STACKELBERG PRICING POLICY IN DYADIC CAPITAL-CONSTRAINED SUPPLY CHAIN CONSIDERING BANK’S DEPOSIT AND LOAN BASED ON DELAY PAYMENT SCHEME

BING-BING CAO AND ZAI-JING GONG
School of Management
Guangzhou University, Guangzhou 510006, China

TIAN-HUI YOU*
Department of Information Management and Decision Sciences
School of Business Administration
Northeastern University, Shenyang 110169, China

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Abstract. In reality, supply chain member may apply for loan from bank when he/she is capital-constrained, or may deposit idle capital to bank when he/she is well-funded. This study focuses on the Stackelberg pricing policy considering bank’s deposit and loan based on delay payment scheme in a dyadic capital-constrained supply chain. First, the market demand is given, and then the profit functions of supply chain members are built. According to Stackelberg game, the four pricing models are constructed for four scenarios. By solving models, optimal pricing policies of supply chain members for each scenario can be determined. Finally, impacts of the interest rate for fixed deposit by installments, deposit rate and loan rate on optimal pricing policies are analyzed. The research results show that, in manufacturer capital-constrained situation, these rates can affect optimal pricing policies and profits; in retailer capital-constrained situation, these rates have no effect on them, but the interest rate for fixed deposit by installments can still affect them. Our study provides a feasible way for supply chain members in pricing decision considering bank’s deposit and loan based on delay payment scheme in a dyadic capital-constrained supply chain, and contributes to the theoretical research on the capital-constrained supply chain management and the management practice for capital-constrained supply chain members with bank’s deposit and loan.

1. Introduction. In reality, the retailer needs to transfer the payment to manufacturer. According to the difference of transfer times, the payment can be transferred in several ways [23, 6, 36, 14, 1, 19, 10], where the delay payment scheme is regarded
as a common and effective way for many supply chain systems since it can relieve the retailer’s capital pressure [23, 1]. In a supply chain system, the supply chain members may be capital-constrained because of prepayment to the upstream in supply chain, backlog inventories or un-received payment from the downstream, and may also be well-funded because of the payment received in time [15]. For the capital-constrained supply chain members, they usually need to apply for bank loan to maintain their production and operation activities [19, 12, 31, 39, 5, 21, 8, 13, 18, 29]. For the well-funded supply chain members, they may deposit the idle capital to bank for benefit. In addition, during selling period, the retailer can also deposit the sales revenue to bank by installment for interest earning. Under the consideration of the above situation comprehensively, how to determine the optimal pricing policies of manufacturer and retailer based on delay payment scheme for the achievement of profit expectation is a noteworthy and important issue.

The problem studied in this paper is how to determine the optimal policies of wholesale price and retail price in considering of bank’s deposit and loan in capital-constrained supply chain based on delay payment scheme and Stackelberg game. The key point to this problem is how to describe the interaction process of manufacturer and retailer considering deposit rate, loan rate and the interest rate for fixed deposit by installments in different capital-constrained situations, how to build profit functions of manufacturer and retailer in dyadic supply chain based on delay payment scheme in different capital-constrained situations, and how to construct the Stackelberg pricing models for different supply chain power structures in different capital-constrained situations based on Stackelberg game.

Our study has three motivations. First, in reality, the supply chain member may be well-funded or capital constrained; the well-funded supply chain member may deposit the idle capital, the capital-constrained supply chain member may apply for the bank loan, and the retailer may deposit the sales revenue to bank by installment. Thus, the deposit rate, loan rate and interest rate for fixed deposit by installments will affect the optimal policies of supply chain members. Second, the supply chain has different capital-constrained situations and different power structures for each capital-constrained situation. The optimal policies of supply chain members for these situations are generally different. Thus, it is significant to conduct a study on optimal policies of supply chain members for each supply chain power structure in these situations. Third, existing studies pay little attention to pricing policy in dyadic capital-constrained supply chain considering bank’s deposit and loan for delay payment scheme based on Stackelberg game. The related results are not suitable for solving this pricing decision problem. Thus, it is necessary to study theories and models on pricing decisions considering bank’s deposit and loan with capital constraint for delay payment scheme based on Stackelberg game.

The main contribution of this study is four-fold. First, we propose a new pricing problem in dyadic capital-constrained supply chain considering bank’s deposit and loan based on delay payment scheme. Second, we build the profit functions of manufacturer and retailer for two capital-constrained situations by analyzing the operation processes of the supply chain based on delay payment scheme in the potential capital-constrained situations. Third, we construct four Stackelberg pricing models considering the capital constraint and bank’s deposit and loan based on delay payment scheme for four scenarios. Fourth, we determine the optimal policies of manufacturer and retailer, and discuss the impacts of the interest rate for fixed deposit by installments, deposit rate and loan rate on their optimal policies and
profits. On the basis, we provide the managerial insights for guiding practice in the area of Stackelberg pricing in capital-constrained supply chain.

The rest of this paper is organized as follows. Section 2 reviews the existing related literature. Section 3 gives the problem description, the assumption and the notation. Section 4 provides demand function, and then builds profit functions of manufacturer and retailer for two capital-constrained situations based on delay payment scheme. Section 5 constructs the Stackelberg pricing models considering the capital constraint and bank’s deposit and loan based on delay payment scheme for four scenarios. Section 6 analyzes the optimal policies of manufacturer and retailer for four scenarios, and discusses impacts of the model parameters, i.e., the interest rate for fixed deposit by installments, deposit rate and loan rate, on the optimal policies and profits. Section 7 gives managerial insights of this study for guiding practice in four scenarios. Section 8 summarizes the main conclusions and then presents the prospects of the further research. All proofs are provided in technical Appendices.

2. Literature review. Recently, the direct study on Stackelberg pricing policy in dyadic capital-constrained supply chain considering bank’s deposit and loan based on delay payment scheme is still lacking, but the related research results can be seen, these results mainly focus on the following four aspects: the pricing decision based on delay payment scheme, the supply chain coordination based on delay payment scheme, the pricing decision in capital-constrained supply chain and the coordination in capital-constrained supply chain. It is necessary to point out that, in recent years, there has been a multiple of studies in these fields, and it is difficult to exhaust the existing literature. For the sake of brevity, we only pour attention to the latest and most representative studies here.

For the study on the pricing decision based on delay payment scheme, for example, Ouyang et al. [23] propose an economic order quantity model for deteriorating items with partially permissible delay in payments, and show the rationality of constructed model by numerical study. Chen and Kang [7] study integrated models with permissible delay in payments for determining the optimal replenishment policy, and illustrate the feasibility of proposed integration models. Giri and Maiti [12] develop a supply chain model under two-level permissible delay in payments, and demonstrate the coordination policy of the supply chain. Soni [26] derives some useful theoretical results to characterize the optimal solutions for non-zero and zero ending inventory system, and show that it is more beneficial to keep higher inventory level even. Jin et al. [19] study the optimal ordering and financing decisions under advance selling and delayed payment for a capital-constrained supply chain, and identify the conditions under which advance selling strategy or delayed payment strategy is preferable. Li et al. [22] develop an inventory model interfaced with marketing, operations and finance in a supplier-retailer chain, and demonstrate that an increase in the fraction of advance payment raises selling price.

For the study on the supply chain coordination based on delay payment scheme, for example, Jaber and Osman [17] propose a centralized model with delay in payments, and show that the retailer orders in larger quantities than its economic order quantity for coordination. Duan et al. [9] study a two-level supply chain coordination problem for fixed lifetime products with permissible delay in payments, and show that providing longer credit period than the retailer’s order period is not commonly applicable. Gao et al. [11] propose a delay-in-payment contract to
coordinate the supply chain, and find that a base-stock policy is optimal. Aljazzar et al. [2] investigate a coordination of a three-level supply chain by coupling of delay in payments and price discounts, and find that the coupling increases supply chain profit more than using only a single mechanism at a time. Ebrahimi et al. [10] propose a delay-in-payment contract for coordinating a periodic review supply chain, and show that the proposed coordination scheme considerably improves the profitability of supply chain. Taleizadeh et al. [28] develop a delay-in-payment contract for a single-item two-echelon supply chain, and show the impacts of cost parameters on the decision variables and the profit.

For the study on the pricing decision in capital-constrained supply chain, for example, Zhou et al. [40] propose a single-period inventory and payment model with partial trade credit, and find that partial trade credit may be detrimental to capital-constrained retailer. Zhou et al. [39] discuss how a capital-constrained retailer determines his optimal financing mode, and show that adopting financing service improves retailer’s performance. Zhang et al. [37] extend the credit financing models by incorporating retailer’s default risk into the decision problems, and reveal that the profits under bank credit are independent of retailer’s default risk. Jaggi et al. [18] study the inventory and credit decision model for deteriorating items under permissible delay in payments, and find that the model is best suitable for the emerging retail markets.

For the study on the coordination in capital-constrained supply chain, for example, Xu et al. [32] investigate the methods for coordinating the call center outsourcing supply chain with financial constraint, and show that the cost sharing contract can achieve channel coordination. Xiao et al. [31] examine the coordination of capital-constrained supply chain, and show that revenue-sharing and buyback contracts can coordinate under some conditions, while all-unit quantity discount contract fails. Cao and Yu [5] investigate the interaction of financial decision and operational decision in an emission-dependent supply chain with capital constrained retailer, and find that the optimal ordering quantity is irrelevant to carbon emission cap under centralized decision. Chen et al. [8] set up a modified newsvendor model with trade credit, and show that trade credit coordinating the supply chain requires an extremely long credit period. Wu et al. [29] focus on how carbon emissions reduction affects the operations and financing decisions for a capital-constrained green supply chain, and find that a supply chain with a contract outperforms a non-contract supply chain in production quantity and emissions reduction.

It can be seen from above analysis that the existing research results have important and significant scientific value and have made great contributions to the further study on the capital-constrained supply chain decision based on the payment scheme. However, the above results seldom focus on the situation where the well-funded manufacturer or retailer can deposit the idle capital to bank for benefit and the retailer can deposit the sales revenue by installment to bank for benefit in capital-constrained supply chain based on delay payment scheme. In reality, the situation happens commonly, and supply chain members need the theoretical results to guide them in their decisions. Therefore, we emphatically study the Stackelberg pricing policies in dyadic capital-constrained supply chain considering bank’s deposit and loan based on delay payment scheme. Specifically, we first analyze the capital-constrained situation of manufacturer and retailer based on delay payment scheme. Then, we provide the demand function and build the profit functions of
manufacturer, retailer and supply chain for the capital-constrained situations. Furthermore, according to the Stackelberg game, we construct the Stackelberg pricing model for each power structure of supply chain in each capital-constrained situation. By solving the constructed models, we determine the optimal policies and profits of manufacturer and retailer. Finally, we analyze the impacts of the rate for fixed deposit by installment, deposit rate and loan rate on the optimal policies and profits of manufacturer and retailer, and obtain the significant managerial insights to guide manufacturer and retailer in their decisions.

3. Problem description, assumption and notation.

3.1. Problem description. For a dyadic capital-constrained supply chain consisting of a manufacturer and a retailer, the retailer orders from manufacturer according to the market demand information, then the manufacturer produces and delivers the products to retailer before selling period. At the beginning of selling period, the retailer starts to sell the products to the market. In reality, the capital statuses of manufacturer and retailer are uncertain. The manufacturer or retailer may be well-funded or capital-constrained. The capital-constrained situation is mainly caused by the prepayment to the upstream in supply chain, backlog inventories and the un-received payment from the downstream in supply chain. For a certain market scenario at a specific time, the manufacturer and retailer may face the capital-constrained problem. In the dyadic capital-constrained supply chain, the potential capital-constrained situations mainly contain the following three types:

Situation MC: The manufacturer is capital-constrained, while retailer is well-funded.

Situation RC: The retailer is capital-constrained, while manufacturer is well-funded.

Situation MRC: The manufacturer and retailer are both capital-constrained.

It is necessary to point out that, for the delay payment scheme, the retailer transfers the payment to manufacturer at the end of selling period, while the retailer can obtain the sufficient payment from sales revenue at the end of selling period. Obviously, the delay payment scheme relieves retailer’s capital pressure. Thus, in situation MRC, the retailer does not need to apply for bank loan, i.e., for delay payment scheme, the retailer’s capital status will not affect the optimal policies of retailer, manufacturer and supply chain. From above analysis, we show that the operation process in situation MRC is essentially same to the one in situation MC. Basically, this study emphatically focuses on the Stackelberg pricing policy in dyadic capital-constrained supply chain for situations RC and MC.

For situation MC, the manufacturer has no production capital, and thus needs to apply for loan from bank before selling period. The retailer has sufficient capital, i.e., the payment for products, and deposits the idle capital to bank for benefit with respect to the time span of preselling and selling periods. Meanwhile, the retailer can deposit the sales revenue to bank by installment for benefit in selling period. At the end of selling period, the retailer withdraws from bank with interest, and then transfers the payment to the manufacturer. Finally, the manufacturer repays bank loan.

For situation RC, the manufacturer has sufficient production capital, and is able to produce according to the order of retailer. The retailer is capital-constrained, and deposits the sales revenue to bank by installment in selling period. At the end of selling period, the retailer withdraws from bank with interest and transfers the
payment to the manufacturer.

Based on the above analysis, the event time line of dyadic supply chain pricing decision considering bank’s deposit and loan based on delay payment scheme in manufacturer capital-constrained situation and retailer capital-constrained situation can be determined, it is shown in Figure 1.

![Figure 1. Event time line.](image-url)

The problem studied in this paper is how to optimize the decisions of manufacturer and retailer for different supply chain power structures considering bank’s deposit and loan based on delay payment scheme in manufacturer capital-constrained situation and retailer capital-constrained situation, i.e., how does the manufacturer determine the optimal wholesale price and how does the retailer determine the optimal price to achieve their profit expectations in two capital-constrained situations. Specifically, to solve the problem, we focus on the following four aspects:

1. How to describe market demand and build profit functions of manufacturer and retailer considering bank’s deposit and loan based on delay payment scheme in manufacturer capital-constrained situation and retailer capital-constrained situation?
2. How to construct the pricing models based on delay payment scheme for each supply chain power structure in manufacturer capital-constrained situation and retailer capital-constrained situation?
3. How to determine the optimal policies and profits of manufacturer and retailer based on delay payment scheme for each supply chain power structure in manufacturer capital-constrained situation and retailer capital-constrained situation?
4. How do the model parameters (i.e., the interest rate for fixed deposit by installments, deposit rate and loan rate) affect the optimal profits of manufacturer and retailer based on delay payment scheme for each supply chain power structure in manufacturer capital-constrained situation and retailer capital-constrained situation?

3.2. Assumption. To clearly present the study on the Stackelberg pricing decision in dyadic capital-constrained supply chain considering bank’s deposit and loan based on delay payment scheme, we summarize the necessary basic assumptions as follows:

Assumption 1: The information in supply chain is systematic, and both manufacturer and retailer exhibit the perfect rationality.

Assumption 2: The supply chain system and bank operate well; the bankruptcy risk is not considered.

It is necessary to point out that, the bankruptcy situation for supply chain system and bank is not common in reality. Generally, most supply chain systems and banks can operate well in recent good economic environment.
Assumption 3: The retailer can deposit the idle capital to bank for benefit, and can also deposit the sales revenue to bank by installment for benefit.

Assumption 4: The well-funded supply chain member implies that the manufacturer has sufficient production capital, or the retailer has sufficient procurement capital. For example, the well-funded manufacturer implies that the manufacturer has the production capital $cD$ to produce $D$ products; the well-funded retailer implies that the retailer has the procurement capital $wD$ to order $D$ products from manufacturer.

3.3. Notation. In this study, many mathematical symbols are used. In the following, the notation for decision variables, parameters, functions and optimal values is given.

**Decision variables:**
- $w^i$: The wholesale price for manufacturer capital-constrained situation and retailer capital-constrained situation, it is determined by the manufacturer, $w^i > 0$, $i = MC, RC$. Specifically, in manufacturer Stackelberg game, $w^{MS-MC} = w^{MC}$, and $w^{MS-RC} = w^{RC}$; in retailer Stackelberg game, $w^{RS-MC} = w^{MC}$, and $w^{RS-RC} = w^{RC}$;
- $p^i$: The margin price for manufacturer capital-constrained situation and retailer capital-constrained situation, it is determined by the retailer, $p^i > 0$, $i = MC, RC$. Specifically, in manufacturer Stackelberg game, $p^{MS-MC} = p^{MC}$, and $p^{MS-RC} = p^{RC}$; in retailer Stackelberg game, $p^{RS-MC} = p^{MC}$, and $p^{RS-RC} = p^{RC}$.

**Parameters:**
- $a$: The potential intrinsic demand, $a > 0$;
- $b$: The price elasticity, $b \geq 0$;
- $p^i$: The retail price of the retailer for manufacturer capital-constrained situation and retailer capital-constrained situation, it is consisted of manufacturer’s wholesale price and retailer’s margin price, $p^i > 0$, $i = MC, RC$. Specifically, in manufacturer Stackelberg game, $p^{MS-MC} = p^{MC}$, and $p^{MS-RC} = p^{RC}$; in retailer Stackelberg game, $p^{RS-MC} = p^{MC}$, and $p^{RS-RC} = p^{RC}$.
- $c$: The production cost per unit, $c > 0$;
- $T_{pre}$: The time span of preselling period, $T_{pre} > 0$;
- $T_{se}$: The time span of selling period, $T_{se} > 0$;
- $f_M$: The bank loan rate of manufacturer for preselling and selling periods, it is used to describe the loan interest which the manufacturer repaid to bank for the unit capital with respect to the time span of preselling and selling periods, $0 \leq f_M < 1$;
- $I_R$: The bank deposit rate of retailer for preselling and selling periods, it is used to describe the deposit interest which the retailer obtained from bank for the unit capital with respect to the time span of preselling and selling periods, $0 \leq I_R < 1$;
- $C_R$: The interest rate for fixed deposit by installments of retailer for selling period, it is used to describe the deposit interest by installment which the retailer obtained from bank for the unit capital, i.e., unit sale revenue, with respect to the time span of selling period, $0 \leq C_R < 1$;
- $f$: The bank loan rate for unit time span, $0 \leq f < 1$.
$I$: The bank deposit rate for unit time span, $0 \leq I < 1$;

$C_0$: The interest rate for fixed deposit by installments of retailer for unit time span, $0 \leq C_0 < 1$.

**Functions:**

$D$: The demand function, it is related to retail price;

$\pi^i_M$: The profit function of manufacturer for manufacturer capital-constrained situation and retailer capital-constrained situation, $i = MC, RC$. Specifically, in manufacturer Stackelberg game, $\pi^{MS-MC}_M = \pi^{MC}_M$, and $\pi^{MS-RC}_M = \pi^{RC}_M$; in retailer Stackelberg game, $\pi^{RS-MC}_M = \pi^{MC}_M$, and $\pi^{RS-RC}_M = \pi^{RC}_M$.

$\pi^i_R$: The profit function of retailer for manufacturer capital-constrained situation and retailer capital-constrained situation, $i = MC, RC$. Specifically, in manufacturer Stackelberg game, $\pi^{MS-MC}_R = \pi^{MC}_R$, and $\pi^{MS-RC}_R = \pi^{RC}_R$; in retailer Stackelberg game, $\pi^{RS-MC}_R = \pi^{MC}_R$, and $\pi^{RS-RC}_R = \pi^{RC}_R$.

$\pi^i_{SC}$: The profit function of supply chain for manufacturer capital-constrained situation and retailer capital-constrained situation, $i = MC, RC$. Specifically, in manufacturer Stackelberg game, $\pi^{MS-MC}_{SC} = \pi^{MC}_{SC}$, and $\pi^{MS-RC}_{SC} = \pi^{RC}_{SC}$; in retailer Stackelberg game, $\pi^{RS-MC}_{SC} = \pi^{MC}_{SC}$, and $\pi^{RS-RC}_{SC} = \pi^{RC}_{SC}$.

**Optimal values:**

$w^*_{ij}$: The optimal wholesale price for four scenarios, i.e., for manufacturer Stackelberg game and retailer Stackelberg game in manufacturer capital-constrained situation and retailer capital-constrained situation, $j = MS-MC, RS-MC, MS-RC, RS-RC$.

$p^*_{ij}$: The optimal margin price for four scenarios, i.e., for manufacturer Stackelberg game and retailer Stackelberg game in manufacturer capital-constrained situation and retailer capital-constrained situation, $j = MS-MC, RS-MC, MS-RC, RS-RC$.

$p^*_{ij}$: The optimal retail price for four scenarios, i.e., for manufacturer Stackelberg game and retailer Stackelberg game in manufacturer capital-constrained situation and retailer capital-constrained situation, $j = MS-MC, RS-MC, MS-RC, RS-RC$.

$\pi^*_{ij}M$: The optimal profit function of manufacturer for four scenarios, i.e., for manufacturer Stackelberg game and retailer Stackelberg game in manufacturer capital-constrained situation and retailer capital-constrained situation, $j = MS-MC, RS-MC, MS-RC, RS-RC$.

$\pi^*_{ij}R$: The optimal profit function of retailer for four scenarios, i.e., for manufacturer Stackelberg game and retailer Stackelberg game in manufacturer capital-constrained situation and retailer capital-constrained situation, $j = MS-MC, RS-MC, MS-RC, RS-RC$.

$\pi^*_{ij}SC$: The optimal profit function of supply chain for four scenarios, i.e., for the manufacturer Stackelberg game and retailer Stackelberg game in manufacturer capital-constrained situation and retailer capital-constrained situation, $j = MS-MC, RS-MC, MS-RC, RS-RC$. 
4. Profit functions.

4.1. Demand function. In reality, the market demand usually decreases with increasing of the retail price, and vice versa. According to the existing literatures [25, 27, 20, 3, 4, 30], we build the demand function as follows:

\[ D = a - bp. \] (1)

where, \( a \) denotes the market size, it is usually related to quality and function of the product; \( b \) denotes the price elasticity, it is used to describe the consumer’s sensitivity to the unit change of retail price, the higher the sensitivity is, the higher the impact of change of retail price on market demand is, usually, it is related to the consumer’s preference of product and concern about the retail price.

For the convenience of description, we consider the price has two parts, i.e., the manufacturer’s wholesale price \( w \) and the retailer’s margin price \( p_r \). On the basis, the price can be described as

\[ p = p_r + w. \] (2)

4.2. Profit functions for situation MC. In the supply chain consisted of capital-constrained manufacturer and well-funded retailer under delay payment scheme, to keep the normal operation of supply chain, the manufacturer needs to apply for bank loan to obtain the production capital, then produces according to the order of retailer, and deliver the products to the retailer before selling period; at the end of selling period, the manufacturer will receive the payment, and repays the bank loan. The retailer has sufficient capital to afford the payment for order. In preselling period, retailer orders the product from manufacturer. For the delay payment scheme, retailer can deposit the idle capital into the bank with deposit rate. Before selling period, the retailer receives the product. At the beginning of selling period, the retailer sells them to the market, and deposit the sales revenue into the bank with the interest rate for fixed deposit by installments. At the end of selling period, the retailer withdraws the fund and transfers the payment to manufacturer, and then the manufacturer repays the bank loan. The structure and interaction process of supply chain system in manufacturer capital-constrained situation can be seen in Figure 2.

**Figure 2.** The structure and interaction process of supply chain system in manufacturer capital-constrained situation.

In preselling period, the manufacturer needs to apply for bank loan \( cD \), and repays \( cDf_M \) to the bank, where \( f_M \) denotes the manufacturer’s loan rate with respect to the time span of preselling and selling periods, it can be described by bank rate and length of preselling and selling periods, i.e.,

\[ f_M = f(T_{pre} + T_{se}). \] (3)
Meanwhile, the well-funded retailer can deposit the payment \( wD \) into bank to obtain the interest revenue \( wDI_R \), where \( I_R \) denotes retailer’s bank deposit rate with respect to the time span of preselling and selling periods, it can be described by the bank deposit rate and length of preselling and selling periods, i.e.,

\[
I_R = I (T_{pre} + T_{se}).
\]

In addition, in selling period, the retailer can deposit the sales revenue into bank by installment with the interest rate for fixed deposit by installments. The retailer’s total sales revenue in selling period is \( pD \), the obtained interest revenue by installment is \( pDC_R \), where \( C_R \) denotes retailer’s interest rate for fixed deposit by installments for time span of selling period, it can be described by interest rate by installment for unit time span and length of selling period, i.e.,

\[
C_R = C_0 T_{se}.
\]

Based on the above analysis, according to the literatures [3, 4], the profit functions of manufacturer and retailer for situation MC can be determined, i.e.,

\[
\pi_{MC}^M = (w_{MC} - c) D - cDf_M, \tag{6}
\]

\[
\pi_{MC}^R = (p_{MC} - w_{MC}) D + p_{MC} DC_R + w_{MC} DI_R. \tag{7}
\]

According to Eqs. (1) and (2), the profit functions of manufacturer and retailer can be converted into the following equations, i.e.,

\[
\pi_{MC}^M = (w_{MC} - (1 + f_M) c) [a - b (p_{MC} + w_{MC})], \tag{8}
\]

\[
\pi_{MC}^R = [(1 + C_R) p_{MC} + (C_R + I_R) w_{MC}] [a - b (p_{MC} + w_{MC})]. \tag{9}
\]

Furthermore, by Eqs. (8) and (9), the profit function of supply chain can be determined, i.e.,

\[
\pi_{SC}^M = \pi_{MC}^M + \pi_{MC}^R = [(1 + C_R) p_{MC} + (1 + C_R + I_R) w_{MC} - (1 + f_M) c] \cdot [a - b (p_{MC} + w_{MC})]. \tag{10}
\]

4.3. Profit functions for situation RC. In this situation, the retailer is capital constrained. The manufacturer does not need to apply for bank loan, and can produce and deliver products according to the order of retailer in preselling period. The retailer also does not need to apply for bank loan. At the beginning of selling period, the retailer sells the products into the market, and deposits the sales revenue into bank with the interest rate for fixed deposit by installments. At the end of selling period, the retailer withdraws from bank and transfers the payment to manufacturer. The structure and interaction process of supply chain system in retailer capital-constrained situation can be seen in Figure 3.

Based on above analysis, we know that the retailer can deposit the sales revenue to bank with the interest rate for fixed deposit by installments in selling period. Retailer’s total sales revenue is \( pD \), and the additional interest return is \( pDC_R \). Then, according to the literatures [3, 4], the profit functions of manufacturer and retailer for situation RC can be determined, i.e.,

\[
\pi_{RC}^M = (w_{RC} - c) D, \tag{11}
\]

\[
\pi_{RC}^R = (p_{RC} - w_{RC}) D + p_{RC} DC_R. \tag{12}
\]

According to Eqs. (1) and (2), the profit functions of manufacturer and retailer can be converted into the following equations, i.e.,

\[
\pi_{RC}^M = (w_{RC} - c) [a - b (p_{RC} + w_{RC})], \tag{13}
\]
\[
\pi_{RC} = \left(1 + C_R p_R + w_R C_R \right) \left[a - b \left(p_R + w_R \right)\right].
\]  
(14)

Furthermore, by Eqs. (13) and (14), the profit function of supply chain can be determined, i.e.,
\[
\pi_{SC} = \pi_{R}^{RC} + \pi_{M}^{RC} = \left(1 + C_R p_R + (1 + C_R) w_R - c \right) \left[a - b \left(p_R + w_R \right)\right].
\]  
(15)

5. Models. Based on above analysis, we try to construct the pricing models. Here, according to the Stackelberg game \([3, 4, 24, 34, 38]\), we consider the following four scenarios: manufacturer is the leader in supply chain and capital constrained (MS-MC), retailer is the leader in supply chain and manufacturer is capital constrained (RS-MC), manufacturer is the leader in supply chain and retailer is capital constrained (MS-RC), retailer is the leader in supply chain and capital constrained (RS-RC). Here, according to Stackelberg game, the leader in supply chain refers to supply chain member who has the prior right to make decision, for example, when the manufacturer is the leader in supply chain, the manufacturer can first decide his decision variable, and then the retailer decide her decision variable according to the optimal decision of the manufacturer. The pricing model for each scenario is constructed in the following.

For scenario MS-MC, according to the Stackelberg game and profit functions of manufacturer and retailer for MC, the pricing model in manufacturer Stackelberg game in manufacturer capital-constrained situation considering bank’s deposit and loan based on delay payment scheme can be constructed, i.e.,
\[
\text{Model 1 : } \max_{w^{MS-MC}} \pi_{M}^{MS-MC} \quad \text{s.t. } \max_{p^{MS-MC}} \pi_{R}^{MS-MC}
\]

Similarly, for scenarios RS-MC, MS-RC and RS-RC, the pricing models can be constructed, respectively, i.e.,
\[
\text{Model 2 : } \max_{p^{RS-MC}} \pi_{R}^{RS-MC} \quad \text{s.t. } \max_{w^{RS-MC}} \pi_{M}^{RS-MC}
\]
\[
\text{Model 3 : } \max_{w^{MS-RC}} \pi_{M}^{MS-RC} \quad \text{s.t. } \max_{p^{MS-RC}} \pi_{R}^{MS-RC}
\]
6. Optimal policies. By referring to the literature [39, 4, 30, 16, 33, 35, 41], we try to solve the constructed models and obtain the optimal policies of supply chain members. In the following, we provide the specific solution process.

6.1. Optimal policy for scenario MS-MC. For scenario MS-MC, by solving Model 1, the optimal wholesale price and retail price can be determined. Specifically, the manufacturer first determines the wholesale price, then the retailer determines the margin price according to the determined wholesale price, further the profits of manufacturer, retailer and supply chain can be determined. Therefore, we can obtain the following theorem, corollary and propositions.

**Theorem 6.1.** For scenario MS-MC, there is the uniquely optimal policy of wholesale price \(w_{\ast MS-MC}\) and margin price \(p_{r\ast MS-MC}\), i.e.,

\[
\begin{align*}
\pi_{MS-MC}^s &= \frac{(1 + C_0 T_{se}) a}{2} + \frac{[1 + f(T_{pre} + T_{se})] c}{2}, \\
p_{r\ast MS-MC} &= -\frac{[1 + 2 C_0 T_{se} + I(T_{pre} + T_{se})] [1 + f(T_{pre} + T_{se})] b c}{4 b (1 + C_0 T_{se})} \\
&\quad + \frac{[1 - 3 I(T_{pre} + T_{se}) - 2 C_0 T_{se}] a}{4 b [1 - I(T_{pre} + T_{se})]}.
\end{align*}
\]

**Proof.** The proof can be seen in Appendix. □

**Corollary 1.** For scenario MS-MC, the retailer’s optimal retail price is uniquely determined, i.e.,

\[
p_{r\ast MS-MC} = \frac{3a}{4b} + \frac{[1 + f(T_{pre} + T_{se})] [1 - I(T_{pre} + T_{se})] c}{4 (1 + C_0 T_{se})}.
\]

Because it is easy to see directly, we do not provide the proof process here.

According to Theorem 6.1 and Eqs. (8)-(10), we can determine optimal profits of manufacturer \(\pi_{M\ast MS-MC}\), retailer \(\pi_{R\ast MS-MC}\) and supply chain \(\pi_{SC\ast MS-MC}\), i.e.,

\[
\begin{align*}
\pi_{M\ast MS-MC} &= \frac{(1 + C_0 T_{se}) a - [1 + f(T_{pre} + T_{se})][1 - I(T_{pre} + T_{se})] bc}{8b [1 - I(T_{pre} + T_{se})] (1 + C_0 T_{se})}^2, \\
\pi_{R\ast MS-MC} &= \frac{(1 + C_0 T_{se}) a - [1 + f(T_{pre} + T_{se})][1 - I(T_{pre} + T_{se})] bc}{16b (1 + C_0 T_{se})}^2, \\
\pi_{SC\ast MS-MC} &= \frac{(1 + C_0 T_{se}) a - [1 + f(T_{pre} + T_{se})][1 - I(T_{pre} + T_{se})] bc}{16b [1 - I(T_{pre} + T_{se})] (1 + C_0 T_{se})}^2.
\end{align*}
\]

Based on above analysis, we can obtain the following propositions:

**Proposition 1.** For scenario MS-MC, \(w_{\ast MS-MC}\), \(p_{r\ast MS-MC}\) and \(p_{\ast MS-MC}\) are related to parameters \(C_0\), \(I\) and \(f\), i.e.,

a) \(w_{\ast MS-MC}\) increases with \(C_0\), \(I\) and \(f\);
b) \( p^{*}_{MS-MC} \) decreases with \( C_0, I \) and \( f \);

c) \( p^{*}_{MS-MC} \) decreases with \( C_0 \) and \( I \), but increases with \( f \).

Proof. The proof can be seen in Appendix.

a) in proposition 1 shows that, the optimal wholesale price of manufacturer can be affected by the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate in scenario MS-MC. Specifically, the higher the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate are, the higher the optimal wholesale price is. It means that the manufacturer could increase his wholesale price to improve his own profit when the retailer obtains more revenue (i.e., the interest for fixed deposit by installments) from the bank. In addition, when the bank loan rate increases, the manufacturer could adjust the wholesale price to shift the loss caused by bank loan interest to retailer for the equilibrium.

b) in proposition 1 shows that, for scenario MS-MC, the higher the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate are, the lower the optimal margin price is. It means that the retailer could decrease the margin price to transfer the part of profit to the manufacturer when the retailer obtains more revenue (i.e., the interest for fixed deposit by installments) from the bank. In addition, when the bank loan rate increases, the retailer can decrease the margin price to make up the loss of manufacturer caused by the bank loan interest for the equilibrium.

c) in proposition 1 shows that, the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate can affect the optimal retail price of retailer. Specifically, the higher the interest rate for fixed deposit by installments and bank deposit rate are, the lower the optimal retail price is; but the higher the bank loan rate is, the higher the optimal retail price is. The reason why the retail price decreases is that the decreasing extent of margin price is greater than the increasing extent of wholesale price. It means that, the higher the interest rate for fixed deposit by installments and bank deposit rate are, the higher the profit of retailer is, and the decreasing of margin price of retailer plays a leading role in the change of retail price. The decreasing of retail price can improve the market demand, and further can transfer the part of retailer’s profit to the manufacturer for the equilibrium. In addition, when the bank loan interest which the manufacturer needs to pay increases, the profit of manufacturer will decrease to some extent and the increasing of wholesale price of manufacturer plays a leading role in the change of retail price, thus the loss of manufacturer caused by bank loan interest can be made up.

Proposition 2. For scenario MS-MC, \( \pi^*_{MS-MC} \), \( \pi^*_{RS-MC} \), and \( \pi^*_{SC-MC} \) are related to parameters \( C_0, I \) and \( f \). Specifically, if \((1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc \geq 0\), then

a) \( \pi^*_{MS-MC} \) increases with \( C_0 \) and \( I \), but decreases with \( f \);

b) \( \pi^*_{RS-MC} \) increases with \( C_0 \) and \( I \), but decreases with \( f \);

c) \( \pi^*_{SC-MC} \) increases with \( C_0 \) and \( I \), but decreases with \( f \).

Rather, if \((1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc < 0\), then

d) \( \pi^*_{MS-MC} \) decreases with \( C_0 \) and \( I \), but increases with \( f \);
e) $\pi^{MS-MC}_R$ decreases with $C_0$ and $I$, but increases with $f$;

f) $\pi^{MS-MC}_{SC}$ decreases with $C_0$ and $I$, but increases with $f$.

Proof. The proof can be seen in Appendix.

Proposition 2 shows that, under a certain condition, the profits of manufacturer, retailer and supply chain can be affected by the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate in scenario MS-MC. Specifically, the profits of manufacturer, retailer and supply chain increase with the interest rate for fixed deposit by installments and bank deposit rate, but decrease with the bank loan rate, this is because the interest rate for fixed deposit by installments and bank deposit interest will improve the profit of retailer and further improve the profit of supply chain. The equilibrium of supply chain can be obtained if the retailer transfers the part of profit to manufacturer by reducing the margin price. In addition, the profit of supply chain will decrease since the bank loan interest reduces directly the profit of manufacturer and reduce indirectly the profit of retailer.

d), e) and f) in proposition 2 show that, for scenario MS-MC, the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate can affect the profits of manufacturer, retailer and supply chain under an opposite condition. Specifically, the profits of manufacturer, retailer and supply chain decrease with the interest rate for fixed deposit by installments and bank deposit rate, but increase with the bank loan rate; this is because the manufacturer and retailer transfer the profits to each other by adjusting the wholesale price and margin price for the equilibrium.

Proposition 2 shows that, the impact trends of deposit interest rate by installment, bank deposit rate and bank loan rate on the profits of manufacturer, retailer and supply chain are same in scenario MS-MC, thus the manufacturer and retailer can actively cooperate in the negotiation with bank for the beneficial finance environment.

6.2. Optimal policy for scenario RS-MC. For scenario RS-MC, by solving Model 2, the optimal wholesale price and retail price can be determined. Then, we can obtain the following theorem, corollary and propositions.

\textbf{Theorem 6.2.} For scenario RS-MC, there is the uniquely optimal policy of wholesale price $w^{RS-MC}$ and margin price $p^{RS-MC}_r$, i.e.,

$$w^{RS-MC} = \frac{(1 + C_0T_{se})a + [1 + f(T_{se} + T_{pre})][3 + C_0T_{se} - I (T_{se} + T_{pre})]bc}{2b [2 + C_0T_{se} - I (T_{se} + T_{pre})]},$$

$$p^{RS-MC}_r = \frac{[1 - I (T_{se} + T_{pre})]a - [1 + f(T_{se} + T_{pre})][1 + C_0T_{se}]bc}{b [2 + C_0T_{se} - I (T_{se} + T_{pre})]}.$$

\textbf{Proof.} The proof can be seen in Appendix.

On the basis, according to Eq. (2) and Theorem 6.2, we can obtain the following corollary, i.e.,

\textbf{Corollary 2.} For scenario RS-MC, the retailer’s optimal retail price is uniquely determined, i.e.,

$$p^{RS-MC}_r = \frac{[1 + f(T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})]bc}{2b [2 + C_0T_{se} - I (T_{se} + T_{pre})]}$$
Because it is easy to see directly, we do not provide the proof process here.

According to Theorem 6.2 and Eqs. (8)-(10), we can determine optimal profits of manufacturer $\pi^*_{M-RS-MC}$, retailer $\pi^*_{R-RS-MC}$ and supply chain $\pi^*_{SC-RS-MC}$, i.e.,

$$\pi^*_{M-RS-MC} = \left\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})] bc\right\}^2 \cdot \frac{4b [2 + C_0 T_{se} - I (T_{se} + T_{pre})]}{4b [2 + C_0 T_{se} - I (T_{se} + T_{pre})]^2},$$

$$\pi^*_{R-RS-MC} = \left\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})] bc\right\}^2 \cdot \frac{4b [2 + C_0 T_{se} - I (T_{se} + T_{pre})]}{4b [2 + C_0 T_{se} - I (T_{se} + T_{pre})]^2},$$

$$\pi^*_{SC-RS-MC} = \left\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})] bc\right\}^2 \cdot \frac{4b [2 + C_0 T_{se} - I (T_{se} + T_{pre})]}{4b [2 + C_0 T_{se} - I (T_{se} + T_{pre})]^2} \cdot [3 + C_0 T_{se} - I (T_{se} + T_{pre})].$$

Based on above analysis, we can obtain the following propositions:

**Proposition 3.** For scenario RS-MC, $w^*_{RS-MC}$, $p^*_{R-RS-MC}$ and $p^*_{SC-RS-MC}$ are related to parameters $C_0$, $I$ and $f$, i.e.,

- a) $w^*_{RS-MC}$ increases with $C_0$, $I$ and $f$;
- b) $p^*_{R-RS-MC}$ decreases with $C_0$, $I$ and $f$;
- c) $p^*_{SC-RS-MC}$ decreases with $C_0$ and $I$, but increases with $f$.

**Proof.** The proof can be seen in Appendix.

a) in proposition 3 shows that, for scenario RS-MC, the higher the deposit interest rate by installment, bank deposit rate and bank loan rate are, the higher the optimal wholesale price is. Since the impact trends are same to the ones in scenario MS-MC, so we do not repeat it here.

b) in proposition 3 shows that, bank rates can affect the optimal margin price. Specifically, the higher the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate are, the lower the optimal margin price is. Since the impact trends are same to the ones in scenario MS-MC, so we do not repeat it here.

c) in proposition 3 shows that, the retail price is directly related to bank rates. Specifically, the higher the interest rate for fixed deposit by installments and bank deposit rate are, the lower the optimal retail price is; but the higher the bank loan rate is, the higher the optimal retail price is. Since the impact trends are same to the ones in scenario MS-MC, so we do not repeat it here.

**Proposition 4.** For scenario RS-MC, $\pi^*_{M-RS-MC}$, $\pi^*_{R-RS-MC}$ and $\pi^*_{SC-RS-MC}$ are related to parameters $C_0$, $I$ and $f$. Specifically, if $(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})] bc \geq 0$, then

- a) $\pi^*_{M-RS-MC}$ increases with $C_0$ and $I$, but decreases with $f$;
- b) $\pi^*_{R-RS-MC}$ increases with $C_0$ and $I$, but decreases with $f$;
- c) $\pi^*_{SC-RS-MC}$ increases with $C_0$ and $I$, but decreases with $f$.

Rather, if $(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})] bc < 0$, then

- d) $\pi^*_{M-RS-MC}$ decreases with $C_0$ and $I$, but increases with $f$. 

e) \( \pi^*_{RS-MC} \) decreases with \( C_0 \) and \( I \), but increases with \( f \);

f) \( \pi^*_{RS-MC} \) decreases with \( C_0 \) and \( I \), but increases with \( f \).

Proof. The proof can be seen in Appendix.

a), b) and c) in proposition 4 show that, for scenario RS-MC, the profits of manufacturer, retailer and supply chain increase with the interest rate for fixed deposit by installments and bank deposit rate, but decrease with the bank loan rate, this is because the interest for fixed deposit by installments and bank deposit interest will improve the profit of retailer and further improve the profit of supply chain. The equilibrium of supply chain can be realized if the retailer transfers the part of profit to manufacturer by reducing the margin price. In addition, the profit of supply chain will decrease since the bank loan interest reduces directly the profit of manufacturer and reduce indirectly the profit of retailer. Since the impact trends are same to the ones in scenario MS-MC, so we do not repeat it here.

d), e) and f) in proposition 4 show that, these profits decrease with the interest rate for fixed deposit by installments and bank deposit rate, but increase with the bank loan rate in scenario RS-MC. Since the impact trends are same to the ones in scenario MS-MC, so we do not repeat it here.

Proposition 4 shows that, the impact trends of interest rate for fixed deposit by installments, bank deposit rate and bank loan rate on the profits of manufacturer, retailer and supply chain are same in scenario RS-MC, thus the manufacturer and retailer can actively cooperate in the negotiation with bank for the beneficial finance environment. Since the impact trends are same to the ones in scenario MS-MC, so we do not repeat it here.

It can be seen from propositions 1-4 that, in situation MC, the difference about the impacts of supply chain power structures on the optimal policies of manufacturer and retailer is not obvious; the impacts of supply chain power structures on the optimal policies of manufacturer and retailer are not obvious either; however, for each supply chain power structure, the impacts of the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate on the policies of manufacturer and retailer are obvious. It means that the improvement of profits of manufacturer and retailer depends on the external finance environment of supply chain when the manufacturer is capital constrained under delay payment scheme, thus the manufacturer and retailer can cooperate in the negotiation with bank to seek for the beneficial interest rate for fixed deposit by installments, bank deposit rate and bank loan rate.

6.3. Optimal policy for scenario MS-RC. For scenario MS-RC, the optimal wholesale price and retail price can be determined by solving Model 3. Then, we can obtain the following theorem, corollary and propositions.

**Theorem 6.3.** For scenario MS-RC, there is the uniquely optimal policy of wholesale price \( w^*_{MS-RC} \) and margin price \( p^*_{r,MS-RC} \), i.e.,

\[
\begin{align*}
w^*_{MS-RC} &= \frac{a (1 + C_0 T_{se}) + bc}{2b}, \\
p^*_{r,MS-RC} &= \frac{(1 + C_0 T_{se}) (1 - 2C_0 T_{se}) a + (1 + 2C_0 T_{se}) bc}{4b (1 + C_0 T_{se})}.
\end{align*}
\]

Proof. The proof can be seen in Appendix.
On the basis, according to Eq. (2) and Theorem 6.3, we can obtain the following corollary, i.e.,

**Corollary 3.** For scenario MS-RC, the retailer’s optimal retail price is uniquely determined, i.e.,

$$p^*_{MS-RC} = \frac{3(1 + C_0 T_{se}) a + bc}{4b (1 + C_0 T_{se})}.$$  

(30)

Because it is easy to see directly, we do not provide the proof process here.

According to Theorem 6.3 and Eqs. (13)-(15), we can determine optimal profits of manufacturer $\pi^*_{MS-RC}$, retailer $\pi^*_{MS-RC}$ and supply chain $\pi^*_{MS-RC}$, i.e.,

$$\pi^*_{MS-RC} = \frac{[(1 + C_0 T_{se}) a - bc]^2}{8b (1 + C_0 T_{se})},$$  

(31)

$$\pi^*_{MS-RC} = \frac{[(1 + C_0 T_{se}) a - bc]^2}{16b (1 + C_0 T_{se})},$$  

(32)

$$\pi^*_{MS-RC} = \frac{3[(1 + C_0 T_{se}) a - bc]^2}{16b (1 + C_0 T_{se})}.$$  

(33)

Based on above analysis, we can obtain the following propositions:

**Proposition 5.** For scenario MS-RC, $w^*_{MS-RC}$, $p^*_{MS-RC}$ and $p^*_{MS-RC}$ are related to parameter $C_0$, i.e.,

- a) $w^*_{MS-RC}$ increases with $C_0$;
- b) $p^*_{MS-RC}$ decreases with $C_0$;
- c) $p^*_{MS-RC}$ decreases with $C_0$.

**Proof.** The proof can be seen in Appendix.

a) in proposition 5 shows that, for scenario MS-RC, the higher the interest rate for fixed deposit by installments is, the higher the optimal wholesale price is. It means that the manufacturer could increase his wholesale price to improve his own profit when the retailer obtains the additional interest for fixed deposit by installments from the bank.

b) in proposition 5 shows that, the higher the interest rate for fixed deposit by installments is, the lower the optimal margin price is in scenario MS-RC. It means that the retailer could decrease the margin price to transfer the part of profit to manufacturer when the retailer obtains additional deposit interest by installment from the bank, and thus improve the profit of manufacturer.

- c) in proposition 5 shows that, the retail price can be affected by the deposit interest rate by installment. Specifically, the higher the deposit interest rate by installment is, the lower the optimal retail price is in scenario MS-RC. The reason why the retail price decreases is that the decreasing extent of margin price is greater than the increasing extent of wholesale price. It means that, the higher the interest rate for fixed deposit by installments is, the more important role the decreasing of margin price of retailer plays in the change of retail price, and further the higher the extent of impact on the manufacturer’s profit is.

**Proposition 6.** For scenario MS-RC, $\pi^*_{MS-RC}$, $\pi^*_{MS-RC}$ and $\pi^*_{MS-RC}$ are related to parameter $C_0$, i.e.,
a) $\pi^*_{MS-RC}$ increases with $C_0$;
b) $\pi^*_{RS-RC}$ increases with $C_0$;
c) $\pi^*_{SC-RC}$ increases with $C_0$.

Proof. The proof can be seen in Appendix.

Proposition 6 shows that, for scenario MS-RC, the profits of manufacturer, retailer and supply chain increase with the interest rate for fixed deposit by installments. The equilibrium can be obtained with respect to a fixed interest rate for fixed deposit by installments. The reason why the profit of supply chain increases is that the interest for fixed deposit by installments can directly improve the profit of retailer and further improve the profit of manufacturer.

In addition, in scenario MS-RC, the impact trends of the interest rate for fixed deposit by installments on the profits of manufacturer, retailer and supply chain are also the same in scenario MS-RC, thus the manufacturer and retailer can also actively cooperate in the negotiation with bank for the beneficial interest rate for fixed deposit by installments.

6.4. Optimal policy for scenario RS-RC. For scenario RS-RC, by solving Model 4, we can obtain the following theorem, corollary and propositions.

Theorem 6.4. For scenario RS-RC, there is the uniquely optimal policy of wholesale price $w^*_{RS-RC}$ and margin price $p^*_{RS-RC}$, i.e.,

$$w^*_{RS-RC} = \frac{(1 + C_0 T_{se}) a + (3 + 2C_0 T_{se}) bc}{2b(2 + C_0 T_{se})},$$

$$p^*_{RS-RC} = \frac{a - (1 + C_0 T_{se}) bc}{b(2 + C_0 T_{se})},$$

(34) (35)

Proof. The proof can be seen in Appendix.

On the basis, according to Eq. (2) and Theorem 6.4, we can obtain the following corollary, i.e.,

Corollary 4. For scenario RS-RC, the retailer’s optimal retail price is uniquely determined, i.e.,

$$p^*_{RS-RC} = \frac{(3 + C_0 T_{se}) a + bc}{2b(2 + C_0 T_{se})}.$$  (36)

Because it is easy to see directly, we do not provide the proof process here.

According to Theorem 6.4 and Eqs. (13)-(15), we can determine optimal profits of manufacturer $\pi^*_{M-RC}$, retailer $\pi^*_{R-RC}$ and supply chain $\pi^*_{SC-RC}$, i.e.,

$$\pi^*_{M-RC} = \frac{[(1 + C_0 T_{se}) a - bc]^2}{4b(2 + C_0 T_{se})^2},$$

$$\pi^*_{R-RC} = \frac{[(1 + C_0 T_{se}) a - bc]^2}{4b(2 + C_0 T_{se})^2},$$

$$\pi^*_{SC-RC} = \frac{[(1 + C_0 T_{se}) a - bc]^2}{4b(2 + C_0 T_{se})^2}(3 + C_0 T_{se}).$$

(37) (38) (39)

Based on above analysis, we can obtain the following propositions:
Proposition 7. For scenario MS-RC, \( w^{RS-RC} \), \( p^{RS-RC}_r \) and \( p^{RS-RC} \) are related to parameter \( C_0 \), i.e.,

a) \( w^{RS-RC} \) increases with \( C_0 \);

b) \( p^{RS-RC}_r \) decreases with \( C_0 \);

c) \( p^{RS-RC} \) decreases with \( C_0 \).

Proof. The proof can be seen in Appendix.

a) in proposition 7 shows that, the higher the interest rate for fixed deposit by installments is, the higher the optimal wholesale price is in scenario RS-RC. Since the impact trends are same to the ones in scenario MS-RC, so we do not repeat it here.

b) in proposition 7 shows that, for scenario RS-RC, the higher the interest rate for fixed deposit by installments is, the lower the optimal margin price is. Since the impact trends are same to the ones in scenario MS-RC, so we do not repeat it here.

c) in proposition 7 shows that, the retail price can be affected by the interest rate for fixed deposit by installments. Specifically, the higher the interest rate for fixed deposit by installments is, the lower the optimal retail price is. Since the impact trends are same to the ones in scenario MS-RC, so we do not repeat it here.

Proposition 8. For scenario MS-RC, \( \pi^{RS-RC}_M \), \( \pi^{RS-RC}_R \) and \( \pi^{RS-RC}_{SC} \) are related to parameter \( C_0 \), i.e.,

a) \( \pi^{RS-RC}_M \) increases with \( C_0 \);

b) \( \pi^{RS-RC}_R \) increases with \( C_0 \);

c) \( \pi^{RS-RC}_{SC} \) increases with \( C_0 \).

Proof. The proof can be seen in Appendix.

Proposition 8 shows that, for scenario RS-RC, the profits of manufacturer, retailer and supply chain are still not related to the bank deposit rate and bank loan rate, but are related to the interest rate for fixed deposit by installments. Specifically, the profits of manufacturer, retailer and supply chain increase with the interest rate for fixed deposit by installments. Since the impact trends are same to the ones in scenario MS-RC, so we do not repeat them here.

Proposition 8 also shows that, for scenario RS-RC, the impact trends of the interest rate for fixed deposit by installments on profits of manufacturer, retailer and supply chain do not have significant difference, thus the manufacturer and retailer can still actively cooperate in the negotiation with bank for the beneficial interest rate for fixed deposit by installments.

It can be seen from propositions 5-8 that, in situation RC, the difference about the impacts of supply chain power structures on the optimal policies of manufacturer and retailer is not obvious; however, for each supply chain power structure, the impacts of interest rate for fixed deposit by installments on the policies of manufacturer and retailer are obvious. It means that the improvement of profits of manufacturer and retailer depends on the external finance environment of supply chain when the retailer is capital constrained under delay payment scheme, thus the manufacturer and retailer can cooperate in the negotiation with bank to seek for the beneficial interest rate for fixed deposit by installments.
It can be seen from propositions 1-8 that, the optimal policies and profits of manufacturer and retailer are highly related to the capital-constrained situation of supply chain, but lowly related to the supply chain power structures. Meanwhile, in different capital-constrained situation of supply chain, the sensitivity degrees of optimal policies and profits of manufacturer and retailer with respect to the interest rate for fixed deposit by installments are generally the same, but the sensitivity degrees of them with respect to bank deposit rate or bank loan rate are different. Obviously, in the real decision process, the manufacturer and retailer need to consider the interest rate for fixed deposit by installments, bank interest rate and bank loan rate.

7. Managerial insights. According to above theoretical research, the practical implications of this study can be obtained as shown in the following:

(1) In scenario MS-MC, both optimal policies of manufacturer and retailer are related to the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate. For the manufacturer, the delay payment scheme will increase the financial pressure, and the manufacturer needs to apply for bank loan and bears the loss of bank loan interest; for the retailer, the delay payment scheme is very beneficial scheme. In this scenario, the manufacturer needs to bear more operation cost of supply chain, and can keep the profitability by adjusting the wholesale price.

(2) In scenario RS-MC, both optimal policies of manufacturer and retailer are related to the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate. Hence, in the real decision process, manufacturer and retailer needs to simultaneously consider the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate, and can make optimal decision according to the impact trend of different parameters. The retailer needs to play the leading role in supply chain, and shifts the capital pressure to the manufacturer for the equilibrium; the manufacturer needs to apply for the bank loan to obtain the sufficient production capital.

(3) In scenario MS-RC, both optimal policies of manufacturer and retailer are related to the interest rate for fixed deposit by installments, but not related to the bank deposit rate and bank loan rate. Hence, in the real decision process, the manufacturer and retailer do not need to concern the bank deposit rate and bank loan rate, but need to consider the impacts of the interest rate for fixed deposit by installments on the respective optimal policies of manufacturer and retailer. In this scenario, the manufacturer can actively undertake the capital pressure, and can share the benefit to the capital-constrained retailer under the delay payment scheme for the equilibrium.

(4) In scenario RS-RC, the delay payment scheme can shift the capital pressure of retailer to manufacturer, and further relieve the retailer’s capital pressure. In this scenario, the retailer plays the leading role in supply chain. The retailer does not need to apply for the bank loan, but can deposit the sales revenue to bank by installment for the benefit; the manufacturer plays following role in supply chain, and has to bear the capital pressure of whole supply chain. In addition, both manufacturer and retailer need to consider the impacts of the interest rate for fixed deposit by installments on their optimal policies and profits, and determine the corresponding optimal decision according to the interest rate for fixed deposit by installments provided by bank.

(5) For a capital-constrained situation, the difference of respective optimal policies of each supply chain member is not obvious for different power structures of
supply chain. For a certain power structure of supply chain, the optimal policies of each supply chain member are different in different capital-constrained situations. It shows that the manufacturer and retailer need to pour attention to the capital-constrained situation, i.e., who is capital constrained, but not to the power structure of supply chain, i.e., who plays leading role in supply chain.

(6) The bank plays an important role in the decision on optimal policies of manufacturer and retailer. In real decision process, the manufacturer and retailer need to make optimal decisions and response to the bank. The interest rate for fixed deposit by installments can improve the profit of retailer, and further affect optimal policy of manufacturer, thus the retailer needs to pay attention to the interest rate for fixed deposit by installments; the interest rate for fixed deposit by installments can improve the profit of manufacturer in some conditions, thus the manufacturer also needs to consider the positive impact of bank's deposit and loan.

8. Conclusions. In this paper, we studied the Stackelberg pricing problem in dyadic capital-constrained supply chain considering bank's deposit and loan based on delay payment scheme. For the situations that the manufacturer was capital constrained or the retailer was capital constrained, the profit functions of manufacturer, retailer and supply chain were built based on delay payment scheme, and further the four Stackelberg pricing models were constructed for four scenarios, by solving the models, the optimal policies for different scenarios were determined, then the impacts of model parameters on optimal policies and profits of manufacturer, retailer and supply chain were analyzed.

The research results show that, in situation MC, both optimal wholesale price of manufacturer and optimal margin price of retailer can be affected by the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate, and for different power structures of supply chain, the corresponding impacts of each parameter have no obvious differences. The results also show that in situation RC, both optimal wholesale price of manufacturer and optimal margin price of retailer cannot be affected by bank deposit rate and bank loan rate, but can be affected by the interest rate for fixed deposit by installments, and for different power structures of supply chain, the corresponding impacts of this parameter also have no obvious differences. In addition, for the different capital constrained situations, the optimal policies and profits of manufacturer and retailer are all different. Obviously, for delay payment scheme, it is necessary to conduct the study on the impacts of the interest rate for fixed deposit by installments, bank deposit rate and bank loan rate on optimal policies of manufacturer and retailer in different capital constrained situations.

The models can be used to solve the pricing problem in dyadic capital-constrained supply chain under the consideration of bank's deposit and loan, and these models are mainly suitable for the capital-constrained supply chain consisting of the micro, small-size or medium-size manufacturers and retailers, the retailers can be, for examples, some individual household offline store or some online retailers in Tmall, Taobao or Jingdong Mall, the manufacturer can be the ones of food or clothes etc.

Through the study in this paper, we obtain some theoretical implication: (1) We propose a new research problem, i.e., the pricing problem in dyadic capital-constrained supply chain considering bank’s deposit and loan based on delay payment scheme. (2) We build the corresponding profit functions of supply chain members and then construct four new pricing decision models considering the impact of the bank’s deposit and loan based on delay payment scheme. (3) We provide
the important optimal policies for supply chain members by solving the constructed models according to the standard solution method based on Stackelberg game. (4) We explore and show innovatively the impact of the impact of interest rate for fixed deposit by installments, deposit rate and loan rate on optimal pricing policies. This study extends the research scope of supply chain management with capital constraint, and provides the reference and guidance for the further study.

For the follow-up studies, we will consider the bankruptcy risk, and pay attention to the impacts of risk preferences of supply chain members on optimal policies of supply chain members with capital constraint, and study the pricing and coordination of dyadic capital-constrained supply chain in this situation.

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Appendix.

The proof of Theorem 6.1. According to Eq. (8), the profit function of the retailer for scenario MS-MC can be determined, i.e.,

\[ \pi_{R}^{MS-MC} = \left[ (1 + C_{R}) p_{r}^{MS-MC} + (C_{R} + I_{R}) w^{MS-MC} \right] \cdot \left[ a - b \left( p_{r}^{MS-MC} + w^{MS-MC} \right) \right]. \] (A1)

Let \( d\pi_{R}^{MS-MC} / dp_{r}^{MS-MC} = 0 \), then the response function of the retailer can be determined, i.e.,

\[ p_{r}^{MS-MC} = \frac{(1 + C_{R}) a - (1 + 2C_{R} + I_{R}) bw^{MS-MC}}{2b(1 + C_{R})}. \] (A2)

According to Eq. (9), the profit function of the manufacturer for scenario MS-MC can be determined, i.e.,

\[ \pi_{M}^{MS-MC} = \left[ w^{MS-MC} - (1 + f_{M}) c \right] \left[ a - b \left( p_{r}^{MS-MC} + w^{MS-MC} \right) \right]. \] (A3)

By Eq. (A.2), the Eq. (A.3) can be converted into the following equation, i.e.,

\[ \pi_{M}^{MS-MC} = \left\{ a - \frac{(1 + C_{R}) a - (1 + 2C_{R} + I_{R}) bw^{MS-MC}}{2b(1 + C_{R})} + w^{MS-MC} \right\} \cdot \left[ w^{MS-MC} - (1 + f_{M}) c \right]. \] (A4)

On the basis, the first and second order derivatives of profit function of manufacturer \( \pi_{M}^{MS-MC} \) with respect to \( w^{MS-MC} \) can be determined, i.e.,

\[ \frac{d\pi_{M}^{MS-MC}}{dw^{MS-MC}} = \frac{(1 + C_{R}) a + (1 - I_{R})(1 + f_{M}) bc - 2(1 - I_{R}) bw^{MS-MC}}{2(1 + C_{R})}, \] (A5)

\[ \frac{d^{2}\pi_{M}^{MS-MC}}{d(w^{MS-MC})^{2}} = -\frac{(1 - I_{R}) b}{1 + C_{R}}. \] (A6)

According to Eq. (A.6), for \( 0 \leq I_{R} < 1 \), we have that \( d^{2}\pi_{M}^{MS-MC} / d(w^{MS-MC})^{2} < 0 \), further we know that profit function of manufacturer \( \pi_{M}^{MS-MC} \) is a concave function with respect to \( w^{MS-MC} \), thus we know that there is unique wholesale price \( w^{*MS-MC} \) which maximizes profit function of manufacturer.
Furthermore, according to the first order condition, the optimal wholesale price of manufacturer \( w^{MS-MC} \) can be determined, i.e.,

\[
    w^{MS-MC} = \frac{(1 + C_R) a}{2(1 - I_R)b} + \frac{(1 + f_M) c}{2}.
\]  

(A7)

On the basis, according to Eq. (A.2), the optimal margin price of retailer \( p^{*MS-MC}_r \) can be determined, i.e.,

\[
    p^{*MS-MC}_r = \frac{(1 - 3I_R - 2C_R)b}{4b(1 - I_R)} = \frac{(1 + 2C_R + I_R)(1 + f_M)bc}{4b(1 + C_R)}.
\]  

(A8)

According to Eqs. (3)-(5), the Eqs. (A.7) and (A.8) can be converted into the following equations, i.e.,

\[
    w^{*MS-MC} = \frac{(1 + C_0T_{se}) a}{2[1 - I(T_{pre} + T_{se})]b} + \frac{[1 + f(T_{pre} + T_{se})] c}{2},
\]  

(A9)

\[
    p^{*MS-MC}_r = \frac{(1 + 2C_0T_{se} + I(T_{pre} + T_{se})[1 + f(T_{pre} + T_{se})]bc}{4b(1 + C_0T_{se})} + \frac{[1 - 3I(T_{pre} + T_{se}) - 2C_0T_{se}]a}{4b[1 - I(T_{pre} + T_{se})]}.
\]  

(A10)

**The proof of Proposition 1.** According to Eq. (16)-(18), the first order derivatives of \( w^{*MS-MC}, p^{*MS-MC}_r \) and \( p^{*MS-MC}_s \) with respect to \( C_0, I \) and \( f \) can be determined, i.e.,

\[
    \frac{\partial w^{*MS-MC}}{\partial C_0} = \frac{2b[1 - I(T_{pre} + T_{se})]}{aT_{se}},
\]  

(A11)

\[
    \frac{\partial w^{*MS-MC}}{\partial I} = \frac{(1 + C_0T_{se}) (T_{pre} + T_{se}) a}{2b[1 - I(T_{pre} + T_{se})]^2},
\]  

(A12)

\[
    \frac{\partial p^{*MS-MC}_r}{\partial f} = \frac{(T_{pre} + T_{se})c}{2},
\]  

(A13)

\[
    \frac{\partial p^{*MS-MC}_r}{\partial C_0} = - \frac{[1 + f(T_{pre} + T_{se})][1 - I(T_{pre} + T_{se})]cT_{se}}{4(1 + C_0T_{se})^2}
\]  

\[- \frac{aT_{se}}{4(1 + C_0T_{se})^2},
\]  

(A14)

\[
    \frac{\partial p^{*MS-MC}_r}{\partial I} = - \frac{(T_{pre} + T_{se}) (1 + C_0T_{se}) a}{2b[1 - I(T_{pre} + T_{se})]^2} - \frac{(T_{pre} + T_{se}) [1 + f(T_{pre} + T_{se})] c}{4(1 + C_0T_{se})},
\]  

(A15)

\[
    \frac{\partial p^{*MS-MC}_r}{\partial f} = \frac{[1 + 2C_0T_{se} + I(T_{pre} + T_{se})]cT_{se}}{4(1 + C_0T_{se})}
\]  

(A16)

\[
    \frac{\partial p^{*MS-MC}_r}{\partial C_0} = - \frac{[1 + f(T_{pre} + T_{se})][1 - I(T_{pre} + T_{se})]cT_{se}}{4(1 + C_0T_{se})^2},
\]  

(A17)

\[
    \frac{\partial p^{*MS-MC}_r}{\partial I} = - \frac{(T_{pre} + T_{se}) [1 + f(T_{pre} + T_{se})] c}{4(1 + C_0T_{se})},
\]  

(A18)

\[
    \frac{\partial p^{*MS-MC}_r}{\partial f} = \frac{[1 - I(T_{pre} + T_{se})](T_{pre} + T_{se})c}{4(1 + C_0T_{se})}.
\]  

(A19)

For Eqs. (A.11), (A.14), (A.17) and (A.19), since \( 0 \leq I_R < 1 \) and \( I_R = I(T_{pre} + T_{se}) \), we have \( 1 - I(T_{pre} + T_{se}) > 0 \), further we know that \( \partial w^{*MS-MC}/\partial C_0 > 0, \partial p^{*MS-MC}_r/\partial C_0 < 0, \partial p^{*MS-MC}_s/\partial C_0 < 0, \) and \( \partial p^{*MS-MC}_r/\partial f > 0 \). For
Eqs. (A.12), (A.13), (A.15)-(A.16) and (A.18), we know that $\partial w^{*MS-MC}/\partial f > 0$, $\partial w^{*MS-MC}/\partial I > 0$, $\partial p^{*MS-MC}/\partial f > 0$, $\partial p^{*MS-MC}/\partial I < 0$, $\partial p^{*RS-MC}/\partial f < 0$ and $\partial p^{*RS-MC}/\partial I < 0$.

The proof of Proposition 2. According to Eqs. (19)-(21), the first order derivatives of $\pi^{*MS-MC}_M$, $\pi^{*MS-MC}_R$ and $\pi^{*MS-MC}_{SC}$ with respect to $C_0$, $I$ and $f$ can be determined, i.e.,

\[
\frac{\partial \pi^{*MS-MC}_M}{\partial C_0} = \frac{\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc\} T_{se}}{8b [1 - I (T_{se} + T_{pre})] (1 + C_0 T_{se})^2},
\]

\[
\cdot \{(1 + C_0 T_{se}) a + [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc\}.
\]

(A20)

\[
\frac{\partial \pi^{*MS-MC}_M}{\partial I} = \frac{\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc\}}{8b [1 - I (T_{se} + T_{pre})]^2 (1 + C_0 T_{se})}.
\]

(A21)

\[
\frac{\partial \pi^{*MS-MC}_M}{\partial f} = - \frac{\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc\}}{8 (1 + C_0 T_{se})},
\]

(A22)

\[
\frac{\partial \pi^{*MS-MC}_R}{\partial C_0} = \frac{\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc\} T_{se}}{16b (1 + C_0 T_{se})^2},
\]

(A23)

\[
\cdot \frac{[1 + f (T_{se} + T_{pre})] T_{se}}{8 (1 + C_0 T_{se})},
\]

(A24)

\[
\frac{\partial \pi^{*MS-MC}_R}{\partial I} = \frac{\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc\}}{8 (1 + C_0 T_{se})},
\]

(A25)

\[
\frac{\partial \pi^{*MS-MC}_{SC}}{\partial C_0} = \frac{\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})] [1 - I (T_{se} + T_{pre})] bc\} T_{se}}{16b [1 - I (T_{se} + T_{pre})] (1 + C_0 T_{se})^2},
\]

(A26)

\[
\cdot \frac{[3 - I (T_{se} + T_{pre})] T_{se}}{8b [1 - I (T_{se} + T_{pre})]^2 (1 + C_0 T_{se})},
\]

(A27)
\[
\frac{\partial \pi^{*}_{SC}}{\partial f} = -\left\{(1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})] bc\right\} \\
\cdot \frac{[3 - I (T_{se} + T_{pre})] (T_{se} + T_{pre}) c}{8 (1 + C_0 T_{se})}. \tag{A28}
\]

Based on above equations, we can obtain the following results:

(1) for \((1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})] bc \geq 0\), we have that \(\partial \pi^*_M / \partial C_0 \geq 0\), \(\partial \pi^*_M / \partial I \geq 0\), \(\partial \pi^*_M / \partial f \leq 0\), \(\partial \pi^*_R / \partial C_0 \geq 0\), \(\partial \pi^*_R / \partial I \geq 0\), \(\partial \pi^*_R / \partial f \leq 0\), \(\partial \pi^*_M / \partial C_0 \geq 0\), \(\partial \pi^*_M / \partial I \geq 0\) and \(\partial \pi^*_M / \partial f \leq 0\);

(2) for \((1 + C_0 T_{se}) a - [1 + f (T_{se} + T_{pre})][1 - I (T_{se} + T_{pre})] bc < 0\), we have that \(\partial \pi^*_M / \partial C_0 < 0\), \(\partial \pi^*_M / \partial I < 0\), \(\partial \pi^*_M / \partial f > 0\), \(\partial \pi^*_R / \partial C_0 < 0\), \(\partial \pi^*_R / \partial I < 0\), \(\partial \pi^*_R / \partial f > 0\).

The proof of Theorem 6.2. According to Eq. (9), the profit function of manufacturer for scenario RS-MC can be determined, i.e.,
\[
\pi^+_M = \left[w^R_{MS-MC} - (1 + f_M) c \right] \left[a - b (p^R_{RS-MC} + w^R_{RS-MC})\right]. \tag{B1}
\]

Let \(d \pi^+_M / dw^R_{RS-MC} = 0\), then the response function of manufacturer can be determined, i.e.,
\[
u^R_{RS-MC} = \frac{a + (1 + f_M) bc}{2b} - \frac{1}{2} p^R_{RS-MC}. \tag{B2}
\]

According to Eq. (8), the profit function of retailer for scenario RS-MC can be determined, i.e.,
\[
\pi^R_{RS-MC} = \left[(1 + CR) p^R_{RS-MC} + (CR + IR) w^R_{RS-MC}\right] \\
\cdot \left[a - b (p^R_{RS-MC} + w^R_{RS-MC})\right]. \tag{B3}
\]

By Eq. (B.2), the Eq. (B.3) can be converted into the following equation, i.e.,

\[
\pi^R_{RS-MC} = \left\{(1 + CR) p^R_{RS-MC} + (CR + IR) \left[\frac{a + (1 + f_M) bc}{2b} - \frac{1}{2} p^R_{RS-MC}\right]\right\} \\
\cdot \left[a - b \left[p^R_{RS-MC} + \left(\frac{a + (1 + f_M) bc}{2b} - \frac{1}{2} p^R_{RS-MC}\right)\right]\right]. \tag{B4}
\]

On the basis, the first and second order derivatives of profit function of retailer with respect to \(p^R_{RS-MC}\) can be determined, i.e.,
\[
d \pi^R_{RS-MC} / dp^R_{RS-MC} = \frac{(1 - IR) a - (1 + f_M) (1 + CR) bc - (2 + CR - IR) bp^R_{RS-MC}}{2}, \tag{B5}
\]
\[
d^2 \pi^R_{RS-MC} / d(p^R_{RS-MC})^2 = \frac{(2 + CR - IR) b}{2}. \tag{B6}
\]

According to Eq. (B.6), for \(0 < IR < 1\), we have that \(d^2 \pi^R_{RS-MC} / d(p^R_{RS-MC})^2 < 0\), further we know that profit function of retailer \(\pi^R_{RS-MC}\) is a concave function with respect to \(p^R_{RS-MC}\), thus we know that there is unique margin price \(p^*_{RS-MC}\) which maximizes profit function of retailer.
Furthermore, according to the first order condition, the optimal margin price of retailer $p^*_{r\text{-}\text{MC}}$ can be determined, i.e.,

$$p^*_{r\text{-}\text{MC}} = \frac{(1 - I_R) a - (1 + f_M) (1 + C_R) bc}{b(2 + C_R - I_R)}. \quad (B7)$$

On the basis, according to Eq. (B.2), the optimal wholesale price of manufacturer $w^*_{\text{RS-MC}}$ can be determined, i.e.,

$$w^*_{\text{RS-MC}} = \frac{(1 + C_R) a + (1 + f_M) (3 + 2C_R - I_R) bc}{2b(2 + C_R - I_R)}. \quad (B8)$$

According to Eqs. (3)-(5), the Eqs. (B.7) and (B.8) can be converted into the following equations, i.e.,

$$p^*_{r\text{-}\text{MC}} = \frac{[1 - I (T_{se} + T_{pre})] a - [1 + f (T_{se} + T_{pre})] (1 + C_0T_{se}) bc}{b[2 + C_0T_{se} - I (T_{se} + T_{pre})]}, \quad (B9)$$

$$w^*_{\text{RS-MC}} = \frac{(1 + C_0T_{se}) a + [1 + f (T_{se} + T_{pre})] [3 + 2C_0T_{se} - I (T_{se} + T_{pre})] bc}{2b[2 + C_0T_{se} - I (T_{se} + T_{pre})]} \quad (B10).$$

**The proof of Proposition 3.** According to Eq. (23)-(24), the first order derivatives of $w^*_{\text{RS-MC}}, p^*_{r\text{-}\text{MC}}$ and $p^*_{\text{RS-MC}}$ with respect to $C_0$, $I$ and $f$ can be determined, i.e.,

$$\frac{\partial w^*_{\text{RS-MC}}}{\partial C_0} = \frac{[1 - I (T_{pre} + T_{se})] T_{se} \{a + [1 + f (T_{pre} + T_{se})] bc\}}{b[2 + C_0T_{se} - I (T_{pre} + T_{se})]^2}, \quad (B11)$$

$$\frac{\partial w^*_{\text{RS-MC}}}{\partial I} = \frac{(1 + C_0T_{se}) (T_{pre} + T_{se}) \{a + [1 + f (T_{pre} + T_{se})] bc\}}{2b[2 + C_0T_{se} - I (T_{pre} + T_{se})]^2}, \quad (B12)$$

$$\frac{\partial w^*_{\text{RS-MC}}}{\partial f} = \frac{[3 + 2C_0T_{se} - I (T_{pre} + T_{se})] (T_{pre} + T_{se}) c}{2[2 + C_0T_{se} - I (T_{pre} + T_{se})]}, \quad (B13)$$

$$\frac{\partial p^*_{r\text{-}\text{MC}}}{\partial C_0} = -\frac{[1 - I (T_{pre} + T_{se})] T_{se} \{a + [1 + f (T_{pre} + T_{se})] bc\}}{b[2 + C_0T_{se} - I (T_{pre} + T_{se})]^2}, \quad (B14)$$

$$\frac{\partial p^*_{r\text{-}\text{MC}}}{\partial I} = -\frac{(T_{pre} + T_{se}) (1 + C_0T_{se}) \{a + [1 + f (T_{pre} + T_{se})] bc\}}{b[2 + C_0T_{se} - I (T_{pre} + T_{se})]^2}, \quad (B15)$$

$$\frac{\partial p^*_{r\text{-}\text{MC}}}{\partial f} = -\frac{(1 + C_0T_{se}) (T_{pre} + T_{se}) c}{2 + C_0T_{se} - I (T_{pre} + T_{se})}, \quad (B16)$$

$$\frac{\partial p^*_{\text{RS-MC}}}{\partial C_0} = -\frac{[1 - I (T_{pre} + T_{se})] T_{se} \{a + [1 + f (T_{pre} + T_{se})] bc\}}{2b[2 + C_0T_{se} - I (T_{pre} + T_{se})]^2}, \quad (B17)$$

$$\frac{\partial p^*_{\text{RS-MC}}}{\partial I} = -\frac{(1 + C_0T_{se}) (T_{pre} + T_{se}) \{a + [1 + f (T_{pre} + T_{se})] bc\}}{2b[2 + C_0T_{se} - I (T_{pre} + T_{se})]^2}, \quad (B18)$$

$$\frac{\partial p^*_{\text{RS-MC}}}{\partial f} = \frac{[1 - I (T_{pre} + T_{se})] (T_{pre} + T_{se}) c}{2[2 + C_0T_{se} - I (T_{pre} + T_{se})]}. \quad (B19)$$

For Eqs. (B.11), (B.13), (B.14), (B.16), (B.17) and (B.19), since $0 \leq I_R < 1$ and $I_R = I (T_{pre} + T_{se})$, we have $1 - I (T_{pre} + T_{se}) > 0$, further we know that
\[ \frac{\partial w^{rs-mc}}{\partial C_0} > 0, \frac{\partial w^{rs-mc}}{\partial f} > 0, \frac{\partial p^{rs-mc}}{\partial C_0} < 0, \frac{\partial p^{rs-mc}}{\partial f} < 0, \frac{\partial p^{rs-mc}}{\partial C_0} < 0 \text{ and } \frac{\partial p^{rs-mc}}{\partial f} > 0. \] For Eqs. (B.12), (B.15) and (B.18), we know that \[ \frac{\partial w^{rs-mc}}{\partial I} > 0, \frac{\partial p^{rs-mc}}{\partial I} < 0 \text{ and } \frac{\partial p^{rs-mc}}{\partial I} < 0. \]

**The proof of Proposition 4.** According to Eqs. (25)-(27), the first order derivatives of \( \pi^{rs-mc}_M, \pi^{rs-mc}_R \) and \( \pi^{rs-sc}_SC \) with respect to \( C_0, I \) and \( f \) can be determined, i.e.,

\[
\frac{\partial \pi^{rs-mc}_M}{\partial C_0} = \left\{ (1 + C_0 T_{se}) a - [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] \right\} b c \\
\quad \cdot \frac{a + [1 + f (T_{pre} + T_{se})] b c} {2b[2 + C_0 T_{se} - I (T_{pre} + T_{se})]^3},
\]

(B20)

\[
\frac{\partial \pi^{rs-mc}_M}{\partial I} = \left\{ (1 + C_0 T_{se}) a - [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] \right\} b c \\
\quad \cdot \frac{a + [1 + f (T_{pre} + T_{se})] b c} {2b[2 + C_0 T_{se} - I (T_{pre} + T_{se})]^3},
\]

(B21)

\[
\frac{\partial \pi^{rs-mc}_M}{\partial f} = - \left\{ (1 + C_0 T_{se}) a - [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] \right\} b c \\
\quad \cdot \frac{\left[ 1 - I (T_{pre} + T_{se}) (T_{pre} + T_{se}) c \right]} {4b[2 + C_0 T_{se} - I (T_{pre} + T_{se})]^2},
\]

(B22)

\[
\frac{\partial \pi^{rs-mc}_R}{\partial C_0} = \left\{ (1 + C_0 T_{se}) a - [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] \right\} T_{se} \\
\quad \cdot \left\{ [3 + C_0 T_{se} - 2I (T_{pre} + T_{se}) a + [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] b c \right\} \left( T_{pre} + T_{se} \right),
\]

(B23)

\[
\frac{\partial \pi^{rs-mc}_R}{\partial I} = \left\{ (1 + C_0 T_{se}) a + [1 + f (T_{pre} + T_{se})] [3 + 2C_0 T_{se} - I (T_{pre} + T_{se})] b c \right\} \left( T_{pre} + T_{se} \right),
\]

(B24)

\[
\frac{\partial \pi^{rs-mc}_R}{\partial f} = - \left\{ (1 + C_0 T_{se}) a - [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] b c \right\} \\
\quad \cdot \frac{\left[ 1 - I (T_{pre} + T_{se}) (T_{pre} + T_{se}) c \right]} {2b[2 + C_0 T_{se} - I (T_{pre} + T_{se})]^3},
\]

(B25)

\[
\frac{\partial \pi^{rs-sc}_SC}{\partial C_0} = \left\{ (1 + C_0 T_{se}) a - [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] \right\} T_{se} \\
\quad \cdot \left\{ [M1 + [1 - I (T_{pre} + T_{se})] \left\{ 2 [3 + C_0 T_{se} - I (T_{pre} + T_{se})] a + M2 \right\} \right\},
\]

(B26)

where \( M1 = (1 + C_0 T_{se}) [2 + C_0 T_{se} - I (T_{pre} + T_{se})] a \) and \( M2 = f (T_{pre} + T_{se}) \cdot [4 + C_0 T_{se} - I (T_{pre} + T_{se})] b c + [4 + C_0 T_{se} - I (T_{pre} + T_{se})] b c,\)

\[
\frac{\partial \pi^{rs-mc}_SC}{\partial I} = \left\{ (1 + C_0 T_{se}) a - bc M3 \right\} (T_{pre} + T_{se})
\]
\[
\frac{\partial \pi_M^{*RS-MC}}{\partial f} = \frac{-\{(1 + C_0 T_{se}) a - [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] bc\}}{4b[2 + C_0 T_{se} - I (T_{pre} + T_{se})]^3}, \quad (B27)
\]

where \( M4 = (1 + C_0 T_{se}) a [4 + C_0 T_{se} - I (T_{pre} + T_{se})], \ M5 = [1 - I (T_{pre} + T_{se})][2 + C_0 T_{se} - I (T_{pre} + T_{se})], \ M6 = 2[3 + C_0 T_{se} - I (T_{pre} + T_{se})] (1 + C_0 T_{se}) \) and \( M3 = [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] \).

\[
\frac{\partial \pi_{SC}^{*RS-MC}}{\partial f} = \frac{\{1 + C_0 T_{se}) a - [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] bc\}}{[1 - I (T_{pre} + T_{se})][3 + C_0 T_{se} - I (T_{pre} + T_{se})] (T_{se} + T_{pre})^2}. \quad (B28)
\]

Based on above equations, we can obtain the following results:

1. for \((1 + C_0 T_{se}) a [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] bc \geq 0, \) we have that \( \partial \pi_M^{*RS-MC} / \partial C_0 \geq 0, \partial \pi_M^{*RS-MC} / \partial I \geq 0, \partial \pi_M^{*RS-MC} / \partial f \leq 0, \partial \pi_{SC}^{*RS-MC} / \partial C_0 \geq 0, \partial \pi_{SC}^{*RS-MC} / \partial I \geq 0, \partial \pi_{SC}^{*RS-MC} / \partial f \leq 0, \partial \pi_{SC}^{*RS-MC} / \partial C_0 \geq 0, \partial \pi_{SC}^{*RS-MC} / \partial I \geq 0 \) and \( \partial \pi_{SC}^{*RS-MC} / \partial f \leq 0; \)

2. for \((1 + C_0 T_{se}) a [1 + f (T_{pre} + T_{se})] [1 - I (T_{pre} + T_{se})] bc < 0, \) we have that \( \partial \pi_M^{*RS-MC} / \partial C_0 < 0, \partial \pi_M^{*RS-MC} / \partial I < 0, \partial \pi_M^{*RS-MC} / \partial f > 0, \partial \pi_{SC}^{*RS-MC} / \partial C_0 < 0, \partial \pi_{SC}^{*RS-MC} / \partial I < 0, \partial \pi_{SC}^{*RS-MC} / \partial f > 0, \partial \pi_{SC}^{*RS-MC} / \partial C_0 < 0, \partial \pi_{SC}^{*RS-MC} / \partial I < 0 \) and \( \partial \pi_{SC}^{*RS-MC} / \partial f > 0. \)

The proof of Theorem 6.3. According to Eq. (13), the profit function of retailer for scenario MS-RC can be determined, i.e.,

\[
\pi_{R}^{MS-RC} = \left[(1 + C_R) p_r^{MS-RC} + w^{MS-RC} C_R\right] \left[a - b \left(p_r^{MS-RC} + w^{MS-RC}\right)\right]. \quad (C1)
\]

Let \( d p_{R}^{MS-RC} / dp_r^{MS-RC} = 0, \) then the response function of retailer can be determined, i.e.,

\[
p_r^{MS-RC} = \frac{(1 + C_R) a - b (1 + 2C_R) w^{MS-RC}}{2b (1 + C_R)}. \quad (C2)
\]

According to Eq. (14), the profit function of manufacturer for scenario MS-RC can be determined, i.e.,

\[
\pi_{M}^{MS-RC} = \left[w^{MS-RC} - c\right] \left[a - b \left(p_r^{MS-RC} + w^{MS-RC}\right)\right]. \quad (C3)
\]

By Eq. (C.2), the Eq. (C.3) can be converted into the following equation, i.e.,

\[
\pi_{M}^{MS-RC} = \left\{ a - b \left[\frac{(1 + C_R) a - b (1 + 2C_R) w^{MS-RC}}{2b (1 + C_R)} + w^{MS-RC}\right]\right\} \left(w^{MS-RC} - c\right). \quad (C4)
\]

On the basis, the first and second order derivatives of profit function of manufacturer \( \pi_{M}^{MS-RC} \) with respect to \( w^{MS-RC} \) can be determined, i.e.,

\[
\frac{d \pi_{M}^{MS-RC}}{d w^{MS-RC}} = \left(1 + C_R\right) a - 2bw^{MS-RC} + bc \quad \frac{d^2 \pi_{M}^{MS-RC}}{d (w^{MS-RC})^2} = \frac{b}{1 + C_R}. \quad (C5, C6)
\]

According to Eq. (C.6), we have that \( d^2 \pi_{M}^{MS-RC} / d (w^{MS-RC})^2 < 0, \) further we know that profit function of manufacturer \( \pi_{M}^{MS-RC} \) is a concave function with
respect to \( w^{MS-RC} \), thus we know that there is unique wholesale price \( w^{*MS-RC} \) which maximizes profit function of manufacturer.

Furthermore, according to the first order condition, the optimal wholesale price of manufacturer \( w^{*MS-RC} \) can be determined, i.e.,

\[
w^{*MS-RC} = \frac{a(1 + C_R) + bc}{2b}.
\]

On the basis, according to Eq. (C.2), the optimal margin price of retailer \( p^{*MS-RC} \) can be determined, i.e.,

\[
p^{*MS-RC} = \frac{(1 + C_R)(1 - 2C_R)a - (1 + 2C_R)bc}{4b(1 + C_R)}.
\]

According to Eq. (5), the Eqs. (C.7) and (C.8) can be converted into the following equations, i.e.,

\[
\begin{align*}
\pi &= \frac{a(1 + C_R) + bc}{2b}, \\
p^{*MS-RC} &= \frac{(1 + C_R)(1 - 2C_R)a - (1 + 2C_R)bc}{4b(1 + C_R)}.
\end{align*}
\]

**The proof of Proposition 5.** According to Eqs. (28)-(30), the first order derivatives of \( w^{*MS-RC} \), \( p^{*MS-RC} \) and \( p^{*MS-RC} \) with respect to \( C_0 \) can be determined, i.e.,

\[
\begin{align*}
\frac{\partial w^{*MS-RC}}{\partial C_0} &= \frac{aT_{se}}{2b}, \\
\frac{\partial p^{*MS-RC}}{\partial C_0} &= -\frac{2(1 + C_R)T_{se}^2a + bc}{4b(1 + C_R)T_{se}^2}, \\
\frac{\partial p^{*MS-RC}}{\partial C_0} &= -\frac{bcT_{se}}{4b(1 + C_R)T_{se}^2}.
\end{align*}
\]

Obviously, \( \partial w^{*MS-RC}/\partial C_0 > 0 \), \( \partial p^{*MS-RC}/\partial C_0 < 0 \) and \( \partial p^{*MS-RC}/\partial C_0 < 0 \).

**The proof of Proposition 6.** According to Eqs. (31)-(33), the first order derivatives of \( \pi^{*MS-RC} \), \( \pi^{*MS-RC} \) and \( \pi^{*MS-RC} \) with respect to \( C_0 \) can be determined, i.e.,

\[
\begin{align*}
\frac{\partial \pi^{*MS-RC}}{\partial C_0} &= \frac{[(1 + C_R)T_{se}](a - bc)[(1 + C_R)T_{se}]a + bcT_{se}}{16b(1 + C_R)T_{se}^2}, \\
\frac{\partial \pi^{*MS-RC}}{\partial C_0} &= \frac{[(1 + C_R)T_{se}](a - bc)[(1 + C_R)T_{se}]a + bcT_{se}}{8b(1 + C_R)T_{se}^2}, \\
\frac{\partial \pi^{*MS-RC}}{\partial C_0} &= \frac{3[(1 + C_R)T_{se}](a - bc)[(1 + C_R)T_{se}]a + bcT_{se}}{16b(1 + C_R)T_{se}^2}.
\end{align*}
\]

Given that \( D = a - bp \geq 0 \) and \( p > c \), we have \( (1 + C_R)T_{se}a - bc \geq 0 \), further we know that \( \partial \pi^{*MS-RC}/\partial C_0 > 0 \), \( \partial \pi^{*MS-RC}/\partial C_0 > 0 \) and \( \partial \pi^{*MS-RC}/\partial C_0 > 0 \).
The proof of Theorem 6.4. According to Eq. (14), the profit function of manufacturer for scenario RS-RC can be determined, i.e.,

\[
\pi_{M}^{RS-RC} = (w_{RS-RC} - c) \left[ a - b \left( p_{r}^{RS-RC} + w_{RS-RC} \right) \right].
\] (D1)

Let \( \frac{d\pi_{M}^{RS-RC}}{dw_{RS-RC}} = 0 \), then the response function of manufacturer can be determined, i.e.,

\[
w_{RS-RC} = \frac{a + bc}{2b} - \frac{1}{2}p_{r}^{RS-RC}.
\] (D2)

According to Eq. (13), the profit function of retailer for scenario RS-RC can be determined, i.e.,

\[
\pi_{R}^{RS-RC} = \left[(1 + C_{R}) p_{r}^{RS-RC} + w_{RS-RC}C_{R}\right] \left[a - b \left( p_{r}^{RS-RC} + w_{RS-RC} \right) \right].
\] (D3)

By Eq. (D.2), the Eq. (D.3) can be converted into the following equation, i.e.,

\[
\pi_{R}^{RS-RC} = \left[(1 + C_{R}) p_{r}^{RS-RC} + \left( \frac{a + bc}{2b} - \frac{1}{2}p_{r}^{RS-RC} \right) \right] C_{R}
\cdot \left[ a - b \left( \frac{a + bc}{2b} + \frac{1}{2}p_{r}^{RS-RC} \right) \right].
\] (D4)

On the basis, the first and second order derivatives of profit function of retailer with respect to \( p_{r}^{RS-RC} \) can be determined, i.e.,

\[
\frac{d\pi_{R}^{RS-RC}}{dp_{r}^{RS-RC}} = \frac{a - (1 + C_{R}) bc - (2 + C_{R}) bp_{r}^{RS-RC}}{2},
\] (D5)

\[
\frac{d^{2}\pi_{R}^{RS-RC}}{d(p_{r}^{RS-RC})^{2}} = \frac{-b}{2} \left( 2 + C_{R} \right).
\] (D6)

According to Eq. (D.6), we have that \( \frac{d^{2}\pi_{R}^{RS-RC}}{d(p_{r}^{RS-RC})^{2}} < 0 \), further we know that profit function of retailer \( \pi_{R}^{RS-RC} \) is a concave function with respect to \( p_{r}^{RS-RC} \), thus we know that there is unique margin price \( p_{r}^{*RS-RC} \) which maximizes profit function of retailer.

Furthermore, according to the first order condition, the optimal margin price of retailer \( p_{r}^{*RS-RC} \) can be determined, i.e.,

\[
p_{r}^{*RS-RC} = \frac{a - (1 + C_{R}) bc}{b(2 + C_{R})}.
\] (D7)

On the basis, according to Eq. (D.2), the optimal wholesale price of manufacturer \( w^{*RS-RC} \) can be determined, i.e.,

\[
w^{*RS-RC} = \frac{(1 + C_{R}) a + (3 + 2C_{R}) bc}{2b(2 + C_{R})}.
\] (D8)

According to Eq. (5), the Eqs. (D.7) and (D.8) can be converted into the following equations, i.e.,

\[
p_{r}^{*RS-RC} = \frac{a - (1 + C_{0}T_{se}) bc}{b(2 + C_{0}T_{se})},
\] (D9)

\[
w^{*RS-RC} = \frac{(1 + C_{0}T_{se}) a + (3 + 2C_{0}T_{se}) bc}{2b(2 + C_{0}T_{se})}.
\] (D10)
The proof of Proposition 7. According to Eqs. (34)-(36), the first order derivatives of \( w^{RS-RC} \), \( p_r^{RS-RC} \) and \( p^*_{RS-RC} \) with respect to \( C_0 \) can be determined, i.e.,
\[
\frac{\partial w^{RS-RC}}{\partial C_0} = \frac{(a + bc) T_{sc}}{2b(2 + C_0 T_{sc})^2}, \quad (D11)
\]
\[
\frac{\partial p_r^{RS-RC}}{\partial C_0} = -\frac{(a + bc) T_{sc}}{b(2 + C_0 T_{sc})^2}, \quad (D12)
\]
\[
\frac{\partial p^*_{RS-RC}}{\partial C_0} = -\frac{(a + bc) T_{sc}}{2b(2 + C_0 T_{sc})^2}, \quad (D13)
\]
Obviously, \( \frac{\partial w^{RS-RC}}{\partial C_0} > 0, \frac{\partial p_r^{RS-RC}}{\partial C_0} < 0 \) and \( \frac{\partial p^*_{RS-RC}}{\partial C_0} < 0 \).

The proof of Proposition 8. According to Eqs. (37)-(39), the first order derivatives of \( \pi^*_{RS-RC} \), \( \pi^*_{R}^{RS-RC} \) and \( \pi^*_{SC}^{RS-RC} \) with respect to \( C_0 \) can be determined, i.e.,
\[
\frac{\partial \pi^*_{R}^{RS-RC}}{\partial C_0} = \frac{\left[(1 + C_0 T_{sc})a - bc\right]\left[(3 + C_0 T_{sc})a + bc\right] T_{se}}{4b(2 + C_0 T_{sc})^2}, \quad (D14)
\]
\[
\frac{\partial \pi^*_{M}^{RS-RC}}{\partial C_0} = \frac{\left[(1 + C_0 T_{sc})a - bc\right]\left(a + bc\right) T_{se}}{2b(2 + C_0 T_{sc})^3}, \quad (D15)
\]
\[
\frac{\partial \pi^*_{SC}^{RS-RC}}{\partial C_0} = \frac{\left[2(3 + C_0 T_{sc})a + (1 + C_0 T_{sc})(2 + C_0 T_{sc})a + (4 + C_0 T_{sc}) bc\right]}{4b(2 + C_0 T_{sc})^3} T_{se}, \quad (D16)
\]

Given that \( D = a - bp \geq 0 \) and \( p > c \), we have \( (1 + C_0 T_{sc})a - bc \geq 0 \), further we know that \( \frac{\partial \pi^*_{R}^{RS-RC}}{\partial C_0} > 0, \frac{\partial \pi^*_{M}^{RS-RC}}{\partial C_0} > 0 \) and \( \frac{\partial \pi^*_{SC}^{RS-RC}}{\partial C_0} > 0 \).

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E-mail address: bbcao_neu@163.com
E-mail address: gongzaijing@163.com
E-mail address: thyou@mail.neu.edu.cn