Strategic Provision of Trade Credit in a Dual-Channel Supply Chain

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Abstract. This paper focuses on a dual-channel supply chain composed of a capital-constraint bricks-and-mortar retailer and a manufacturer, where a manufacturer can sell products through traditional retail channel and direct online channel simultaneously. Supplementary pricing strategy and competitive pricing strategy are simulated in our model, and we find that the former one is the better choice for manufacture when the retailer suffers capital constraint. In our analysis, the capital constraint on retailer could mitigate the price competition between two channels, and it may be beneficial to the manufacturer under certain conditions. Our findings show that the manufacturer should provide trade credit to retailers strategically rather than provide it unconditionally. We present two trade-credit strategies (trade credit with positive interest rate and trade-credit with zero interest rate) and suggest manufacture choose appropriate trade-credit strategies according to the initial capital of retailer. To guide the manufacturer when and how to provide trade credit, we conduct several numerical simulations based on our results, and further plot out the feasible region for each trade credit strategy based on corresponding conditions.

Keywords: Dual-channel supply chain · Capital constraint · Trade credit · Direct sales cost · Acceptance level of the direct online channel

1 Introduction

Nowadays, most manufacturers prefer to join the dual-channel supply chain, which combines direct online channel with a physical retail channel. Manufacturers such as P&G, IBM, Nike, Sony, Huawei, Granz, Gree, etc. have succeeded in selling products through establishing official shopping websites or founding flagship stores on some B2C platforms. Some retail giants such as Wal-Mart and Gome have owned mature physical stores and often play a dominated role in a supply chain through intervening manufacturers' pricing strategies such as wholesale price or retail price etc. So some manufacturers may break up the cooperation with retail giants if they cannot endure the disadvantage in the supply chain. Like the Chinese manufacturer, Gree Inc had withdrawn all kinds of products from the retail giant Gome's physical stores in 2004,

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and turn to cooperate with other small or medium retailers. However, although small or medium retailers will not intervene in manufacturers' pricing strategies, they usually have some capital constraint problems and require the manufacturer to provide financing support. It is common that small and medium firms are difficult to obtain financial supports from financial intermediaries such as banks [1]. So it is a very practical issue to help manufacturers explore how to offer financial service to small or medium retailers strategically.

Trade credit is the common economic phenomenon in a supply chain, it is used by the supplier for encouraging a capital-constraint retailer to order more quantity. Delay in payment is the most prominent feature of trade credit, and it is classified into several categories by Piasecki [2], Molamohamadi et al. [3, 4], which includes (1) pay as sold; (2) pay as sold during a predefined period; (3) pay as sold after a and (4) pay for the prior order at the time of establishing the new replenishment. Trade credit usually means the third type of delay in payment, which means that the retailer is permitted predefined period to delay payment until the end of the credit period and be charged interest by supplier. With trade credit, a capital-constraint retailer could get full order quantity by paying an initial capital and paying off the unpaid amount based on an interest rate after the sales season ends (Cai et al. [5]). Trade credit is widely studied in the single-channel supply chain to demonstrate it is beneficial to supply chain members, but few studies address trade credit in a dual-channel supply chain. In the single-channel supply chain, the retailer's capital constraint traditionally been delivered to have adverse side effects on manufacturer's profit because it causes the retailer cannot afford full order quantity. However, the capital constraint on retailer could mitigate the price competition between channels in dual-channel supply chain; thus manufacturer may benefit form it. Different from the traditional view, this paper puts forward that retailer's capital constraint is a double-edged sword for the manufacturer, and it is important to manufacturer to make a strategic provision of trade credit. In this research, we try to investigate when and how a manufacturer should adopt trade credit in a dual-channel supply chain.

In dual-channel supply chain, manufacturer should afford the cost of selling products through direct online channel, including building cost, advertising cost and operating cost, etc. Therefore, there is a need to incorporate direct channel sales cost. But most of the existing papers assume the sales cost in a direct channel is zero for simplicity of calculation, only a few literatures consider it. Such like Chen et al. [6], Xu et al. [7], Xiong et al. [8], and Yan et al. [9] respectively discuss different kinds of strategies for dual-channel supply chain considering direct channel sales cost. Extending to these papers, we probe into the manufacturer's pricing and trade credit strategy considering the sales cost in the direct channel.

Furthermore, an important difference between two channels is that consumers can really inspect and immediately possess product through the traditional retail channel, but consumers not only face some uncertainty due to the lack of detailed physical inspection but also need the patience to wait for the delivery lead time through direct online channel. Balasubramanian [10], Liang and Huang [11], and Kacen et al. [12] present that consumers' acceptance level of direct online channel is generally lower than that of traditional retail channel. Then many studies are conducted based on their researches, such as Chiang et al. [13], Zhang et al. [14], Pei and Yan [15], Hua et al. [16] and Rofin and Mahanty [17] study dual-channel supply chain considering consumers' acceptance level of direct channel. Therefore, besides the sales cost in direct channel, the consumers' acceptance level of the direct channel also has nonnegligible effect to manufacturer's profit.

Our model focus on the Stackelberg game between manufacturer and retailer, by incorporating sales cost in the direct channel and consumers' acceptance of direct channel simultaneously, there are three key questions should be taken into consideration by manufacture:

(1) Is the capital constraint on retailer is always bad for itself?
(2) If the capital constraint on retailer is harmful to manufacture's benefit, is providing trade credit to retailer the better choice?
(3) If manufacture decides to provide trade credit to retailer, how should manufacture make appropriate pricing and trade credit strategy?

In this paper, the first contribution is demonstrating that manufacture may benefit from the capital constraint on retailer in a dual-channel supply chain, especially when consumers' acceptance level of the direct channel is relatively high and the unit sales cost in the direct channel is relatively low. The second contribution is that we present the equilibrium pricing and trade credit strategy in different situations. Lastly, we plot out the feasible region for trade credit strategies, which help the manufacturer provide trade credit strategically.

We organized the remainder of this paper as follows. In Sect. 2, we review the relevant literature. In Sect. 3, we introduce the benchmark model which without trade credit. In Sect. 4, we expand the benchmark model with trade credit setting. In Sect. 5, we comprehensively condect serval numerical simulations. In Sect. 6, we finally make conclusions of our results.

2 Relevant Literature

There have been many researches on trade credit. Haley and Higgins [18] firstly discuss trade credit policy by jointly considering the optimal order quantity and payment time. Goyal [19] develops economic order quantity (EOQ) model under trade credit and present the optimal replenishment policy. Based on Goyal's work, many researchers study inventory models under trade credit and serval scholars have reviewed existing literature. Chang et al. [20] present a review of inventory literature about trade credit by dividing related articles into five categories. According to different model characteristics, Soni et al. [21] classify inventory studies into three categories. Extending to Chang et al. [20]'s work, Molamohamadi [4] reviews the related literature exhaustively through classifying trade credit contract into six categories. Since our emphasis is trade credit provision to a capital-constraint retailer in dual-channel supply chain, this research is primarily relevant to three literature streams, including trade credit in a capital-constraint supply chain, and the sales cost in direct channel, and consumers' acceptance of direct online channel.

The first stream of literature addresses trade credit in a capital-constraint supply chain. Xu and Birge [22] discuss the optimal decisions depend on a firm's financial constraint under trade credit. Daripa and Nilsen [23] investigate the theory of inter-firm credit which consists of prepayment and delayed payment (trade credit) and find that most of the credit is provided at a zero interest rate. Chen and Wang [24] prove supply chain members can share the risk from the market in a trade credit contract and points that not only the order quantity but also the trade credit contract terms are sufficiently effected by retailer's initial budget. Some literature make comparisons between trade credit financing (TCF) and bank credit financing (BCF) for capital-constraint supply chain. Such as considering supplier and retailer are capital-constraint simultaneously, Kouvelis and Zhao [25] investigate Stackelberg games between supply chain members, and find that retailer is more likely to choose TCF rather than BCF if supplier could provide an optimal trade credit contract. By only considering the retailer suffers capital constraint problem, Jing et al. [26] find that the equilibrium region of TCF will shrink if the initial buget of retailer is improved to high enough. Gupta [27] compares TCF with BCF considering both financing tools are not competitively priced. Different from Gupta [27]'s work, Chen [28] assumes there exists competition between TCF and BCF, and demonstrates both supply chain members are worse off under BCF than TCF, but TCF is more difficult to implement in practice than BCF since the retailer may cheat on manufacturer about the true initial budget. Cai et al. [5] present TCF and BCF can be complementary or substitutable if the retailer's internal capital satisfy corresponding conditions. Most literature in this stream reveal that the optimal decision of supply chain members and the optimal trade credit contract terms are significantly influenced by the retailer's initial capital budget level. However, few of them incorperate operational considerations within a capital-constraint and dual-channel supply chain setting. To fill the literature gap, this paper explores how does the retailer's initial capital level influences the decesions of supply chain members and the terms of trade credit contract under a capital-constraint and dual-channel supply chain.

Next, we review the literatures related to the sales cost in direct channel. Most of the existing papers assume the sales cost in direct channel is zero for simplicity of calculation in dual-channel supply chain, only few literature consider it. Such as Chen et al. [6] suggest manufacturer adopt a share-profit channel strategy when the sales cost in direct channel is relatively high as well as the inconvenience cost of retailer is relatively low. Xu et al. [7] investigate the optimal price and delivery lead time decisions in a dual-channel supply chain and find that the manufacturer should choose appropriate channel structure according to the value of direct channel cost and consumer acceptance of the online channel. Xiong et al. [8] point out that the manufacturer would like to adopt direct channel only when its sales cost is low enough. Yan et al. [9] present that expansion of e-channel could bring Pareto gains to dual-channel supply chain members if direct sales cost and product durability satisy certain conditions. Extending to above literature, this paper aims to study the influence of sales cost in direct channel on dual-channel supply chain members' decision-making, and demonstrates that the direct sales cost should not be ignored in trade credit strategy.

The last stream of studies is related to consumers' acceptance of direct online channel. Based on building normative model or conducting empirical research, Balasubramanian [10] and Liang and Huang [11] prove that consumers' acceptance level of traditional retail channel is generally higher that that of direct online channel. Considering consumers' acceptance level of direct online channel, Chiang et al. [13] explore the pricing strategy under dual-channel supply chain. Extending Chiang et al. [13]'s work, Yan et al. [29], Xu et al. [7] and Zhang et al.[14] respectively investigate the influence of consumers' acceptance on advertisement strategy, service strategy and channel selection strategy under dual-channel supply chain. Kacen et al. [12] find that both the categories and attributes of goods affect consumers' acceptance level of online channel. Consumers' acceptance level is also called "channel substitutability" or "channel preference" etc. by some scholars. Such as Pei and Yan [15] present that higher channel substitutability is more beneficial to channel members if the manufacturer invests in an added national advertising in dual-channel supply chain. Hua et al. [16] find that the customers' preference level of direct channel has a positive effect on direct sales price. Rofin and Mahanty [17] present that the direct channel preference level is positively related to direct channel demand, and a high direct channel preference level will lead to a high online sale price and a low offline sale price. Existing literature show that the consumers' acceptance of direct online channel significantly affect all kinds of strategies in a dual-channel supply chain, so this paper also accommodates this factor into our model.

Above all, in this research, we consider the sales cost in direct channel and consumers' acceptance of direct channel simultaneously, and try to explore a capital-constraint and dual-channel supply chain fundamental for the efficiency of trade credit strategy.

3 Dual-Channel Supply Chain Without Trade Credit Service

Considering a dual-channel supply chain composed of a manufacturer and a capital-constraint physical retailer, the manufacturer produces a kind of product at a unit production cost c and sells the product through both direct online channel (hereafter called direct channel) and traditional retail channel (hereafter called retail channel). In direct channel, the manufacturer directly sells the product to consumers at the price p_{do} and endures a unit sales cost in direct channel z_d; in retail channel, manufacturer supplies retailer at a wholesale price w, and the retailer sells the product at the price p_{ro} in physical store and occurs a unit sales cost in retail channel z_r. Since the wholesale price of product is the result of competition among multiple manufacturers in the market, and it changes infrequently relative to the retail price, in line with Gupta [27], Chen and Wang [24] and Cai et al. [5], we assume the wholesale price w is an exogenous parameter. All notations are summarized in Table 1. Three scenarios, denoted by the subscript $i = o, c, tc$, are identified. They include (1) the retailer has no capital constraint ($i = o$); (2) the retailer suffers capital constraint but without trade credit provision ($i = c$); (3) the retailer suffers capital constraint and is financed by trade credit from manufacturer ($i = tc$).

Table 1. Notation summary

c	Unit production cost
z_d	Unit sales cost in the direct channel
z_r	Unit sales cost in the retail channel
w	Wholesale price
v	Consumer's valuation of the product
t_r	Unit transportation cost, $t_r \geq 0$
t_d	Logistic delivery cost, $t_d \geq 0$
θ	Consumers' acceptance level of direct channel,$0 < \theta \leq 1$
x	Consumer's location, $xU[0, 1]$
B	Retailer's initial capital budget
q_i	Retailer's order quantity of under scenario i, $i = o, c, tc$
r	The interest rate for delay payment in trade credit, $r \geq 0$
p_{di}	The sales price in the direct channel under scenario i, $i = o, c, tc$
p_{ri}	The retail price under scenario i, $i = o, c, tc$
L	Delay payment of retailer, $L \geq 0$

3.1 Consumer Utility and Purchase Decision

Similar to Chiang et al. [13], Yan et al. [29], Xu et al. [7] and Zhang et al. [14], we respectively denote a consumer's valuation of the product by v in retail channel and θv in direct channel, where the parameter θ is called the consumers' acceptance level of direct channel. According to the research results of Liang and Huang [11] and Kacen et al. [12], most of the consumers are prefer buying goods from bricks and mortar to web-based channel since there are more uncertainty and risk in online buying. So, we develop model in this paper with$0 < \theta \leq 1$. Assume each consumer's location x ($xU[0, 1]$) is uniformly distributed along a unit line and the retailer is at the location 0. If a consumer located at x ($xU[0, 1]$) travels to retailer's store will incur a transportation cost$t_r x$, where t_r) is the unit transportation cost. Then the utility function of one consumer who buy the product through traveling to retailer's store is: ($i = o, c, tc$)

$$U_{ri} = v - p_{ri} - t_r x \tag{1}$$

As for the consumer who to buy from the direct channel, besides the product's sales price, he needs to afford logistic delivery cost rather than transportation cost. Form any manufacturers' official shopping websites (such like Huawei, Gree Inc), it can be easy to find that the difference of logistic delivery cost among different regions in a country is not significant, and the delivery cost is even free if the consumption amount attains to some threshold at most cases. Therefore, we assume a consumer needs to pay a constant logistic delivery cost t_d ($t_d \geq 0$) if he buy a product through the manufacturer's website directly, and his utility function is: ($i = o, c, tc$)

$$U_{di} = \theta v - p_{di} - t_d \tag{2}$$

To assure that the manufacturer has an incentive to exploit direct channel, it is appropriate to assume consumer's valuation of the product in retail channel satisfies $v < w + z_r + 2t_r$. Condition $v < w + z_r + 2t_r$ indicates the retailer cannot completely cover the whole market, so the manufacturer could improve market demand efficiently through building direct channel. And we further assume $v > w + z_r$ to ensure the demand in retail channel is non-negative. In addition, we normalize consumers' amount to 1, and suppose any individual consumer can buy (at most) one product from one channel. A consumer will buy from retail channel (or direct channel) if his utility generated by the channel is non-negative, but he would like to choose the channel which can bring bigger utility to him if both channels can generate positive consumer utility simultaneously. Then we can find the threshold of consumer's location is $\frac{v-p_r-\theta v+p_d+t_d}{t_r}$, consumers located in $0 \le x \le \frac{v-p_r-\theta v+p_d+t_d}{t_r}$ will buy from the retail channel, and whom located in $\frac{v-p_r-\theta v+p_d+t_d}{t_r} < x \le 1$ will buy from the direct channel.

3.2 Pricing Strategy of the Manufacturer When Retailer Has no Capital Constraint ($i = o$)

When retailer has no capital constraint, we respectively denote the online direct selling price and retail price of the product by p_{do} and p_{ro}. According to the consumers' purchase decisions in Sect. 3.1, the order quantity of retailer q_o equals to $\frac{v-p_{ro}-\theta v+p_{do}+t_d}{t_r}$, then the retailer's profit function $\pi_{ro}(p_{ro})$ is:

$$\pi_{ro}(p_{ro}) = (p_{ro} - w)q_o = (p_{ro} - w - z_r)\frac{v - p_{ro} - \theta v + p_{do} + t_d}{t_r} \tag{3}$$

The market share obtained by manufacturer through building the direct channel is $\left(1 - \frac{v-p_{ro}-\theta v+p_{do}+t_d}{t_r}\right)$, and the profit function $\pi_{mo}(p_{do})$ is:

$$\begin{aligned}\pi_{mo}(p_{do}) =&(w-c)q_o + (p_{do} - c - z_d)(1 - q_o)\\ =&(w-c)\frac{v - p_{ro} - \theta v + p_{do} + t_d}{t_r} + (p_{do} - c - z_d)\left(1 - \frac{v - p_{ro} - \theta v + p_{do} + t_d}{t_r}\right)\end{aligned} \tag{4}$$

The first part of Eq. (4) is the wholesale revenue in retail channel, and the latter part is the profit generated by direct channel. Suppose both manufacturer and the retailer are independent of each other and respectively maximize own profit. We utilize a manufacturer-leader Stackelberg game to explore the optimal prices of supply chain members. The manufacturer first decides the direct sales price p_{do}, then retailer makes the optimal response and decide the retail price p_{ro} in the physical store. To ensure that both channels' market demand and the marginal profit are non-negative, we can reasonably infer the constraint conditions $w + z_r \le p_{ro} \le v$ and $c + z_d \le p_{do} \le \theta v - t_d$ about the direct sales price p_{do} and the retail price p_{ro}. Thus the retailer and the manufacturers' optimization problems are respectively as follows:

$$Max_{p_{ro}} \pi_{ro}(p_{ro}),\ st. w + z_r \le p_{ro} \le v \tag{5}$$

$$Max_{p_{do}} \pi_{mo}(p_{do}),\ st. c + z_d \le p_{do} \le \theta v - t_d \tag{6}$$

Base on backward induction method, we present the equilibrium prices for both channels in Table 2, where $z_{d1} = \theta v - t_d - 2t_r + v - 2w - z_r$, $z_{d2} = \theta v - c - t_d$. It can be found that the equilibrium prices of both channels are simultaneously affected by the consumers' acceptance level of direct channel θ and the unit sales cost in direct channel z_d.

Table 2 shows that if the value of consumers' acceptance level of direct channel θ is no more than the threthold $\frac{t_d+c}{v}$, the manufacturer doesn't need to build direct channel. If the value of θ is higher than $\frac{t_d+c}{v}$, the direct channel is also unattractive to manufacturer as long as the unit sales cost in direct channel z_d is relatively high, i.e., exceeds threshold z_{d2}. Otherwise, both players in dual-channel supply chain should decide the optimal price based on the value of θ and z_d. In addition, the equilibrium prices p_{d0} and p_{r0} are monotonically increasing and decreasing with respect to θ respectively, it shows that a higher consumers' acceptance of the direct channel will bring a higher direct sales price and lower retail price. These findings are in line with the results presented by Hua et al. [16] and Rofin and Mahanty [17].

Table 2. Equilibrium prices when the retailer has no capital constraint

When $\theta > \frac{t_d+2t_r-v+2w+z_r}{v}$	$0 \leq z_d < z_{d1}$	$z_{d1} \leq z_d < z_{d2}$	$z_d \geq z_{d2}$
p_{r0}	$\frac{1}{4}(1-\theta)v + w + \frac{1}{4}z_d + \frac{1}{4}t_d + \frac{1}{2}t_r + \frac{3}{4}z_r$	$\frac{1}{2}v + \frac{1}{2}w + \frac{1}{2}z_r$	$\frac{1}{2}v + \frac{1}{2}w + \frac{1}{2}z_r$
p_{d0}	$w + \frac{1}{2}z_d - \frac{1}{2}t_d + t_r - \frac{1}{2}(1-\theta)v + \frac{1}{2}z_r$	$\theta v - t_d$	*N/A*
When $\frac{t_d+c}{v} < \theta \leq \frac{t_d+2t_r-v+2w+z_r}{v}$	$0 \leq z_d < z_{d2}$		$z_d \geq z_{d2}$
p_{r0}	$\frac{1}{2}v + \frac{1}{2}w + \frac{1}{2}z_r$		$\frac{1}{2}v + \frac{1}{2}w + \frac{1}{2}z_r$
p_{d0}	$\theta v - t_d$		*N/A*
When $0 < \theta \leq \frac{t_d+c}{v}$	irrelevant to z_d		
p_{r0}	$\frac{1}{2}v + \frac{1}{2}w + \frac{1}{2}z_r$		
p_{d0}	*N/A*		

There are two pricing strategies for manufacturer in direct channel. The one is the supplementary pricing strategy which sets a relatively high direct sales price to just absorbing the market demand which cannot be satisfied by the retailer, obviously, there is no competition between p_{d0} and p_{r0} in supplementary pricing strategy. Another one is the competitive pricing strategy. Besides absorbing the market demand which cannot be satisfied by the retailer, the manufacturer could poach the retailer's market share by setting a relatively low direct sales price. We point the optimal pricing strategy for manufacturer in Proposition 1.

Proposition 1. If the unit online direct selling cost z_d does not exceed the threshold z_{d2}, the manufacturer should build a direct channel, and choose appropriate pricing strategy according to the value of the consumers' acceptance level of direct channel θ and the unit sales cost in direct channel z_d:

(1) when $\theta > \frac{t_d+2t_r-v+2w+z_r}{v}$, the manufacturer should adopt the competitive pricing strategy with setting $p_{do} = w + \frac{1}{2}z_d - \frac{1}{2}t_d + t_r - \frac{1}{2}(1-\theta)v + \frac{1}{2}z_r$ if $0 \le z < z_{d1}$, and supplementary price strategy with setting $p_{do} = \theta v - t_d$ if $z_{d1} \le z < z_{d2}$.
(2) when $\frac{t_d+c}{v} < \theta \le \frac{t_d+2t_r-v+2w+z_r}{v}$, the manufacturer should adopt the supplementary pricing strategy with setting direct sales piece $p_{do} = \theta v - t_d$;
(3) when $0\ \theta \le \frac{t_d+c}{v}$, manufacturer doesn't need to build direct channel.

Proposition 1 shows that the manufacturer should adopt the competitive pricing strategy in direct channel only when consumers' acceptance level of direct channel is relatively high as well as the unit sales cost in direct channel is relatively low. Otherwise, the supplementary pricing strategy should be the better choice.

3.3 Pricing Strategy of the Manufacturer When Retailer Suffers Capital Constraint ($i = c$)

According to the result presented by Proposition1, the manufacturer doesn't need to build a direct channel when the unit sales cost in direct channel z_d exceeds the threshold z_{d2}, so this paper only pays attention to the situation that z_d satisfies $0 \le z_d < z_{d2}$. In this section, We consider the retailer has an initial capital B which is insufficient to afford order quantity q_o, i.e., $B < w \cdot q_o$ (where $q_o = \frac{v-p_{ro}-\theta v+p_{do}+t_d}{t_r}$). According to Table 1, the equilibrium prices of both channel (p_{ro}, p_{do}) depend on the value of parameter θ and z_d, sequentially the optimal order quantity of retailer q_o is also determined by the value of the two parameters. So retailer will face a capital constraint problem under the following situations presented in Lemma 1.

Lemma 1. The retailer will face a capital constraint problem,

(1) when $\theta \le \frac{t_d+2t_r-v+2w+z_r}{v}$, the retailer's initial capital satisfies $B \le \frac{w}{2}\frac{(v-w-z_r)}{t_r}$;
(2) when $\theta > \frac{t_d+2t_r-v+2w+z_r}{v}$, the retailer's initial capital satisfies $B < \frac{w}{4}\frac{((1-\theta)v+z_d+t_d+2t_r-z_r)}{t_r}$ if $0 \le z < z_{d1}$, and $B < \frac{w}{2}\frac{(v-w-z_r)}{t_r}$ if $z_{d1} \le z_d < z_{d2}$.

With a capital constraint problem, the retailer can only make order quantity $\frac{B}{w}$ based on his initial capital, then the equilibrium prices in two channels should be further explored. The product's direct sales price and retail price are respectively denoted by p_{dc} and p_{rc}. The retailer's profit function $\pi_{rc}(p_{rc})$ and the manufacturer's profit function $\pi_{mc}(p_{dc})$ are as follows:

$$\pi_{rc}(p_{rc}) = (p_{rc} - w - z_r)\frac{B}{w} \tag{7}$$

$$\pi_{mc}(p_{dc}) = (w - c)\frac{B}{w} + (p_{dc} - c - z)\left(1 - \frac{B}{w}\right) \tag{8}$$

The manufacturer should set $c + z \leq p_{dc} \leq \theta v - t_d$ to ensure that the market demand and the marginal profit of the product in the direct channel are non-negative. As for the retailer, besides positive marginal profit, it is very important to control the market demand not less than the order quantity $\frac{B}{w}$ in the retail channel through setting the retail price satisfying $w + z_r \leq p_{rc} \leq \frac{((1-\theta)v+p_{dc}+t_d)w-Bt_r}{w}$. So the optimization problems for dual-channel supply chain players are as follows:

$$Max_{p_r}\pi_{rc}(p_{rc}), st.w + z_r \leq p_{rc} \leq \frac{((1-\theta)v + p_{dc} + t_d)w - Bt_r}{w} \tag{9}$$

$$Max_{p_d}\pi_{mc}(p_{dc}), st.c + z_d \leq p_{dc} \leq \theta v - t_d \tag{10}$$

According to the backward induction method, we try to explore the equilibrium solutions to the manufacturer-leader Stackelberg game. Since the retailer's profit function $\pi_{rc}(p_{rc})$ is monotonically increasing with retail price p_{rc}, then the response function of retail price can be firstly obtained:

$$p_{rc}(p_{dc}) = \frac{((1-\theta)v + p_{dc} + t_d)w - Bt_r}{w} \tag{11}$$

Because the profit function of manufacturer is monotonically increasing with the direct sale price, we can obtain

$$p_{dc} = \theta v - t_d \tag{12}$$

After substituting (12) into (11), it can be found that the optimal retail price is:

$$p_{rc} = \frac{vw - Bt_r}{w} \tag{13}$$

In Proposition 2, we present the manufacturer's pricing strategy and the influence from the retailer's capital constraint on manufacturer's profit.

Proposition 2. If a retailer has a capital constraint and owns initial capital B,

(1) manufacturer should always adopt the supplementary pricing strategy, and the equilibrium prices in two channels are $p_{dc} = \theta v - t_d$ and $p_{rc} = \frac{vw-Bt_r}{w}$ respectively;
(2) compare to without capital constraint, the retailer has a capital constraint will increase the manufacturer's profit if $\theta > \frac{t_d+w}{v}$ and $0 \leq z_d < z_{d3}$; Otherwise, it will decrease the manufacturer's profit, where $z_{d3} = \theta v - t_d - w$.

When the retailer has a capital constraint problem, Proposition 2 firstly shows that the supplementary pricing strategy is the better choice for manufacturer rather than the competitive pricing strategy. There is no need to compete with the retailer on price because the maximum profit can be realized through setting the highest direct sales price

$p_{dc} = \theta v - t_d$. Secondly, the equilibrium retail price p_{rc} is positively related with the retailer's initial capital B and irrelevant to the consumers' acceptance level of the direct channel θ. While the equilibrium direct sales price p_{dc} is positively correlated with θ.

Furthermore, unlike the traditional view that the capital constraint on retalier is only bad for manufacturer's profit, Proposition 2 reveals that the retailer's capital constraint has a two-way impact on manufacturer's profit. On the one hand, the capital constraint on retailer could ease price competition between two channels, thus it has a positive effect on improving the marginal profit of manufacturer. On the other hand, it reduces the retailer's order quantity, which has a negative impact on manufacturer's wholesale income. When consumers' acceptance level of direct channel is relatively high and the unit sales cost in direct channel is relatively low, the positive impact from the retailer's capital constraint is bigger than negative impact, so the capital constraint on retailer is good for manufacturer. In other cases, the retailer's capital constraint is harmful to manufacturer's profit, so it is reasonable that there exists an incentive for manufacturer to provide financial service to retailer. To clearly describing when is retailer's capital constraint beneficial to manufacturer, we further plot out the benifical region for manufacturer according to the corresponding conditions presented in Proposition 2 (see Fig. 1). Figure 1 shows that the capital constraint on retailer is good to manufacturer's profit in *Area II*, but the opposite occurs in *Area I*.

4 A Dual-Channel Supply Chain with Trade Credit Service ($i = tc$)

We accommodate a specific financial service which is trade credit in this section, and further discuss trade credit strategy in a dual-channel supply chain. To avoid default risk, suppliers often encourage retailers to pay off unpaid amount early by designing the appropriate trade credit contract. In a single-channel supply chain, Kouvelis and Zhao [25] incorporate interest rate and discounted wholesales price into the trade credit contract, and Cai et al. [5] discuss credit limit and interest rate in the trade credit contract. Different from them, we jointly optimize the pricing strategy and trade credit strategy by just considering the interest rate into the contract under a dual-channel supply chain.

Based on Proposition 2, it can be found that the manufacturer has an incentive to provide trade credit only when its profit is pulled down by retailer's capital constraint. The corresponding conditions are identified in Lemma 2.

Lemma 2. Manufacturer will have incentive to provide trade credit in following two cases:

Case (1): consumers' acceptance level of the direct channel is too low, i.e., $\frac{t_d+c}{v} < \theta \leq \frac{t_d+w}{v}$ and $z_{d3} \leq z_d < z_{d2}$.
Case (2): both consumers' acceptance level of the direct channel and the unit sales cost in direct channel are relatively high, i.e.,$\theta > \frac{t_d+w}{v}$ and $z_{d3} \leq z_d < z_{d2}$.

Above cases are included in the *Area I* of Fig. 1, if financed by trade credit, the retailer who owns a capital constraint could realize larger order quantity than that can be afforded by his initial capital B. Served by trade credit, the retailer only needs to make a partial payment with his initial capital B firstly, then realize full order quantity $\frac{B+L}{w}$ right away, where $L(L \geq 0)$ is the delay payment. And the retailer must pay off the delay payment L to the manufacturer at an interest rate $r(r \geq 0)$ after the sales season ends. In the manufacturer-leader Stackelberg game, manufacturer firstly decides the terms in trade credit contract which including online direct selling price p_{dtc} and the interest rate r, then the retailer makes the optimal response to manufacturer's strategy and decide the delay payment L and retail price p_{rtc}.The retailer's profit function $\pi_{rtc}(p_{rtc}, L)$ and the manufacturer's profit function $\pi_{mtc}(p_{dtc}, r)$ can be described as follows:

$$\pi_{rtc}(p_{rtc}, L) = (p_{rtc} - w - z_r)\frac{B+L}{w} - L(1+r) \tag{14}$$

$$\pi_{mtc}(p_{dtc}, r) = (w-c)\frac{B+L}{w} + (p_{dtc} - c - z)\left(1 - \frac{B+L}{w}\right) + Lr \tag{15}$$

As the same as Sect. 3.3, the manufacturer should set $c + z_d \leq p_{dtc} \leq \theta v - t_d$ to ensure that the market demand and the marginal profit of the product in direct channel are non-negative. Besides positive marginal profit, it is important for the retailer to control the market demand not less than the order quantity $\frac{B+L}{w}$ in retail channel through setting the retail price satisfying $w + z_r \leq p_{rtc} \leq \frac{((1-\theta)v+p_{dtc}+t_d)w-(B+L)t_r}{w}$. So the optimization problems for dual-channel supply chain players are as follows:

$$Max_{p_{rtc},,L}\pi_{rtc}(p_{rtc}, L), st.\begin{cases} w + z_r \leq p_{rtc} \leq \frac{((1-\theta)v+p_{dtc}+t_d)w-(B+L)t_r}{w} \\ L \geq 0 \end{cases} \tag{16}$$

$$Max_{p_{dtc},r}\pi_{stc}(p_{dtc}, r), st.\begin{cases} c + z_d \leq p_{dtc} \leq \theta v - t_d \\ r \geq 0 \end{cases} \tag{17}$$

The equilibrium solutions and are presented in Table 3, where $B_1 = \frac{w(v-2w-z_r)}{2t_r}$, $B_2 = \frac{((1+\theta)v-z_d-z_r-t_d-3w)w}{2t_r}$.

Table 3. Equilibrium outcomes with trade credit service

	$0 \leq B < B_2$	$B_2 \leq B < B_1$	$B_1 \leq B < \frac{w}{2}\frac{(v-w-z_r)}{t_r}$
p_{rtc}	$\frac{1}{4}\frac{((3+\theta)v-z_d+z_r-t_d)w-2Bt_r+w^2}{w}$	$\frac{1}{2}v + w + \frac{1}{2}z_r$	$\frac{vw-Bt_r}{w}$
L	$\frac{1}{4}\frac{((1-\theta)v+z_d-z_r+t_d)w-2Bt_r-w^2}{t_r}$	$\frac{1}{2}\frac{vw-2Bt_r-2w^2-wz_r}{t_r}$	N/A(no trade credit)
p_{dtc}	$\theta v - t_d$	$\theta v - t_d$	$\theta v - t_d$
r	$\frac{1}{2}\frac{((1+\theta)v-z_d-z_r-t_d)w-2Bt_r-3w^2}{w^2}$	0	N/A(no trade credit)

After making a comparison between the value of p_{rtc} in Table 3 and p_{rc} in Proposition 2, it can be found that $p_{rc} \geq p_{rtc}$ is always holding. It indicates that the retailer will decrease the retail price of the product under trade credit, so trade credit intensifies the price competition between two channels. We further investigate whether the provision of trade credit is beneficial to the manufacturer, and present the pricing strategy and trade credit strategy in Proposition 3.

Proposition 3. When manufacturer's profit is pulled down by retailer's capital constraint, the manufacturer should adopt the supplementary pricing strategy with $p_{dtc} = \theta v - t_d$, and strategically provide trade credit based on the value of the retailer's initial capital B and the value of unit sales cost z_r in retail channel:

(1) When the value of unit sales cost in retail channel z_r is low enough to satisfy $z_r < (1+\theta)v - t_d - z_d - 3w$, (1 * roman) the manufacturer should provide trade credit to the retailer with a positive interest rate $r = \frac{1}{2}\frac{((1+\theta)v - z_d - z_r - t_d)w - 2Bt_r - 3w^2}{w^2}$ if $0 \leq B < B_2$,; (2 * roman) the manufacturer should provide trade credit to the retailer for free with $r = 0$ if $B_2 \leq B < B_1$; (3 * roman) the manufacturer does not need to provide trade credit if $B_1 \leq B < \frac{w}{2}\frac{(v-w-z_r)}{t_r}$.
(2) When the value of unit sales cost in retail channel z_r satisfies $(1+\theta)v - t_d - z_d - 3w \leq z_r < v - 2w$, (1 * roman) the manufacturer should provide trade credit to the retailer for free with $r = 0$ if $0 \leq B < B_1$; (2 * roman) the manufacturer does not need to provide trade credit if $B_1 \leq B < \frac{w}{2}\frac{(v-w-z_r)}{t_r}$.
(3) When the value of unit sales cost in retail channel z_r is high enough to satisfy $v - 2w \leq z_r < v - w$, the manufacturer does not need to provide trade credit.

Proposition 3 puts forward two trade credit strategies: trade credit with positive interest rate and trade credit with zero interest rate. The results guide the manufacturer when and how to provide trade credit. Although trade credit could increase the manufacturer's wholesale revenue and bring income by interest rate, it also will lead the manufacturer to suffer profit loss since the price competition between two channels is intensified. On one hand, when the value of unit sales cost in retail channel is relatively low, the increment of manufacturer's profit is lower than the profit loss under the trade credit if the value of the retailer's initial capital is relatively high, i.e., $B_1 \leq B < \frac{w}{2}\frac{(v-w-z_r)}{t_r}$, so there is no need to provide trade credit at all. If the value of the retailer's initial capital is relatively low, i.e., $0 \leq B < B_2$, the opposite is true and the manufacturer should provide trade credit with a positive interest rate. And note that when the value of retailer's initial capital is neither relatively high nor relatively low, i.e., $B_2 \leq B < B_1$, the manufacturer would like to choose a zero interest rate to expand the wholesale income. This result is consistent with the conclusion of Daripa and Nilsen [23] that much of the trade credit is supplied at zero interest. On the other hand, when the value of unit sales cost in retail channel z_r is extremely high (i.e., $v - 2w \leq z_r < v - w$), the retailer would not chose trade credit service even if manufacturer provides it, since low retail price and high sales cost lead to low marginal profit under trade credit. So there is no need to provide trade credit under this situation.

To guide the manufacturer when and how to provide trade credit, we further plot out the feasible region for each trade credit strategy based on the corresponding condition (see Fig. 5). Our results implicate that making trade credit strategy according to the retailer's initial capital and the unit sales cost in retail channel can effectively avoid the cheating problem which is presented by Chen [28] that the retailer may cheat on the manufacturer about the true initial budget.

5 Numerical Simulation

Base on several numerical simulation examples, we comprehensively explore more managerial insights of pricing and trade credit strategies in a dual-channel supply chain.

5.1 Without Trade Credit

We first test the two-way impact from the retailer's capital constraint on the manufacturer's profit. With the following base parameter set $w = 0.3$, $t_d = 0.2$, $t_r = 0.3$, $c = 0.1$, $v = 0.8$, $B = 0.2$, we obtain Fig. 1 based on the results presented in Proposition 2.

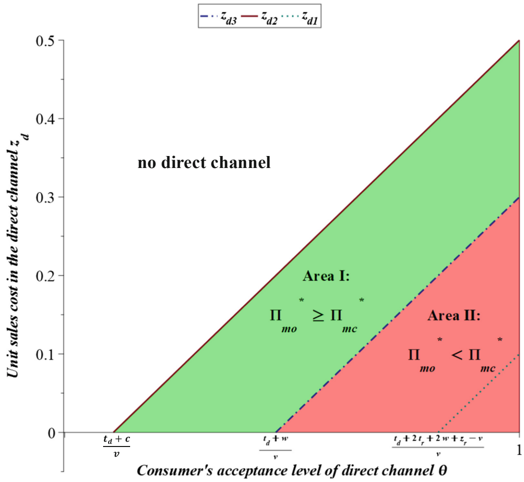

Fig.1. Manufacturer's profit under two scenarios ($i = o, c$)

Figure 1 shows that when consumers' acceptance level of the direct channel is relatively high and the unit sales cost in direct channel is relatively low (i.e., in *Area II*), manufacture can benefit from the capital constraint on retailer, while the opposite occurs in *Area I*.

5.2 With Trade Credit

Respectively explore the impact of trade credit on retailer's order quantity, retail price, manufacturer's profit, and further describe the feasible region for each trade credit strategy based on corresponding conditions. According to Lemma 2, the next four numerical studies have been developed under conditions which both consumers' acceptance level of the direct channel and unit sales cost in direct channel are relatively high (i.e., $\theta > \frac{t_d+w}{v}$ and $z_{d3} \leq z < z_{d2}$). With the following base parameter set $\theta = 0.65$, $w = 0.2$, $t_d = 0.2$, $t_r = 0.3$, $c = 0.1$, $v = 0.8$, $z_r = 0.1$, $z_d = 0.8$, we first respectively plot the order quantity of retailer Q_o, $Q_c(B)$, and $Q_{tc}(B)$ under three scenarios: (1) the retailer has no capital constraint; (2) the retailer suffers capital constraint but without trade credit

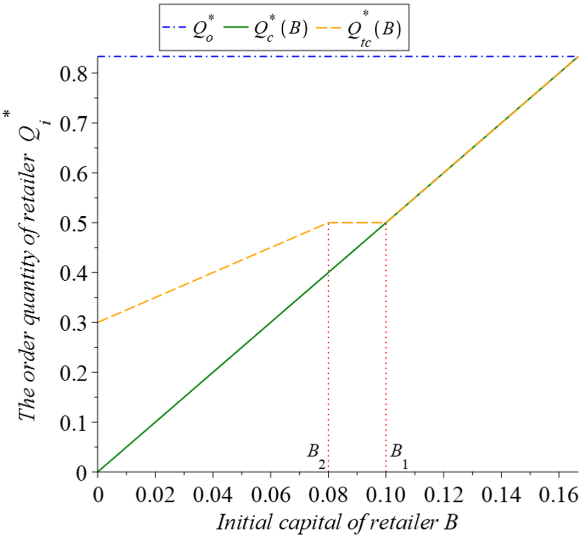

Fig. 2. Retailer's optimal order quantity under three scenarios ($i = o, c, tc$)

provision; (3) the retailer suffers capital constraint and is financed by trade credit from the manufacturer.

Figure 2 shows that under the above three scenarios, the retailer's order quantity always meets $Q_c(B) \leq Q_{tc}(B) \leq Q_o$. It indicates that capital constraint compel the retailer to reduce his order quantity from the Q_o to $Q_c(B)$, while the trade credit could improve his order quantity from $Q_c(B)$ to $Q_{tc}(B)$. It's worth noting that the retailer will not improve his order quantity $Q_{tc}(B)$ up to Q_o even if the manufacturer serves him with trade credit for free. Since the trade credit with zero interest rate puts down the retail price although it improves the order quantity, therefore blindly pursuing the order level without capital constraint may not bring the maximum profit.

Then we describe the retail price p_{ro}, $p_{rc}(B)$, and $p_{rtc}(B)$ under the above three scenarios in Fig. 3.

Figure 3 shows that $p_{ro} \leq p_{rtc}(B) \leq p_{rc}(B)$ is holding. It can be interpreted that capital constraint make the retailer rise the retail price from p_{ro} to $p_{rc}(B)$, while trade credit could decrease the retail price from $p_{rc}(B)$ to $p_{rtc}(B)$. Note that even financed by trade credit for free, the retailer with capital constraint is reluctant to drop the retail price $p_{rc}(B)$ to p_{ro} since a small marginal profit is not beneficial to him. It's interesting that if the trade credit interest rate in a single-channel supply chain is zero, the order quantity and retail price decided by the retailer with capital-constraint can be the same as that in the case of no capital constraint. However, in the dual-channel supply chain of this paper, the trade credit with zero interest rate doesn't make the retailer's order quantity and retail price reach the level of no capital constraint.

Next, we make a comparison among the profit of manufacturer under the above three scenarios in Fig. 4.

If the retailer's capital constraint is harmful to manufacturer (such as in the Cases described in Lemma 2), Fig. 4 exhibits that providing trade credit can greatly improve

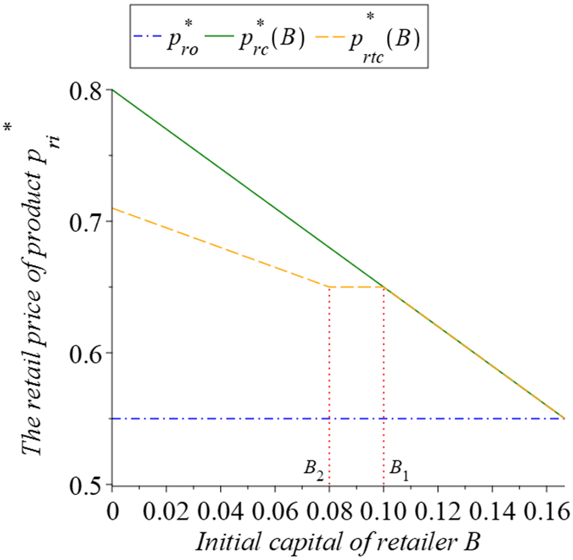

Fig. 3. The equilibrium retail price under three scenarios ($i = o, c, tc$)

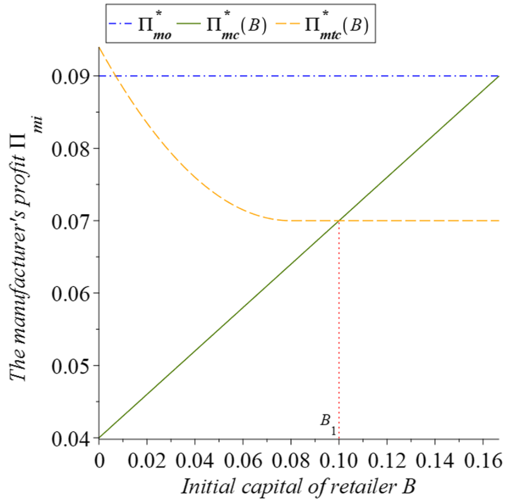

Fig. 4. The manufacturer's profit under three scenarios ($i = o, c, tc$)

manufacturer's profit to far exceed that without capital constraint when retailer B's initial capital is extremely low. But for the manufacturer, benefits brought by trade credit provision gradually shrinks to zero as B increases up to B_1, so no provision of trade credit is the better choice for the manufacturer when $B \geq B_1$.

Last, according to the results presented Proposition 3, the conditions about z_r (the unit sales cost in retail channel) and the conditions about B (the initial capital of retailer) could form a closed area in a two-dimensional plane. With the parameter set $\theta = 0.65$, $w = 0.2$, $t_d = 0.2$, $t_r = 0.3$, $c = 0.05$,$z_d = 0.25$ and $v = 0.8$, we plot out the feasible region of each trade credit strategy for manufacturer in Fig. 5.

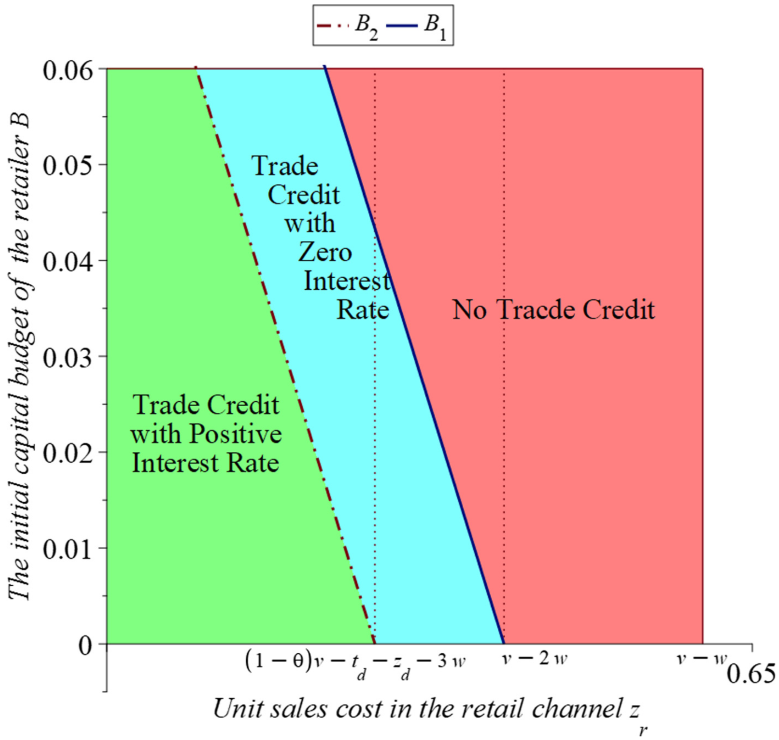

Fig. 5. The feasible region of trade credit strategy

Figure 5 is a two-dimensional plan that takes z_r as the X-axis and B as the Y-axis. The boundaries of each region respectively correspond to the thresholds of B presented in Proposition 3. We can clearly observe the feasible regions for manufacturer to adopt each trade credit strategy.

6 Conclusions

It is important for a manufacturer to effectively provide trade credit to a retailer who suffer capital constraint in a dual-channel supply chain. We carefully study pricing and trade credit strategies for manufacture in this research.

Through building Stackelberg game model with a manufacturer-leader and a retailer-follower, we first reveal the closed-form equilibrium prices for both supply chain members and find that the equilibrium prices are simultaneously affected by unit direct sale cost and consumers' acceptance level of the direct channel. Supplementary pricing strategy and competitive pricing strategy are presented in our results, we conclude that the former one is the better choice for manufacture when retailer suffers capital constraint. Moreover, when manufacturer's profit is threatened by retailer's capital constraint, we verify the manufacturer should provide trade credit to retailer strategically rather than provide it unconditionally. We further present two trade credit strategies (trade credit with positive interest rate as well as trade credit with zero interest rate) and suggest manufacture choose appropriate trade credit strategy according to retailer's initial capital and unit sales cost in retail channel. To guide the manufacturer when and how to provide trade credit, we further conduct serval numerical simulations to plot out the feasible region for each trade credit strategy based on the corresponding condition.

From management perspectives, the first implication of our findings is that the capital constraint of retailer plays the role of a "double-edged sword" in a dual-supply chain, the manufacturer should make good use of it. The second implication warns manufacturers that it is necessary to pay attention to the unit sale cost both in retail and direct channels, these factors have a significant impact on manufacturer's pricing and trade credit strategy. Last, for manufacturers who aim to design optimal trade credit strategies, they should carefully make a tradeoff between the benefit from trade credit provision (including expanded wholesale revenue and income brought by interest rate) and the profit loss from intensified price competition.

However, there are some limitations on our modle. Although we suppose there is one retailer in a dual-channel supply chain, considering multiple-competitive retailers would be more meaningful. In our model, the consumers' acceptance level of the direct online channel is public information, but both members of the supply chain may not be able to obtain the exact value of it. So it is necessary to absorb uncertainties of parameters in the future.

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