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Financing and information sharing in capital-constrained supply chain

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A B S T R A C T

This paper focuses on financing choices and information-sharing strategies in the capital-constrained supply chain. We model four scenarios with the capital constraints of the respective manufacturer and retailer using bank credit financing (BCF) and trade credit financing (TCF) approaches to address financing problems, and investigate the retailer's willingness to share demand forecasting information. We find that TCF is an equilibrium financing choice for a capital-constrained supply chain. However, when a capital-constrained member chooses TCF, sharing demand information over the supply chain becomes more difficult. The interactions between the choices of financing approach and information sharing based on the game equilibriums, as well as the conditions that encourage the well-funded member to offer TCF in the capital-constrained supply chains, have also been analytically explored and numerically verified. Additional managerial insights are provided for discussions.

A R T I C L E   I N F O

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Supply chain;
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1. Introduction

Capital is the basic guarantee for smooth operations and management of supply chains, nevertheless, many enterprises are capital-constrained during startup phases [1]. According to Enterprise Surveys (World Bank Group, 2018), which encompass more than 135,000 enterprises in 139 countries, 53.6 % of the enterprises require a loan, and 26.5 % cited access to finance as a major restriction. Both the manufacturer and the retailer may face capital constraints. In March 2018, Peugeot Citroen immediately issued a supply disruption warning when noticed that up to 85 % of the major suppliers were facing financing difficulties. A total of 19 % of U.S. retailers closed their stores due to capital-constrained reasons in the first half of 2019, and more than 7,000 retail stores were finally closed. In 2020, the outbreak of the COVID-19 pandemic posed great challenges to the stability of the supply chain system and undermined the shortage of funds in the supply chain [2]. Many companies suffer from budget pressure had to close down a mass of their factories and stores. On March 23, 2020, Tesla temporarily suspended production at its two plants in New York and California. In May, the first major fashion retailer, J. Crew Group Inc. filed for bankruptcy, followed by Neiman Marcus, a luxury department store, and in

December, Debenhams, a British retail giant with more than 230 years of history, declared bankruptcy.

To ease the capital constraints, a firm may have access to more than one financing sources. Bank credit financing (BCF) is a common financing approaches provided by banks for firms to meet the financing requirements. In 2016, 20 % of China's small and medium-sized firms (SMEs) borrowed from banks [3], To increase the overall efficiency of the entire supply chain, large well-funded firms often provide trade credit financing (TCF) to the participants within the supply chain in practice. Ford Motor Credit Company LLC, a wholly-owned subsidiary of Ford Motor Company, offers wholesale loans to dealers to finance the purchase of vehicle inventory, as well as loans to dealers to finance working capital and enhancements to dealership facilities [4]. And Haier provides trade credit to its small partners to alleviate their financial strain [5]. However, the related research seem to have opposing opinions on whether capital-constrained buyers/retailers should adopt BCF or TCF. Through numerical research, Zhou and Groenevelt [6] contend that bank credit is better than trade credit. Whereas Kouvelis and Zhao [7] pointed out that if the retailer is provided an effectively constructed scheme, they would always choose supplier financing over bank financing. Jing *et al*. [8] demonstrate that TCF (BCF) is the unique financing equilibrium when production costs are below (above) a certain threshold, when both bank credit and trade credit are available.

Specifically, for the capital-constrained supply chain with the coexistence of bank and trade credits, demand uncertainty and information asymmetry should also be emphasized. Demand uncertainty would not only aggravate the internal difficulties of enterprises' operations but also exert external financing pressure on capital-constrained enterprises [9]. Internally, it necessitates greater financial investment in inventory management to prevent stock-outs, while externally, the uncertain sales revenue makes it harder for firms to maintain robust cash flow and may raise the risk of default, a critical factor for their lending agents or institutions in determining the interest rate. Wang *et al*. [1] have shown that increased demand uncertainty may prompt lenders to charge a higher interest rate, which would further impact the decisions and performance of supply chain participants in the lending market. Therefore, demand forecasting is important for capital-constrained enterprises because it is an effective way to reduce demand uncertainty [10]. If the retailer shares demand information with the upstream manufacturer, it would help the manufacturer improve the accuracy of demand forecasting. Thus, the problem would be whether the retailer decides to share private demand information with the upstream manufacturer in a capital-constrained supply chain. Given that both manufacturers and retailers may face increasing capital constraints, wherein the uncertain demand and asymmetric information further complicate the financing for the capital-constrained member, this paper addresses the following issues: How does a capital-constrained member make financing choices in the face of asymmetric demand information? Will the retailer share demand information when the capital-constrained member addresses the financing problem through BCF and TCF respectively? How will the information be shared with different financing choices? All the above-mentioned problems are key to capital-constrained supply chain management under information asymmetry.

However, while the theoretical studies on respective financing and information sharing are abundant, there is limited research focusing on supply chain management that considers both demand information asymmetry and capital constraints at an operational level. This paper shows the equilibrium choices of financing and information-sharing strategies for an information-asymmetric supply chain with either capital-constrained manufacturers or retailers. Based on the game equilibriums, the interactions between the above two strategies (i.e., financing vs. information sharing) are analysed, and the conditions that the well-funded member is willing to provide TCF are further discussed.

This paper contributes to the state-of-the-art research in three ways: First, we identify the financing choices, i.e., BCF or TCF, that the capital-constrained manufacturer/retailer prefers to take in the face of asymmetric demand information. We find that TCF is an equilibrium financing choice in both scenarios with capital constraints of manufacturer and retailer. Second, we further analyse the correlation between the choice of financing approach and information sharing.

Although the capital-constrained member's financing choice does not directly affect the retailer's information-sharing strategy, the value of information sharing has changed: when the capital-constrained member opts for TCF, the retailer is less willing to share demand information in case of losing profits. Third, we consider the bank deposit and loan rates for the choice of BCF in the construction of the game model and numerically analyse the ranges of deposit and loan rates that urge the well-funded member become willing to provide TCF.

The rest of the paper is organized as follows. Section 2 reviews the relevant literature and Section 3 introduces the model framework. In Section 4, the game model when capital-constrained manufacturer adopts BCF and TCF are built respectively, and the equilibrium solutions are discussed. And the game equilibriums of the model when capital-constrained retailer adopts BCF and TCF are analysed in Section 5. Based on the equilibrium results, the impact of the financing approach on the value of information sharing is explored in Section 6, and the willingness of the well-funded member to provide TCF in Section 7. Section 8 is the numerical study. The last section summarizes the conclusions and provides additional managerial insights for discussions.

2. Literature review

This is an interface study of operations management and finance in which the financing options in a capital-constrained supply chain are investigated. It is a typical practice for enterprises suffering capital constraint to establish alternate financing approaches with distinct decisional dynamics amongst supply chain participants. Numerous studies have investigated the selection of financing approaches in a capital-constrained supply chain when alternative capital sources are available [11-16], wherein a significant amount of research has shown the effect of demand uncertainty on the efficiency of BCF and TCF. Jing *et al*. [8] conclude that BCF should be used under high demand uncertainty to increase channel efficiency. Overall, TCF is more lucrative than BCF for the manufacturer provided manufacturing costs and demand fluctuation are modest but is less profitable otherwise. Based on this study, Chen *et al*. [17] further verify that TCF improves the efficiency of the channel compared with bank credit. The retailer shares the demand risk with the manufacturer under TCF, and the manufacturer's risk sharing effectively reduces the retailer's marginal cost, which causes the retailer to increase the order quantity. Increased inventory at the store improves anticipated product sales, hence increasing the manufacturer's earnings. They conclude that trade credit is the only financing equilibrium in wholesale price contracts. According to Zhao and Arnd [18], the retailer may select between two pre-shipment finance mechanisms (APD, advance payment discount; BPOF, buyer-backed purchase order financing) to alleviate the supplier's financial difficulties. They discover that the retailer chooses APD over BPOF until the marginal cost of financial hardship outweighs the value of the unit discount. They demonstrate that the financing equilibrium zone of APD grows with both the retailer's internal capital level and demand fluctuation. The decisional dynamics of a supply chain that includes a supplier and a capital-constrained retailer that selects between BCF and TCF are examined by Shi *et al*. [9] in relation to demand uncertainty reduction (DUR). They recommend that when DUR is high and wholesale price is exogenous and cheap, the retailers should take TCF. And retailers should only take TCF, when the wholesale price is determined endogenously. and both DUR and manufacturing costs are low.

Notably, the research described above has mostly focused on choosing a financing approach, and some of them have shown that reducing demand uncertainty would impact the efficacy of BCF and TCF. But all the above literature is conducted under information symmetry. None of them has examined the information-sharing decision of retailers in a capital-constrained supply chain. Information sharing decision, that is, whether to share information based on the self-interest of the information holder, is the core issue in the field of information sharing. In recent years, much study has been undertaken on the relationship between information sharing and supply chain operation decisions. Mishra *et al*. [19] demonstrate that in both make-to-order and make-to-stock situations, sharing the forecast unconditionally by the retailer is advantageous for the manufacturer but detrimental for the retailer. However, Li and Zhang [20] conclude that if the level of demand uncertainty is moderate, the retailer has an incentive to voluntarily share the information manufacturer in the make-to-stock situations. Lai *et al*. [21] demonstrate that forecast sharing from the port can not only increase profitability for both partners, but also encourage investments in sustainability, even when the carrier is risk-averse in the marine supply chain. Liu *et al*. [22] investigate information sharing in a fresh-produce e-commerce supply chain in which the supplier provides freshness-keeping effort, and the e-tailer offers value-added services. They discover that information sharing is more likely to happen when the supplier is more cost-effective in investment in freshness-keeping or when the e-tailer is more effective in service investment. Li *et al*. [23] focus on a supply chain in which the manufacturer buys a component from the supplier who has private information on supply disruption risk. They discover that when the supplier's initial reliability is low in the pull regime, greater information transparency may be damaging to the manufacturer, but the high-type supplier might surprise provide a significant return under information asymmetry. Wang *et al*. [24] investigate information sharing in secondary supply chains in the presence of potential supplier intrusion and find that the degree of information sharing by retailers was not related to supplier intrusion. Liu *et al*. [25] study the information-sharing problem in a secondary supply chain consisting of two homogeneous manufacturers and a value-added retailer and find that when value-added services are cost-inefficient, the manufacturer's receipt of information shared by the retailer hurts its profit instead. Guan *et al*. [26] develop the information-sharing strategies for two competing supply chains and conclude that when one supply chain chooses an information-sharing strategy will affect the strategy choice of the other supply chain. Yan *et al*. [27] analyse the impact of blockchain technology on supply chain information coordination and conclude that blockchain technology can effectively reduce supply chain operating costs.

However, very few studies consider the effect of information sharing on the financing options of a capital-constrained supply chain, as far as we are aware. To take advantage of this research opportunity, this research seeks to analyse the equilibrium choices of financing approach and information-sharing strategy in a capital-constrained supply chain with the analysis of the interactions between financing channel choice and information-sharing decisions.

3. Model framework

Consider a capital-constrained supply chain consisting of a manufacturer (he) and a retailer(she) with asymmetric demand information. The manufacturer or the retailer facing capital constraints chooses between BCF and TCF when challenged with financing problems. BCF is a common financing approach whereby capital constraints are eased by bank loans, whereas TCF with capital-constrained manufacturer/retailer differs. When the manufacturer faces capital constraints, the retailer can offer TCF through advance payment. On the other hand, if the retailer is capital-constrained, TCF is provided via deferred payment from the manufacturer. Thus, it is important for the capital-constrained member to determine which financing approach should be adopted. The proximity to the customers facilitates the retailer to receive more accurate information about the market demand than the manufacturer does. It enables the retailer to determine whether to share the demand information with the manufacturer. This paper explores the equilibrium financing decision of the capital-constrained member and the equilibrium information-sharing decision of the retailer, as well as the interplay of the above two decisions.

The sequence of the game when manufacturer faces capital constraints is as follows. Before the selling season, the retailer decides whether to share the information, and the manufacturer decides whether to accept the information if retailer is willing to share. Then the manufacturer determines wholesale price w ($w > c$), and the retailer determines retail price retail price p ($p > w$) and places the order. After receiving the order, the manufacturer begins production with per-unit production cost c if he has sufficient funds, otherwise, he resorts to TCF or BCF for financing. When production is completed, the manufacturer sells the products to the retailer at w and deposits profits into bank. During the selling season, the retailer sells products in the market at p, and also deposits the sales proceeds on zero deposit and withdrawal. At the end of the sales season, the manufacturer and retailer take back the principal and interest on the deposit, and the manufacturer pays off the debt. If the retailer is capital-constrained, she pays for the product upon receipt by taking out a loan from the bank or at the end of the sale season through a deferred payment option offered by the manufacturer.

3.1 Demand function

The demand function is written as $D = a - bp + \varepsilon$, where a refers to the market size and b the demand elasticity of retail price. ε is the randomness of market demand, which is assumed to be normally distributed with a mean of 0 and a variance of σ^2. We assume that the retailer has private demand forecasting information γ, i.e., $\gamma = \varepsilon + \delta$, where δ captures the noise in the forecast error, which is also normally distributed with a mean of 0 and a variance of σ_0^2. According to the existing literature [19, 21], we denote $H = E[\varepsilon|\gamma] = \frac{\sigma^2\gamma}{\sigma_0^2+\sigma^2}$ and $Var[\varepsilon|\gamma] = \frac{\sigma^2\sigma_0^2}{\sigma_0^2+\sigma^2}$, where H refers to the market demand fluctuation.

3.2 Model assumptions

To facilitate the construction of the models, we have the following assumptions:

(1) The capital-constrained member's initial capital is assumed to be zero.
(2) No moral hazard exists. Both the manufacturer and retailer are creditworthy and the loan will be repaid at the conclusion of the sales period;.
(3) No bankruptcy risk happens. The supply chain system and the bank operate in good conditions in the game and there are no extreme changes in the market environment.
(4) During the s season, the retailer deposits the sales revenue in the bank on a zero-deposit basis, disregarding the self-retaining non-deposit.

4. Manufacturer's choice with capital constraints

4.1 Analysis of trade credit financing

The retailer can ease the manufacturer's capital constraints by paying in advance, which is a typical type of TCF. The sequence of the game when a capital-constrained manufacturer adopts TCF is shown in Fig. 1.

When the retailer is not willing to share demand information, the manufacturer has to determine the wholesale price according to his private information. The expected profit functions of the manufacturer and the retailer can be described as follows:

$$E[\pi_{M1}^{MN}] = (1 + I_M)(w_1^{MN} - c)(a - bp_1^{MN} + E[\varepsilon]) \quad (1)$$

$$E[\pi_{R1}^{MN}] = [(1 + I_R)p_1^{MN} - w_1^{MN}](a - bp_1^{MN} + E[\varepsilon|\gamma]) \quad (2)$$

where I_M and I_R refer to the deposit rate of the manufacturer and the retailer. We express $I_M = (t_{pre} + t_{se})i_M$ and $I_R = t_{se}i_R$, wherein t_{pre} denotes the length of lead time, t_{se} the length of sales period, i_M the bank deposit rate and i_R the deposit rate for zero deposit and withdrawal.

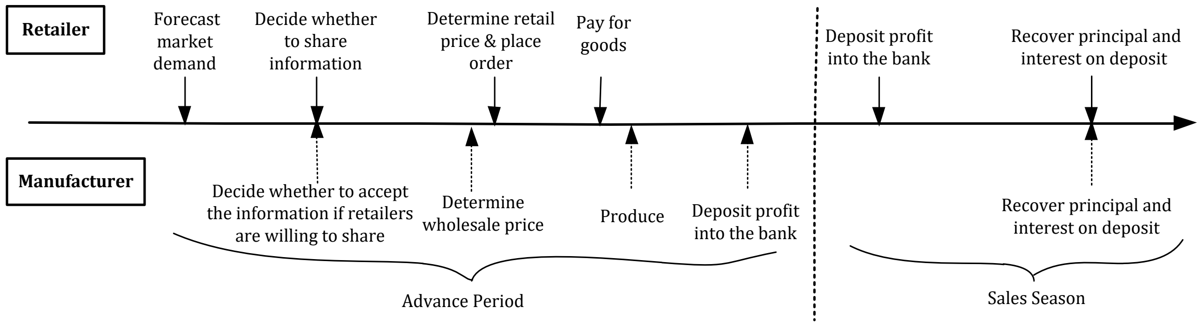


Fig. 1 The sequence of events with manufacturer's choice of TCF

When the retailer decides to share her private demand forecasting information, the manufacturer determines the wholesale price depending on the information shared by the retailer. The expected profit functions of the manufacturer and the retailer are written as:

$$E[\pi_{M1}^{MI}] = (1 + I_M)(w_1^{MI} - c)(a - bp_1^{MI} + E[\varepsilon|\gamma]) \tag{3}$$

$$E[\pi_{R1}^{MI}] = [(1 + I_R)p_1^{MI} - w_1^{MI}](a - bp_1^{MI} + E[\varepsilon|\gamma]). \tag{4}$$

By solving with back induction, we can get the equilibriums of the game with retailer's sharing or not sharing demand information as shown in Table 1.

Table 1 The game equilibriums with manufacturer's choice of TCF

	No information sharing	Information sharing
p_1^*	$p_1^{MN*} = \frac{(3a + 2H)(1 + I_R) + bc}{4b(1 + I_R)}$	$p_1^{MI*} = \frac{3(a + H)(1 + I_R) + bc}{4b(1 + I_R)}$
w_1^*	$w_1^{MN*} = \frac{a(1 + I_R) + bc}{2b}$	$w_1^{MI*} = \frac{(a + H)(1 + I_R) + bc}{2b}$
π_{R1}^*	$\pi_{R1}^{MN*} = A_1$	$\pi_{R1}^{MI*} = B_1$
π_{M1}^*	$\pi_{M1}^{MN*} = (1 + I_M)C_1 - \frac{H^2(1 + I_R)(1 + I_M)}{8b}$	$\pi_{M1}^{MI*} = 2(1 + I_M)B_1$
π_{SC1}^*	$\pi_{SC1}^{MN*} = A_1 + (1 + I_M)C_1 - \frac{H^2(1 + I_R)(1 + I_M)}{8b}$	$\pi_{SC1}^{MI*} = (3 + 2I_M)B_1$

Note: $A_1 = \frac{[(a+2H)(1+I_R)-bc]^2}{16b(1+I_R)}$, $B_1 = \frac{[(a+H)(1+I_R)-bc]^2}{16b(1+I_R)}$, $C_1 = \frac{[(a-H)(1+I_R)-bc]^2}{16b(1+I_R)}$. The deposit rate of the respective manufacturer and retailer and the bank loan rate is denoted as $I_M = (t_{pre} + t_{se})i_M, I_R = t_{se}i_R$ where t_{pre}, t_{se}, i_M, and i_R represent the length of lead time, the length of sales period, the bank deposit rate and the deposit rate for zero deposit and withdrawal respectively.

According to the game equilibriums, when the manufacturer faces capital constraints and adopts TCF, the optimal wholesale price is positively related to the retailer's deposit rate and deposit time regardless of whether she shares demand information. Inversely, the optimal retail price is negatively related to the retailer's deposit rate and deposit time. Both the optimal wholesale price and retail price are independent of the manufacturer's deposit rate and deposit time.

The retailers' profits are only positively related to the retailer's time deposit rate of small savings for lump-sum withdrawal over time, which is independent of the manufacturers' deposit rate and time. In contrast, the manufacturers' profits are positively correlated not only with both members' deposit rates and time but also with the retailer's time deposit rate of small savings for lump-sum withdrawal over time.

4.2 Analysis of bank credit financing

BCF refers to the financing channel where the manufacturer raises seed money from bank loans. The sequence of events when a capital-constrained manufacturer adopts BCF is shown in Fig. 2.

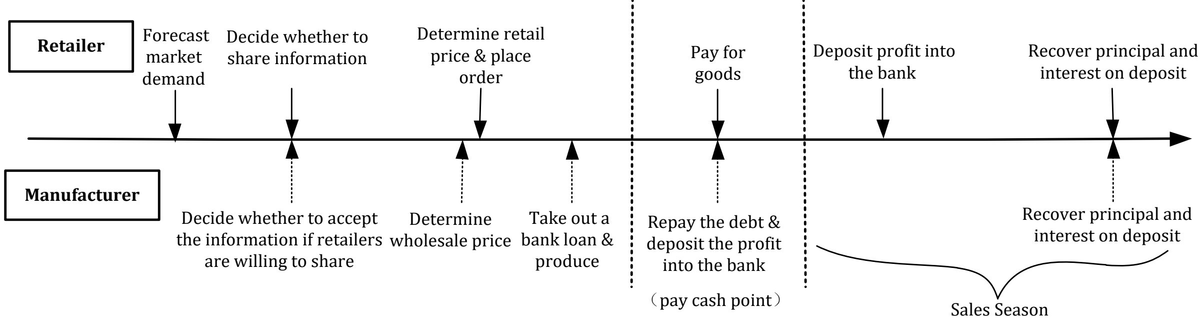


Fig. 2 The sequence of events with manufacturer's choice of BCF

When the retailer does not share demand information, the manufacturer can only determine the wholesale price based on his private information. The expected profit functions of the manufacturer and the retailer are as follows:

$$E[\pi_{M2}^{MN}] = [(1+I_M)w_2^{MN} - (1+I_M+J_M)c](a - bp_2^{MN} + E[\varepsilon]) \tag{5}$$

$$E[\pi_{R2}^{MN}] = [(1+I_R)p_2^{MN} - w_2^{MN}](a - bp_2^{MN} + E[\varepsilon|\gamma]) \tag{6}$$

On the other hand, if the retailer shares her private demand forecasting information with the manufacturer, the wholesale price is chosen according to the information that is shared by retailer. The expected profit functions of the manufacturer and the retailer can be described as follows:

$$E[\pi_{M2}^{MI}] = [(1+I_M)w_2^{MI} - (1+I_M+J_M)c](a - bp_2^{MI} + E[\varepsilon|\gamma]) \tag{7}$$

$$E[\pi_{R2}^{MI}] = [(1+I_R)p_2^{MI} - w_2^{MN}](a - bp_2^{MI} + E[\varepsilon|\gamma]) \tag{8}$$

By solving the above formulas, we derive the game equilibriums with alternative information-sharing decisions of the retailer, which is shown in Table 2.

Table 2 The game equilibriums with manufacturer's choice of BCF

	No information sharing	Information sharing
p_2^*	$p_2^{MN*} = \frac{(3a+2H)(1+I_M)(1+I_R) + bc(1+I_M+J_M)}{4b(1+I_M)(1+I_R)}$	$p_2^{MI*} = \frac{3(a+H)(1+I_M)(1+I_R) + bc(1+I_M+J_M)}{4b(1+I_M)(1+I_R)}$
w_2^*	$w_2^{MN*} = \frac{a(1+I_M)(1+I_R) + bc(1+I_M+J_M)}{2b(1+I_M)}$	$w_2^{MI*} = \frac{(a+H)(1+I_M)(1+I_R) + bc(1+I_M+J_M)}{2b(1+I_M)}$
π_{R2}^*	$\pi_{R2}^{MN*} = A_2$	$\pi_{R2}^{MI*} = B_2$
π_{M2}^*	$\pi_{M2}^{MN*} = C_2 - \frac{H^2(1+I_M)(1+I_R)}{8b}$	$\pi_{M2}^{MI*} = 2(1+I_M)B_2$
π_{SC2}^*	$\pi_{SC2}^{MN*} = A_2 + C_2 - \frac{H^2(1+I_M)(1+I_R)}{8b}$	$\pi_{SC2}^{MI*} = (3+2I_M)B_2$

Note: $A_2 = \frac{[(a+2H)(1+I_R)(1+I_M) - bc(1+I_M+J_M)]^2}{16b(1+I_R)(1+I_M)^2}$, $B_2 = \frac{[(a+H)(1+I_R)(1+I_M) - bc(1+I_M+J_M)]^2}{16b(1+I_R)(1+I_M)^2}$, $C_2 = \frac{[(a-H)(1+I_R)(1+I_M) - bc(1+I_M+J_M)]^2}{16b(1+I_R)(1+I_M)^2}$.
The deposit rate of the respective manufacturer and retailer and the bank loan rate is denoted as $I_M = t_{se} i_M$, $I_R = t_{se} i_R$ and $J_M = t_{pre} j_M$, where t_{pre}, t_{se}, i_M, i_R and j_M represent the length of lead time, the length of sales period, the bank deposit rate, the deposit rate for zero deposit and withdrawal and the bank loan rate respectively.

A comparison with the previous conclusions in Section 4.1 shows that when the manufacturer faces capital constraints and adopts BCF, both the optimal wholesale price and the optimal retail price are related to the manufacturer's bank deposit and loan interest rate, as well as the length of lead time and sales period. Meanwhile, the profits of both the retailer and manufacturer depend on the manufacturer's loan rate and the length of lead time. The rest of the conclusions are similar to those in the previous section.

4.3 Information sharing strategy with manufacturer's capital constraints

By comparing the game equilibriums in the scenarios with retailer's sharing or not sharing demand information, we have the following analytical results for the information-sharing strategy when the manufacturer is capital-constrained.

Proposition 1: The retailer's equilibrium information sharing strategy with the manufacturer's capital constraints is given as:

(1) When the actual market demand fluctuates positively (i.e., $H > 0$), regardless of the capital-constrained manufacturer's choice of TCF or BCF, the wholesale price and the retail price will both increase if the retailer shares demand information, i.e., $w_1^{MI*} > w_1^{MN*}$, $w_2^{MI*} > w_2^{MN*}$, $p_1^{MI*} > p_1^{MN*}$ and $p_2^{MI*} > p_2^{MN*}$. Meanwhile, the retailer's profit will decrease while the manufacturer's profit grows, i.e., $\pi_{R1}^{MN*} > \pi_{R1}^{MI*}$, $\pi_{R2}^{MN*} > \pi_{R2}^{MI*}$, $\pi_{M1}^{MN*} < \pi_{M1}^{MI*}$ and $\pi_{M2}^{MN*} < \pi_{M2}^{MI*}$. Thus, it is not wise for the retailer to share demand information.

(2) When the actual market demand fluctuates negatively (i.e., $H < 0$), regardless of the capital-constrained manufacturer's choice of TCF or BCF, the wholesale price and the retail price will go down with the retailer's information sharing decision, i.e., $w_1^{MI*} < w_1^{MN*}$, $w_2^{MI*} < w_2^{MN*}$, $p_1^{MI*} < p_1^{MN*}$ and $p_2^{MI*} < p_2^{MN*}$. Meanwhile, the retailer's profit will be improved and the manufacturer's profit will decrease, i.e., $\pi_{R1}^{MN*} < \pi_{R1}^{MI*}$,$\pi_{R2}^{MN*} < \pi_{R2}^{MI*}$, $\pi_{M1}^{MN*} > \pi_{M1}^{MI*}$and $\pi_{M2}^{MN*} > \pi_{M2}^{MI*}$. As a result, the manufacturer will not accept the offer of information sharing even if the retailer is willing to.

In conclusion, with positively fluctuating demand, the manufacturer may raise the wholesale price given the demand information shared by the retailer, which will exacerbate the double marginalization effect. It results in the retailer's no willingness of sharing demand information. In contrast, with negatively fluctuating demand, the demand information shared by the retailer may force the manufacturer to reduce the wholesale price. Even if it encourages the retailer to share demand information, the manufacturer will not accept it because his profit will be reduced. In summary, information sharing can't be realized in a supply chain with a capital-constrained manufacturer.

4.4 Manufacturer's financing choice with capital constraints

Given the game equilibriums of the capital-constrained manufacturer adopting TCF and BCF, we have the following analytical results for the equilibrium financing approach for the manufacturer.

Proposition 2: The profits of both the retailer and the manufacturer will be improved if the capital-constrained manufacturer chooses TCF, regardless of whether the retailer shares demand information or not, i.e., $\pi_{M1}^{MI*} > \pi_{M2}^{MI*}$, $\pi_{R1}^{MI*} > \pi_{R2}^{MI*}$, $\pi_{M1}^{MN*} > \pi_{M2}^{MN*}$ and $\pi_{R1}^{MN*} > \pi_{R2}^{MN*}$. Therefore, TCF is the equilibrium financing choice for the capital-constrained manufacturer.

5. Retailer's choice with capital constraints

5.1 Analysis of trade credit financing

The retailer's financing problem is possibly solved by deferred payment, which is a typical type of TCF provided by the manufacturer. The sequence of decisions when the capital-constrained retailer adopts TCF is shown in Fig. 3.

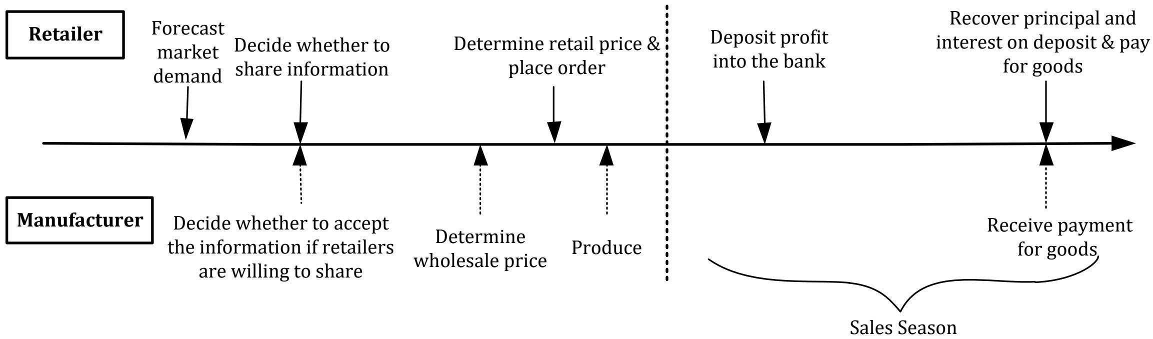


Fig. 3 The sequence of events with capital-constrained retailer's choice of TCF

For the retailer's decision not to share demand information, the manufacturer can only determine the wholesale price based on private information. The expected profit functions of the manufacturer and the retailer can be described as follows:

$$E[\pi_{M3}^{RN}] = (w_3^{RN} - c)(a - bp_3^{RN} + E[\varepsilon]) \tag{9}$$

$$E[\pi_{R3}^{RN}] = [(1 + I_R)p_3^{RN} - w_3^{RN}](a - bp_3^{RN} + E[\varepsilon|\gamma]) \tag{10}$$

When the retailer shares her private demand forecasting information, the manufacturer determines the wholesale price depending on the information shared by the retailer. The expected profit function of the manufacturer and the retailer are given as:

$$E[\pi_{M3}^{RI}] = (w_3^{RI} - c)(a - bp_3^{RI} + E[\varepsilon|\gamma]) \tag{11}$$

$$E[\pi_{R3}^{RI}] = [(1 + I_R)p_3^{RI} - w_3^{RI}](a - bp_3^{RI} + E[\varepsilon|\gamma]) \tag{12}$$

Solving with the back induction method, we show the game equilibriums when the retailer shares demand information or not in Table 3.

Table 3 The game equilibriums with capital-constrained retailer's choice of TCF

	No information sharing	Information sharing
p_3^*	$p_3^{RN*} = \frac{(3a + 2H)(1 + I_R) + bc}{4b(1 + I_R)}$	$p_3^{RI*} = \frac{3(a + H)(1 + I_R) + bc}{4b(1 + I_R)}$
w_3^*	$w_3^{RN*} = \frac{a(1 + I_R) + bc}{2b}$	$w_3^{RI*} = \frac{(a + H)(1 + I_R) + bc}{2b}$
π_{R3}^*	$\pi_{R3}^{RN*} = A_3$	$\pi_{R3}^{RI*} = B_3$
π_{M3}^*	$\pi_{M3}^{RN*} = C_3 - \frac{H^2(1 + I_R)}{8b}$	$\pi_{M3}^{RI*} = 2B_3$
π_{SC3}^*	$\pi_{SC3}^{RN*} = A_3 + C_3 - \frac{H^2(1 + I_R)}{8b}$	$\pi_{SC3}^{RI*} = 3B_3$

Note: $A_3 = \frac{[(a+2H)(1+I_R)-bc]^2}{16b(1+I_R)}$, $B_3 = \frac{[(a+H)(1+I_R)-bc]^2}{16b(1+I_R)}$, $C_3 = \frac{[(a-H)(1+I_R)-bc]^2}{8b(1+I_R)}$. Denote $I_R = t_{se}i_R$ as the retailer's deposits, where t_{se} refers to the length of sales period, i_R the deposit rate for zero deposit and withdrawal.

5.2 Analysis of bank credit financing

The retailer may also go for bank loans to deal with the financing problem. The sequence of decisions when the capital-constrained retailer adopts BCF is shown in Fig. 4.

Without information sharing from the retailer, the manufacturer chooses the wholesale price solely dependent on his private information. The expected profit functions of the manufacturer and the retailer are as follows:

$$E[\pi_{M4}^{RN}] = (1 + I_M)(w_4^{RN} - c)(a - bp_4^{RN} + E[\varepsilon]) \tag{13}$$

$$E[\pi_{R4}^{RN}] = [(1 + I_R)p_4^{RN} - (1 + J_R)w_4^{RN}](a - bp_4^{RN} + E[\varepsilon|\gamma]) \tag{14}$$

While the retailer decides to share, the manufacturer determines the wholesale price according to the information shared by the retailer. The expected profit functions of the manufacturer and the retailer are described as:

$$E[\pi_{M4}^{RI}] = (1 + I_M)(w_4^{RI} - c)(a - bp_4^{RI} + E[\varepsilon|\gamma]) \tag{15}$$

$$E[\pi_{R4}^{RI}] = [(1 + I_R)p_4^{RI} - (1 + J_R)w_4^{RI}](a - bp_4^{RI} + E[\varepsilon|\gamma]) \tag{16}$$

Thus, we have the game equilibriums when the retailer shares or does not share demand information, as summarized in Table 4.

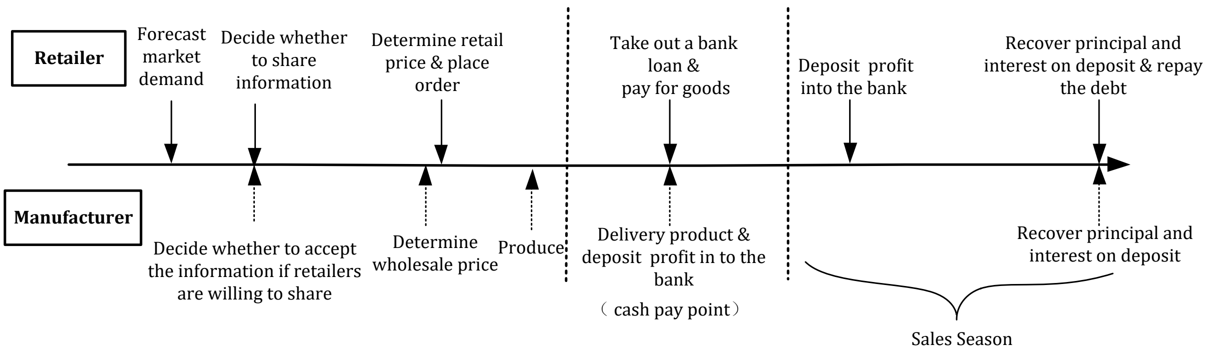


Fig. 4 The sequence of events with capital-constrained retailer's choice of BCF

Table 4 The game equilibriums with capital-constrained retailer's choice of BCF

	No information sharing	Information sharing
p_4^*	$p_4^{RN*}=\frac{(3a+2H)(1+I_R)+bc(1+J_R)}{4b(1+I_R)}$	$p_4^{RI*}=\frac{3(a+H)(1+I_R)+bc(1+J_R)}{4b(1+I_R)}$
w_4^*	$w_4^{RN*}=\frac{a(1+I_R)+bc(1+J_R)}{2b(1+J_R)}$	$w_4^{RI*}=\frac{(a+H)(1+I_R)+bc(1+J_R)}{2b(1+J_R)}$
π_{R4}^*	$\pi_{R4}^{RN*}=A_4$	$\pi_{R4}^{RI*}=B_4$
π_{M4}^*	$\pi_{M4}^{RN*}=(1+I_M)C_4$	$\pi_{M4}^{RI*}=\frac{2(1+I_M)}{(1+J_R)}B_4$
π_{SC4}^*	$\pi_{SC4}^{RN*}=A_4+(1+I_M)C_4$	$\pi_{SC4}^{RI*}=\frac{(3+2I_M+J_R)}{(1+J_R)}B_4$

Note: $A_4=\frac{[(a+2H)(1+I_R)-bc(1+J_R)]^2}{16b(1+I_R)}$, $B_4=\frac{[(a+H)(1+I_R)-bc(1+J_R)]^2}{16b(1+I_R)}$, $C_4=\frac{[(a-H)(1+I_R)-bc(1+J_R)]^2-H^2(1+I_R)^2}{8b(1+I_R)(1+J_R)}$. The deposit rate of the respective manufacturer and retailer and the bank loan rate is denoted as $I_M=t_{se}i_M, I_R=t_{se}i_R$ and $J_M=t_{pre}j_M$, where t_{pre}, t_{se}, i_M, i_R and j_M represent the length of lead time, the length of sales period, the bank deposit rate, the deposit rate for zero deposit and withdrawal and the bank loan rate respectively.

5.3 Information sharing strategy with retailer's capital constraints

Comparing the game equilibriums obtained from Table 5 (i.e., information sharing vs. no information sharing), we have the following propositions with regard to the information-sharing strategy when the retailer faces capital constraints.

Proposition 3: The equilibrium information-sharing strategy in a supply chain with retailer's capital constraints is provided as follows:

(1) When the actual market demand fluctuates positively (i.e., $H>0$), regardless of whether the financially constrained retailer takes TCF or BCF, the wholesale price and the retail price will be improved if the retailer shares demand information, i.e., $w_3^{RI*}>w_3^{RN*}$, $w_4^{RI*}>w_4^{RN*}$, $p_3^{RI*}>p_3^{RN*}$ and $p_4^{RI*}>p_4^{RN*}$. Meanwhile, the retailer's profit will decrease while the manufacturer's profit grows, i.e., $\pi_{R3}^{RN*}>\pi_{R3}^{RI*}$, $\pi_{R4}^{RN*}>\pi_{R4}^{RI*}$, $\pi_{M3}^{RN*}<\pi_{M3}^{RI*}$ and $\pi_{M4}^{RN*}<\pi_{M4}^{RI*}$. As a consequence, the retailer has no motives to share demand information.

(2) When the actual market demand fluctuates negatively (i.e., $H<0$), regardless of whether the financially constrained retailer takes TCF or BCF, the wholesale price and the retail price will be reduced if the retailer shares demand information, i.e., $w_3^{RI*}<w_3^{RN*}$, $w_4^{RI*}<w_4^{RN*}$, $p_3^{RI*}<p_3^{RN*}$ and $p_4^{RI*}<p_4^{RN*}$. Meanwhile, the retailer's profit will increase while that of the manufacturer decreases, i.e., $\pi_{R3}^{RN*}<\pi_{R3}^{RI*}$, $\pi_{R4}^{RN*}<\pi_{R4}^{RI*}$, $\pi_{M3}^{RN*}>\pi_{M3}^{RI*}$and $\pi_{M4}^{RN*}>\pi_{M4}^{RI*}$. Therefore, the manufacturer will choose not to accept the information-sharing offer even if the retailer has a willingness to share.

In conclusion, with positively fluctuating demand, the manufacturer may raise the wholesale price given the demand information shared by the retailer, which will exacerbate the double marginalization effect. It results in the retailer's no willingness of sharing demand information. In contrast, with negatively fluctuating demand, the demand information shared by the retailer may force the manufacturer to reduce the wholesale price. Even if it encourages the retailer to share demand information, the manufacturer will not accept it because his profit will be reduced.

In summary, information sharing can't be realized in a supply chain with a capital-constrained retailer.

5.4 Retailer's financing choice with capital constraints

Given the game equilibriums of the capital-constrained manufacturer's choice between TCF and BCF, we have the following analytical results for the equilibrium financing strategy when the retailer is capital-constrained.

Proposition 4: The profits of both the retailer and the manufacturer will be improved if the capital-constrained retailer chooses TCF, regardless of whether the retailer shares demand information or not, i.e., $\pi_{M3}^{RI*} > \pi_{M4}^{RI*}, \pi_{R3}^{RI*} > \pi_{R4}^{RI*}, \pi_{M3}^{RN*} > \pi_{M4}^{RN*}$ and $\pi_{R3}^{RN*} > \pi_{R4}^{RN*}$. Therefore, TCF is the equilibrium financing choice for the capital-constrained retailer. Because BCT increases the cost of retailer.

6. Impact of financing choice on the value of information sharing

According to Proposition 1 and Proposition 3, we conclude that it is not wise for the retailer to share demand forecasting information regardless of the capital-constrained member's financing choice (i.e., TCF vs. BCF). However, will the financing choice have an impact on the value of information sharing? Is information sharing beneficial to the whole supply chain? Can manufacturer incentivize the retailer to share demand forecasting information through unilateral payment? To answer the above questions, we conduct the value analysis of information sharing based on the game equilibriums for the capital-constrained member adopting TCF and BCF respectively to look at the impact of capital constraints and financing choices on the value of information sharing.

The value of information sharing to the manufacturer and retailer is denoted as v_{Mj}^{i}, v_{Rj}^{i}, and the value of information sharing to the supply chain as v_j. Then we have:

$$v_{Mj}^{i} = \pi_{Mj}^{iI*} - \pi_{Mj}^{iN*} \tag{17}$$

$$v_{Rj}^{i} = \pi_{Rj}^{iI*} - \pi_{Rj}^{iN*} \tag{18}$$

$$v_j = v_{Mj}^{i} + v_{Rj}^{i} \tag{19}$$

where $i = M, R, j = 1, 2, 3, 4$, M means the manufacturer faces capital constraints, R means the retailer faces capital constraints, 1 means the capital-constrained manufacturer adopts TCF, 2 means the capital-constrained manufacturer adopts BCF, 3 means the capital-constrained retailer adopts TCF, 4 means the capital-constrained retailer adopts BCF.

The value of information sharing calculated based on Eqs. 17 to 19, and the following results can be derived.

Result 1: When $H > 0$, the value of information sharing to the retailer is negative with $|v_{R1}^{M}| > |v_{R2}^{M}|$ and $|v_{R3}^{R}| > |v_{R4}^{R}|$, which suggests that the retailer loses more profit from sharing demand information so that she is less willing to share while TCF is used. When $H < 0$, the value of information sharing to the manufacturer is negative with $|v_{M1}^{M}| > |v_{M2}^{M}|$ and $|v_{M3}^{R}| > |v_{M4}^{R}|$, whereby the manufacturer suffers greater profit loss if he accepts the demand information shared by the retailer. Thus, the manufacturer becomes passive toward retailer's information sharing under TCF.

From Result 1, it is clear that information sharing is more difficult to achieve when the capital-constrained member adopts TCF, notwithstanding cost savings and efficiency improvements in financing.

Result 2: When TCF is adopted, the retailer's profit loss from sharing information is equal under capital constraints of alternative supply chain members, i.e., $v_{R1}^{M} = v_{R3}^{R}$. On the other hand, with BCF on condition that $1 + t_{se}i_M - \frac{t_{pre}j_R}{t_{se}j_R} > 0$, the retailer's profit loss from sharing information is higher under the manufacturer's capital constraints, whereas it would remain higher under the retailer's capital constraints if $1 + t_{se}i_M - \frac{t_{pre}j_R}{t_{se}j_R} < 0$.

From Result 2, what is interesting is that the capital constraint concern has zero effect on the value of information sharing to the retailer once TCF is used. However, this conclusion does not hold when the capital-constrained member prefers BCF.

Result 3: In a capital-constrained supply chain with either TCF or BCF being chosen, when the actual market demand fluctuates positively (i.e., $H > 0$), the value of information sharing to the supply chain remains positive, i.e., $v_1 > 0$, $v_2 > 0$, $v_3 > 0$, and $v_4 > 0$. At this point, information sharing can increase the overall profits of the supply chain. When the actual market demand fluctuates negatively (i.e., $H < 0$), the value of information sharing to the supply chain remains negative, i.e., $v_1 < 0$, $v_2 < 0$, $v_3 < 0$, and $v_4 < 0$. At this point, information sharing can't increase the overall profits of the supply chain.

When the actual market demand fluctuates positively, result 3 further verifies that information sharing brings benefits to the whole supply chain, which is expected to achieve through contract design such as a single-sided payment contract.

7. Well-funded member's willingness to offer trade credit financing

The above analysis concludes that TCF is an equilibrium financing choice for capital-constrained supply chains. However, the well-funded member's offering of TCF leads to his/her loss of the interest earned from depositing the fund in the bank. Thus, the well-funded member needs to trade off the gains and losses of providing TCF. In the following, we derive the conditions on which the well-funded member is willing to offer TCF with the respective capital-constrained manufacturer and retailer.

Result 4: Given the capital constraints for the manufacturer, if the retailer shares demand information, the condition that the retailer is willing to provide TCF is

$$\frac{bcj_M\left[2(a+H)W - bc\left(2 + 2t_{se}i_M + t_{pre}j_M\right)\right]}{2i_R[(a+H)^2W^2 - b^2c^2(1+t_{se}i_M)^2]} > 1, \tag{20}$$

whereas if the retailer does not share demand information, the condition that the retailer is willing to provide TCF is

$$\frac{bcj_M\left[2(a+2H)W - bc\left(2 + 2t_{se}i_M + t_{pre}j_M\right)\right]}{2i_R[a(a+2H)W^2 - b^2c^2(1+t_{se}i_M)^2 + 2HWbc(1+t_{se}i_M)]} > 1, \tag{21}$$

where $W = (1 + t_{se}i_R)(1 + t_{se}i_M)$.

Result 5: Given the capital constraints for the retailer, if the retailer shares information, the conditions that the manufacturer is willing to provide TCF is

$$\frac{(1+t_{se}j_R)(1-t_{se}i_M)[N + Ht_{se}i_R]^2}{(1+t_{se}i_M)[N + Ht_{se}i_R - bct_{se}j_R]^2} > 1, \tag{22}$$

whereas if the retailer does not share information, the conditions that the manufacturer is willing to provide TCF is,

$$\frac{(1+t_{se}j_R)(1-t_{se}i_M)\{N^2 - 2HN\}}{(1+t_{se}i_M)\{[N - bct_{se}j_R]^2 - 2H(1+t_{se}i_R)[N - bct_{se}j_R]\}} > 1, \tag{23}$$

where $N = a(1 + t_{se}i_R) - bc$.

We observe that the willingness of the well-funded member to provide internal financing to the capital-constrained member is related to the demand fluctuation type and the deposit and loan rates for the respective manufacturer and retailer. In the following section, we will derive the varying ranges of j_M, i_R, and H for retailer's willingness to offer TCF, and the ranges of j_R, i_M and H for manufacturer's willingness to offer TCF using numerical analysis.

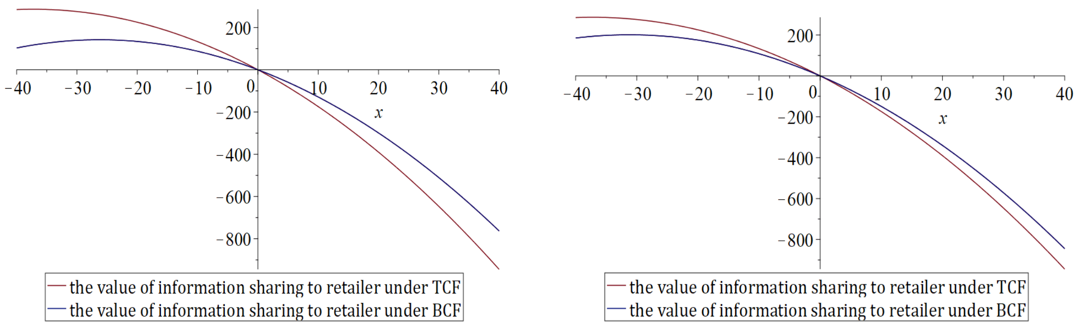
8. Numerical analysis

In this section, we first numerically verify the relevant conclusions, and then we analyse the willingness of the well-funded member to provide TCF. Parameters are set as follows: $a = 130, b = 1, c = 10, H\epsilon(-40{,}40), i_R = 0.1, i_M = 0.1, j_M = 0.15, j_R = 0.15,$ and $t_{se} = t_{pre} = 1$.

8.1 Impact of financing choices on the value of information sharing

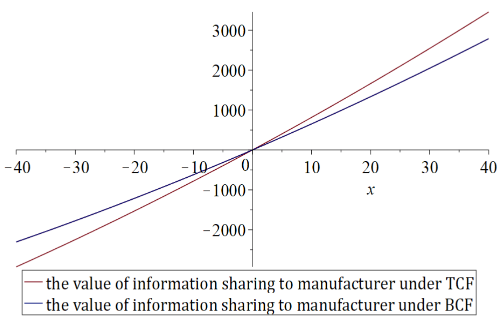
The impacts of the financing choices on the value of information to the manufacturer and the retailer are depicted in Fig. 5 and Fig. 6. The x-axis represents market demand fluctuation in Fig. 5 and Fig. 6. The y-axis represents the profit of retailer in Fig. 5, and y-axis represents the profit of manufacturer in Fig. 6. From Fig. 5, the absolute value of information sharing to the retailer adopting TCF is greater than that adopting TCF. When $H > 0$, the value of information sharing to the retailer is negative, where the retailer suffers greater profit loss adopting TCF and becomes more reluctant to share demand information. When $H < 0$, the value of information sharing to the retailer is positive, which suggests that the retailer enjoys improved profits adopting TCF and is more willing to share demand information. The conclusions are independent of the takers of capital constraints in the supply chain. As shown in Fig. 6, the value of information sharing to the manufacturer is positive when $H > 0$, which indicates that the manufacturer gains more from information sharing while adopting TCF. When $H < 0$, the conclusion is the opposite. The arithmetic analysis is consistent with the conclusions from Result 1.

In summary, we numerically verify that sharing information benefits the manufacturer rather than the retailer when the actual market demand fluctuates positively, and vice versa if the actual market demand fluctuates negatively, which is irrelevant with the takers of capital constraints in the supply chain. In particular, when TCF is adopted, it should be also noted that the capital-constrained member's financing choice may exert a more numerically significant effect on the value of information.



(a) Manufacturer's capital constraints (b) Retailer's capital constraints

Fig. 5 Impact of financing choices on the value of information sharing to retailer



(a) Manufacturer's Capital constraints (b) Retailer's Capital constraints

Fig. 6 Impact of financing choices on the value of information sharing to manufacturer

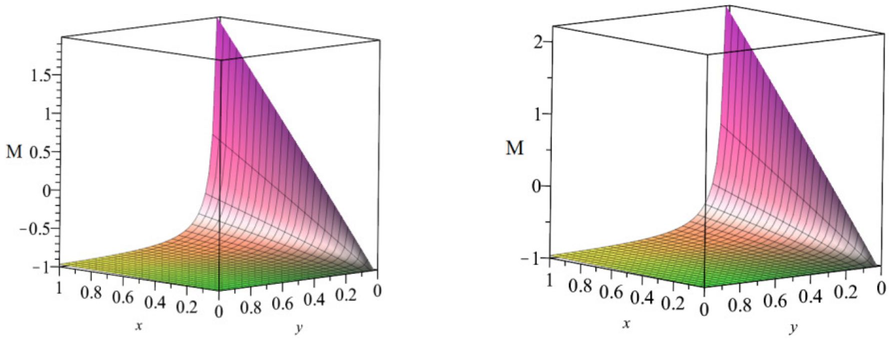
8.2 Willingness analysis of well-funded member to provide trade credit financing

Firstly, we capture the conditions for the retailer's willingness to offer TCF to the capital-constrained manufacturer, as shown in Fig. 7. Assume that $H = 10$, the x-axis represents the retailer's deposit rate and the y-axis is the manufacturer's loan rate. The vertical axis gives M $(\text{i. e.}, M = \pi_{R1}^{MI*} - \pi_{R2}^{MI*} - w_1^{MI*}(a - bp_1^{MI*} + H)t_{pre}i_R)$, which indicates the difference between the incremental revenue and reduced interest income when the retailer provides TCF. Specifically, $M > 0$ means that the retailer is willing to offer TCF, while $M < 0$ indicates that the retailer is reluctant to offer TCF.

With information sharing from the retailer, the impact of the loan rate and deposit rate on the retailer's willingness to provide TCF is shown in Fig. 7(a). We observe that the varying range of the rates that encourage the retailer to offer TCF satisfies $x\epsilon[0.16,1], y\epsilon[0.01,0.06]$. When the retailer chooses not to share demand information, the impact of the loan rate and the deposit rate on the retailer's willingness to provide TCF is depicted in Fig. 7(b), wherein the varying range of the rates that encourages the retailer to offer TCF locate within $x\epsilon[0.15,1]$ and $y\epsilon[0.01,0.06]$.

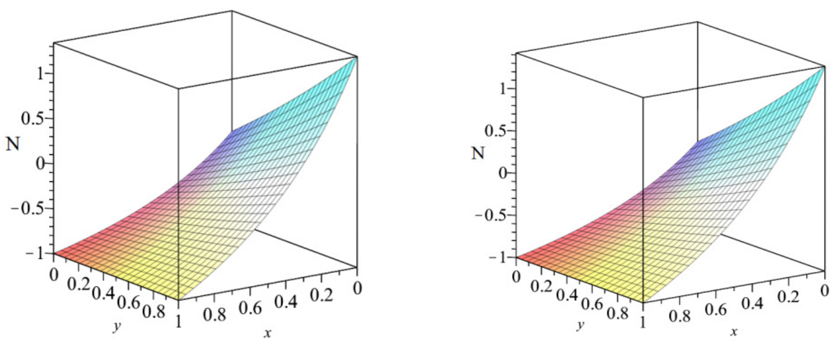
Then, we capture the conditions for the manufacturer's willingness to offer TCF to the capital-constrained retailer in Fig. 8. Likewise, the x-axis denotes the manufacturer's deposit rate and the y-axis the retailer's loan rate. With the retailer's information sharing, the condition that allows the manufacturer to accept delayed payment (i.e., offer TCP) is given as $x\epsilon[0,0.4], y\epsilon[0.01,1]$, whereas the counterpart condition without the retailer's information sharing satisfies $x\ \epsilon[0,0.41], \mathrm{y}\epsilon[0,1]$.

According to our numerical analysis, we show that the deposit rate of the well-funded member that allows for offering TCF varies much lower for the manufacturer than for the retailer, while the varying condition of the bank loan rate that encourages the capital-constrained member to choose TCF is much laxer for the manufacturer than for the retailer. It may suggest that TCF is possible to be a popular financing approach if the manufacturer is capital-constrained. Moreover, the impacts of the retailer's information sharing decisions on the varying ranges of the rates are very slight, regardless of the capital constraint of either the manufacturer or the retailer.



(a) With retailer's information sharing (b) Without retailer's information sharing

Fig. 7 The conditions for the retailer's willingness to offer TCF to the capital-constrained manufacturer



(a) With retailer's information sharing (b) Without retailer's information sharing

Fig. 8 The conditions for the manufacturer's willingness to offer TCF to the capital-constrained retailer

9. Conclusion

We model four scenarios of the capital-constrained supply chain using BCF and TCF to address financing problems, with the consideration of the retailer's decisions on sharing demand information or not. We derive the equilibrium financing and information-sharing strategies with the capital constraints of the manufacturer and the retailer respectively and find that TCF is an equilibrium financing choice for a capital-constrained supply chain. The retailer has no willingness to share demand forecasting information if the actual demand fluctuates positively, whereas she prefers to share when the actual demand fluctuates negatively but the manufacturer is reluctant to accept in case of profit loss.

By comparing the equilibriums of the game, we further analyse the interactions between the financing and information-sharing strategies and provide useful managerial insights. First, when a capital-constrained member chooses TCF, it becomes more difficult to share demand information over the supply chain. Second, when the capital-constrained member, either manufacturer or retailer, adopts TCF, the value of information sharing to the retailer would not change; however, this conclusion does not hold if BCF is used in the capital-constrained supply chain. Third, sharing demand information over the supply chain is always beneficial to the system, whereby the contract design, such as a single-sided payment contract, should be emphasized to facilitate information sharing. Finally, we provide the conditions that encourage the well-funded member to offer TCF in the capital-constrained supply chain. Given the benefits that TCF brings to the reduction of financing costs and the improvement of financing efficiency, we suggest that capital-constrained companies should respond to financial crises through TCF. To improve demand forecasting information sharing over the supply chain, the design of incentive mechanisms in capital-constrained supply chains is necessary and imperative. This will be one of the future directions of our research. In addition, this paper assumes that there is no insolvency risk for capital-constrained firms, which deserves a further understanding in the future research of capital-constrained supply chains. Also, it should be emphasized that the concerns of international crises, such as wars, pandemics and lack of raw materials, become an urgent and imperative topic in today's capital-constrained supply chains, which needs more targeted modelling and discussion in our extension studies.

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