Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 8575338, 15 pages
https://doi.org/10.1155/2022/8575338

Research Article

The Effect of Bank Financing under Supply Chain-to-Chain Competition

Li Gu [1] and Guitian Liang [2]

[1] *School of Innovation Design, Guangzhou Academy of Fine Arts, Guangzhou, China*
[2] *Department of Administrative Management, Jinan University, Guangzhou 510632, China*

Correspondence should be addressed to Guitian Liang; lianggt@hotmail.com

Received 17 May 2022; Revised 6 October 2022; Accepted 31 October 2022; Published 14 November 2022

Academic Editor: Arunava Majumder

We consider two supply chains, each consisting of one supplier and one retailer. The two retailers are involved in Cournot competition and purchase one single product only from the supplier in the same supply chain. The two suppliers are heterogenous in the production cost. In addition, both retailers are in short of capital, hence both of them need to raise bank loans. All players are risk neutral and their objectives are to maximize their own profit. Based on these features, we establish an analytical model and characterize each player's optimal decision. Compared to the benchmark model when both retailers have sufficient capital, we find that, in optimal, each supplier provides a lower wholesale price to its own retailer. Moreover, when one of the supplier's cost is small enough, the corresponding supply chain's competitive advantage is amplified by the financial cost (i.e., loan interest), generating a larger selling quantity to the market. Therefore, the supply chain achieves a higher profit than the benchmark case, while the other supply chain is worse off. However, if the difference of the two suppliers' costs is not that significant, all players in the two supply chains would be worse off. Moreover, the numerical experiment further shows that when each supplier's cost is low enough, both retailers can be better off even if they are capital-constrained. Our results provide useful insights into the supply chain competition when retailers use bank loans to finance their operations.

1. Introduction

1.1. Motivation. Due to serious health consideration, the pandemic of COVID-19 has led to restrictive containment means such as social distancing, remote working and the closure of commercial activities, resulting in huge operational challenges to many firms around the world. According to a survey of 995 firms in China, if the epidemic continues, 85% of the respondents will run out of cash flow to support their businesses in three months [1]. Without sufficient working capital, firm's operational decisions, including procurement, production, wholesaling, and retailing, will be highly confined. Limiting working capital has become a critical issue to many firms, especially small ones. Hence, it is of great importance to consider liquidity constraint in operations management.

The problem of capital constraint of firms not only affects their own development but also adversely affects other members in the supply chain. Supply chain is the integration of internal and interenterprise resources, whereby each member in the supply chain utilizes its own core competitiveness and cooperates to realize the maximum value of the entire supply chain. Apparently, anyone's dilemma in the supply chain will cause a chain effect to other members. If the upstream supplier lacks funds, it will lead to supply interruption or delay in delivery, and the downstream buyer's production plan or sales plan will be affected. On the other hand, if the downstream retailer is short of capital, the entire supply chain will be insufficiently motivated and the scale of trading will be affected. Such restriction or even suspension will eventually influence the demand of end customers to the supply chain. Our paper considers the scenario where the downstream retailer in the supply chain does not have sufficient capital to support the procurement activity. To know how to handle the inefficiency due to capital shortage is vital for the future development of firms as well as the supply chain.

In addition to the negative impact on the short-term sales profits, in the long run, supply shortages in the supply chain due to insufficient capital will also affect the market share of products [2]. Without efficiency in serving the market demand, not only the retailer, but also the whole supply chain will lose the competitiveness especially when facing severe market competition. The current market competition is no longer a desperate struggle between individual firms; the competition between supply chains that coordinated and integrated by independent individual firms is increasingly becoming a concerned topic. If a company wants to gain an advantage in the competition and continue to operate, it depends greatly on the ability of the supply chain to survive. In today's challenging market, only those who can coordinate the upstream and downstream relationships of the supply chain and integrate all resources to better meet the needs of consumers can win the war of competition [3].

To obtain adequate working capital, firms are in need of short-term financing to execute their operational actions. Bank loans are one of the most prevalent sources for short-term financing [4]. From a report of the global lending market, where the major companies in the market are commercial banks, the lending around the world is expected to grow from 6036.37 billion USD in 2020, to 8809.55 billion USD in 2025 at a compound annual growth rate of 6% [5]. The increase of the global lending market is sending a clear message that firms are in lack of cash flow to continue their commercial activities. In addition, taking financial decision into consideration has been a heated topic in academia. For instance, Gong et al. [6] consider a firm with insufficient capital has to issue short-term loan from an outside lender. The firm's objective is to maximize the expected profit during a long-term inventory management. They find that the short-term financing is able to help the firm better control the inventory and improve profit. Iancu et al. [7] indicate bank loans with financial covenants can help the borrowing firm reduce the agency cost, and therefore obtain the full benefits of the operational flexibility. Using a screening model, Alan and Gaur [8] point out that information asymmetry can be mitigated with the usage of inventory-based financing from the bank. All of the earlier works manifest the significance of liquidity constraint and the important role of financing on firm's operations management.

1.2. Research Gap. However, most of the previous works studying bank loans are focusing on the context of a single supply chain. The literature rarely consider the problem of retailers borrowing bank loans in a supply chain-to-chain framework. Hence, the real-world practice and academic research studies are bringing to the forefront several research questions: What are the competing firms' optimal operational decisions when they are lack of capital and have to borrow bank loans? What are their suppliers' behaviors compared to the case of sufficient capital? What's the impact to the supply chain? How is the supply chain competition affected? What are the implications of retailer's capital constraint for supply chain efficiency and the profitability of each party in the chain?

In an attempt to answer these questions, we establish a game-theoretical model that studies the effect of capital-constrained retailers in competing supply chains. Each supply chain sells one identical product and includes a supplier and a retailer, both being neutral in our problem. Each retailer can only purchase the product from the supplier in the same chain; and each supplier can only supply the retailer in the same chain. We consider Cournot competition between the two retailers; i.e., they compete in quantity with each other. The supplier provides a price-only contract to the retailer, whereby the contract contains only the wholesale price. Moreover, both retailers are in short of working capital, which is not able to fulfill their procurement requirements; therefore, external short-term funding is needed. We consider bank loans to be the source of short-term financing, under which the loan contract contains the interest rate and the loan repayment demand. That is, after the revenue is realized, the retailer that raises bank loan needs to pay back the loan principle and the loan interest.

1.3. Solution Methodology. Our model is based on a supply chain management framework which involves multiple players interacting with each other. Therefore, the game theory is a basic method in this paper to formulate the model. To solve each player's model and obtain their optimal solution, the game theory and convex analysis are utilized to derive the profit function and therefore the corresponding solution. We also apply constrained optimization to solve the global solution for the whole supply chain. The abovementioned methods are widely used in the supply chain management literature [9–11]. In addition, we use numerical examples to further examine our main results and find that all of them hold true in the numerical study.

1.4. Main Results and Contributions. Based on the abovementioned model, we solve the problem and characterize each member's optimal decision. Specifically, in the baseline model that considers retailers need to borrow bank loans, we find that in optimality, the marginal value of the initial capital level to each retailer is exactly equal to the interest rate, while the supplier's profit is not affected by the retailer's initial capital level. However, we find that supplier's optimal wholesale price is decreasing in the interest rate, which is because the supplier is eager to encourage the retailer to purchase more products, since the order quantity is already weakened due to the existence of financial cost (i.e., the interest rate). The supplier can obtain more profit only when the retailer has a higher market share compared to the other one. Furthermore, we find that whether each retailer's optimal order quantity increases in the interest rate depends on the cost difference of the two suppliers. In particular, when one supplier's cost is small enough compared to the other one, the corresponding retailer's optimal order quantity is increasing in the interest rate, while the other retailer's order quantity is decreasing. This result is due to the fact that in the presence of a significant cost gap between the suppliers, the financial cost of the bank loan further exacerbates this gap and therefore enhances the cost advantage in the competition. That is, the supplier with a lower cost can offer a much lower wholesale price to the retailer, inducing a higher order quantity and therefore grasping a larger market share to the supply chain.

To understand the impact of capital-constrained retailers in supply chain competition, we also conduct a benchmark model whereby both retailers have sufficient capital. From the result of the baseline model, we already know that the supplier offers a lower wholesale price. The comparison between the benchmark and baseline models further indicates that the wholesale price difference is increasing in the market size; i.e., if the market size is bigger, each supplier will offer a lower wholesale price when retailers are capital-constrained. This result indicates that a larger market size indeed intensifies the competition between the two supply chains. In addition, we find that when there is a sufficient cost difference between the two suppliers, one retailer will have a higher order quantity in the baseline model than in the benchmark model, while the other retailer's order quantity is lower on the contrary. We also compare each member's, as well as the supply chain's profit under the two models. Similar to the quantity comparison result, when the suppliers' costs are greatly different, the supply chain with a lower cost can have a better profit that in the benchmark, and so does each member in the same supply chain. Moreover, we have different findings for the retailer's profit comparison. Specifically, when both suppliers' costs are small enough, we find that each retailer can have a better profit than that in the benchmark. In this case, the suppliers are suffering loss from the financial cost.

Following are our contributions:

(1) To the best of our knowledge, we are the first to consider a model that incorporates chain-to-chain competition and capital-constrained retailers which require bank loans to conduct their procurements. More specifically, We consider two supply chains, each consisting of one supplier and one retailer. Each retailer purchases one single product only from the supplier in the same supply chain; the two retailers are competing with each other in the quantity. In addition, the two suppliers are heterogenous in the production cost. Our model and the theoretical results may inspire further studies along this direction.

(2) We fully derive and solve each player's optimal decision, and we also characterize the impact of bank financing to the supply chain competition in comparison with the benchmark model when both retailers have sufficient capital.

(3) Our results demonstrate that under supply chain competition, the financial cost from bank loans could enhance the competitive advantage for the supply chain when the corresponding supplier's production cost is lower, which will achieve a higher profit for each player in the supply chain.

(4) We conduct several numerical studies to examine and confirm our theoretical results. Moreover, we also identify that if both suppliers' production costs are small enough, then both retailers can be better off than the benchmark case even if they are capital-constrained.

The reminder of the paper is organized as follows. We review the related literature in Section 2. In Section 3, we introduce the problem and establish the baseline model. We also formulate a benchmark model where both retailers have adequate capital. In Section 4, we compare the results of the benchmark model and the baseline model and then explain the managerial insights. Section 5 offers the concluding remarks. Unless otherwise indicated, all the proofs are provided in the Appendix. Throughout the paper, we use "increasing" and "decreasing" in a nonstrict sense, that is, they represent "nondecreasing" and "nonincreasing," respectively.

2. Literature Review

This paper considers competing supply chains when retailers are capital-constrained. Therefore, we will conduct the literature review into two parts: in the first part, we will review the research that studies the chain-to-chain competition in various scenarios; in the second part, we will review the research that investigates the interaction of operations management and finance.

2.1. Supply Chain Competition. Our paper is closely related to the literature on chain-to-chain competition, which can be divided into the following two categories: (1) how chain-to-chain competition influences the operational and marketing decision with various environments and (2) equilibrium supply chain structure.

2.1.1. Operational and Marketing Decisions under Chain-to-Chain Competition. Most of the previous works fall into the first category, which considers how chain-to-chain competition influences the operational and marketing decision with various environments. Ha and Tong [12] study an information sharing problem between the manufacturer and a retailer in two competing supply chains. They show that the contract type and the investment cost of information sharing play a vital role in conducting information sharing. Ha et al. [9] extend the above work to consider Cournot and Bertrand competition in the presence of production diseconomies of scale. They demonstrate that information sharing benefits a supply chain when the production diseconomy is large and either competition is less intense or at least one retailer's information is less accurate (information is more accurate) for Cournot (Bertand) competition. Liu et al. [13] consider two supply chains that sell substitutable products with different market sizes. They derive the optimal advertising strategy and also discuss how the advertising strategy would affect the supply chain efficiency and the social welfare. Bian et al. [14] study the two-way information problem in supply chains when both the manufacturer and the retailer have partial information on demand. In the presence of remanufacturing, Wu and Zhou [15] examine the impact of supply chain competition on the optimal reverse channel choice of manufacturers.

Besides the abovementioned papers, many other works investigate this area to allow more features such as customer rebate and retailer incentive promotions [16], contract choice game [17], contract design [18, 19], supply uncertainty [20], Green and sustainable supply chains [21–23], manufacturer rebate [24], strategic inventory [25], and information sharing strategies [26]. Our paper differs from the abovementioned research studies from that we consider capital-constrained retailers and investigate the impact of such feature on each member's decision as well as the chain-to-chain competition.

2.1.2. Equilibrium Supply Chain Structure. The second category investigates the equilibrium supply chain structure. McGuire and Staelin [27] are one of the first researchers who studied chain-to-chain competition, under which the supplier can decide whether to integrate into retailing or sell the product through a dedicated retailer. Gupta and Loulou [28] consider different degrees of substitutability and study how process innovation influences the equilibrium channel structure. Wu et al. [29] consider two competing supply chains that sell substitutable products, where the market demand is a newsvendor type of multiplicative form. They examine the effect of uncertain demand and production cost on the equilibrium channel structure. Wu et al. [30] extend McGuire and Staelin [27] to consider demand uncertainty and joint pricing and quantity decisions, under three possible supply chain strategies: vertical integration, manufacturer's stackelberg, and bargaining on the wholesale price. Wu and Mallik [31] study cross sales where at least one retailer sells both products of the suppliers. They show that cross sale is feasible when retailers are in quantity competition or in a capacity constrained price competition. However, a pure Bertrand price competition is not suitable for cross sales. Zhao and Shi [32] consider two competing supply chains, each with multiple upstream suppliers producing complementary products and selling to a single buyer. They show that with a strong market competition and a small number of suppliers, a decentralized supply chain is preferred under a consignment with revenue sharing contract. Li et al. [33] study the problem of partial vertical centralization in competing supply chains. Yang et al. [34] examine the competitiveness of supply chains and study the impact of green marginal manufacturing cost, demand sensitivity of green level and governmental interventions, on channel structure strategy. However, these papers disregard the real-world practice that retailers may be in short of capital and do not incorporate this element in their models.

2.2. Interface of Operations Management and Finance. The field of the interface between operations management and finance focuses on the study of interactions between operational and financial decisions. To have a better understanding on the models that consider operational and financial decisions, we refer the reader to Zhao and Huchzermeier [35] for a detailed review. Iancu et al. [7] consider a capital-strapped firm borrows from a bank under inventory-based financing (IBF). They show that in the presence of operating flexibility in replenishing or partially liquidating inventory, the IBF covenants can help eliminate the agency cost and therefore the firm obtains the full benefits as in the first-best case. Alan and Gaur [8] consider a bank that has incomplete information about a borrower's demand, and they establish a stylized screening model to capture the features of asset-based lending (ABL) from the bank. They show that ABL allows the bank to affect each firm type's decision and also mitigate information asymmetry. Jiang et al. [36] assume that both the supplier and the retailer are capital constrained and study the impact of the retailer's credit rating on each member's decisions.

Several papers study the interaction of operations (such as inventory decisions) and long-term financial decisions (such as capital structure). For instance, Xu and Birge [37–39] consider how the capital structure affects the retailer's operational decisions with different approaches and perspectives. Hu and Sobel [40] study a multi-echelon inventory model with random demand and the objective of optimizing the expected present value of dividends. They show that under financial constraints, the echelon base stock policy is not optimal generally. In the presence of default risk, Li et al. [41] establish a dynamic inventory model of an equity-financed firm. They show that the optimal target inventory level and financial decision variables are nondecreasing functions of the levels of inventory and retained earnings. In addition, the authors prove that a myopic policy is optimal to maximize the present value. Fu et al. [42] study a capital-constrained firm uses inventory financing to obtains additional capital to satisfy stochastic demand in a multiperiod setting. They find that when the firm with capital shortage predicts to encounter high demands in a future period, it may strategically overstock its inventory in earlier periods in order to secure the necessary capital.

Most of the related works consider supply chain management problem, which is also known as supply chain finance. This area focuses on the impacts of short-term financing options such as trade credit, bank credit, and short-term loans on capital-constrained firms' operational decisions. Example includes studies of Buzacott and Zhang [43], Kouvelis and Zhao [4], Cai et al. [44], Deng et al. [45], Tunca and Zhu [46], Yang and Birge [47], and Chen et al. [48], Yang et al. [49]. Kouvelis and Zhao [50] consider credit ratings' influence on a retailer's choice between bank financing and supplier financing. They conclude that retailer's financing decision is a threshold policy on supplier's credit rating level; the supplier always prefer good rating retailer. In addition to the abovementioned literature, many supply chain financing studies investigate the role of financing on various aspects of supply chain management, such as capacity investment [51], production technology choices [52], channel competition [53, 54], deterrent of product adulteration [55], green supply chain [56], remanufacturing [57], and manufacturer encroachment [58].

Evidently, the literature on interface of operations management and finance is fruitful. Nevertheless, while some of the papers consider financing problem in a single supply chain, we find that supply chain-to-chain competition have not been well studied in this area. Hence, we believe that this paper is able to enrich the relevant literature.

3. The Model

We consider two supply chains (indexed by 1 and 2) selling one single product in the same market. Each supply chain contains one supplier (she) and one retailer (he), and we assume that each supplier only supplies the retailer in the same chain. Throughout the paper, we assume that all players are risk neutral; that is, all of them pursue to maximize their own profit. The product is produced before the selling season (which is often true since the production lead time is long relative to the length of the selling season); therefore, both retailers have only one chance to purchase from the suppliers, and replenishment is not allowed since a contract is often signed for a whole season. Supplier i's unit cost is denoted by c_i, and the wholesale price to retailer i is denoted by w_i.

The two retailers compete with each other in quantity, i.e., they are in Cournot competition. Following the convention in literature [9–11], we use the following inverse demand function:

$$p = A - q_1 - q_2, \tag{1}$$

where p is the market price, A is the market size, and q_i, $i = 1, 2$, is retailer i's order quantity. In addition, retailer i incurs a constant retailing cost, which is normalized to zero. This is a common assumption in the literature. The structure of the supply chain competition is illustrated in Figure 1.

Retailer i's initial capital level is m_i, and we assume that both retailers are in short of capital, i.e., we have $m_i < w_i q_i$ for $i = 1, 2$. Therefore, they need external capital to support their businesses. Both retailers have the access to bank loans and the interest rate offered by the bank is denoted by r. After the realization of revenue, both retailers need to pay the loan principle and interest back to the bank. To avoid triviality, we assume $c_i < w_i < (1 + r)w_i < p$, meaning that each member is profitable in the business. Conversely, the two suppliers have sufficient on-hand cash flow to supply the product to the retailers.

The sequence of events is as follows. First, in the two supply chains, the two suppliers simultaneously determine the wholesale price and then offer the price-only contract to their corresponding retailers. Secondly, observing the wholesale price, the retailers simultaneously decide the loan amounts, which we denote by $y_i, i = 1, 2$, and the order quantities q_i. Finally, after satisfying the market demand, both retailers conduct the loan repayment to the bank. Table 1 summarizes the notation.

3.1. Assumptions. For ease of exposition, we summarize the model's assumptions in this subsection.

Assumption 1. Both retailers are selling the same single product in the same market and they are involved in Cournot competition. In addition, each supplier only supplies the retailer in the same chain.

Assumption 2. All players are risk neutral.

Assumption 3. Both retailer are short of capital and both of them issue bank loans.

Assumption 4. The system parameters satisfy $c_i < w_i < (1 + r)w_i < p$; that is, each supplier's cost must be smaller than its wholesale price, and the wholesale price plus the interest must be smaller the market price. This is to ensure that each member is profitable in the business.

3.2. Benchmark: When Retailers Have Sufficient Capital. We first study a benchmark model that considers each retailer's initial capital level is able to fulfill the demand of procurement. In this case, there is no need for retailer i to raise bank loan. We denote π^n_{ri} as retailer i's profit, then we have

$$\pi^n_{ri} = (p - w_i)q_i = \left(A - w_i - q_j - q_i\right)q_i, \tag{2}$$

where $i, j = 1, 2, i \neq j$. Retailer i determines q_i to maximize π^n_{ri}. Then, with retailer i's order quantity q_i, the supplier's profit can be formulated as follows:

$$\pi^n_{si} = (w_i - c_i)q_i. \tag{3}$$

Supplier i decides w_i to maximize π^n_{si}. Under the benchmark model, we have the following result.

Lemma 1. *When both retailers have sufficient capital, supplier i's optimal wholesale price is* $w^n_i = 15A + 8c_i + 2c_j/15$, *retailer i's optimal order quantity is* $q^n_i = 2(5A - 7c_i + 2c_j)/45$, *and the retail price is* $p^n = 5A + 2c_1 + 2c_2/9$. *Therefore, retailer i's profit is* $\pi^n_{ri} = 4(5A - 7c_i + 2c_j)^2/2025$ *and supplier i's profit is* $\pi^n_{si} = 2(5A - 7c_i + 2c_j)^2/675$. *Correspondingly, the supply chain i's total profit is as follows:*

$$\Pi^n_i = \frac{2\left(5A - 7c_i + 2c_j\right)^2}{405}. \tag{4}$$

Lemma 1 demonstrates each member's optimal decision and the corresponding profit. We find that the supplier's wholesale price not only increases in her cost but also in the other supplier's cost. On the other hand, each retailer's order quantity is decreasing in his supplier's cost but instead is increasing in his competitor's supplier's cost; and this is also true for the supply chain's profit. Based on the above-mentioned result, we can compare the two supply chains in terms of the supplier's cost c_i.

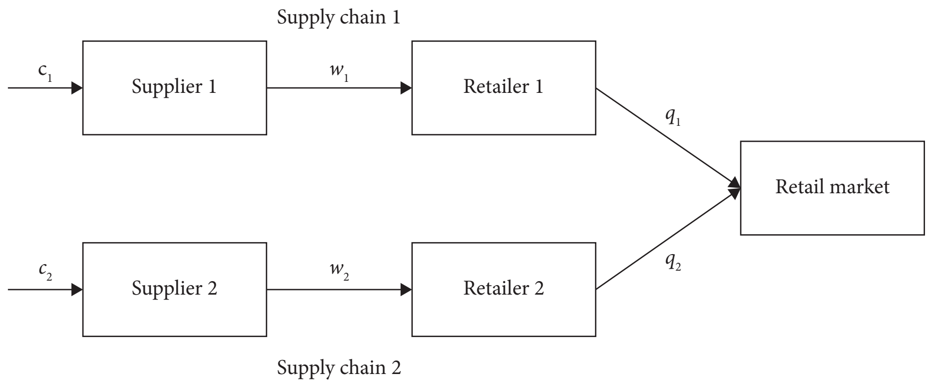

Figure 1: Structure of supply chain competition.

Corollary 1. *When both retailers have sufficient capital, if $c_1 \le c_2$, then we have $q_1^n \ge q_2^n$, $w_1^n \le w_2^n$, $\pi_{r1}^n \ge \pi_{r2}^n$, $\pi_{s1}^n \ge \pi_{s2}^n$, and $\Pi_1^n \ge \Pi_2^n$.*

Corollary 1 manifests the fact when the supply chain has a lower cost (i.e., the supplier's cost), then the selling quantity is larger compared with the other competing supply chain. In this case, the cost advantage achieves a better profit to the supply chain as well as each member in the supply chain.

3.3. When Retailers Are Capital-Constrained. In this subsection, we study the problem when retailer i, $i = 1, 2$, suffers from a shortage of funds, therefore he needs to borrow money from a bank loan. With the initial capital level m_i, the order quantity q_i, the loan amount y_i, and the interest rate of bank loan r, retailer i's profit function can be formulated as follows:

$$\pi_{ri} = pq_i - (1+r)y_i - m_i, \tag{5}$$

where the first term is the revenue of selling the product to the market, and the second term is the loan repayment to the bank. Therefore, the first two terms are retailer i's terminal cash flow after demand arrives. Based on the profit function, retailer i's problem is as follows:

$$\max_{\substack{q_i \ge 0, l_i \ge 0, \\ w_i q_i \le m_i + y_i}} \pi_{ri}. \tag{6}$$

The first two constraints mean that the order quantity and loan amount should be nonnegative; the last constraint indicates that retailer i's procurement should not exceed the on-hand cash after borrowing from the bank. One can easily verify that in optimality it must have $w_i q_i = m_i + y_i$, meaning that retailer i borrows up to the exact capital level such that the on-hand cash is equal to the purchasing price of products. This is because the bank loan is costly (i.e., the interest rate) to the retailer.

Anticipating retailer i's order quantity q_i, the supplier i's profit is $(w_i - c_i)q_i$ and her decision is the wholesale price. Solving the problems of supplier i and retailer i, we obtain the following result:

Table 1: Notation.

w_i	The wholesale price provided to retailer $i, i = 1, 2$
c_i	The unit cost of supplier i
q_i	The order quantity of retailer i
y_i	The loan amount of retailer i
A	The market size
p	The market price
r	The interest rate of bank loans
π_{ri}	The profit of retailer i
π_{si}	The profit of supplier i
Π_i	The profit of supply chain i
π_{ri}^n	The profit of retailer i without capital constraint.
π_{si}^n	The profit of supplier i without capital constraint.
Π_i^n	The profit of supply chain i without capital constraint.

Lemma 2. *When both retailers are in short of capital, supplier i's optimal wholesale price is $w_i^* = 5A + 2(1+r)(4c_i + c_j)/15(1+r)$, retailer i's optimal order quantity is $q_i^* = 2(5A - (1+r)(7c_i - 2c_j))/45$, the optimal loan amount is $y_i^* = w_i^* q_i^* - m_i$, and the retail price is $p^* = 5A + 2(1+r)(c_1 + c_2)/9$. Therefore, retailer i's profit is $\pi_{ri} = 4(5A - (1+r)(7c_i - 2c_j))^2/2025 + rm_i$ and supplier i's profit is $\pi_{si} = 2(5A - (1+r)(7c_i - 2c_j))^2/675(1+r)$. Correspondingly, the supply chain i's total profit is as follows:*

$$\Pi_i = \frac{2(5+2r)\left(5A - (1+r)\left(7c_i - 2c_j\right)\right)^2}{2025(1+r)} + rm_i. \tag{7}$$

Lemma 2 presents the results when each retailer has insufficient capital. We can see that different from Lemma 1, each player's decision and the corresponding profit is related to the interest rate. In particular, the wholesale and market prices are larger with bank loans while the order quantity and the profit are lower. In addition, similar to Corollary 1, one can easily verify that if supply chain i has cost advantage (i.e., $c_i \le c_j$, $i, j = 1, 2, i \ne j$), then a higher profit is achievable.

Corollary 2. *When both retailers are capital-constrained, we have the following results:*

(1) $\partial \pi_{ri}/\partial m_i = \partial \Pi_i/\partial m_i = r$;

(2) w_i^* is decreasing in r;

Table 2: Comparison between models of CS and CC.

	CS model	CC model
Retailer i's order quantity $q_i^n\,(q_i^*)$	$2(5A-7c_i+2c_j)/45$	$2(5A-(1+r)(7c_i-2c_j))/45$
Supplier i's wholesale price $w_i^n\,(w_i^*)$	$5A+8c_i+2c_j/15$	$5A+2(1+r)(4c_i+c_j)/15(1+r)$
Retail price $p^n\,(p^*)$	$5A+2c_1+2c_2/9$	$5A+2(1+r)(c_1+c_2)/9$
Retailer i's profit $\pi_{ri}^n\,(\pi_{ri})$	$4(5A-7c_i+2c_j)^2/2025$	$4(5A-(1+r)(7c_i-2c_j))^2/2025+rm_i$
Supplier i's profit $\pi_{si}^n\,(\pi_{si})$	$2(5A-7c_i+2c_j)^2/675$	$2(5A-(1+r)(7c_i-2c_j))^2/675(1+r)$
Supply chain i's profit $\Pi_{ri}^n\,(\Pi_{ri})$	$2(5A-7c_i+2c_j)^2/405$	$2(5+2r)(5A-(1+r)(7c_i-2c_j))^2/2025(1+r)+rm_i$

(3) for $i, j = 1, 2, i \neq j$, when $c_i \leq 2c_j/7$, q_i^* is increasing in r while q_j^* is decreasing in r; when $c_i \in (2c_j/7, 7c_j/2)$, both q_i^* and q_j^* are decreasing in r; when $c_i \geq 7c_j/2$, q_j^* is increasing in r while q_i^* is decreasing in r.

When both retailers are in short of capital, Corollary 2 (1) implies that retailer i's profit is increasing in his own capital level m_i, which is an intuitive result. In addition, from Lemma 2, we know that supplier i's profit is independent of m_i. Therefore, we can conclude that supply chain i's profit is also increasing in the retailer's capital m_i. Moreover, we find that the slope of π_{ri} on m_i is exactly the interest rate r, indicating that when retailer i's initial capital increases one unit, the profit increases r unit. This is due to the fact the financial cost of bank loan is r; for each loan amount borrowed, retailer i needs to pay the interest r to the bank.

Corollary 2 (2) suggests that as the interest rate increases, supplier i's optimal wholesale price w_i^* should be lower. When r increases, retailer i's cost of borrowing is higher, which restrains his order quantity from the supplier. In this case, supplier i's profit is weakened with a lower order quantity. In order to encourage the retailer to purchase more products, the supplier has to lower the wholesale price. From the perspective of the entire supply chain, if the supplier i does not lower her wholesale price, retailer i will have a lower order quantity such that the supply chain may lose certain market share; in this case, the supply chain suffers profit attenuation, resulting in a lower profit to the supplier. To avoid the loss of competitive advantage, supplier i will have to reduce the wholesale price, ensuring a significant order quantity from retailer i.

Corollary 2 (3) demonstrates that each retailer's order quantity could either increase or decrease in the interest rate r, which depends on the relationship of the two suppliers' unit costs. In particular, when supplier i's cost is low enough (i.e., $c_i \leq 2c_j/7$), then retailer i's order quantity is increasing in r while his competitor's order quantity is decreasing. This is because supply chain i has a significant cost advantage; when both retailers are capital-constrained, the interest rate further amplifies the cost difference, making the supply chain with a lower cost has a higher selling quantity. On the other hand, when the cost difference of the two suppliers are not too large (i.e., $c_i \in (2c_j/7, 7c_j/2)$), neither the supply chain possesses the cost advantage; therefore, both supply chains' quantities are reduced in the presence of bank loans with interest rate r.

4. The Impact of Capital Constraint on Supply Chain Competition

In this section, we compare each member's optimal decision and the corresponding profit of each supply chain when the two retailers have and do not have sufficient capitals. For the ease of exposition, we use "CS" to represent the model when the retailers are capital-sufficient and "CC" to represent the model when the retailers are capital-constrained. We first reexhibit the results of Lemmas 1 and 2 in Table 2.

Proposition 1. *Compared to the CS model, when the retailers are capital-constrained, supplier i will offer a lower wholesale price. In addition, we have the following:*

(1) $w_i^n - w_i^*$ is increasing in A;

(2) $w_i^n - w_i^* = w_j^n - w_j^*$, $i, j = 1, 2, i \neq j$.

Proposition 1 shows that if the retailer has to borrow money from the bank, the supplier should offer a lower wholesale price compared with the CS model, in order to motivate the retailer to maintain a certain level of procurement; this result is consistent with Corollary 2 (2). In addition, we find that the wholesale price gap (i.e., $w_i^n - w_i^*$) is increasing in the market size A. That is, supplier i should provide a lower wholesale price with a larger market size. As the market size is larger, both supply chains will try hard to seize more share of the market; by providing a lower wholesale price, supplier i encourages the retailer to order more products. Finally, we find that, regardless of the heterogeneity between the two supply chains (the costs of suppliers, the initial capital levels of retailers), the wholesale price differences between the CS and CC models are the same. This suggests that both suppliers should reduce the same level of wholesale price to encounter the situation when both retailers are capital-constrained.

Proposition 2. *Compared to the CS model, when both retailers are capital-constrained, for $i, j = 1, 2, i \neq j$, we have the following results:*

(1) When $c_i \leq 2c_j/7$, retailer i's optimal order quantity is larger while retailer j has a smaller order quantity, i.e., $q_i^* \geq q_i^n$ and $q_j^* < q_j^n$;

(2) When $c_i \in (2c_j/7, 7c_j/2)$, both retailers's optimal order quantities are smaller, i.e., $q_i^* < q_i^n$ and $q_j^* < q_j^n$;

(3) When $c_i \geq 7c_j/2$, retailer j's optimal order quantity is larger while retailer i has a smaller order quantity, i.e., $q_j^* \geq q_j^n$ and $q_i^* < q_i^n$.

From Proposition 2, we know that the relationship of retailer i's optimal order quantities under the CS and CC models depends greatly on the cost comparison of the two suppliers. From Table 2, one can easily verify that the total order quantities of the two retailers are smaller in the CC model, i.e., $q_1^* + q_2^* < q_1^n + q_2^n$. However, Proposition 2 tells us that the individual order quantity could be either higher or lower under CC model compared with the CS model. Specifically, when supplier i's cost is small enough (i.e., $c_i \leq 2c_j/7$), retailer i can order a higher number of product than that under CS model, while his competitor, retailer j, $j \neq i$, has a lower order quantity. When either retailer has to borrow the bank loan and pays the interest, the cost is higher than the CS model; to guarantee that retailer i orders enough products to secure certain market share, supplier i needs to lower the wholesale price. We find that, with a smaller cost, supplier i is able to provide a smaller wholesale price than supplier j, under which retailer i's order quantity can be even more than that under the CS model. In other words, the cost advantage of supplier i is reinforced in the presence of bank loan; therefore, the supplier i can place a lower wholesale price to help retailer i seize more market share, generating a higher profit to the supply chain i. However, when the cost difference of suppliers are not that significant, the bank loans increase the cost burden of both retailers; and in this case neither of the suppliers can benefit from the competition since neither of them has a significant cost advantage. Therefore, both retailers' order quantities are lower under the CC model.

We demonstrate our above theoretical results through a numerical example as follows.

Example 1. Suppose the system parameters are as follows: supplier i's cost satisfies $c_i \in [0, 10]$; the two retailers' initial capital levels are $m_1 = 50$ and $m_2 = 70$; the market size is $A = 100$; the bank's interest rate is $r = 0.2$.

We plot the result of Proposition 2 in Figure 2. Figure 2 is divided into three regions, whereby each retailer's quantity comparison under the CS and CC models depends on the relationship of c_1 and c_2. When the cost of either supplier is significantly smaller than the other one (i.e., region 1 or 2 in the figure), one retailer will have a higher order quantity while the other one is lower. In region 3, neither of the supply chains has the cost advantage, and therefore both retailers are suffered from the financial cost, leading to lower order quantities.

Proposition 3. *Compared to the CS model, when the retailers are capital-constrained, the retail price is lower, i.e., $p^* < p^n$.*

Proposition 3 indicates that the retail price of the product is higher under the CC model, which is an intuitive result since to each supply chain, the cost is increased due to the external financial cost, under which the total quantities of the two retailers are smaller compared to the CS model. This implies that with retailers' capital constraints and the entry of bank loans, the whole system (including the two supply chains) is worse off compared to the CS model.

Proposition 4. *When the retailers are capital-constrained, if supplier i's cost satisfies*

$$c_i \leq \frac{2c_j}{7} + \frac{1}{7}\left(\frac{5A}{2+r} - \sqrt{\left(\frac{5A}{2+r}\right)^2 - \frac{2025m_i}{4(2+r)}}\right), \quad i, j = 1, 2, i \neq j. \tag{8}$$

Then retailer i's profit is higher than that in the CS model, i.e., $\pi_{ri} \geq \pi_{ri}^n$.

Proposition 4 presents an interesting result: under the CC model, if supplier i's cost is sufficiently small compared to the other supplier, then retailer i can achieve a higher profit than when both retailers are capital-sufficient. This result is consistent with Proposition 2 that when retailers have to borrow bank loan, the cost advantage is enhanced, therefore the supply chain has a better competitive advantage and earns a higher profit. In this case, we find that the corresponding retailer could also benefit from the competition. In addition, from Proposition 4, one can easily verify that when m_i increases, the right hand side of the inequality increases, meaning that when retailer i's initial capital level is higher, he is more likely to have a better profit under the supply chain competition.

Notice that Proposition 4 focuses on one retailer's perspective. Taking both retailers into consideration and continue with Example 1, Figure 3 presents different regions with respect to the cost relationship of the suppliers. Specifically, we find that when both suppliers' cost are small enough, each retailer can have a better profit under the CC model (regions 1). This implies that even though both retailers are capital constrained, they can earn more money than when they have sufficient capital. This is because, when supplier i's cost is low, she is able to provide a low enough wholesale price, which could be lower than that in the CS model even if it is multiplied by the interest rate. In this case, the retailer actually benefits from the small wholesale price. Indeed, the supplier has a lower profit in this case, since she would like to induce a higher order quantity with a small wholesale price. In addition, when one supplier's cost is small enough compared with the other one's cost (i.e., regions 2 and 3), the corresponding retailer could still have a higher profit, while the other retailer is worse off under the CC model. In fact, under this case, the supplier with a lower cost earns a better profit. This intuition is mainly from the competition. Lastly, when both suppliers' costs are high (region 4), each retailer has a worse profit under the CC model.

Proposition 5. *When the retailers are capital-constrained, if supplier i's cost c_i satisfies*

$$c_i \leq \frac{2c_j}{7} - \frac{5A}{7\sqrt{1+r}}, \quad i, j = 1, 2, i \neq j. \tag{9}$$

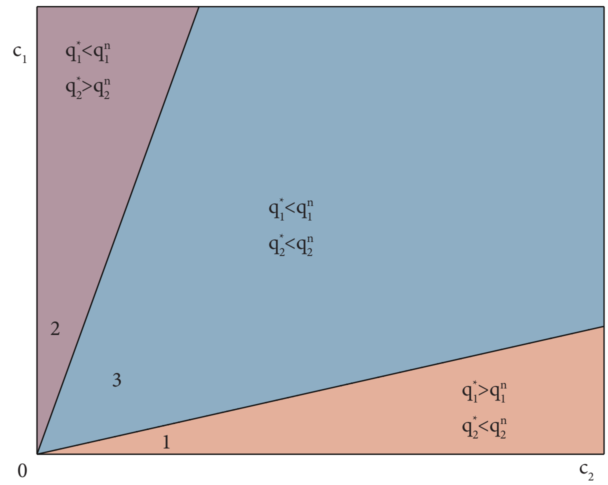

Figure 2: Regions of quantity comparison.

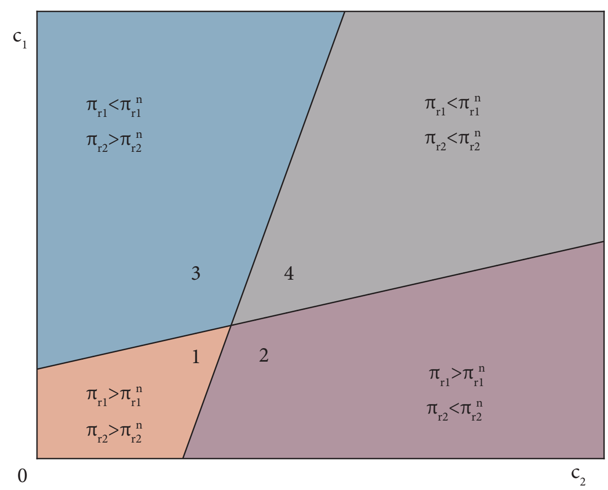

Figure 3: Regions of retailer profit comparison.

Then, supplier i's profit is higher than that in the CS model, i.e., $\pi_{si} \geq \pi_{si}^n$.

Proposition 5 again confirms the fact that when supplier i's cost is small enough, supply chain i can have more competitive advantage when both retailers borrow from the bank, therefore the profit is higher compared to the CS model. In this case, supplier i benefits from the competition and also achieves a higher profit. We continue with Example 1 and depict Figure 4 to further illustrate the result. Regions 1 and 2 are where one of the supplier's cost can be distinguished from the other one. In this case, the one with lower cost can win from the supply chain competition. Region 3 is where the two costs of suppliers are relative close, under which neither of the supply chains cannot dominate the other one in the competition. Instead, the competition makes both supply chain become worse off, and so as the suppliers. Different from Figure 3, there does not exist a region where both suppliers can be better off under the CC model.

Proposition 6. *When the retailers are capital-constrained, there exists a value $\overline{c}_i > 0$ such that if supplier i's cost satisfies $c_i \leq 2c_j/7 - \overline{c}_i$, then supply chain i's profit is higher than that in the CS model, i.e., $\Pi_i \geq \Pi_i^n$.*

Proposition 6 is a natural result from Propositions 4 and 5, whereby the financial cost of bank loan further strengthens the competitiveness of the supply chain with a lower cost (of the supplier). Similarly, the result of Proposition 6 is illustrated in Figure 5 under Example 1. Based on different values of c_1 and c_2, we also partition three regions on the profits of the two supply chains. Although both retailers may be better off under the CC model (i.e., region 1 of Figure 3), we find that

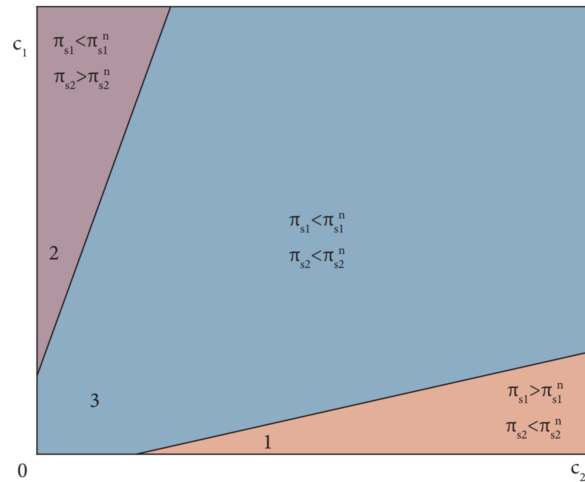

Figure 4: Regions of supplier profit comparison.

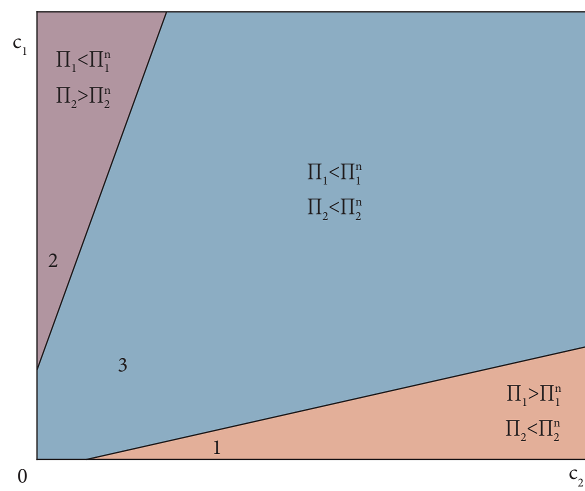

Figure 5: Regions of supply chain profit comparison.

as either one of or both suppliers obtain a lower profit, the two supply chains cannot generate better profits simultaneously.

5. Conclusions

This paper considers two heterogenous supply chains competing in the same retail market with the same product. The key feature is that we simultaneously study supply chain-to-chain competition and retailer's capital constraint within a game-theoretical model. In order to support the operational activity, the retailer needs to raise funds from the bank. The two important issues, supply chain competition and bank financing, have been extensively addressed in literature, but as separate problems. We show that the financial cost of bank loan distorts each member's decision in the supply chain, compared to the case when the retailers have sufficient capital. In particular, when the retailer borrows bank loan with the interest rate, the supplier will lower her wholesale price, in order to encourage the retailer's order quantity. We also find that the financial cost could change the two competing supply chains' competitiveness. If one supplier's cost is relatively small compared to the other supplier, the supply chain will have an enhanced competitive advantage, as the cost difference would be amplified by the financial cost. In this case, the retailer will order more quantities than the case of sufficient capital, while the other retailer orders less. Therefore, the supply chain with a lower supplier cost gains a higher market share, achieving a higher profit; the supplier and the retailer therein could also earn a better profit. We also conduct several numerical examples on our model, and we find that when both suppliers' costs are very small, each retailer can be better off, whereby the suppliers and the supply chains are worse off. That is, the retailers are benefiting from capital constraint, while the supply chains (or equivalently, the suppliers) pay the price of bank loans.

The practical and theoretical applications of this work are demonstrated as follows. First, the practical application of the paper is that under supply chain competition, the financial cost could enhance the competitive advantage for the supply chain with a lower supplier cost, achieving a better profit for each member in the supply chain; in addition, if both suppliers costs are sufficiently low, then both retailers can be better off than the benchmark case even if they are capital-constrained. Second, the theoretical application of the paper is that we shed light on the theoretical development of considering supply chain to chain competition with the interface of operations management and finance. Our model provides a possible direction of the future research that can be extended to incorporating various features, such as price competition and trade credit.

5.1. Importance and Relevance. The results of the paper deliver several insight implications to the business. First, when the downstream retailer is lack of capital, to maintain the competitiveness, the supplier needs to lower her wholesale price, which is depending on the product costs. Second, if the supplier already possesses the competitive advantage, then she would not hesitate to encourage her retailer to issue bank loans. Third, when the cost advantage is not sufficient high, then the suppliers will be hurt under the chain-to-chain competition, while the retailers may instead better off.

5.2. Future Research. This study can be extended in different directions. First, it is desirable to consider the Bertrand competition instead of the Cournot competition to see the impact of capital-constrained retailers. Second, it would be also interesting to study the case when the supplier, rather than the retailer, that has financial distress. In this case, whether the financial cost of bank loans will intensify the competition requires deeper investigation. Since supply chain finance is another frequently used financing option [4, 44, 49] for firms with limited working capital, we can extend the model to consider that the retailers borrow from their own suppliers. Lastly, if each supply chain has more than two echelons, then it is meaningful to see the influence of capital constraint in multi-echelon supply chains.

Appendix

Proofs

Proof. From equation (2), for retailer 1, his profit function is $\pi_{r1}^n = (A - w_1 - q_2 - q_1)q_1$. Given w_1 and q_2, one can easily verify that π_{r1}^n is concave in q_1. Taking derivative, and we can have the first order condition (FOC) as follows:

$$\frac{\partial \pi_{r1}^n}{\partial q_1} = (A - w_1 - q_2) - 2q_1 = 0. \tag{A.1}$$

Similarly, for retailer 2, we have the following FOC:

$$\frac{\partial \pi_{r2}^n}{\partial q_2} = (A - w_2 - q_1) - 2q_2 = 0. \tag{A.2}$$

Solving equations (A.1) and (A.2), we have $q_1 = A - 2w_1 + w_2/3$ and $q_2 = A - 2w_2 + w_1/3$. Plugging into (3), we have

$$\pi_{si}^n = (w_i - c_i)q_i = (w_i - c_i)\frac{A - 2w_i + w_j}{3}, \tag{A.3}$$

which is concave in w_i given $w_j, j \neq i$. Therefore, the FOCs for the two suppliers are as follows:

$$\begin{aligned}\frac{\partial \pi_{s1}^n}{\partial w_1} &= \frac{A + 2c_1 - 4w_1 + w_2}{3} = 0,\\ \frac{\partial \pi_{s2}^n}{\partial w_2} &= \frac{A + 2c_2 - 4w_2 + w_1}{3} = 0.\end{aligned} \tag{A.4}$$

Solving the equations, we have $w_1^n = 15A + 8c_1 + 2c_2/15$ and $w_2^n = 15A + 8c_2 + 2c_1/15$. Therefore, the optimal order quantity for retailer i is $q_i^n = 2(5A - 7c_i + 2c_j)/45$, and the corresponding retail price is $p^n = A - q_1^n - q_2^n = 5A + 2c_1 + 2c_2/9$. Retailer i's profit is as follows:

$$\pi_{ri}^n = (p^n - w_i^n)q_i^n = \frac{4\left(5A - 7c_i + 2c_j\right)^2}{2025}, \tag{A.5}$$

and the supplier i's profit is as follows:

$$\pi_{si}^n = (w_i^n - c_i)q_i^n = \frac{2\left(5A - 7c_i + 2c_j\right)^2}{675}. \tag{A.6}$$

Therefore, supply chain i's profit is $\Pi_i^n = 2(5A - 7c_i + 2c_j)^2/405$. The proof is complete. □

Proof. According to Lemma 1, we have

$$\begin{aligned} q_1^n - q_2^n &= \frac{2(5A - 7c_1 + 2c_2)}{45} - \frac{2(5A - 7c_2 + 2c_1)}{45}\\ &= \frac{2(c_2 - c_1)}{5}.\end{aligned} \tag{A.7}$$

Therefore, when $c_1 \leq c_2$, we have $q_1^n \geq q_2^n$. Similarly, $w_1^n - w_2^n = 2(c_1 - c_2)/5$; when $c_1 \leq c_2$, we have $w_1^n \leq w_2^n$. For the other inequalities, the proof is similar and we omit the details here. □

Proof. The proof is quite similar to that of Lemma 1; therefore, we omit the details here. □

Proof. For (2), from Lemma 2, one can easily have that $\partial \pi_{ri}/\partial m_i = \partial \Pi_i/\partial m_i = r$. For (3), $\partial w_i^*/\partial r = -A/3(1 + r)^2 < 0$, indicating that w_i^* is decreasing in r. For (5), we have

$$\begin{aligned}\frac{\partial q_i^*}{\partial r} &= \frac{2\left(2c_j - 7c_i\right)}{45},\\ \frac{\partial q_j^*}{\partial r} &= \frac{2\left(2c_i - 7c_j\right)}{45}.\end{aligned} \tag{A.8}$$

Therefore, when $c_i \leq 2c_j/7$, $\partial q_i^*/\partial r \geq 0$ and $\partial q_j^*/\partial r < 0$; when $c_i \in (2c_j/7, 7c_j/2)$, $\partial q_i^*/\partial r < 0$ and $\partial q_j^*/\partial r < 0$; when $c_i \geq 7c_j/2$, $\partial q_i^*/\partial r < 0$ and $\partial q_j^*/\partial r \geq 0$. The proof is complete. □

Proof. From Table 2, we have

$$w_i^n - w_i^* = \frac{5A + 8c_i + 2c_j}{15} - \frac{5A + 2(1+r)(4c_i + c_j)}{15(1+r)} = \frac{Ar}{3(1+r)}, \tag{A.9}$$

which is increasing in A. In addition, we can also have $w_j^n - w_j^* = Ar/3(1+r)$, which equals to $w_i^n - w_i^*$. □

Proof. From Table 2, for $i, j = 1, 2, i \neq j$, we have

$$\begin{aligned} q_i^* - q_i^n &= \frac{2(5A - 7c_i + 2c_j)}{45} - \frac{2(5A - (1+r)(7c_i - 2c_j))}{45} = \frac{2r(7c_i - 2c_j)}{45}, \\ q_j^* - q_j^n &= \frac{2(5A - 7c_j + 2c_i)}{45} - \frac{2(5A - (1+r)(7c_j - 2c_i))}{45} = \frac{2r(7c_j - 2c_i)}{45}. \end{aligned} \tag{A.10}$$

Therefore, when $c_i \leq 2c_j/7$, $q_i^* \geq q_i^n$ and $q_j^* < q_j^n$; when $c_i \in (2c_j/7, 7c_j/2)$, $q_i^* < q_i^n$ and $q_j^* < q_j^n$; when $c_i \geq 7c_j/2$, $q_j^* \geq q_j^n$ and $q_i^* < q_i^n$. □

Proof. The proof is directly from Table 2 and is straightforward. □

Proof. From Table 2, we have

$$\begin{aligned} \pi_{ri} - \pi_{ri}^n &= \frac{4(5A - (1+r)(7c_i - 2c_j))^2}{2025} + rm_i - \frac{4(5A - 7c_i + 2c_j)^2}{2025} \\ &= -\frac{4r}{2025}\left(10A(7c_i - 2c_j) - (2+r)(7c_i - 2c_j)^2\right) + rm_i \\ &= \frac{4r(2+r)}{2025}(7c_i - 2c_j)^2 - \frac{40Ar}{2025}(7c_i - 2c_j) + rm_i. \end{aligned} \tag{A.11}$$

Let $\pi_{ri} - \pi_{ri}^n \geq 0$, then we have

$$\frac{4r(2+r)}{2025}(7c_i - 2c_j)^2 - \frac{40Ar}{2025}(7c_i - 2c_j) + rm_i \geq 0. \tag{A.12}$$

Solving the above inequality, we obtain as follows:

$$7c_i - 2c_j \leq \frac{5A}{2+r} - \sqrt{\left(\frac{5A}{2+r}\right)^2 - \frac{2025m_i}{4(2+r)}} \text{or} 7c_i - 2c_j \geq \frac{5A}{2+r} + \sqrt{\left(\frac{5A}{2+r}\right)^2 - \frac{2025m_i}{4(2+r)}}. \tag{A.13}$$

Since we have $m_i < w_i^* q_i^*$ and $7c_i - 2c_j < 5A/1+r$ (we need to ensure $q_i^* > 0$), therefore the region of $7c_i - 2c_j \geq 5A/2+r+\sqrt{(5A/2+r)^2 - 2025m_i/4(2+r)}$ should be removed. Therefore, we conclude that when

$$c_i \leq \frac{2c_j}{7} + \frac{1}{7}\left(\frac{5A}{2+r} - \sqrt{\left(\frac{5A}{2+r}\right)^2 - \frac{2025m_i}{4(2+r)}}\right), \quad i, j = 1, 2, i \neq j. \tag{A.14}$$

We have $\pi_{ri} \geq \pi_{ri}^n$. □

Proof. Denote $x = \sqrt{1+r}$. From Table 2, we know

$$\begin{aligned} \pi_{si}^n &= \frac{2(5A - 7c_i + 2c_j)^2}{675}, \\ \pi_{si} &= \frac{2(5A - (1+r)(7c_i - 2c_j))^2}{675(1+r)} \\ &= \frac{2(5A - x^2(7c_i - 2c_j)/x)^2}{675}. \end{aligned} \tag{A.15}$$

Since $5A - (1+r)(7c_i - 2c_j) > 0$, to compare π_{si}^n and π_{si}, it suffices to compare $5A - 7c_i + 2c_j$ and $5A - x^2(7c_i - 2c_j)/x$. Then,

$$\frac{5A - x^2\left(7c_i - 2c_j\right)}{x} - \left(5A - 7c_i + 2c_j\right) = \frac{5A(1-x) + x(1-x)\left(7c_i - 2c_j\right)}{x}. \tag{A.16}$$

Let $\pi_{si} \geq \pi_{si}^n$, i.e.,

$$\frac{5A(1-x) + x(1-x)\left(7c_i - 2c_j\right)}{x} \geq 0. \tag{A.17}$$

Then, we can obtain that $c_i \leq 2c_j/7 - 5A/7\sqrt{1+r}$. The proof is complete. □

Proof. From Table 2, we have

$$\Pi_i - \Pi_i^n = \frac{2(5+2r)\left(5A - (1+r)\left(7c_i - 2c_j\right)\right)^2}{2025(1+r)} + rm_i - \frac{2\left(5A - 7c_i + 2c_j\right)^2}{405}. \tag{A.18}$$

The proof is quite similar to the that of Proposition 4, so we omit the detail here. However, we can obtain that

$$\bar{c}_i = \frac{1}{7}\sqrt{\left(\frac{15A}{(1+r)(7+2r)}\right)^2 + \frac{75A^2 - 2025m_i(1+r)}{(1+r)(7+2r)}} - \frac{15A}{7(1+r)(7+2r)}. \tag{A.19}$$

□

Data Availability

The authors confirm that the data supporting the findings of this study are available within the article.

Conflicts of Interest

The authors declare that they have no potential conflicts of interest.

Acknowledgments

This study was supported by the Humanity and Social Science Youth Foundation of Ministry of Education of China (22YJCZH037) to Li Gu and was also supported by the Humanity and Social Science Youth Foundation of Ministry of Education of China (21YJC630071) to Guitian Liang.

References

[1] Insight and Info, "Report on China's cash management service market in 2020," 2020, http://baogao.chinabaogao.com/jinrongyinhang/475009475009.html.

[2] M. Giannetti, M. Burkart, and T. Ellingsen, "What you sell is what you lend? Explaining trade credit contracts," *Review of Financial Studies*, vol. 24, no. 4, pp. 1261–1298, 2011.

[3] C. Li, L. Huang, N. Duric, H. Zhang, and C. Rowe, "Agile Supply Chain: competing in volatile markets," *Ultrasonics*, vol. 49, no. 1, pp. 61–72, 2009.

[4] P. Kouvelis and W. Zhao, "Financing the newsvendor: supplier vs. bank, and the structure of optimal trade credit contracts," *Operations Research*, vol. 60, no. 3, pp. 566–580, 2012.

[5] The Business Research Company, *Lending Global Market Report 2021: COVID-19 Impact and Recovery to 2030*, Research and Markets, Dublin, Ireland, 2021.

[6] X. Gong, X. Chao, and D. Simchi-Levi, "Dynamic inventory control with limited capital and short-term financing," *Naval Research Logistics*, vol. 61, no. 3, pp. 184–201, 2014.

[7] D. A. Iancu, N. Trichakis, and G. Tsoukalas, "Is operating flexibility harmful under debt?" *Management Science*, vol. 63, no. 6, pp. 1730–1761, 2017.

[8] Y. Alan and V. Gaur, "Operational investment and capital structure under asset-based lending," *Manufacturing & Service Operations Management*, vol. 20, no. 4, pp. 637–654, 2018.

[9] A. Y. Ha, S. Tong, and H. Zhang, "Sharing demand information in competing supply chains with production diseconomies," *Management Science*, vol. 57, no. 3, pp. 566–581, 2011.

[10] J. Xu, V. N. Hsu, and B. Niu, "The impacts of markets and tax on a multinational firm's procurement strategy in China," *Production and Operations Management*, vol. 27, no. 2, pp. 251–264, 2018.

[11] V. N. Hsu, W. Xiao, and J. Xu, "The impact of tax and transfer pricing on a multinational firm's strategic decision of selling to a rival," *Production and Operations Management*, vol. 28, no. 9, pp. 2279–2290, 2019.

[12] A. Y. Ha and S. Tong, "Contracting and information sharing under supply chain competition," *Management Science*, vol. 54, no. 4, pp. 701–715, 2008.

[13] B. Liu, G. G. Cai, and A. A. Tsay, "Advertising in asymmetric competing supply chains," *Production and Operations Management*, vol. 23, no. 11, pp. 1845–1858, 2014.

[14] W. Bian, J. Shang, and J. Zhang, "Two-way information sharing under supply chain competition," *International Journal of Production Economics*, vol. 178, pp. 82–94, 2016.

[15] X. Wu and Y. Zhou, "The optimal reverse channel choice under supply chain competition," *European Journal of Operational Research*, vol. 259, no. 1, pp. 63–66, 2017.

[16] O. C. Demirag, P. Keskinocak, and J. Swann, "Customer rebates and retailer incentives in the presence of competition and price discrimination," *European Journal of Operational Research*, vol. 215, no. 1, pp. 268–280, 2011.

[17] B. X. Li, Y. W. Zhou, J. Z. Li, and S. P. Zhou, "Contract choice game of supply chain competition at both manufacturer and retailer levels," *International Journal of Production Economics*, vol. 143, no. 1, pp. 188–197, 2013.

[18] Y. Fang, B. Shou, Y. Wang, and Z. Hua, "Equilibrium contracting strategy under supply chain to supply chain competition," in *Proceedings of the 2013 10th International Conference on Service Systems and Service Management*, pp. 316–321, IEEE, Hong Kong, China, July 2013, https://doi.org/10.1109/ICSSSM.2013.6602586.

[19] H. Zhao, J. Chen, and X. Ai, "Contract strategy in the presence of chain to chain competition," *International Journal of Production Research*, vol. 60, no. 6, pp. 1913–1931, 2022.

[20] Y. Fang and B. Shou, "Managing supply uncertainty under supply chain Cournot competition," *European Journal of Operational Research*, vol. 243, no. 1, pp. 156–176, 2015.

[21] J. Wang, Q. Wan, and M. Yu, "Green supply chain network design considering chain-to-chain competition on price and carbon emission," *Computers & Industrial Engineering*, vol. 145, Article ID 106503, 2020.

[22] W. Deng, L. Feng, X. Zhao, and Y. Lou, "Effects of supply chain competition on firms' product sustainability strategy," *Journal of Cleaner Production*, vol. 275, Article ID 124061, 2020.

[23] T. Xia, Y. Wang, L. Lv, L. Shen, and T. C. E. Cheng, "Financing decisions of low-carbon supply chain under chain-to-chain competition," *International Journal of Production Research*, pp. 1–24, 2022.

[24] H. He, X. Ai, G. Wang, and L. Zhong, "Manufacturer rebate strategy under chain to chain competition," *Journal of the Operational Research Society*, pp. 1–15, 2022.

[25] X. Li, Y. Li, and Y. J. Chen, "Strategic inventories under supply chain competition," *Manufacturing & Service Operations Management*, vol. 24, no. 1, pp. 77–90, 2022.

[26] H. Xu, X. Liu, H. Huang, Y. Zhou, and Y. Wei, "Innovation information sharing between two competitive supply chains," *International Transactions in Operational Research*, vol. 29, no. 1, pp. 471–495, 2022.

[27] T. W. McGuire and R. Staelin, "An industry equilibrium analysis of downstream vertical integration," *Marketing Science*, vol. 2, no. 2, pp. 161–191, 1983.

[28] S. Gupta and R. Loulou, "Process innovation, product differentiation, and channel structure: strategic incentives in a duopoly," *Marketing Science*, vol. 17, no. 4, pp. 301–316, 1998.

[29] C. Wu, N. C. Petruzzi, and D. Chhajed, "Vertical integration with price-setting competitive newsvendors," *Decision Sciences*, vol. 38, no. 4, pp. 581–610, 2007.

[30] D. Wu, O. Baron, and O. Berman, "Bargaining in competing supply chains with uncertainty," *European Journal of Operational Research*, vol. 197, no. 2, pp. 548–556, 2009.

[31] C. Wu and S. Mallik, "Cross sales in supply chains: an equilibrium analysis," *International Journal of Production Economics*, vol. 126, no. 2, pp. 158–167, 2010.

[32] X. Zhao and C. Shi, "Structuring and contracting in competing supply chains," *International Journal of Production Economics*, vol. 134, no. 2, pp. 434–446, 2011.

[33] J. Li, S. Yang, V. Shi, and S. Zhai, "Partial vertical centralization in competing supply chains," *International Journal of Production Economics*, vol. 224, Article ID 107565, 2020.

[34] D. Yang, J. Wang, and D. Song, "Channel structure strategies of supply chains with varying green cost and governmental interventions," *Sustainability*, vol. 12, no. 1, p. 113, 2019.

[35] L. Zhao and A. Huchzermeier, "Operations-finance interface models: a literature review and framework," *European Journal of Operational Research*, vol. 244, no. 3, pp. 905–917, 2015.

[36] W. H. Jiang, L. Xu, Z. S. Chen, K. Govindan, and K. S. Chin, "Financing equilibrium in a capital constrained supply Chain: the impact of credit rating," *Transportation Research Part E: Logistics and Transportation Review*, vol. 157, Article ID 102559, 2022.

[37] X. Xu and J. R. Birge, *Joint production and financing decisions: modeling and analysis. Working Paper*, The University of Chicago Graduate School of Business, Chicago, Illinois, 2004.

[38] X. Xu and J. R. Birge, "Equity valuation, production, and financial planning: a stochastic programming approach," *Naval Research Logistics*, vol. 53, no. 7, pp. 641–655, 2006.

[39] X. Xu and J. R. Birge, "Operational decisions, capital structure, and managerial compensation: a news vendor perspective," *The Engineering Economist*, vol. 53, no. 3, pp. 173–196, 2008.

[40] Q. J. Hu and M. J. Sobel, "Echelon base-stock policies are financially sub-optimal," *Operations Research Letters*, vol. 35, no. 5, pp. 561–566, 2007.

[41] L. Li, M. Shubik, and M. J. Sobel, "Control of dividends, capital subscriptions, and physical inventories," *Management Science*, vol. 59, no. 5, pp. 1107–1124, 2013.

[42] K. Fu, X. Gong, V. N. Hsu, and J. Xue, "Dynamic inventory management with inventory-based financing," *Production and Operations Management*, vol. 30, no. 5, pp. 1313–1330, 2021.

[43] J. A. Buzacott and R. Q. Zhang, "Inventory management with asset-based financing," *Management Science*, vol. 50, no. 9, pp. 1274–1292, 2004.

[44] G. G. Cai, X. Chen, and Z. Xiao, "The roles of bank and trade credits: theoretical analysis and empirical evidence," *Production and Operations Management*, vol. 23, no. 4, pp. 583–598, 2014.

[45] S. Deng, C. Gu, G. G. Cai, and Y. Li, "Financing multiple heterogeneous suppliers in assembly systems: buyer finance vs. bank finance," *Manufacturing & Service Operations Management*, vol. 20, no. 1, pp. 53–69, 2018.

[46] T. I. Tunca and W. Zhu, "Buyer intermediation in supplier finance," *Management Science*, vol. 64, no. 12, pp. 5631–5650, 2018.

[47] S. A. Yang and J. R. Birge, "Trade credit, risk sharing, and inventory financing portfolios," *Management Science*, vol. 64, no. 8, pp. 3667–3689, 2018.

[48] X. Chen, V. Hsu, G. Lai, and Y. Li, "Financing a sustainable supply chain," 2020, https://ssrn.com/abstract=3685076.

[49] H. Yang, W. Zhuo, L. Shao, and S. Talluri, "Mean-variance analysis of wholesale price contracts with a capital-constrained retailer: trade credit financing vs. bank credit financing," *European Journal of Operational Research*, vol. 294, no. 2, pp. 525–542, 2021.

[50] P. Kouvelis and W. Zhao, "Who should finance the supply chain? Impact of credit ratings on supply chain decisions," *Manufacturing & Service Operations Management*, vol. 20, no. 1, pp. 19–35, 2018.

[51] F. de Vericourt and D. Gromb, "Financing capacity investment under demand uncertainty: an optimal contracting approach," *Manufacturing & Service Operations Management*, vol. 20, no. 1, pp. 85–96, 2018.

[52] J. Chod and J. Zhou, "Resource flexibility and capital structure," *Management Science*, vol. 60, no. 3, pp. 708–729, 2014.

[53] H. Peura, S. A. Yang, and G. Lai, "Trade credit in competition: a horizontal benefit," *Manufacturing & Service Operations Management*, vol. 19, no. 2, pp. 263–289, 2017.
[54] C. Sun, X. Zhang, Y. W. Zhou, and B. Cao, "Pricing, financing and channel structure for capital-constrained dual-channel supply chains with product heterogeneity," *International Journal of Production Economics*, vol. 253, p. 108591, 2022.
[55] V. Babich and C. S. Tang, "Managing opportunistic supplier product adulteration: deferred payments, inspection, and combined mechanisms," *Manufacturing & Service Operations Management*, vol. 14, no. 2, pp. 301–314, 2012.
[56] Z. Lai, G. Lou, H. Ma, S. H. Chung, X. Wen, and T. Fan, "Optimal green supply chain financing strategy: internal collaborative financing and external investments," *International Journal of Production Economics*, vol. 253, p. 108598, 2022.
[57] Y. Zheng, Y. Zhao, N. Wang, X. Meng, and H. Yang, "Financing decision for a remanufacturing supply chain with a capital constrained retailer: a study from the perspective of market uncertainty," *International Journal of Production Economics*, vol. 245, Article ID 108397, 2022.
[58] L. H. Zhang and C. Zhang, "Manufacturer encroachment with capital-constrained competitive retailers," *European Journal of Operational Research*, vol. 296, no. 3, pp. 1067–1083, 2022.