comparing (3) and (17), we can get that when $w^t - \lambda = c$, the retailer's decision is same as centralized supply chain's decision, i.e., the decentralized supply chain achieves coordination.

Substituting $w^t - \lambda = c$ into (17), we obtain the retailer and manufacturer's profit function:

$$\Pi_R^t = \Pi_S^v - \left(w^t - c\right) T \tag{18}$$

$$\Pi_M^t = \left(w^t - c\right) T \tag{19}$$

From (18) and (19), the supply chain members can accommodate arbitrary divisions of the profit by varying T. However, in reality, only when the retailer and manufacturer's profits must be Pareto improving under coordination, will they accept the coordination contract. It is namely to satisfy the following inequality group:

$$\begin{cases} \Pi_R^t - \Pi_R^{d*} \ge 0 \\ \Pi_M^t - \Pi_M^{d*} \ge 0 \end{cases} \tag{20}$$

Because $\Pi_R^t + \Pi_M^t = \Pi_S^v > \Pi_R^{d*} + \Pi_M^{d*}$ and the supply chain members can accommodate arbitrary divisions of the profit by varying T, the inequality group (20) is not an empty set. In additional, from the above, we know that under the different intervals of θ, the price decisions are also different. Hence, under the different intervals of θ, T has the different ranges of values. We then can get the following proposition.

Proposition 5.2. *The sales rebate and penalty contract can coordinate the supply chain if $\lambda = w^t - c$, the detailed ranges of T's values are as follows:*

(1) If $\theta < \theta^\alpha$, $T \in \left[\frac{(1-b_r-c)^2}{8(w^t-c)}, \frac{3(1-b_r-c)^2}{16(w^t-c)}\right]$;

(2) If $\theta^\alpha \le \theta < \theta^\gamma$, $T \in \left[\frac{(1-b_r-c)^2}{8(w^t-c)}, \frac{8\theta(\theta-b_e-c)(b_r+c)+\theta(3+\theta)(1-b_r-c)^2-4(\theta+b_e+c)(\theta-b_e-c)}{16\theta(1-\theta)(w^t-c)}\right]$;

(3) If $\theta^\gamma \le \theta \le \theta^\beta$, $T \in \left[\frac{(\theta-b_e-c)^2}{8\theta(w^t-c)}, \frac{(\theta-b_e-c)[8\theta-4(\theta+b_e+c)-(1+3\theta)(\theta-b_e-c)]}{16\theta(1-\theta)(w^t-c)}\right]$;

(4) If $\theta > \theta^\beta$, $T \in \left[\frac{(\theta-b_e-c)^2}{8\theta(w^t-c)}, \frac{3(\theta-b_e-c)^2}{16\theta(w^t-c)}\right]$.

6. **Numerical Examples.** In this section, we focus on the impact of the sales target T on the profits under coordination. We use the following numbers as the base values of the parameters: $\theta = 0.7$, $b_r = 0.3$, $b_e = 0.1$, $c = 0.1$, $w^t = 0.2$, $\lambda = 0.1$.

In Figure 3, we keep other parameters constant and change the sales target T. Under the coordination contract, we use Π_R^t, Π_M^t and Π_S^t to represent the retailer, manufacturer and total supply chain's expected profits respectively. Correspondingly, under the wholesale price contract, we use Π_R^d, Π_M^d and Π_S^d to represent the retailer, manufacturer and total supply chain's expected profits respectively.

Figure 3 shows that Π_S^t is always higher than Π_S^d. It implies that it always improves the profits of the supply chain by using the sales rebate and penalty contract. From Figure 3, we also can find that $\Pi_R^t > \Pi_R^d$ and $\Pi_M^t > \Pi_M^d$ only when $T \in [0.455, 0.67]$. Therefore, by choosing a suitable sales target T, the retailer and manufacturer under the sales rebate and penalty contract can reach Pareto improvement, which is consistent with Proposition 5.2.

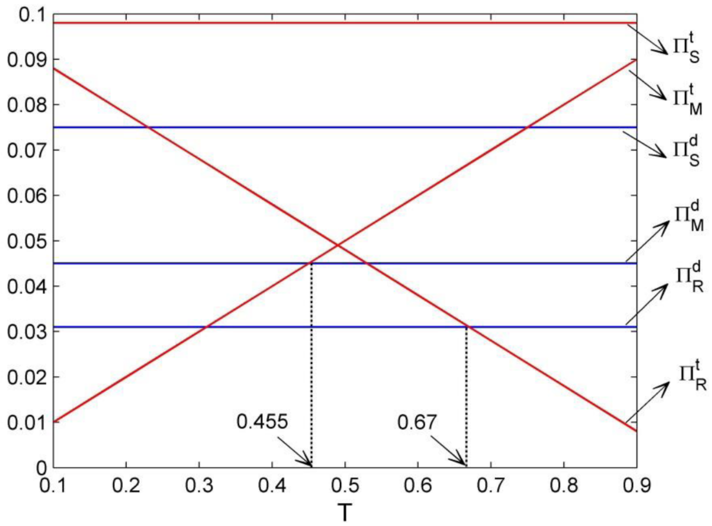

FIGURE 3. The impact of T on profits

7. **Conclusions.** The main purpose of this paper is to study supply chain coordination under considering the dual-channel retailer. To end this, we set up a two-echelon supply chain model with a manufacturer and a dual-channel retailer. According to the mathematical model, we first discuss the retailer's demand functions for online and/or offline channel. Based on it, we then derive the optimal price decisions under the centralized and decentralized supply chain. Our results show that the price decision under the decentralized supply chain is not consistent with the price decision under the centralized supply chain, which means the commonly used wholesale price contract cannot coordinate supply chain. We further study supply chain coordination and develop a sales rebate and penalty contract which can perfectly coordinate supply chain and achieve win-win outcome.

There are two interesting topics for further research. First, in business practice, many dual-channel retailers start to try some lateral coordination strategies between the online channel and offline channel, such as "Preorder-online, pickup-in-store", "Preorder-online, store-delivery" and "Preorder-online, store-return". What impact of these lateral coordination strategies on the supply chain coordination? Second, this paper just considers a manufacturer and a dual-channel retailer. In reality, the channel structure is much more complicated than this. What happens when competition is introduced among multiple manufacturers and/or dual-channel retailers? We believe answers to these research questions will help firms and managers design more practical contracts to improve supply chain performance.

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