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Research article

Green supply chain finance strategies with market competition and financial constraints

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ABSTRACT

In the context of sustainable development, market competition is intensifying, and financial constraints have emerged as a significant hindrance to green project investment. Green Supply Chain Finance (GSCF), characterized by long-term collaboration, has emerged as a crucial financial approach to mitigate corporate financial limitations and channel capital flows into environmentally friendly industries. We propose a two-echelon supply chain with one supplier and two competing retailers over a single period and investigate ordering, sales, and financing decisions simultaneously under competition. Retailers constrained by financial considerations may secure GSCF or traditional bank financing (BF) loans. This study investigates the influence of competition on pricing and sales strategies during the selling season. The results demonstrate that retailers select between clearance and responsive selling strategies based on the level of market competition. During the ordering season, retailers share the product market equally when interest rates are uniform, and the supplier formulates a supply chain contract while considering the financing interest rate. In the presence of differential interest rates, retailers may not always opt for the GSCF, even when they offer an interest rate advantage, due to the comprehensive impacts of operational and financial strategies. Remarkably, competitive retailers do not choose the GSCF when their initial green investment capital surpasses a certain threshold.

1. Introduction

Green Supply Chain Finance (GSCF) implies the deep integration of green supply chains and supply chain finance. Its primary aim is to promote the application of sustainable development and environmentally friendly practices in supply chain financing while ensuring the efficient flow of capital, information, and logistics. Within the GSCF framework, financial institutions tailor GSCF programs and provide holistic financial solutions to the entire supply chain [1]. The core enterprise (CE) assesses potential borrowers' environmental compliance and compiles a roster of accredited environmentally responsible entities. GSCF agreements allow borrowers to secure lower interest rates, a privilege they would not readily attain when acting independently through conventional banking

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channels [2]. Take the cooperation between *Apple* and *Citibank* as an example. To achieve green and sustainable development, *Apple* (the CE) and *Citibank* collaborate on GSCF. In the whole process of financing, the upstream and downstream green suppliers need to continuously provide real and compliant enterprise green rating information to obtain funds from *Citibank* and *Apple*'s decision on whether to continue the cooperation. This methodology has been widely adopted in various industries [3–5]. Extensive research on financial constraints in supply chains has concentrated predominantly on financing modalities and supply chain finance (SCF) mechanism designs [6].

This study investigates scenarios where GSCF represents a viable alternative for retailers to traditional BF. More specifically, we probe the influence of competition on the choice of the financing mechanism. Financial constraints weaken firms' market positions, and competition accentuates the repercussions of such financial constraints [7]. Retailers must strike a delicate balance between financing costs and the associated benefits derived from meeting incremental demands. Responsive pricing has emerged as an effective tool for mitigating demand uncertainty [8], while that corresponding to responsive pricing is clearance pricing. Notably, retailers' decision-making processes encompass two distinct stages: ordering and sales. Given the competitive landscape and financial constraints, both these factors make pricing an intricate matter.

Compared to BF, the GSCF significantly spreads the financing risks and promotes environmentally conscious behavior, while at the same time offering an interest rate advantage. Nevertheless, retailers must carefully weigh the pros and cons of financing and the absence thereof [9,10]. Unlike traditional investments, green investments balance economic and environmental effects to realize environmental protection [11]. GSCF integrates carbon emissions allowances, pollution discharge permits, and other environmental factors into its application and approval processes. Loans are only granted to those who meet audit criteria. Under the GSCF, suppliers typically require retailers to pledge sufficient initial green investment capital and maintain a predetermined environmental governance level as collateral. An adequate initial green investment capital is a prerequisite for GSCF applications in the context of specific transactions. Therefore, skillful management of the initial green investment capital during the operational and financial phase is crucial for the companies [12]. This study elucidates how retailers may grapple with financial constraints when placing orders, necessitating concurrent consideration of financing avenues through GSCF or BF.

Trinasolar (688599. SH) is a leading enterprise in China's distributed photovoltaic industry, with primary applications in residential and commercial solar power stations. Faced with challenges in distributed installations, *MyBank* has provided it with a GSCF solution. By synchronizing a list of potential demand distributors with *MyBank*, the bank utilizes its digital SCF system, the "Dyad System" to identify creditworthy clients. This strategic collaboration effectively supported *Trinasolar*'s channel expansion and enhanced its competitiveness within the industry chain. Under the GSCF paradigm, two factors may influence retailers' profitability: the financing effect due to interest rate differentials and financing ratios and the operational impact of competition and supply chain agreements. The financing effect manifests as a difference in interest rates. Given the interest rate advantage of the GSCF, retailers are inclined to adopt environmentally conscious practices to qualify. Nonetheless, they must also consider the potential implications of interest rates on wholesale prices, encapsulating the operational effects. Competitive retailers may opt out of the GSCF if their initial green investment capital exceeds a certain threshold; high-volume retailers may not even consider such a financing approach. These insights underscore retailers' ability to devise strategies that balance financing and sustainable operations.

This study contributes significantly to the existing body of knowledge by examining the equilibrium in ordering and sales within a financially constrained supply chain. Doing so, it enriches the literature on decision-making in the context of GSCF. Notably, we delineate the dynamics of competition between retailers influenced by disparities in interest rates. Our research enhances the current understanding of GSCF by incorporating several structural features associated with GSCF, including a linear demand function, competition, and interest rate advantage, thereby fostering enduring and resilient supply chain partnerships. These findings offer valuable insights for managers, affording them a deeper understanding of the interplay between operational and financial considerations and guiding their decisions in a competitive and sustainable environment. Although the proposed model centers on retailers, its framework can be readily extended to diverse settings, including the GSCF of manufacturers (core enterprises), upstream suppliers (potential borrowers), and green supply chain management.

The remainder of this paper is organized as follows: Section 2 presents a comprehensive literature review. Section 3 introduces the model and expounds on retailers' pricing decisions. Section 4 examines retailers' ordering choices by considering interest rate disparities. Section 5 presents numerical simulations to elucidate the holistic decision-making process. Finally, Section 6 concludes.

2. Literature review

Our research intersects several academic domains, including studies on pricing and sales strategies amid demand uncertainty, competition within green supply chains, and equilibrium strategies for the GSCF.

Extensive examination of pricing and sales strategies has unfolded along two primary perspectives: mitigating demand uncertainty [13,14] and attaining channel coordination [2,15]. Responsive and clearance pricing have been introduced in response to stochastic demand patterns [16–18]. Operational efficiency has also been scrutinized by incorporating price-sensitive demand considerations [19–21]. Lai [1,12] explores the choice of optimal financing options for financially constrained manufacturers in different situations of the green supply chain. When demand is uncertain, suppliers adopting green supply will provide credit guarantees for financially constrained manufacturers, realizing a green strategy to reduce operational and financing risks and improve supply chain efficiency. Instead, Xiao [22]explores channel coordination in the presence of financial constraints. Kouvelis [23] proves that revenue sharing contracts can achieve channel coordination. Further, they analyze the impact of credit ratings on supply chain decisions [24]. Song [25] demonstrates that a revenue-sharing contract for a green supply chain improves its profitability. Ranjan [26] aims to prove the quality of green products, and channel harmonization is achieved through a residual profit-sharing mechanism. Our work shares a kinship with the channel coordination literature; however, it delves deeper into retailers' financial constraints. Yang [27] considers two capital constrained retailers competing in a green supply chain and designs a revenue sharing contract for trade credit and bank financing within the green supply chain to coordinate profit distribution. By contrast, our focus is a supplier offering a wholesale price contract to competitive retailers under financial constraints. Unlike most studies in this domain that delve into channel coordination, our study focuses on retailers' decisions to accept and select their preferred financing modes.

The Cournot oligopoly is a commonly employed framework for scrutinizing competition within supply chains [28–30]. Models of this nature are prevalent in operations management [31–33]. Our model also considers deterministic demand and price competition, emphasizing the impact of competition on retailers' operational and financial decisions. Existing studies typically assume that SCF contracts involve a single supplier and retailer, reflecting the customarily unique nature of financing agreements designed for specific borrowers [34,35]. From the perspective of green investment, adopting trade credit financing by capital constrained retailers leads to better environmental protection levels in green supply chains than in BF [36]. Zhang [37] compares the optimal financing decision regarding whether a green supply chain adopts green investment in a single- or dual-channel environment when the capital constrained subject is a manufacturer. In addition, to achieve the financing equilibrium of green credit and hybrid financing, the manufacturer's initial capital and the consumer's environmental preferences are crucial factors that influence the financing decisions of the green supply chain [38]. In practice, retailers must navigate competitive product markets, while SCF contracts target the entire supply chain, with banks extending credit to the entire supply chain. Consequently, the incorporation of competition into the SCF context has significant relevance.

SCF conventionally thrives in long-term relationships between core enterprises and potential borrowers. The credit evaluation process addresses risk related issues. For example, risk averse manufacturers' risk aversion coefficients and fairness preferences affect the quality and environmental friendliness of their products, as well as the profitability of the overall green supply chain [39,40]. The use of cost sharing contracts can help increase the greenness of the products and the retail price, which can increase the profitability of the green supply chain system [41]. Since all supply chain members are risk-averse, a "cost + risk-sharing" contract can coordinate the green supply chain and realize the Pareto optimization of each subject [42]. Instead, operations management predominantly assesses the impact of initial working capital and product costs on decision-making processes [43]. In the presence of a critical mass of retailers' initial working capital, participation in financing can increase profits for all green supply chain members [44]. Appropriate configurations of financing contracts can substantially facilitate effective supply chain financing [45]. Nonetheless, the studies referenced thus far neglect the competitive dynamics among retailers. Brander [46] establishes the limited liability effect of enterprise capital structures on market competition, expanding the assumption of a single firm in a competitive environment. Subsequent research has reaffirmed the influence of competition on investment decisions. A burgeoning body of literature focuses on new SCF modalities [47–49].

A few studies address pricing strategies that consider financial constraints in green supply chain management. However, a lack of systematic analysis of this issue is observed. Furthermore, previous studies overlook the interactions among GSCF system participants (suppliers, banks, and retailers), as well as the impact of competition, initial green investment capital, and interest rates. To the best of our knowledge, no comprehensive investigation has explored the intersection of market competition and financing decisions in the GSCF mode. This study fills this research gap by constructing a game model for participants in a financially constrained supply chain with an initial green investment. It also examines the impact of initial green investment capital on retailers' decision-making, thus providing a valuable contribution to this field.

3. The model

This study establishes a two-echelon supply chain system comprising a supplier and two competitive retailers, with the supplier providing homogeneous products to the retailers. Retailers make ordering decisions based on market demand forecasts. They may encounter funding shortages during the ordering process, necessitating concurrent financing decisions. Demand is revealed once the sales period commences, and retailers sell products to downstream consumers. After sales, loans are repaid using generated sales revenue.

3.1. Market demand

This section provides a succinct and precise exposition of the experimental findings, their interpretations, and conclusions. The inverse demand function is represented by equation (1) (Li et al. [15], Zhang et al. [21], Yang et al. [27], Raghavan et al. [35]):

$$p_i = a - b\left(q_i^c + \theta q_j^c\right) \tag{1}$$

where i=*1,2*, and j=*3-i* denote two retailers. The symbol p_i signifies the retail price, and q_i^c and q_j^c represent the sales levels of each retailer. The parameter θ falls within the range of [0,1] and gauges the extent of market competition. A value of θ approaching 0 signifies independent retailers, whereas a value of θ approaching 1 indicates intense competition between the two retailers. The variable a designates the market size, and a larger a corresponds to higher market revenue and marginal output returns. b serves as the market sensitivity coefficient for pricing. The supplier offers a wholesale price contract with a wholesale price w, and the unit product cost is c with $c < w < p < a$. No other costs are incurred during the selling season.

The sequence of events in operating and financing is shown in Fig. 1.

1. The supplier establishes wholesale prices and financing contracts before the selling season (Stage 1). Retailers make order decisions $q_{i(j)}$ while concurrently determining their financing choices, either GSCF or BF. GSCF features an interest rate of r_0, whereas BF involves interest rates $r_{i(j)}$. Subsequently, the supplier produces and delivers the products to their respective retailers. Retailers make payments to suppliers upon receiving orders.
2. Following the realization of demand (Stage 2), retailers establish retail prices $p_{i(j)}$ and sales quantities $q^c_{i(j)}$. After the selling season, retailers use their sales revenues to settle debt obligations.
3. All figures and tables, such as Fig. 1, Table 1, and others, are reported in the main text.

3.2. Financing modes

We assume that the initial green investment capital of retailer i is B_i, and the loan size of retailer i is expressed as $L_i = wq_i - B_i$ (Huang et al. [49]). Retailers can independently choose between GSCF and BF as their preferred financing mode. In the case of GSCF, the bank extends credit to the entire supply chain for green operations, with the core supplier providing a guarantee to downstream firms as part of a unified lending arrangement featuring an interest rate of r_0. When opting for BF, the interest rate $r_{i(j)}$ is higher due to lower credit ratings, namely, $r_0 \le r_{i(j)}$. We assume a risk-free interest rate of zero and competitive capital markets to prevent this discount effect. Under GSCF, banks disburse loans for specific transactions, with payments directly routed to the supplier through the bank. The supplier maintains strict control over the product flow to mitigate capital transfer risk. The key notations of the model are listed in Table 1.

3.3. Retailers' selling decisions

Retailers' trading activities encompass two stages: ordering and financing, involving orders from the supplier and financing from the bank, and product sales, fulfilling market demand with ordered quantities. We initially analyze sales decisions to determine pricing and sales quantities.

At the beginning of the selling season, both retailers optimize their sales quantities q_i^c and q_j^c to maximize sales revenue. Without loss of generality, we assume that $q_i < q_j$, and the revenue functions of the two retailers are represented by equation (2) and equation (3) (Luo et al. [44], Yang et al. [47]):

$$max \prod\nolimits_i = p_i q_i^c = \left[a - b\left(q_i^c + \theta q_j^c\right)\right] q_i^c \ s.\ t.\ q_i^c \in [0, q_i] \tag{2}$$

$$max \prod\nolimits_j = p_j q_j^c = \left[a - b\left(q_j^c + \theta q_i^c\right)\right] q_j^c \ s.t.\ q_j^c \in [0, q_j], \tag{3}$$

Based on the retailers' revenue equations, we propose Proposition 1 on the retailers' pricing and selling strategies.

Proposition 1. *Pricing and sales strategies are contingent on market competition, and equilibrium retail prices are determined as follows*:

$$\begin{cases} p_i = \dfrac{a}{2+\theta} & p_j = \dfrac{a}{2+\theta} & \theta \in \left(\dfrac{a}{bq_i} - 2, 1\right] \\ p_i = \dfrac{a}{2}(2-\theta) - \dfrac{bq_i}{2}\left(2-\theta^2\right) & p_j = \dfrac{1}{2}\left(a - \theta b q_i\right) & \theta \in \left(\dfrac{1}{q_i}\left(\dfrac{a}{b} - 2q_j\right), \dfrac{a}{bq_i} - 2\right] \\ p_i = a - b\left(q_i + \theta q_j\right) & p_j = a - b\left(q_j + \theta q_i\right) & \theta \in \left[0, \dfrac{1}{q_i}\left(\dfrac{a}{b} - 2q_j\right)\right] \end{cases}$$

The retailers' selling quantities are:

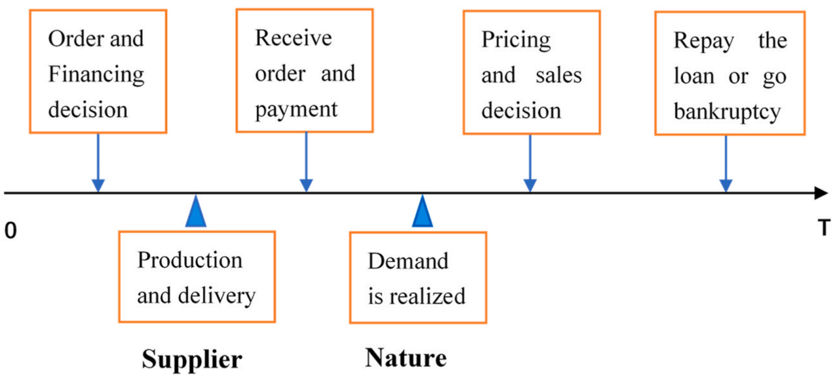

Fig. 1. The sequence of events in operating and financing.

Table 1
Definitions of some important notations.

Notation	Definitions
a	Market size
b	Market sensitivity coefficient of pricing, with $b > 0$
θ	Market competition level, with $\theta \in [0,1]$
$q_{i(j)}$	Order size of the retailer $i(j)$
$q^c_{i(j)}$	Sales quantity of retailer $i(j)$, with $q^c_{i(j)} \le q_{i(j)}$
c	Unit production cost, with $c > 0$
w	Unit wholesale price, with $w > c$
$p_{i(j)}$	Unit retail price, with $p_{i(j)} \in (w(1 + r_{i(j)}), a)$
r_0	GSCF interest rate
$r_{i(j)}$	BF interest rate of retailer $i(j)$, with $r_{i(j)} > r_0$
$L_{i(j)}$	Loan size of retailer $i(j)$, with $L_{i(j)} = wq_{i(j)} - B_{i(j)}$
$B_{i(j)}$	Initial green investment capital of retailer $i(j)$
$\Pi_{i(j)}$	Sales revenue of retailer $i(j)$
$\pi_{i(j)}$	Expected profit retailer $i(j)$
π_s	Expected profit of the supplier

$$\begin{cases} q_i^c = \dfrac{a}{(2+\theta)b} & q_j^c = \dfrac{a}{(2+\theta)b} & \theta \in \left(\dfrac{a}{bq_i} - 2, 1\right] \\ q_i^c = q_i & q_j^c = \dfrac{1}{2}\left(\dfrac{a}{b} - \theta q_i\right) & \theta \in \left(\dfrac{1}{q_i}\left(\dfrac{a}{b} - 2q_j\right), \dfrac{a}{bq_i} - 2\right] \\ q_i^c = q_i & q_j^c = q_j & \theta \in \left[0, \dfrac{1}{q_i}\left(\dfrac{a}{b} - 2q_j\right)\right] \end{cases}.$$

Based on the intervals of competition level, we obtain $q_i, q_j \in \left[\frac{a}{3b}, \frac{a}{2b}\right]$.

Proposition 1 indicates that market competition significantly influences retailer pricing and sales. Both retailers opt for clearance selling and sell their initial order quantities at low competition levels. Retailer i establishes a higher equilibrium product price $(p_i > p_j)$, but retailer j, with larger orders, attains higher revenue. At moderate competition levels, the retailer with fewer orders (retailer i) follows a clearance selling strategy, whereas the retailer with greater orders (retailer j) adopts a partial selling strategy. Retailer j's sales scale is influenced by the competition level and retailer i's order scale, both of which display negative correlations. Under intense competition, both retailers favor partial selling strategies and share the market equally. Sales quantities exhibit a negative relationship with the competition level.

Retail prices are influenced by the sales level. Corollary 1 is obtained by comparing the sales scale of retailers under different competitive levels.

Corollary 1. The retailers' market scales are affected by the competition level, and the comparison of the sales revenue satisfies the following condition: when $\theta \in \left(\frac{1}{q_i} - 2, 1\right]$, we obtain $\Pi_i = \Pi_j$; when $\theta \in \left[0, \frac{1}{q_i} - 2\right]$, we obtain $\Pi_i \le \Pi_j$.

Corollary 1 underlines the influence of the order size on market share. Under low competition levels, a retailer with more orders (retailer j) captures a larger market share than a retailer with fewer orders (retailer i). In a fiercely competitive market, both retailers divide downstream markets evenly. Proposition 1 reveals that by the end of the selling season, both retailers have surplus inventory to meet market demand and achieve equitable distribution in the market.

4. Retailers' ordering decisions

The analysis of retailers' sales decisions in Subsection 3.3 reveals that the competition level and order quantities influence retailer selling and pricing decisions. In the first stage, retailers facing financial constraints must make dual order and financing decisions. This subsection offers an in-depth examination of the retailers' decisions in the first stage.

4.1. *Ordering decision with unified interest rate*

In the first stage, retailers determine their order quantities based on forecasts of market competition. This subsection predominantly addresses retailer ordering decisions rather than financing options. Consequently, the financing interest rate is represented uniformly as r, namely, $r = r_0 = r_{i(j)}$. The subsequent analysis assigns varying values based on different interest rates. Without loss of generality, we assume that θ follows a uniform distribution within the range [0,1]. Accordingly, we formulate the expected profits of the two retailers by equation (4) and equation (5):

$$\pi_i = \prod\nolimits_i - wq_i(1+r) + B_i r \ s.t. \ q_i \in [0, q_j] \tag{4}$$

$$\pi_j = \prod\nolimits_j - wq_j(1+r) + B_j r \ s.t. \ q_j \ge q_i, \tag{5}$$

By combining these expressions with Proposition 1, we derive Proposition 2.

Proposition 2. *When the competition level follows a uniform distribution within* $[0,1]$, *competitive retailers exhibit equal equilibrium ordering in the first stage, namely,* $q_i^* = q_j^*$, *where* $q_i^* = q_j^* = \frac{w(1+r)+2a-\sqrt{[w(1+r)]^2+4aw(1+r)}}{4b}$.

Proposition 2 illustrates that, under equilibrium conditions, the expected order quantities of the two competitive retailers are equal. Even if the loan interest rates for retailers are the same, differences may exist in the retailers' market sizes during this period. A comparison of the net profits of the retailers under equilibrium conditions yields Corollary 2.

Corollary 2. *With an equal market share and loan interest rate, the retailers' profits are affected by the initial green investment capital. When* $B_i > B_j$, *we obtain* $\pi_i > \pi_j$; *when* $B_i < B_j$, *we obtain* $\pi_i < \pi_j$; *when* $B_i = B_j$, *both retailers have equal profits.*

Corollary 2 emphasizes that even when two competitive retailers share the downstream product market evenly, differences in net profit can persist due to financing costs. A lower level of initial green investment capital results in higher financing costs incurred through loans, diminishing the final net profit for retailers compared with their competitors. Proposition 2 and Corollary 2 assume identical interest rates. When different loan interest rates are available to retailers, they can also impact the final net profit, which we examine in detail later. Under identical loan interest rates, we analyze the retailers' equilibrium order quantities and derive Corollary 3.

Corollary 3. *Under equilibrium conditions, retailers' order quantities are related to the wholesale price, interest rate, market size, and market sensitivity coefficient of pricing, with* $\frac{dq^*}{dw} < 0$, $\frac{dq^*}{dr} < 0$, $\frac{dq^*}{da} > 0$, $\frac{dq^*}{db} < 0$, *respectively.*

Corollary 3 *reveals that the wholesale price and financing interest rate correlate negatively with equilibrium order quantities. A higher wholesale price results in a lower order quantity, whereas a higher financing interest rate increases the cost of retailer order financing, affecting order levels. Market size positively correlates with order quantities; the larger the market, the more retailers are inclined to place orders to meet market demand. The market sensitivity coefficient of pricing is negatively correlated with the order quantities. A higher sensitivity coefficient leads to a greater impact of sales scale changes on product market pricing, affecting the retailer profit forecasts, which are ultimately reflected in order quantity decisions and show a negative correlation.*

For the supplier, the wholesale price is a decision variable. The supplier's expected revenue during the ordering process consists of net revenue from product production and sales and potential guarantee liability, referred to as loss cost. Loss costs are incurred when a retailer's sales revenue at the end of the period is insufficient to cover the principal's interest in the loan. In other words, the loss cost equals the loan's principal and interest minus sales revenue. By combining the retailers' loan and sales expressions, we represent the supplier's loss cost by equation (6):

$$loss = max\left[(wq_i - B_i)(1+r) - \prod\nolimits_i, 0\right] + max\left[(wq_j - B_j)(1+r) - \prod\nolimits_j, 0\right] \tag{6}$$

Combining this expression with Proposition 2, we obtain Corollary 4 concerning the supplier's loss cost.

Corollary 4. When market competition follows a uniform distribution, and the retailers' loan interest rates are consistent, the supplier's credit guarantee will not incur loss costs, and both retailers can repay the principal and interest of the loan on time.

Corollary 4 indicates that competitive retailers with equal order quantities and market share in an equilibrium state experience positive expected income under a predefined market size. At this juncture, the supplier is not obligated to provide a guarantee. The wholesale price is an essential decision variable for the supplier. We can express the supplier's expected profit by equation (7):

$$\pi_s = (w - c)(q_i + q_j) \ s.t.\ q_j \geq q_i, \tag{7}$$

Combining this expression with the retailers' equilibrium ordering, we obtain Proposition 3.

Proposition 3. When competition has a uniform distribution, and retailers face the same interest rate, the supplier's profit is positively correlated with wholesale price, and the optimal wholesale price is $w^* = \frac{a}{6(1+r)}$. At this time, the supplier's equilibrium profit is $\pi_s^* = \frac{2a}{3b}\left[\frac{a}{6(1+r)} - c\right]$.

Proposition 3 *demonstrates that the supplier's wholesale price decision is influenced by both the financing interest rate of retailers and the market size. The equilibrium wholesale price exhibits a negative correlation with interest rate and a positive correlation with market size. The supplier profit is also affected by the market sensitivity coefficient of pricing, which shows a negative correlation. This phenomenon may occur because a higher price sensitivity coefficient leads to lower product market prices, affecting retailers' ordering decisions and subsequently affecting the supplier's profit.*

4.2. Ordering decision with differential interest rates

Subsection 4.1 analyzed the supply chain ordering decisions under uniform interest rates. However, financially constrained retailers can choose between GSCF and general BF (loans) in real ordering processes. GSCF holds an interest rate advantage over BF, namely, $r_0 \leq min[r_i, r_j]$. Does the SCF always represent the best choice? How should retailers make their choices? Given the retailer's sales decisions in Subsection 3.3, when facing financial constraints, retailer i's expected profit under GSCF can be expressed by equation (8) and equation (9):

$$\pi_i = \prod_i - wq_i(1+r_0) + B_i r_0 \tag{8}$$

Retailer i's expected profit under BF can be expressed as:

$$\pi_i = \prod_i - wq_i(1+r_i) + B_i r_i, \tag{9}$$

Retailers make independent financing choices, leading to four possible combinations: (GSCF, BF), (GSCF, GSCF), (BF, GSCF), and (BF, BF). By calculating the retailers' equilibrium profits for each combination, we obtain Proposition 4.

Proposition 4. When an interest rate advantage exists for GSCF; under competitive conditions, retailers' ordering decisions are influenced by the interest rate of the chosen financing method, as follows:

$$\begin{cases} q_i^* = q_j^* = \dfrac{w(1+r_j) + 2a - \sqrt{[w(1+r_j)]^2 + 4aw(1+r_j)}}{4b} & (GSCF, BF) \\ q_i^* = q_j^* = \dfrac{w(1+r_0) + 2a - \sqrt{[w(1+r_0)]^2 + 4aw(1+r_0)}}{4b} & (GSCF, GSCF) \\ q_i^* = \dfrac{w(1+r_i) + 2a - \sqrt{[w(1+r_i)]^2 + 4aw(1+r_i)}}{4b}, q_j^* = \dfrac{a}{2b} - \sqrt{\dfrac{wq_i^*(1+r_0)}{2b}} & (BF, GSCF) \\ q_i^* = \dfrac{w(1+max[r_i,r_j]) + 2a - \sqrt{[w(1+max[r_i,r_j])]^2 + 4aw(1+max[r_i,r_j])}}{4b}, q_j^* = \dfrac{a}{2b} - \sqrt{\dfrac{wq_i^*(1+r_j)}{2b}} & (BF, BF) \end{cases}$$

Proposition 4 illustrates that the retailers' order decisions are influenced by their financing modes in a competitive environment. When a retailer chooses GSCF, the equilibrium order quantities of both retailers are equal, and these order quantities are associated with a higher interest rate within the financing portfolio. However, when retailer i selects BF, the order levels of the two retailers differ. Retailer i (with lower orders) is influenced by the higher interest rate within the financing portfolio, whereas retailer j (with higher orders) is affected by the financing interest rate corresponding to their chosen financing method.

Drawing from the expected profit equation of the suppliers in (7), we formulate Proposition 5, addressing the equilibrium wholesale price decision for each financing combination.

Proposition 5. When an interest rate advantage exists for GSCF, the supplier's optimal wholesale price decision is influenced by the financing portfolio and can be expressed as follows:$w^* = \begin{cases} \dfrac{a}{6(1+r_j)} & (GSCF, BF) \\ \dfrac{a}{6(1+r_0)} & (GSCF, GSCF) \\ \dfrac{a}{6(1+r_i)} & (BF, GSCF) \\ \dfrac{a}{6(1+max[r_i,r_j])} & (BF, BF) \end{cases}$.

Proposition 5 demonstrates that the financing interest rate for different financing contract combinations influences a supplier's wholesale price decision. In other words, the supplier's wholesale price can affect the retailer's financing decisions. Notably, the wholesale price is the lowest under combination (BF, BF). In such a scenario, the supplier is not required to bear the guaranteed liability and can transfer some of its rights through low wholesale prices. The wholesale price level is highest when both retailers opt for GSCF. In this case, the retailers share supplier credit through GSCF, compelling the supplier to request a higher wholesale price. Even when only one party chooses GSCF, the supplier may quote a lower wholesale price. This approach helps some retailers secure financing and ensures a stable supply and marketing relationship with others.

Propositions 4 and 5 consider the operational decision-making process of participants under varying financing combinations. When faced with financial constraints, retailers must consider ordering decisions and choose financing modes. It is essential to discuss financing equilibrium strategies in competitive environments. The financing equilibrium strategy is significantly related to the retailer's initial green investment capital level. We set the initial green investment capital levels to $B_1 = \frac{aq_i(r_j - r_0)}{6(1+r_j)(r_i - r_0)}$, $B_2 = \frac{aq_i(2\,min(r_i,r_j) - r_j - r_0)}{6(1+r_j)(r_i - r_0)}$, and $B_3 = \frac{aq_i}{6(r_j - r_0)}\left[1 - \frac{1(1+r_0)}{2(1+r_i)}\left(3 - \sqrt{\frac{(1+r_0)}{(1+r_i)}}\right)\right]$. we derive Proposition 6 for the financing equilibrium strategy.

Proposition 6. When a retailer has an initial green investment capital $B_i \leq B_2$, a Nash equilibrium strategy exists in the financing system. Retailer i chooses GSCF while retailer j chooses BF, namely (GSCF, BF). When $B_i > B_2$, a Nash equilibrium strategy also exists in the financing system. At this time, both retailers choose the bank financing mode, namely (BF, BF).

Proposition 6 reveals that when a retailer's initial green investment capital level is relatively high, both retailers resort to the BF mode. The cost advantage stemming from low wholesale prices outweighs the financing cost advantage associated with GSCF's lower interest rates. Conversely, when retailer i has a low initial green investment capital level, it chooses GSCF to maximize its interest rate advantages and reduce interest costs. The sales scale of retailer j surpasses that of retailer i because the retailers have a larger market share. Compared with GSCF, BF enables retailers to obtain lower wholesale prices, resulting in higher operating profits than the financing costs saved by choosing GSCF. Therefore, regardless of the initial green investment capital levels and those of their competitors, BF consistently proves to be the optimal financing method for retailer j.

5. Numerical analysis

Figs. 2 and 3 depict retailers' pricing and sales decisions in response to varying levels of competition, revealing each retailer's operational strategies. Fig. 2 illustrates that, in environments characterized by low and moderate competition, retailer *i* sets higher prices than retailer *j*. This pricing discrepancy is consistent with the assumption that q_i is less than or equal to q_j. Retailers with higher order quantities tend to offer lower market prices, facilitating increased sales volumes and substantial sales revenue. However, under highly competitive market conditions, both retailers' pricing becomes uniform and lower than the product price observed in environments with moderate to low competition. This finding indicates that retailers use a lower pricing strategy to divide their market share. Because product differentiation is minimal, most consumers in the market adopt a strategic approach, with the market price being the primary determinant of their purchase decisions. Essentially, an inverse relationship exists between market competitiveness and product price. Product prices decrease as competitiveness intensifies. This phenomenon highlights the critical role of product pricing in the operational strategies of markets featuring homogeneous products. Consumer purchasing decisions are heavily influenced by product prices, which affect the retail market's size.

Fig. 3 illustrates sales strategies employed by retailers in various competitive environments. Generally, an inverse relationship exists between the retailer sales volume and competition level. As market competition intensifies, product sales volume decreases. Fig. 2 shows that under highly competitive market conditions, both retailers set identical product prices and capture equal market shares. In such fiercely competitive scenarios, both retailers opt for a responsive sales strategy, resulting in sales volumes lower than their respective order quantities, that is, $q_j^c < q_j$ and $q_i^c < q_i$. Conversely, both retailers employ a clearance sales strategy to sell all available products when competition is low. In this case, the order quantities are equivalent to sales volumes; specifically, $q_j^c = q_j$, and $q_i^c = q_i$. Under moderate competition, a retailer with a higher order quantity (retailer *j*) adopts a responsive sales strategy, leading to sales volumes lower than the order quantity. Meanwhile, the retailer with the lower-order quantity (retailer *i*) employs a clearance sales strategy, resulting in sales volumes equal to the order quantity; that is, $q_j^c < q_j$, and $q_i^c = q_i$.

Figs. 4 and 5 show the retailers' financial strategies under a unified interest rate ($r = r_0 = r_i = r_j$). We introduce the concept of financial risk, using pre interest profit divided by net profit to represent the financial leverage of retailers and characterizing the financial risk caused by the presence of financial expenses (interest). Owing to the same loan interest rate levels, this subsection distinguishes retailers based on their initial green investment capital levels. Fig. 4 shows the financial risks retailers face at three different initial green investment capital levels. Under specific operating strategies (pricing and ordering), the smaller the initial green investment capital level, the higher the financing ratio, and the greater the financial risk. If financing exists, an enterprise's financial leverage is greater than one. Therefore, when the interest rate is fixed, the smaller the initial green investment capital level, the greater the financial leverage. When the initial green investment capital level is low or moderate, under reasonable interest rate conditions, the financial risk increases with an increase in the interest rate and shows a marginal decrease; when the initial green investment capital level is high, the financing scale is small, and the overall financial leverage is a concave function. At this point, the principal and interest are related to interest rate levels. The former is affected by the wholesale prices and order levels. The supplier's wholesale price decisions should consider the reported interest rate level comprehensively. Under the comprehensive influence of corporate profits and financial expenses, an enterprise's financial risk first increases and then decreases, and a financing interest rate exists that maximizes financial risk.

Fig. 4 shows that suppliers and loan providers influence the financial strategy. In the SCF financing mode, the supplier provides a credit guarantee and has a dual impact on the retailer's operations and financing decisions. Fig. 5 shows the comparative relationship

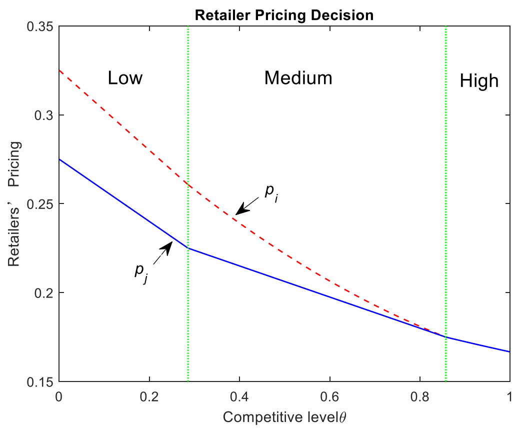

Fig. 2. Retailers' pricing decisions ($a = 0.5$, $b = 0.5$, $q_i = 0.35$, $q_j = 0.45$).

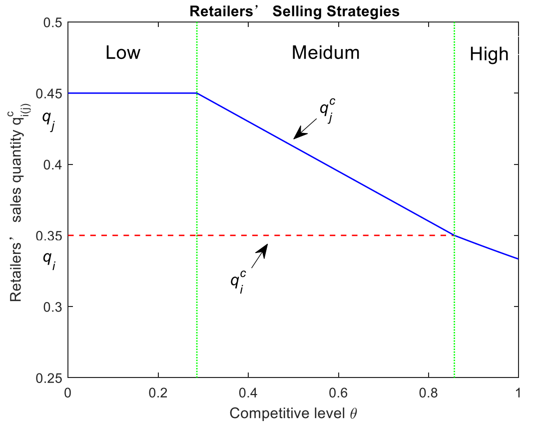

Fig. 3. Retailers' selling strategies ($a = 0.5$, $b = 0.5$, $q_i = 0.35$, $q_j = 0.45$).

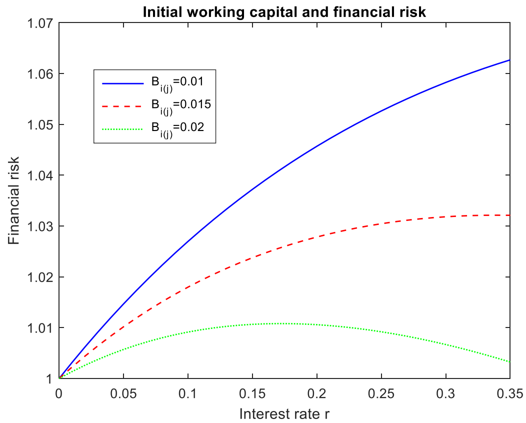

Fig. 4. Retailer's financial risk analysis ($r = r_0 = r_i = r_j$).

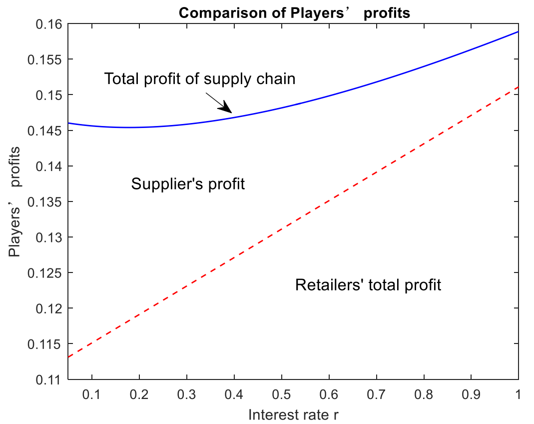

Fig. 5. Comparison of players' profits ($r = r_0 = r_i = r_j$).

between the profits of various participants in the supply chain and the interest rates. Supplier profits show a downward trend with increasing interest rates, namely, a negative correlation is observed between the wholesale price and interest rate level. As interest rates increase, suppliers stimulate retailers to order by reducing the wholesale price and transferring part of the product revenue to downstream retailers, decreasing supplier profit. The overall profit of the retailers shows an upward trend with increasing interest rates, indicating that the operating income generated by a decrease in wholesale prices exceeds the cost caused by an increase in interest expenses. As a result, the scale of retail sales increases, and overall revenue increases. Under this comprehensive effect, the overall revenue of the supply chain first decreases and then increases, demonstrating the feasibility of the GSCF mode. Introducing exogenous capital increases supply chains' overall utility.

When the SCF has an interest rate advantage, that is, $r_0 < min[r_i, r_j]$, Figs. 6 and 7 represent the financing decisions of retailers affected by the initial green investment capital under different r_i and r_j values. Fig. 6(a) shows the profit of retailer i under the four financing combinations ($r_i < r_j$). When the competitor chooses BF, the profit of retailer i is affected by the initial green investment capital. At low levels ($B_i \leq B_2$), retailer i chooses GSCF, while at high levels ($B_i > B_2$), retailer i chooses BF. When the competitor chooses GSCF, BF is always advantageous for retailer i. Overall, retailer i tends to choose GSCF, and the cost advantage of financing the interest rate exceeds the ordering cost advantage brought about by the low wholesale price. In contrast, when retailer i tends to choose BF, the reduced ordering cost value dominates. Fig. 6(b) shows the profit of retailer j under the four financing combinations ($r_i > r_j$). When the competitor chooses BF, retailer j chooses BF as its dominant strategy. When the competitor chooses GSCF, BF is the dominant strategy for retailer j. Overall, the BF is always the best for retailer j. High-order retailers value the advantage of a low wholesale price in the operational process, resulting in higher cost savings than the interest savings brought by GSCF.

By synthesizing the financing decisions of the two retailers in Fig. 6 and combining them with Proposition 6, we obtain a competitive retailer financing portfolio decision under the influence of the initial green investment capital (Fig. 7). At a low initial green investment capital, (GSCF, BF) is a Nash equilibrium solution. At this point, low-order retailer i chooses GSCF. Due to the low initial green investment capital and relatively high financing scale, the retailer enjoys an interest cost advantage, and high-order retailer j decides to borrow from banks and enjoys a lower wholesale price; at a high level of initial green investment capital, the Nash equilibrium solution is (BF, BF). Competitive retailers choose to borrow from banks and give up the interest rate advantage of GSCF. At this time, retailers have higher initial green investment capital, require a smaller loan scale, and are more inclined to enjoy savings in ordering costs because of low wholesale prices.

6. Conclusions

This study presents a model of the ordering and sales decisions of financially constrained retailers operating in a competitive environment. It explores the operational and financial strategies employed by retailers through response and clearance pricing. The analysis of retailers' decision-making under various financing modes yields the following managerial insights.

Under a responsive sales strategy, the retailers' ordering and sales are influenced by the level of competition, which also affects their respective market shares. In a low-competition scenario, a retailer with higher order quantities captures a larger market share. Retailers achieve equal equilibrium order quantities in cases with uniform competitive level distribution under a unified interest rate. Their initial green investment capital influences the retailers' profitability. Furthermore, the supplier incurs no loss in terms of credit guarantees, and both retailers can meet their principal and interest obligations. Suppliers should consider the impact of interest rates when formulating wholesale price contracts. This study underlines the effectiveness of GSCF, emphasizing that suppliers can foster sustainable relationships within the supply chain by supporting financially constrained retailers in implementing GSCF.

When differential interest rates are introduced, retailers' ordering decisions are shaped by the interest rates associated with their chosen financing methods, and the market division is not always equal. Despite an interest rate advantage, retailers do not consistently opt for GSCF. Since financing interest rates also affect the ordering (wholesale) price, retailers make comprehensive decisions that consider operational and financial processes. Specifically, when a lower-order retailer's initial green investment capital is below a specific threshold, the equilibrium financing decision combination is (GSCF, BF). When a lower-order retailer's initial green investment capital exceeds this threshold, the equilibrium financing decision combination becomes (BF, BF). High-order retailers emphasize the cost advantage of ordering, leading to greater cost savings than the interest rate savings provided by GSCF. Bank involvement effectively alleviates supply chain financing issues and enhances overall supply chain operational efficiency. Additionally, the GSCF expansion benefits the scale of banking businesses and contributes to banks' increased competitiveness.

Despite its contributions, this study has limitations that should be considered and addressed in future research. First, our analysis is confined to a two-echelon supply chain with two competitive retailers in a downstream demand market. Multiple levels and complex arrays of members often characterize supply chains. Second, while this study assumes the relative certainty of green initial working capital, in real world scenarios, green investment may be contingent on specific proportions relative to the financing scale, as GSCF might require borrowers to allocate a certain percentage of funds to green investments. Third, our optimization discussions and equilibrium analyses are based on the assumption of common knowledge regarding all model parameters. To enhance the realism of the model, we align our assumptions with actual circumstances observed in practical cases.

Several facets merit attention in future research to advance the discourse on GSCF systems. First, it is crucial to investigate supply chain decision-making processes under uncertain demand and incomplete information conditions. Second, integrating information technology and including green investment costs in our model will be pursued for a more thorough and reliable analysis. Finally, the incorporation of consumer utility into the GSCF system is explored to address the intricacies of retail pricing.

Data availability statement

All relevant data are within the paper.

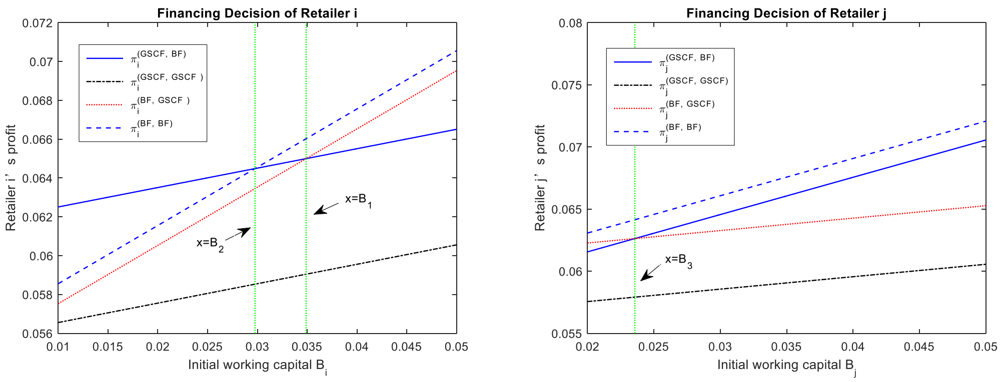

Fig. 6. Financing decisions of retailers ($r_0 < min[r_i, r_j]$). (a) Financing decision of the retailer *i*; (b) Financing decision of the retailer *j*.

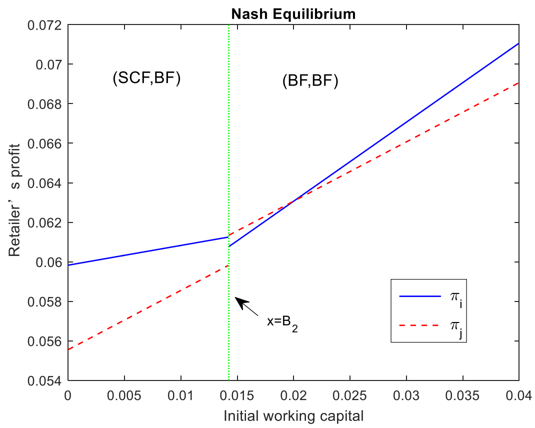

Fig. 7. Financing portfolio decision ($r_0 < min[r_i, r_j]$).

CRediT authorship contribution statement

Jing Huang: Writing – original draft, Validation, Formal analysis, Data curation, Conceptualization. **He Huang:** Writing – original draft, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Yinyuan Si:** Resources, Funding acquisition, Formal analysis, Data curation. **Yuanfei Xu:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Sen Liu:** Writing – review & editing, Resources, Methodology, Investigation, Funding acquisition. **Xuejian Yang:** Visualization, Resources, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Proof of Proposition 1. We can construct the Lagrange equation set for the retailers' revenue equations.

$\begin{cases} L_i = [a - b(q_i^c + \theta q_j^c)]q_i^c + \mu_i q_i^c + \lambda_i(q_i - q_i^c) \\ L_j = [a - b(q_j^c + \theta q_i^c)]q_j^c + \mu_j q_j^c + \lambda_j(q_j - q_j^c) \end{cases}$, where $\mu_i q_i^c = \mu_j q_j^c = \lambda_j(q_j - q_j^c) = 0, \mu_i, \mu_j, \lambda_i, \lambda_j \geq 0$. Taking the first derivative of q_i^c and q_j^c, respectively, $\begin{cases} \dfrac{dL_i}{dq_i^c} = a - b(2q_i^c + \theta q_j^c) + \mu_i - \lambda_i \\ \dfrac{dL_j}{dq_j^c} = a - b(2q_j^c + \theta q_i^c) + \mu_j - \lambda_j \end{cases}$. Using the Kuhn-Tucker condition to solve the problem, there are 9 cases, as follows: (1) When $q_i^c = q_j^c$, we have $\lambda_i = \lambda_j = 0$, $\mu_i = \mu_j = -a < 0$, which contradicts the hypothesis; (2) When $q_i^c = 0$ and $q_j^c \in (0, q_j)$, we have $\lambda_i = \lambda_j = \mu_j = 0$, $q_j^c = \frac{a}{2b}$ and $\mu_i = a\left(\frac{\theta}{2} - 1\right) < 0$, which contradicts the hypothesis; (3) When $q_i^c = 0$ and $q_j^c = q_j$, we have $\lambda_i = \mu_j = 0$, $\lambda_j = a - 2bq_j$ and $\mu_i = -(a - \theta bq_j) < 0$, which contradicts the hypothesis; (4) When $q_i^c \in (0, q_i)$ and $q_j^c = 0$, we have $\lambda_i = \lambda_j = \mu_i = 0$, $\mu_j = a\left(\frac{\theta}{2} - 1\right) < 0$ and $q_i^c = \frac{a}{2b}$, which contradicts the hypothesis; (5) When $q_i^c \in (0, q_i)$ and $q_j^c \in (0, q_j)$, we have $\lambda_i = \lambda_j = \mu_i = \mu_j = 0$, further we obtain $q_i^c = q_j^c = \frac{a}{(2+\theta)b}$, $\theta > \frac{a}{bq_i} - 2$ and $p_i = p_j = \frac{a}{(2+\theta)}$; (6) When $q_i^c \in (0, q_i)$ and $q_j^c = q_j$, we have $\lambda_j = a - bq_j\left(2 + \theta\frac{a - \theta b}{2b}\right)$ and $\lambda_i = \mu_i = \mu_j = 0$, further $(2 - \theta)[a - bq_j(2 + \theta)] > 0$,combining $q_i^c = \frac{a - \theta bq_j}{2b}$,we have $q_i^c - q_j^c = \frac{a - (2+\theta)bq_j}{2b} > 0$, which contradicts the hypothesis $q_j^c = q_j > q_i > q_i^c$; (7) When $q_i^c = q_i^c$ and $q_j^c = 0$, we have $\lambda_j = \mu_i = 0$, $\lambda_i = a - 2bq_i$ and $\mu_j = -(a - \theta bq_i) < 0$, which contradicts the hypothesis; (8) When $q_i^c = q_i$ and $q_j^c \in (0, q_j)$, we have $\lambda_i = \frac{(2-\theta)}{2}[a - bq_i(2 + \theta)] > 0$ and $\lambda_j = \mu_i = \mu_j = 0$, further we obtain $q_j^c = \frac{1}{2}\left(\frac{a}{b} - \theta q_i\right)$, $\theta \in \left(\frac{1}{q_i}\left(\frac{a}{b} - 2q_j\right), \frac{a}{bq_i} - 2\right]$, $p_i = \frac{a}{2}(2 - \theta) - \frac{bq_i}{2}(2 - \theta^2)$, $p_j = \frac{1}{2}(a - \theta bq_i)$; (9) When $q_i^c = q_i$ and $q_j^c = q_j$, we have $\mu_i = \mu_j = 0$, $\lambda_i = a - b(2bq_i + \theta q_j)$ and $\lambda_j = a - b(2q_j + \theta q_i)$, combining $\lambda_i, \lambda_j \geq 0$ and $\theta \leq 1$, we have $\theta \leq \frac{1}{q_i}\left(\frac{a}{b} - 2q_j\right)$, also $p_i = a - b(q_i + \theta q_j)$, $p_j = a - b(q_j + \theta q_i)$. In summary, we have retailers' selling strategy on the competition level: $\begin{cases} q_i^c = \dfrac{a}{(2+\theta)b} & q_j^c = \dfrac{a}{(2+\theta)b} & \theta \in \left(\dfrac{a}{bq_i} - 2, 1\right] \\ q_i^c = q_i & q_j^c = \dfrac{1}{2}\left(\dfrac{a}{b} - \theta q_i\right) & \theta \in \left(\dfrac{1}{q_i}\left(\dfrac{a}{b} - 2q_j\right), \dfrac{a}{bq_i} - 2\right] \\ q_i^c = q_i & q_j^c = q_j & \theta \in \left[0, \dfrac{1}{q_i}\left(\dfrac{a}{b} - 2q_j\right)\right] \end{cases}$; The pricing strategy: $\begin{cases} p_i = \dfrac{a}{2+\theta} & p_j = \dfrac{a}{2+\theta} & \theta \in \left(\dfrac{a}{bq_i} - 2, 1\right] \\ p_i = \dfrac{a}{2}(2 - \theta) - \dfrac{bq_i}{2}(2 - \theta^2) & p_j = \dfrac{1}{2}(a - \theta bq_i) & \theta \in \left(\dfrac{1}{q_i}\left(\dfrac{a}{b} - 2q_j\right), \dfrac{a}{bq_i} - 2\right] \\ p_i = a - b(q_i + \theta q_j) & p_j = a - b(q_j + \theta q_i) & \theta \in \left[0, \dfrac{1}{q_i}\left(\dfrac{a}{b} - 2q_j\right)\right] \end{cases}$. For the intervals of competition level $\theta \in [0, 1]$, we know that thresholds $\frac{1-2q_i}{q_i}$ and $\frac{1-2q_j}{q_i}$ belong to [0,1]. Consequently, we have $q_i, q_j \in \left[\frac{a}{3b}, \frac{a}{2b}\right]$.□

Proof of Corollary 1. During the selling season, retailers make their retail prices separately, compare the sales scales of the two retailers. When $\theta \in \left(\frac{a}{bq_i} - 2, 1\right]$, the two retailers have equal selling quantities; therefore $\Pi_i = \Pi_j$. When $\theta \in \left(\frac{1}{q_i}\left(\frac{a}{b} - 2q_j\right), \frac{a}{bq_i} - 2\right]$, $\Pi_i - \Pi_j = (q_i^c - q_j^c)[a - b(q_i^c + q_j^c)]$, since $a - b(q_i^c + q_j^c) > 0$, $q_i^c - q_j^c = q_i - \frac{1}{2}\left(\frac{a}{b} - \theta q_i\right) \leq q_i - \frac{1}{2}\left[\frac{a}{b} - \left(\frac{a}{bq_i} - 2\right)q_i\right] = 0$,we have $\Pi_i \leq \Pi_j$.When $\theta \in \left[0, \frac{1}{q_i}\left(\frac{a}{b} - 2q_j\right)\right]$, we have $\Pi_i - \Pi_j = (q_i - q_j)[a - b(q_i + q_j)] \leq 0$.To sum up, when $\theta \in \left(\frac{a}{bq_i} - 2, 1\right]$, we have $\Pi_i = \Pi_j$; when $\theta \in \left[0, \frac{a}{bq_i} - 2\right]$, we have $\Pi_i \leq \Pi_j$. □

Proof of Proposition 2. Taking the retailer's equilibrium selling and pricing decisions into the expected profit function, and combining it with the competition level, we can obtain retailer i's profit as follows: $\pi_i = \left[\int_{\frac{a}{bq_i}-2}^{1} \frac{a^2}{(2+\theta)^2 b} dF(\theta) + \int_0^{\frac{1}{q_i}\left(\frac{a}{b}-2q_j\right)} [a - b(q_i + q_j)] dF(\theta) + \int_{\frac{1}{q_i}\left(\frac{a}{b}-2q_j\right)}^{\frac{a}{bq_i}-2} \left[a - bq_i - \frac{\theta}{2}(a - \theta bq_i)\right] dF(\theta)\right] - wq_i(1 + r) + B_i r$, s.t. $q_i \in [0, q_j]$. Simplifying the above equation, we have the following: $\pi_i = \frac{1}{12}\frac{b}{q_i}\left[\left(\frac{a}{b} - 2q_j\right)^3 - \left(\frac{a}{b} - 2q_i\right)^3\right] + \frac{a^2}{6b} - wq_i(1 + r) + B_i r$, s.t. $q_i \in [0, q_j]$. Similarly, we have retailer j's expected profit is as follows: $\pi_j = \frac{1}{12}\frac{b}{q_i}\left[\left(\frac{a}{b} - 2q_i\right)^3 - \left(\frac{a}{b} - 2q_j\right)^3\right] + \frac{a^2}{6b} - wq_j(1 + r) + B_j r$, s.t. $q_j \geq q_i$. We can construct the Lagrange equation set for the retailers' expected profit as follows: $\begin{cases} L_i = \pi_i + \mu_i q_i + \lambda_i(q_j - q_i) \\ L_j = \pi_j + \mu_j(q_j - q_i) \end{cases}$, where $\mu_i q_i = \lambda_i(q_j - q_i) = \mu_j(q_j - q_i) = 0, \mu_i, \mu_j, \lambda_i \geq 0$. Taking the first derivative of equation set as follows: $\begin{cases} \dfrac{dL_i}{dq_i} = \dfrac{1}{12}\dfrac{b}{q_i^2}\left[\left(\dfrac{a}{b} + 4q_i\right)\left(\dfrac{a}{b} - 2q_i\right)^2 - \left(\dfrac{a}{b} - 2q_j\right)^3\right] - w(1 + r) + \mu_i - \lambda_i \\ \dfrac{dL_j}{dq_j} = \dfrac{1}{2}\dfrac{b}{q_i}\left(\dfrac{a}{b} - 2q_j\right)^2 - w(1 + r) + \mu_j \end{cases}$. Using Kuhn-Tucker condition to solve the problem, there are two cases, as follows: (1) When $q_i \in (0,\ q_j)$, we have $\lambda_i = \mu_i = \mu_j = 0$, $\begin{cases} \dfrac{dL_i}{dq_i} > \dfrac{1}{2}\dfrac{b}{q_i}\left(\dfrac{a}{b} - 2q_i\right)^2 - w(1+r) \\ \dfrac{dL_j}{dq_j} < \dfrac{1}{2}\dfrac{b}{q_i}\left(\dfrac{a}{b} - 2q_i\right)^2 - w(1+r) \end{cases}$, which contradicts the hypothesis $\frac{dL_i}{dq_i} = \frac{dL_j}{dq_j} = 0$; (2) When $q_i = q_j$, we have $\mu_i = 0$, $\lambda_i, \mu_j \geq 0$, we obtain $\begin{cases} \lambda_i = \dfrac{1}{2}\dfrac{b}{q_i}\left(\dfrac{a}{b} - 2q_i\right)^2 - w(1+r) \geq 0 \\ \mu_j = \dfrac{1}{2}\dfrac{b}{q_i}\left(\dfrac{a}{b} - 2q_i\right)^2 - w(1+r) \geq 0 \end{cases}$. The condition for the inequality set to hold is that the equation holds, that is $\frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 = w(1+r)$. At this point, the equilibrium order quantity satisfies $q_i^* = \frac{w(1+r)+2a\pm\sqrt{[w(1+r)]^2+4aw(1+r)}}{4b}$. If $q_i^* = \frac{w(1+r)+2a+\sqrt{[w(1+r)]^2+4aw(1+r)}}{4b}$, the product price in a fully competitive state meets $p_i = a - 2bq_i < 0$, this solution does not hold. To sum up, equilibrium ordering $q_i^* = q_j^* = \frac{w(1+r)+2a-\sqrt{[w(1+r)]^2+4aw(1+r)}}{4b}$. □

Proof of Corollary 2. In equilibrium, retailers' profits are $\begin{cases} \pi_i = \dfrac{a^2}{6b} - wq_i^*(1+r) + B_i r \\ \pi_j = \dfrac{a^2}{6b} - wq_i^*(1+r) + B_j r \end{cases}$. By comparison, when $B_i > B_j$, we have $\pi_i > \pi_j$, and retailer i has a higher profit. When $B_i < B_j$, we have $\pi_i < \pi_j$, and retailer j has a higher profit. When $B_i = B_j$, the two retailers have equal profits. □

Proof of Corollary 3. It can be obtained from $q_i^* = \frac{w(1+r)+2a-\sqrt{[w(1+r)]^2+4aw(1+r)}}{4b}$: $\frac{dq_i^*}{dw} = \frac{(1+r)}{4b}\frac{\sqrt{[w(1+r)]^2+4aw(1+r)}-[w(1+r)+2a]}{\sqrt{[w(1+r)]^2+4aw(1+r)}} < 0$, $\frac{dq_i^*}{dr} = \frac{w}{4b}\frac{\sqrt{[w(1+r)]^2+4aw(1+r)}-[w(1+r)+2a]}{\sqrt{[w(1+r)]^2+4aw(1+r)}} < 0$, $\frac{dq_i^*}{da} = \frac{\sqrt{w(1+r)+4a}-\sqrt{w(1+r)}}{2b\sqrt{w(1+r)+4a}} > 0$, $\frac{dq_i^*}{db} = \frac{w(1+r)+2a-\sqrt{[w(1+r)]^2+4aw(1+r)}}{4b^2} < 0$. □

Proof of Corollary 4. From the expression of loss cost, combined with the retailer's expected profit function, the loss cost can be rewritten as: $loss = \max[-\pi_i - B_i, 0] + max[-\pi_j - B_j, 0]$. From Proposition 2, we have $q_i = q_j$ and $\frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 = w(1+r)$ in equilibrium state, the expected profits are: $\begin{cases} \pi_i = \dfrac{a^2}{6b} - \dfrac{b}{2}\left(\dfrac{a}{b} - 2q_i\right)^2 + B_i r \\ \pi_j = \dfrac{a^2}{6b} - \dfrac{b}{2}\left(\dfrac{a}{b} - 2q_i\right)^2 + B_j r \end{cases}$. From Proposition 1 we have $\frac{a}{b} - 2q_i \in \left[0, \frac{a}{3b}\right]$, $\frac{a^2}{6b} - \frac{b}{2}\left(\frac{a}{b} - 2q_i\right)^2 \in \left[\frac{a^2}{9b}, \frac{a^2}{6b}\right]$, therefore, both π_i and π_j are greater than 0, so $loss = 0$, the supplier's loss cost is 0. □

Proof of Proposition 3. From Equation (7) and Proposition 2, we have $\pi_s^* = \frac{1}{4b}(w-c)\left(\sqrt{w(1+r)+4a} - \sqrt{w(1+r)}\right)^2$, taking the first derivative on wholesale price as follows: $\frac{d\pi_s^*}{dw} = \frac{1}{4b}\left(\frac{\sqrt{w(1+r)+4a}-\sqrt{w(1+r)}}{\sqrt{w(1+r)[w(1+r)+4a]}}\right)^2\left[\sqrt{w(1+r)[w(1+r)+4a]} - (w-c)(1+r)\right]$. Setting $A(w) = \sqrt{w(1+r)[w(1+r)+4a]}$, $B(w) = (w-c)(1+r)$, it can be seen that both $A(w)$ and $B(w)$ are greater than 0, combining with $w > c$, $A^2(w) - B^2(w) = 4aw(1+r) + 2wc(1+r)^2 - c^2(1+r)^2 > 4ac(1+r) + c^2(1+r)^2 > 0$. Then $\frac{d\pi_s^*}{dw} > 0$, there is a positive correlation between supplier equilibrium profit and wholesale price. For the value range of wholesale price, firstly $w > c$, the wholesale price is greater than the production cost of the product. Synthesize proposition 1 $q_i \in \left[\frac{a}{3b}, \frac{a}{2b}\right]$ and Proposition 2 $\frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 = w(1+r)$, solving the value range of wholesale prices, $\frac{dw}{dq_i} = -\frac{b}{2(1+r)}\frac{\frac{a}{b}+2q_i}{q_i^2}\left(\frac{a}{b} - 2q_i\right) < 0$. when $q_i = \frac{a}{3b}$, there is an optimal solution for wholesale price, $w^* = \frac{a}{6(1+r)}$, $\pi_s^* = \frac{2a}{3b}\left[\frac{a}{6(1+r)} - c\right]$. □

Proof of Proposition 4. Calculate the order quantity and profit of retailer under four combinations. **Case 1** (SCF,BF): Retailer i choose SCF with interest rate r_0 and retailer j choose BF with interest rate r_j, we can write the retailers' expected profit: $\begin{cases} \pi_i = \dfrac{1}{12}\dfrac{b}{q_i}\left[\left(\dfrac{a}{b} - 2q_j\right)^3 - \left(\dfrac{a}{b} - 2q_i\right)^3\right] + \dfrac{a^2}{6b} - wq_i(1+r_0) + B_i r_0 \\ \pi_j = \dfrac{1}{12}\dfrac{b}{q_i}\left[\left(\dfrac{a}{b} - 2q_i\right)^3 - \left(\dfrac{a}{b} - 2q_j\right)^3\right] + \dfrac{a^2}{6b} - wq_j(1+r_j) + B_j r_j \end{cases}$. Construct the Lagrange equation set as follows, $\begin{cases} L_i = \pi_i + \mu_i q_i + \lambda_i(q_j - q_i) \\ L_j = \pi_j + \mu_j(q_j - q_i) \end{cases}$, taking the first derivative of equation set, $\begin{cases} \dfrac{dL_i}{dq_i} = \dfrac{1}{12}\dfrac{b}{q_i^2}\left[\left(\dfrac{a}{b} + 4q_i\right)\left(\dfrac{a}{b} - 2q_i\right)^2 - \left(\dfrac{a}{b} - 2q_j\right)^3\right] - w(1+r_0) + \mu_i - \lambda_i \\ \dfrac{dL_j}{dq_j} = \dfrac{1}{2}\dfrac{b}{q_i}\left(\dfrac{a}{b} - 2q_j\right)^2 - w(1+r_j) + \mu_j \end{cases}$, using Kuhn-Tucker condition to solve the problem, there are two cases, as follows: (1) When $q_i \in (0, q_j)$, we have $\lambda_i = \mu_i = \mu_j = 0$, $\begin{cases} \frac{dL_i}{dq_i} > \frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 - w(1+r_0) \\ \frac{dL_j}{dq_j} < \frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 - w(1+r_j) \\ \quad < \frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 - w(1+r_0) \end{cases}$, which contradicts the hypothesis $\frac{dL_i}{dq_i} = \frac{dL_j}{dq_j} = 0$; (2) When $q_i = q_j$, we have $\mu_i = 0$, $\lambda_i, \mu_j \geq 0$, we obtain $\begin{cases} \lambda_i = \frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 - w(1+r_0) \geq 0 \\ \mu_j = \frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 - w(1+r_j) \geq 0 \end{cases}$, combing $r_0 < r_j$, we have $\frac{1}{2}\frac{b}{q_i}\left(\frac{a}{b} - 2q_i\right)^2 \in [w(1+r_0), w(1+r_j)]$. Rewrite the above inequality $\left(2bq_i + \frac{a^2}{2bq_i}\right) \in [w(1+r_0) + 2a, w(1+r_j) + 2a]$. Suppose $x = 2bq_i, f(x) = x + \frac{a^2}{x}$. Taking the first and second derivative of a function on $\left[\frac{2}{3}a, a\right]$, we have $f'(x) = 1 - \frac{a^2}{x^2} < 0, f''(x) = \frac{3a^2}{x^3} > 0$. Based on the value range of $f(x)$ and the expected profit expressions, we have $q_i^* = q_j^* = \frac{w(1+r_j)+2a-\sqrt{[w(1+r_j)]^2+4aw(1+r_j)}}{4b}$. **Case 2** (SCF, SCF): similar to Case 1, we have $q_i^* = q_j^* = \frac{w(1+r_0)+2a-\sqrt{[w(1+r_0)]^2+4aw(1+r_0)}}{4b}$. **Case 3** (BF, SCF): similar to Case 1, we have $q_i^* = \frac{w(1+r_i)+2a-\sqrt{[w(1+r_i)]^2+4aw(1+r_i)}}{4b}$, combing with $\frac{dL_j}{dq_j} = 0$, we can obtain $q_j^* = \frac{a}{2b} - \sqrt{\frac{wq_i^*(1+r_0)}{2b}}$. **Case 4** (BF, BF): similar to case 1, (1) When $q_i \in (0, q_j)$ and $r_i > r_j$, the equilibrium ordering quantities are $q_i^* = \frac{w(1+r_i)+2a-\sqrt{[w(1+r_i)]^2+4aw(1+r_i)}}{4b}$, $q_j^* = \frac{a}{2b} - \sqrt{\frac{wq_i^*(1+r_j)}{2b}}$; (2) When $q_i = q_j$ and $r_i \leq r_j$, we have $q_i^* = q_j^* = \frac{w(1+r_j)+2a-\sqrt{[w(1+r_j)]^2+4aw(1+r_j)}}{4b}$. To sum up (1) and (2), we can obtain the equilibrium solutions on Case 4, $q_i^* = \frac{w(1+max[r_i,r_j])+2a-\sqrt{[w(1+max[r_i,r_j])]^2+4aw(1+max[r_i,r_j])}}{4b}$, $q_j^* = \frac{a}{2b} - \sqrt{\frac{wq_i^*(1+r_j)}{2b}}$. □

Proof of Proposition 6. Calculate the expected returns of each retailer under four types of financing combinations, and then conduct a comparative analysis. Combining the results of Proposition 4 and Proposition 5, we first compare the retailer i's financing decisions under four types of financing combinations. For Case 1 (SCF,BF), we have $\pi_i^{(SCF,BF)} = \frac{a^2}{6b} - w^{(SCF,BF)}q_i(1+r_0) + B_ir_0$, for Case 2 (SCF, SCF), we have $\pi_i^{(SCF,SCF)} = \frac{a^2}{6b} - w^{(SCF,SCF)}q_i(1+r_0) + B_ir_0$, for Case 3 (BF, SCF), we have $\pi_i^{(BF,SCF)} = \frac{1}{12}\frac{b}{q_i}\left(\frac{a}{b} - 2q_j^{(BF,SCF)}\right)^3 + \frac{11a}{36}q_i + B_ir_i$, for Case 4 (BF,BF), we have $\pi_i^{(BF,BF)} = \frac{1}{12}\frac{b}{q_i}\left(\frac{a}{b} - 2q_j^{(BF,BF)}\right)^3 + \frac{11a}{36}q_i + B_ir_i$. (1) Compare the expect profit of case 1 and case 2, the profit size is related to the wholesale price, $w^{(SCF,BF)}$ and $w^{(SCF,SCF)}$, profit is small if the wholesale price is high, i.e. $\pi_i^{(SCF,BF)} > \pi_i^{(SCF,SCF)}$. (2) Compare the expect profit of case 3 and case 4, the profit size is related to retailer j's ordering. $q_j^{(BF,SCF)} = \frac{a}{2b} - \frac{a}{6b}\sqrt{\frac{(1+r_0)}{(1+r_i)}}$, $q_j^{(BF,BF)} = \frac{a}{2b} - \frac{a}{6b}\sqrt{\frac{(1+r_j)}{(1+max[r_i,r_j])}}$. Profit is small if the ordering quantity is large, then we need to compare these two orders $q_j^{(BF,SCF)} - q_j^{(BF,BF)} = \frac{a}{6b}\left[\sqrt{\frac{(1+r_j)}{(1+max[r_i,r_j])}} - \sqrt{\frac{(1+r_0)}{(1+r_i)}}\right]$. When $r_i > r_j$, $max[r_i, r_j] = r_i$, $q_j^{(BF,SCF)} - q_j^{(BF,BF)} > 0$; when $r_i \leq r_j$, $max[r_i, r_j] = r_j$, $q_j^{(BF,SCF)} - q_j^{(BF,BF)} > 0$, further we obtain $\pi_i^{(BF,SCF)} > \pi_i^{(BF,BF)}$. (3) Compare the expect profit of case 1 and case 3, the profit size is related to the boundary initial working capital $B_1 = \frac{aq_i(r_j-r_0)}{6(1+r_j)(r_i-r_0)}$. Combining expected profits $\pi_i^{(SCF,BF)} - \pi_i^{(BF,SCF)} = \frac{aq_i(r_j-r_0)}{6(1+r_j)} + B_i(r_0 - r_i)$, when $B_i \leq B_1$, we have $\pi_i^{(SCF,BF)} \geq \pi_i^{(BF,SCF)}$; when $B_i > B_1$, we have $\pi_i^{(SCF,BF)} < \pi_i^{(BF,SCF)}$. (4) Compare the expect profit of case 1 and case 4, the profit size is related to the boundary initial working capital $B_2 = \frac{aq_i(2\ min(r_i,r_j)-r_j-r_0)}{6(1+r_j)(r_i-r_0)}$. Combining with $\pi_i^{(SCF,BF)} - \pi_i^{(BF,BF)} = \frac{aq_i(2\ min[r_i,r_j]-r_j-r_0)}{6(1+r_j)} + B_i(r_0 - r_i)$, when $B_i \leq B_2$, we have $\pi_i^{(SCF,BF)} \geq \pi_i^{(BF,BF)}$; when $B_i > B_2$, we have $\pi_i^{(SCF,BF)} < \pi_i^{(BF,BF)}$. (5) Compare the expect profit of case 2 and case 3, substitute the expressions of wholesale prices and ordering quantity into the expected profit functions, we can obtain $\pi_i^{(SCF,SCF)} - \pi_i^{(BF,SCF)} = B_i(r_0 - r_i) < 0$, i.e. $\pi_i^{(SCF,SCF)} < \pi_i^{(BF,SCF)}$. (6) Compare the expect profit of case 2 and case 4, substitute the expressions of wholesale prices and ordering quantity into the expected profit functions, we can obtain $\pi_i^{(SCF,SCF)} - \pi_i^{(BF,BF)} = \frac{aq_i}{3}\left[\frac{(1+r_i)}{(1+max[r_i,r_j])} - 1\right] + B_i(r_0 - r_i) < 0$, i.e. $\pi_i^{(SCF,SCF)} < \pi_i^{(BF,BF)}$. Based on the above six scenarios, we can draw the following conclusions: (1) when $B_i \leq B_2$, we have $\pi_i^{(SCF,SCF)} < \pi_i^{(BF,SCF)} < \pi_i^{(BF,BF)} < \pi_i^{(SCF,BF)}$; (2) when $B_i \in (B_2, B_1]$, we have $\pi_i^{(SCF,SCF)} < \pi_i^{(BF,SCF)} \leq \pi_i^{(SCF,BF)} < \pi_i^{(BF,BF)}$; (3) when $B_i > B_1$, we have $\pi_i^{(SCF,SCF)} < \pi_i^{(SCF,BF)} < \pi_i^{(BF,SCF)} < \pi_i^{(BF,BF)}$. Then we compare the retailer j's financing decisions under four types of financing combinations. Similarly, we set a threshold initial working capital $B_3 = \frac{aq_i}{6(r_j-r_0)}\left[1 - \frac{1(1+r_0)}{2(1+r_i)}\left(3 - \sqrt{\frac{(1+r_0)}{(1+r_i)}}\right)\right]$, compare the expected profit of 4 cases, we can draw the following conclusions: (1) when $B_j \leq B_3$, we have $\pi_j^{(SCF,SCF)} < \pi_j^{(SCF,BF)} \leq \pi_j^{(BF,SCF)} < \pi_j^{(BF,BF)}$; (2) when $B_j > B_3$, we have $\pi_j^{(SCF,SCF)} < \pi_j^{(BF,SCF)} < \pi_j^{(SCF,BF)} \leq \pi_j^{(BF,BF)}$. Next, we will discuss the Nash equilibrium strategy of financing system. We will divide the discussion into two parts based on the interval of B_2. (1) $B_i \leq B_2$. When retailer i chooses SCF, since $\pi_j^{(SCF,SCF)} < \pi_j^{(SCF,BF)}$, retailer j will choose BF; when retailer i chooses BF, since $\pi_j^{(BF,SCF)} < \pi_j^{(BF,BF)}$, retailer j will choose BF. When retailer j chooses SCF, since

$\pi_i^{(SCF,SCF)} < \pi_i^{(BF,SCF)}$, retailer i will choose BF; when retailer j chooses BF, since $\pi_i^{(BF,BF)} < \pi_i^{(SCF,BF)}$, retailer i will choose SCF. To sum up, there exists a pure strategy Nash equilibrium solution in the game process, i.e. (SCF, BF). (2) $B_i > B_2$. When retailer i chooses SCF, since $\pi_j^{(SCF,SCF)} < \pi_j^{(SCF,BF)}$, retailer j will choose BF; when retailer i chooses BF, since $\pi_j^{(BF,SCF)} < \pi_j^{(BF,BF)}$, retailer j will choose BF. When retailer j chooses SCF, since $\pi_i^{(SCF,SCF)} < \pi_i^{(BF,SCF)}$, retailer i will choose BF; when retailer j chooses BF, since $\pi_i^{(SCF,BF)} < \pi_i^{(BF,BF)}$, retailer i will choose BF. To sum up, there exists a pure strategy Nash equilibrium solution in the game process, i.e. (BF, BF). □

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