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Research article

To provide or not? The financing strategy in the automotive supply chain under asymmetric information

Shanshan Xie[1,2,*], **Jiamuyan Xie**[3] **and Zhixian Zeng**[4]

[1] College of Economics and Trade, Hunan University, Changsha 410079, China

[2] School of Economics and Management, Hunan University of Technology, Zhuzhou 412007, China

[3] Business School, Hunan First Normal University, Changsha 410205, China

[4] Leiyang Branch, Hengyang Tobacco Company, Hunan Tobacco Corporation, Hengyang 421008, China

* **Correspondence:** Email: shanshanxie@hut.edu.cn.

Abstract: This study investigates a supply chain involving a financially capable automobile manufacturer with access to demand information and a resource-limited dealer. The well-capitalized manufacturer holds the authority to determine whether to provide dealer financing. If financing is not offered by the manufacturer, a wholesale price contract is executed, compelling the dealer to seek bank financing. Otherwise, if financing is provided, a trade credit contract is signed, and the dealer will typically opt for the manufacturer's seller financing scheme. By developing a signaling model, this paper analyzes the manufacturer's and the dealer's optimal financing strategies under scenarios of demand information symmetry and asymmetry. The findings show that the manufacturer is more inclined to provide financing, while the dealer's financing strategy is significantly influenced by its initial capital level, potentially leading to financing conflicts under information symmetry. Conversely, under information asymmetry, the financing decisions of both the manufacturer and dealer are considerably affected by market interest rates, further exacerbating financing conflicts within a certain range. Notably, the transformation in financing choices primarily stems from the inference effects induced by the manufacturer's transmission of demand signals, which have adverse effects on the manufacturer while benefiting the dealer.

Keywords: supply chain management; information asymmetry; contract; supply chain financing; signaling game
Mathematics Subject Classification: 90B06

1. Introduction

Within the last few years, the global automotive industry has demonstrated rapid growth [1, 2]. In China, for example, the latest statistics show that in 2024, the production and sales volumes of automobiles increased to 31.282 million units and 31.436 million units, respectively, with the market share of new energy vehicles (NEVs) reaching 40.1% [3]. Against this market backdrop, new entrants in the automotive industry have been actively capturing market share through price competition strategies, and traditional automakers have also had to join the price war to maintain their market competitiveness [4]. Specifically, in 2024, the average price reduction for new NEVs in China was 18,000 yuan, with a reduction ratio of 9.2%; the average price reduction for new conventional gasoline vehicles was 13,000 yuan, with a reduction ratio of 6.8% [5]. This price war has brought significant financial pressure on automotive dealers, who urgently need effective capital operation solutions [6]. Facing capital constraints, automotive dealers typically choose two main financing channels: bank financing and seller financing [7]. Taking Yongda Group as an example, the company has obtained financial support for vehicle procurement and operations through a long-term bank-enterprise cooperative relationship with the China Construction Bank [8]. Meanwhile, an increasing number of automotive dealers are beginning to expand the use of seller financing [9]. SAIC Motor provides trade credit support to Shenxiang Auto Group through its financial services subsidiary, effectively alleviating the dealers' working capital pressure. This financing method is common in developing countries and emerging economies [10]. From an academic research perspective, scholars have explored this phenomenon from different dimensions: [11] analyzed why manufacturers still offer trade credit when bank financing is available, from the perspective of whether the seller provides financing. Subsequent studies have examined the optimal strategy for capital-constrained firms to choose between bank and seller financing, focusing on buyers' financing decisions under symmetric information conditions [12, 13].

Automotive dealers not only face the challenge of capital shortages in their operations but also bear the pressure of insufficient market insights due to information asymmetry [14]. This is especially the case during the initial launch of new vehicles, as manufacturers generally possess a superior understanding of market demand compared to dealers [15]. This phenomenon arises because manufacturers allocate significant resources to market research during the product development phase, ensuring that designs are strategically aligned with consumer needs [16, 17]. For instance, China FAW Group precisely identified market demand by conducting in-depth consumer studies during the early development stages of vehicle models, enabling informed decisions particularly regarding vehicle configurations and power systems [18]. Some dealers may struggle to fully grasp the varied requirements of customers, leading to lagging vehicle configuration adjustments and thus causing a disconnection between services and market demands [19]. Information asymmetry not only affects the supply chain's overall efficiency but can also result in inventory issues such as overstock or shortages, ultimately undermining the supply chain's competitive advantage [16]. It is important to emphasize that market demand insights within the supply chain serve as a crucial resource for businesses and a vital foundation for strategic decisions [20, 21]. In other industries, such as the smartphone manufacturing sector, Xiaomi has achieved dynamic adjustments in production plans by sharing real-time market demand data, effectively mitigating product surpluses resulting from market fluctuations. Consequently, the challenge of demand information asymmetry between manufacturers and dealers warrants thorough investigation.

While existing literature has studied these issues in isolation, the interaction between financing choice and demand signaling under manufacturer-held information remains unexplored. We aim to explore the manufacturer's inclination to offer financing under demand information asymmetry, as well as the dealer's financial decision-making when presented with both bank and seller financing options. Specifically, we construct two scenarios: one where the manufacturer does not provide financing, and another where the manufacturer does provide financing. In the scenario where the manufacturer opts not to extend financing, the dealer can only meet its funding needs through bank financing. Relevant studies [22] have pointed out that when bank financing is adopted, the manufacturer's wholesale price contract can act as a tool for signaling market demand information. Additionally, existing research [23] has shown that trade credit contracts also have the function of signaling market information. This study examines the introduction phase of new automotive products into the market and highlights how the manufacturer leverages its demand information advantage to signal market insights to dealers via wholesale price contracts and trade credit contracts. It also evaluates optimal financial strategies for the manufacturer and the dealer. This study aims to explore the following three key questions:

(1) What are the optimal financing decisions for both the manufacturer and the dealer under symmetric demand information?

(2) Under demand information asymmetry, with the dealer interpreting market signals, what are the optimal financing decisions for both the manufacturer and the dealer?

(3) How does the asymmetry of demand information influence the optimal choices for both the manufacturer and the dealer?

To address these three issues, we construct a dynamic signaling game framework involving a manufacturer with an in-depth understanding of market demand information (she) and a dealer with financial constraints (he), wherein the dealer procures automotive products from the manufacturer for resale to end consumers. In the model, the manufacturer begins by deciding whether to offer the dealer financial support and then proceeds to choose between wholesale price contracts and trade credit contracts. After observing the manufacturer's contract choice, the dealer decides whether to adopt bank financing or seller financing and then adjusts the retail price optimally based on this selection. Finally, the dealer sells the products to the end market.

Our study makes several key contributions. First, we extend the research on supply chain financing decisions, particularly by introducing a novel theoretical framework for designing financing mechanisms in financially constrained supply chains under demand information asymmetry. Second, while existing literature on supply chain contracts has largely focused on operational coordination and risk sharing, studies incorporating information asymmetry have mainly emphasized incentive design to mitigate moral hazard, often overlooking the role of contracts as a means of information transmission. This paper innovatively demonstrates that both wholesale price contracts and trade credit contracts can serve as effective tools for the manufacturers to signal demand to the dealer, thereby highlighting the strategic value of contracts in information revelation. Finally, unlike the traditional literature that mainly examines financing conflicts under symmetric information, this paper anchors its analysis in the realistic context of asymmetric demand information, identifies the roots of financing conflicts, and proposes concrete solutions from a practical standpoint, offering strong practical implications.

2. Literature review

The literature relevant to this study primarily focuses on supply chain finance and signal models under asymmetric demand information. Specifically, scholars have conducted in-depth research in these areas, accumulating substantial research outcomes.

2.1. Supply chain finance

The majority of researchers analyze financing strategies in the capital-constrained supply chain under an information-symmetric environment. For example, Goyal [24] established a seller financing model to study the optimal order quantity and interval for constrained retailers under financial limitations. Protopappa-Sieke and Seifert [25] studied the influence of financial strategies and operational tactics on supply chain performance, revealing that deferred payment increases by upstream firms or decreases by downstream firms aid in reducing corporate operating expenses. Kouvelis and Zhao [13] assumed that both retailers and manufacturers may be subject to capital constraints and showed that optimally priced seller financing is cheaper than traditional bank financing. This arrangement can motivate the retailers to increase order volumes, thereby enhancing supply chain efficiency. Jing et al. [26] believe that when manufacturing costs are low, both the manufacturer and the supply chain are more inclined to choose bank financing; otherwise, seller financing should be selected. Chen [27] compared the differences between seller financing and bank financing under revenue sharing contracts and wholesale price contracts and found that revenue sharing contracts under both seller financing and bank financing can achieve supply chain coordination, where seller financing demonstrates greater benefits compared to bank financing under price contracts. Yang and Birge [28] proposed a comprehensive inventory financing strategy that integrates financial instruments such as cash reserves, trade credit facilities, and short-term borrowings. Zhang et al. [29] compared the traditional credit-guarantee scheme with a data-element guarantee scheme and found that the latter significantly lowered the loan costs while simultaneously improving financing efficiency and transparency. These studies, however, assume perfect information sharing, a condition often violated in practice, as shown by the signaling literature we turn to next. This realization brings into focus the central concern of this paper. Against this background, a number of scholars have begun to shift their attention to seller financing issues under asymmetric information. Wang et al. [30] studied the effect of trade credit contracts on incentives within the supply chain involving a manufacturer and a retailer with differing risk preferences while accounting for the retailer's exclusive knowledge regarding sales costs. Cao and Wang [31] studied the optimal strategies of supply chain participants when both guarantee contract financing (GCF) and seller financing (TCF) were feasible under asymmetric demand information. Fu et al. [20] found that under trade credit conditions, when demand fluctuated significantly, capital-constrained retailers with superior demand information would share private demand information with manufacturers. Existing literature on supply chain financing under asymmetric information has largely focused on the information incentive role of seller financing. In contrast, the decision-making process between bank and seller financing under asymmetric demand conditions has remained relatively underexplored.

2.2. Signal models under demand information asymmetry

Scholars have examined the signaling model of financially unconstrained supply chains under demand information asymmetry. Cachon and Fisher [32] investigated how option contracts can be used to disclose market demand. Since retailers with high demand are willing to purchase more options, high-demand retailers can use the number of options purchased to signal their type. Kong et al. [21] constructed a supply chain involving a single supplier and two competing retailers, where only one retailer possesses exclusive knowledge about demand, and that retailer sends out private information to the supplier by ordering the product. Li et al. [33] investigated the decision-making of the retailer with private signals and discovered that, upon the introduction of channel competition, the retailer aimed to signal to manufacturers that market demand was low, thus reducing competition but amplifying the effect of double marginalization. Jiang et al. [22] found that wholesale price contracts can act as mechanisms for signaling demand. Wang et al. [34] compared the manufacturer with private demand signals using wholesale prices, return prices, and repurchase agreements to signal and found that return prices are a more effective signaling tool than wholesale prices. Although existing studies have enriched the application of signaling theory in supply chain management, little attention has been paid to signaling mechanisms under capital constraints. Therefore, this paper aims to investigate how a manufacturer possessing private demand information can leverage wholesale price contracts and trade credit contracts to disclose demand signals downstream in a capital-constrained supply chain, while simultaneously alleviating downstream firm's dual constraints of financing and information asymmetry.

Table 1 outlines the key distinctions between this study and prior literature. By reviewing the literature, we find that while previous studies have separately examined financing strategies in capital-constrained supply chains and signaling models under asymmetric demand information, there is still a lack of systematic research on the choice between bank and seller financing under asymmetric demand information, as well as the impact of wholesale price contracts and trade credit contracts on financing decisions within the signaling process. Therefore, this paper aims to address this research gap.

Table 1. The difference between this paper and the related literature.

Literature	Supply chain finance		Signal models under demand information asymmetry
	bank financing	seller financing	
Kouvelis and Zhao [13]	✓	✓	
Jing et al. [26]	✓	✓	
Chen [27]	✓	✓	
Fu et al. [20]		✓	
Wang et al. [30]		✓	
Cao and Wang [31]		✓	
Kong et al. [21]			✓
Jiang et al. [22]			✓
Wang et al. [34]			✓
This paper	✓	✓	✓

3. Model characteristics and assumptions

3.1. Description of the supply chain model

We consider a situation in the automotive supply chain where an automotive dealer purchases automotive products from a manufacturer on a wholesale basis and subsequently distributes them to retail consumers. In this process, the dealer faces capital constraints and needs to complete the procurement of automotive products before the start of the sales season. The manufacturer needs to decide whether to provide financing support to the dealer if: (1) the manufacturer does not provide financing support, that is, when the dealer purchases the automotive products, a wholesale price contract w^C ($w^C \geq 0$) is used; (2) the manufacturer provides financing support, a trade credit contract (w^T, r^T) is used, where $w^T \geq 0$ and $r^T \geq 0$. Figure 1 clearly illustrates the source of financing and its mechanism of operation in the automotive supply chain discussed in this paper.

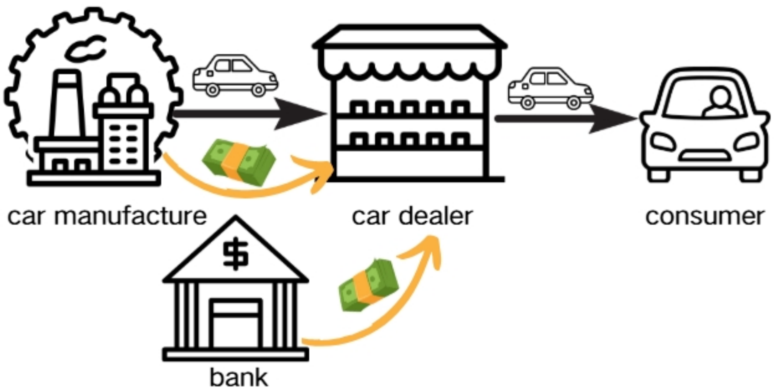


Figure 1. The automotive supply chain's financial resource.

We analyze two scenarios based on whether the manufacturer provides financing, as shown in Figure 2.

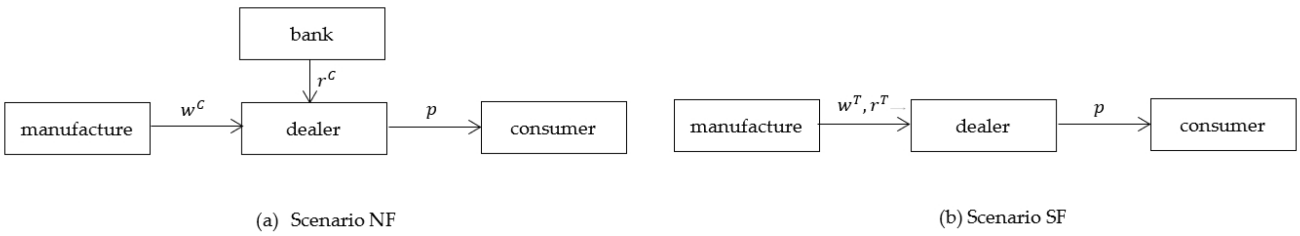


Figure 2. Supply chain structures.

(1) Scenario NF (no financing): The manufacturer does not offer financing support to the dealer and transacts solely through a wholesale price contract. In this situation, the dealer's capital requirements can only be met through bank financing.

(2) Scenario SF (seller financing): The manufacturer provides seller financing support and transacts through a trade credit contract. The dealer has the option to use seller financing as its method of financing.

3.2. Assumptions

Assumption 1. Similar to prior literature [34], the product demand is expressed as $q_i = A_i - \alpha p_i$, where A_i represents the basic demand, $\alpha > 0$ denotes the price sensitivity coefficient, and $p_i \in [0, A_i/\alpha]$ signifies the selling price. The basic demand A_i can take either a high value (A_H) or a low value (A_L), with $A_L < A_H$. The manufacturer has exact knowledge of the actual market demand A_i, $i \in \{H, L\}$, while the dealer doesn't know A_i but only its distribution. The distribution of market demand satisfies $\Pr(A_i = A_H) = \theta$, $\Pr(A_i = A_L) = 1 - \theta$, and $0 < \theta < 1$. We denote the dealer's belief about market demand by A_j where $j \in \{H, L\}$, and when $i = j$, it means that the dealer's belief about the market demand aligns with the actual market state.

Assumption 2. The automotive dealer has an initial capital of B ($B \geq 0$), which is paid in full at the time of ordering [35].

Assumption 3. In the actual operation of the automotive supply chain, vehicles are typically registered under mortgage arrangements, with the collateral value exceeding the wholesale price [36, 37]. This mechanism significantly reduces the risk exposure for creditors. Additionally, manufacturers utilize information systems such as dealer management systems (DMS) to monitor inventory and sales data in real time [32, 38], enabling early detection of operational abnormalities and proactive intervention. Therefore, we assume that there is no risk of dealer bankruptcy [39].

Assumption 4. The production cost of the manufacturer equals c, and the dealer's sales cost is set to zero [34].

Assumption 5. The banking market operates under conditions of perfect competition, and all supply chain members are typically bank-rate takers [13, 26, 31, 40].

Table 2. Symbols and their descriptions.

Symbol	Description
w^C	Wholesale price under wholesale price contracts
r^C	Finance market interest rate
w^T	Trade credit price under trade credit contracts
r^T	Interest rate under trade credit contracts
A_i	Basic demand ($i \in \{H, L\}$)
α	Price sensitivity coefficient ($\alpha > 0$)
p	Selling price ($p \in [0, A_i/\alpha]$)
θ, $(1 - \theta)$	Probability of observing a high (low) demand signal ($0 < \theta < 1$)
i	Market demand observed by the manufacturer ($i \in \{H, L\}$)
j	Dealer's belief regarding the market level ($j \in \{H, L\}$)
B	Dealer's initial capital ($B \geq 0$)
c	Manufacturer's per-unit production cost
w_{LL}^{CS}	Manufacturer's wholesale price in a low market demand under asymmetric information

We adopt the superscripts F, S to differentiate between symmetric and asymmetric information, respectively. The subscripts i, j symbolize the manufacturer's observed market demand and the dealer's belief regarding the market level. For instance, w_{ij}^{CS} denotes the wholesale contract price under asymmetric information when both the manufacturer and the dealer perceive low demand information. Table 2 provides a summary of the key parameters employed in this paper.

4. Optimal financing decisions under symmetric information benchmark

4.1. Scenario NF

The manufacturer and the dealer are well informed about actual market demand of the product under the symmetric information condition. The manufacturer first sets the wholesale price contract w_{ij}^{CF}. According to the wholesale price contract, the dealer makes a decision regarding the product price p_{ij}^{CF}. The interbank market is highly competitive, and its interest rate r_{ij}^{CF} is an exogenous variable. The dealer places an order with the manufacturer, paying an amount B from its own funds and borrowing the remaining funds from the bank to make the payment. With the arrival of the sales season, as market demand is effectively met, the dealer then settles his loans with the bank.

The dealer's profit maximization problem is:

$$\pi(p_{ij}^{CF}) = p_{ij}^{CF} q - (1 + r_{ij}^{CF})(w_{ij}^{CF} q - B) - B. \tag{4.1}$$

The manufacturer's profit maximization problem is:

$$\max_{w_{ij}^{CF}} \Pi(w_{ij}^{CF}) = (w_{ij}^{CF} - c)q. \tag{4.2}$$

The solution is denoted as w_{ij}^{CF*}. The following Lemma 1, describes the symmetric information results.

Lemma 1. *Under conditions of symmetric information benchmark, the manufacturer's wholesale price is* $w_{ij}^{CF*} = \frac{A_i + c\alpha(1+r_{ij}^{CF})}{2(1+r_{ij}^{CF})\alpha}$, *and the profit is* $\Pi(w_{ij}^{CF*}) = \frac{[A_i - c(1+r_{ij}^{CF})\alpha]^2}{8(1+r_{ij}^{CF})\alpha}$. *The dealer's selling price is* $p_{ij}^{CF*} = \frac{3A_j + c(1+r_{ij}^{CF})\alpha}{4\alpha}$, *and the profit is* $\pi(p_{ij}^{CF*}) = Br_{ij}^{CF} + \frac{(A_j - c(1+r_{ij}^{CF})\alpha)^2}{16}$.

As indicated by Lemma 1, as the market demand A_i is observable to the manufacturer and dealer, they base their decisions throughout the game on the actual market demand A_i. What's more, the corresponding benefits obtained by both parties are directly affected by A_i.

4.2. Scenario SF

Similar to the Scenario NF, the manufacturer and the dealer have full knowledge of the real market demand for the product. The manufacturer provides the dealer with a trade credit contract $(w_{ij}^{TF}, r_{ij}^{TF})$, then the dealer sets price p_{ij}^{TF}, and repays the loan and interest after the sales season when demand is realized.

The dealer aims to maximize profits by:

$$\pi(p_{ij}^{TF}) = p_{ij}^{TF} q - (1 + r_{ij}^{TF})(w_{ij}^{TF} q - B) - B. \tag{4.3}$$

The manufacturer's goal to maximize profits is:

$$\max_{w_{ij}^{TF}, r_{ij}^{TF}} \Pi(w_{ij}^{TF}, r_{ij}^{TF}) = (w_{ij}^{TF} - c)q + r_{ij}^{TF}(w_{ij}^{TF} q - B). \tag{4.4}$$

According to the above two equations, the optimal choices for both parties in a symmetric information setting are derived as Lemma 2.

Lemma 2. *Under conditions of symmetric information benchmark, the manufacturer's wholesale price is* $w_{ij}^{TF*} = \frac{A_i + c\alpha}{2\alpha}$*, the interest rate is* $r_{ij}^{TF*} = 0$*, and the profit is* $\Pi(w_{ij}^{TF*}, r_{ij}^{TF*}) = \frac{(A_i - c\alpha)^2}{8\alpha}$*. Meanwhile, the dealer's selling price is* $p_{ij}^{TF*} = \frac{1}{4}(c + \frac{3A_j}{\alpha})$*, and the profit is* $\pi(p_{ij}^{TF*}) = \frac{(A_j - c\alpha)^2}{16\alpha}$.

From Lemma 2, we observe that the optimal wholesale price and selling price decision both depend on the type of market demand. Moreover, the manufacturer's optimal interest rate is established at zero under symmetric information. This indicates that the manufacturer fully understands market demand and is willing to support the dealer's borrowing and ordering with no interest charges.

4.3. Results analysis

By comparing the decisions of the manufacturer and dealer under symmetric demand information, we arrive at Proposition 1.

Proposition 1. *Under conditions of symmetric information, the manufacturer and dealer make the following optimal decisions:*

1. *The manufacturer's wholesale price is lower than the trade credit price, i.e.,* $w_{ij}^{CF*} < w_{ij}^{TF*}$.
2. *The dealer's unit cost in bank financing is higher than that in seller financing.*
3. *The dealer's selling price in bank financing is higher than that in seller financing, i.e.,* $p_{ij}^{CF*} > p_{ij}^{TF*}$.

In bank financing, the dealer is responsible for solving its own funding issues and pays the full amount for the goods. Essentially, the manufacturer doesn't have to account for credit risk under the wholesale price contract. In contrast, the manufacturer offers credit assistance to the dealer under the trade credit contract. This credit service comes at a cost, including the time value of money, potential default risk, as well as the cost of capital occupation. Therefore, the manufacturer needs to add an extra premium in the trade credit price to compensate for these costs, resulting in a higher trade credit price. We also find that the unit cost for the dealer in bank financing is higher than that in seller financing. The dealer's unit cost refers to the unit purchase cost and financing cost. From Lemma 2, the seller financing rate provided by the manufacturer is zero. Although the wholesale price is lower than the trade credit price, the dealer needs to pay interest when financing from the bank, resulting in a higher unit cost than the seller financing situation. Accordingly, the dealer bears higher funding costs and financial risks in bank financing and needs to achieve higher profits through a higher selling price. In seller financing, the dealer's unit cost is lower, and based on maintaining a certain unit profit margin, the selling price determined by the dealer is not high.

Based on the optimal decisions of the manufacturer and dealer under symmetric information, we derived their optimal strategies, as presented in Proposition 2.

Proposition 2. *Under conditions of symmetric information, the manufacturer and dealer make the following optimal strategies:*

1. *The manufacturer is inclined to support financially, primarily by offering trade credit contracts.*
2. *The dealer's financing choice is related to the initial capital B. When* $B > \frac{1}{16}c[2A_L - c(2 + r_{ij}^{CF})\alpha]$*, the dealer tends to opt for bank financing; conversely, the dealer chooses seller financing.*

Proposition 2 demonstrates that a specific financing discordance emerges between the manufacturer and the dealer under symmetric information. As analyzed in Proposition 1, the manufacturer's trade credit price is lower than the wholesale price, which leads to a decrease in the unit profit margin of the manufacturer and a corresponding decrease in the selling price set by the dealer. The increase in sales volume compensates for the decline in the manufacturer's unit profit margin, letting the manufacturer be more inclined to provide trade credit contracts. However, the dealer's financing choice is influenced by the initial capital B. When B exceeds a certain threshold, the dealer has stronger bargaining power in the financing process. Banks may offer more favorable loan terms based on the dealer's financial strength and credit status, such as reduced interest rates and adaptable repayment schedules. Conversely, when B is below a certain threshold, the dealer may lack sufficient collateral or credit limits to obtain bank loans and thus has to choose seller financing. To address the conflicts in financing between the two parties, the manufacturer can offer discounts or rebates to dealers who choose trade credit, or even provide value-added services such as market promotion support, training, or after-sales service to guide the dealer's preference.

5. Optimal financing decisions under asymmetric information

5.1. Scenario NF

In the context of asymmetric information, the market demand is exclusively known to the manufacturer. A manufacturer with high market demand (referred to as the high-demand manufacturer) may disguise herself as a manufacturer with low demand (referred to as the low-demand manufacturer). This disguise allows her to negotiate a lower selling price, thereby increasing unit sales. Conversely, the low-demand manufacturer may be motivated to differentiate herself to ensure the dealer could infer its low demand forecast and charge a correspondingly low selling price. Thus, the low-demand manufacturer has to incur the signaling cost of separating herself from the high-demand manufacturer.

Given the situation, assuming the interest rate is exogenous, the high-demand manufacturer has an incentive to offer a reduced wholesale price to mimic the behavior of the low-demand manufacturer. If it successfully leads the dealer to assume that the market exhibits low demand, then his belief is updated to $j = L$, causing a lower selling price. But the market's actual demand level is high ($i = H$), resulting in high demand realization under low pricing. As for insufficient direct and reliable communication channels, the low-demand manufacturer anticipates the dealer would obtain market demand signals from her offered wholesale price contracts, and therefore, will voluntarily reveal the actual market demand information through the contracts. In order to achieve effective signaling of wholesale prices, the optimal problem for a low-demand manufacturer under information asymmetry is:

$$\begin{aligned} &\max_{w_{LL}^{CS}} \ (w_{LL}^{CS} - c)q \\ &\text{s.t.} \quad \Pi(w_{HL}^{CS}) \leq \Pi(w_{HH}^{CF*}) \\ &\qquad\ \ \Pi(w_{LL}^{CS}) \geq \Pi(w_{LH}^{CF*}). \end{aligned} \tag{5.1}$$

The low-demand manufacturer takes a signaling value w_{LL}^{CS} (potentially unequal to the symmetric information condition), and if the high-demand manufacturer chooses w_{LL}^{CS} as well in order to disguise herself as a low-demand manufacturer, she can get the most benefits as $\Pi_m(w_{HL}^{CS})$; while if the high-demand manufacturer abandons mimicry and opts to provide the wholesale price w_{HH}^{CF*} under symmetric information, the dealer will feed back the market with corresponding sales pricing at high-demand, at which point the manufacturer gains $\Pi_m(w_{HH}^{CF*})$ (i.e., profit when information is symmetric). When $\Pi_m(w_{HL}^{CS})$ does not exceed $\Pi_m(w_{HH}^{CF*})$, the high-demand manufacturer has no disguise motivation, at which point a separating equilibrium conditional on signaling can be achieved. To establish the presence of such a separating equilibrium, we must demonstrate that the low-demand manufacturer lacks any incentive to deviate from the equilibrium to any other non-equilibrium option [41].

Referring to [42], we define the variable $\phi = \frac{A_H - c\alpha(1+r_{ij}^{CF})}{A_L - c\alpha(1+r_{ij}^{CF})}$ to measure the degree of market demand volatility. As a high-value durable consumer good, automobile demand exhibits high sensitivity to market interest rates. On the one hand, rising interest rates increase the financing cost of vehicle purchases, leading consumers to postpone buying decisions and resulting in significant demand fluctuations [43]. On the other hand, interest rate hikes serve as a signal of tightening monetary policy, which undermines consumers' expectations about future income and further suppresses their willingness to make major purchases, thereby amplifying demand uncertainty [44]. The following proposition illustrates a separating equilibrium state where wholesale price contracts signal demand, thereby illustrating the optimal decisions of both parties.

Proposition 3. *When $1 < \phi < 3$, the most efficient separating equilibrium exists as the manufacturer utilizes wholesale price contracts to signal demand to the dealer. In this equilibrium,*

1. *The high-demand manufacturer's wholesale price equals that under symmetric information w_{HH}^{CF*}.*
2. *The low-demand manufacturer's wholesale price is lower than that under symmetric information, i.e., $w_{LL}^{CS*} < w_{LL}^{CF*}$.*
3. *According to wholesale price contracts w_{LL}^{CS*}, the dealer's selling price is lower than that under symmetric information, i.e., $p_{LL}^{CS*} < p_{LL}^{CF*}$.*

Proposition 3 indicates that under the condition of exogenous lending rates, the manufacturer's pricing decision for wholesale price contract is dependent on the demand volatility ϕ. When $\phi \geq 3$, the relative fluctuation in market demand is large, and the high-demand manufacturer mimics the low-demand manufacturer's wholesale price contracts to guide the dealer to lower the selling price and increase product sales, resulting in reduced profits. Driven by self-interest, the high-demand manufacturer would disclose truthful information, thus allowing the low-demand manufacturer to achieve "costless separation" without incurring additional costs to realize a separating equilibrium. Similarly, when $1 < \phi < 3$, the relative fluctuation in market demand is small, and if the high-demand manufacturer imitates the low-demand manufacturer's wholesale price contracts (under symmetric information) in an attempt to lower the dealer's selling price and increase product sales, the high-demand manufacturer can offset the profit loss resulting from the reduction in her wholesale price through the profits it generates. The high-demand manufacturer serves as a rational decision-maker and would necessarily disguise information. To attain a separating equilibrium, the low-demand manufacturer would set a lower wholesale price compared to the scenario under symmetric information. At this point, the reduction in profits resulting from the decline in wholesale pricing represents the extra cost incurred by the low-demand manufacturer to signal information, which is known as the "signaling cost".

5.2. Scenario SF

We find the low-demand manufacturer offering a lower trade credit price provides motivation for the high-demand manufacturer in order to imitate to obtain a lower selling price and higher clearance sales from the dealer under symmetric information conditions.

We determine once more the optimal separating equilibrium, which is the one where the high-demand manufacturer provides the symmetric information contract $(w_{HH}^{TF*}, r_{HH}^{TF*})$ and the low-demand manufacturer offers the trade credit contract $(w_{LL}^{TS}, r_{LL}^{TS})$, then the dealer updates his belief. Thus, the low-demand manufacturer's trade credit contract $(w_{LL}^{TS}, r_{LL}^{TS})$ is determined by the following equation:

$$\begin{aligned} &\max_{w_{LL}^{TS}, r_{LL}^{TS}} \ (w_{LL}^{TS} - c)q + r_L^{\bar{S}}(w_{LL}^{TS} q - B) \\ &\text{s.t.} \quad \Pi(w_{HL}^{TS}, r_{HL}^{TS}) \leq \Pi(w_{HH}^{TF*}, r_{HH}^{TF*}) \\ &\qquad\quad \Pi(w_{LL}^{TS}, r_{LL}^{TS}) \geq \Pi(w_{LH}^{TF*}, r_{LH}^{TF*}). \end{aligned} \tag{5.2}$$

Two constraints act to prevent one type of manufacturer from mimicking another, and we determine the optimal separation. Define $\tau = \dfrac{A_H - c\alpha}{A_L - c\alpha}$, which measures the demand volatility when $r_{ij}^{CF} = 0$. Proposition 4 shows a separating equilibrium state where trade credit contracts signal demand, and portrays the optimal decisions of both parties.

Proposition 4. *When $1 < \tau < 3$, the most efficient separating equilibrium exists as the manufacturer utilizes trade credit contracts to signal demand to the dealer. In this equilibrium:*

1. *The high-demand manufacturer's trade credit price and interest rate are equal to those under symmetric information $(w_{HH}^{TF*}, r_{HH}^{TF*})$.*
2. *The low-demand manufacturer's trade credit price is lower than that under symmetric information, i.e., $w_{LL}^{TS*} < w_{LL}^{TF*}$, and the interest rate is higher than that under symmetric information, i.e., $r_{LL}^{TS*} > r_{LL}^{TF*}$.*
3. *According to the trade credit contracts $(w_{LL}^{TS*}, r_{LL}^{TS*})$, the dealer's selling price is higher than that under symmetric information, i.e., $p_{LL}^{TS*} > p_{LL}^{TF*}$.*

Proposition 4 suggests that the manufacturer's pricing decision for a trade credit contract is dependent on the type of market demand A_i and the demand volatility τ. When $\tau \geq 3$, there is a significant variation in demand, and the high-demand manufacturer can mimic the low-demand type's trade credit contract to induce the dealer to lower the selling price and thus increase product sales. Therefore, the high-demand manufacturer is motivated by profit to disclose truthful and reliable information, and there is no need for the low-demand manufacturer to incur extra costs to attain the separate equilibrium. This means that "costless separation" can be achieved. Similarly, when $1 < \tau < 3$, i.e. the demand volatility is small, the high-demand manufacturer can imitate the optimal trade credit contract of the low-demand manufacturer under symmetric information in an attempt to lower the dealer's selling price and thus increase product sales. Based on the revenue model of the high-demand manufacturer, it is profitable. As a rational decision-maker, the high-demand manufacturer is bound to disguise the information, which means that if the low-demand manufacturer's optimal decision corresponds to the decision made under symmetric information conditions, then the high-demand manufacturer will choose trade credit contract imitation to obtain high returns. Therefore, when the demand volatility is small, the low-demand manufacturer will distort trade credit price downward to achieve the separating equilibrium sharing, and the distortion of the trade credit contract results in a loss of benefit for the low-demand manufacturer, namely the signaling cost.

5.3. Results analysis

In our previous research, it was discovered that manufacturers can employ both wholesale price contracts and trade credit contracts to signal market demand to the dealer; consequently, this leads to a specific loss in profits for the manufacturer and impacts the dealer's decision-making process to a certain degree. According to Proposition 3, when $1 < \phi < 3$, the separating equilibrium exists for the low-demand manufacturer to signal demand via the wholesale price contract. According to Proposition 4, when $1 < \tau < 3$, the separating equilibrium exists for the low-demand manufacturer to signal demand through the trade credit contract. In light of the calculated values for τ and ϕ, we know that $\tau < \phi$. Therefore, we discuss the optimal decisions made by both parties within the range $\tau < \phi < 3$. Based on Propositions 3 and 4, we derive Proposition 5.

Proposition 5. *When demand volatility satisfies $\tau < \phi < 3$, if the market interest rate is high ($r^* < r_{ij}^{CF} < 1$), and if the retailer's initial capital is low ($0 < B < T$), the wholesale price set by the manufacturer will be higher than the trade credit price ($w_{LL}^{CS*} > w_{LL}^{TS*}$). Consequently, the unit cost borne by the dealer under bank financing is also higher than that under trade credit financing, ultimately leading to a higher final selling price under bank financing compared to trade credit ($p_{LL}^{CS*} > p_{LL}^{TS*}$). The expression for r^* and T are detailed in Appendix A.*

Generally speaking, when bank rates are high ($r^* < r_{ij}^{CF} < 1$), the manufacturer's cost of capital for offering trade credit is also high, leading her to increase the trade credit price. However, if the dealer has insufficient capital ($0 < B < T$), high bank financing costs will dampen its willingness to place orders. By reducing trade credit prices at this point, the manufacturer can incentivize the retailer to increase orders, thereby boosting her own sales volume. Although short-term financing costs may rise, growth in sales and market share will bring long-term benefits to the manufacturer. Conversely, when market interest rates are low and the dealer has more of their own funds ($B > T$), it tends to prefer lower-cost bank financing, reducing the attractiveness of seller financing. In such cases, the manufacturer may need to lower wholesale prices or take other measures to maintain sales.

In a high interest rate environment, the unit cost for the dealer utilizing bank financing rises due to increased interest expenses; whereas seller financing often offers lower rates or partial cost absorption by the manufacturer, resulting in a more favorable unit cost. Conversely, when market interest rates are low, the reduced cost of bank financing enhances its appeal relative to seller financing. Accordingly, under high interest rates, the retail price under bank financing increases owing to cost pass-through; under lower rates, prices can be set more competitively. Thus, changes in market interest rates directly influence the dealer's pricing strategies.

According to the distinct decision variables that the two parties face under asymmetric information, we get their optimal strategies, thus leading to Proposition 6.

Proposition 6. *When demand volatility satisfies $\tau < \phi < 3$ and if the market interest rate is relatively high ($r^* < r_{ij}^{CF} < 1$), the manufacturer provides financial support by offering trade credit contracts to* *signal demand. From the dealer's perspective, however, once the rate rises further into the $\frac{16}{9}r^* < r_{ij}^{CF} < 1$ band and the dealer's own capital is high ($B > G$), the dealer will switch to bank financing; otherwise, seller financing remains the first-best choice. The expression for G is detailed in Appendix A.*

Proposition 6 indicates that under asymmetric information, a financing conflict may arise between the manufacturer and the dealer under certain conditions. Specifically, when interest rates are high ($\frac{16}{9}r^* < r_{ij}^{CF} < 1$) and the dealer's own capital is high ($B > G$), such a conflict emerges. The manufacturer tends to offer low-priced trade credit contracts to encourage larger orders from the dealer while also earning interest income. Although bank financing entails a higher wholesale price, the dealer can achieve higher unit profits by raising the retail price because automobiles are high-value products with low demand elasticity, resulting in an overall profit that exceeds that of seller financing. Therefore, the dealer prefers bank financing. To align the financing preferences of both parties, the manufacturer can design hybrid contracts. For instance, it may offer a trade credit package featuring a "low trade credit price plus preferential interest rate" to reduce the appeal of bank financing. Alternatively, a performance-based dynamic discount mechanism could be introduced, providing rebates or interest reductions to dealers who meet sales targets. These measures not only incentivize sales but also enhance the dealer's actual profits, thereby mitigating financing conflicts.

When interest rates are high ($\frac{16}{9}r^* < r_{ij}^{CF} < 1$) and the dealer's own capital is low ($0 < B < G$), no financing conflict arises between the two parties. The manufacturer is generally willing to offer lower trade credit prices. Under these conditions, the dealer can achieve greater pricing flexibility through seller financing, leading to an improved unit profit margin, and thus tends to prefer seller financing.

Furthermore, even when interest rates are low ($0 < r_{ij}^{CF} < r^*$), a conflict in financing preferences may still exist between the manufacturer and the dealer. The manufacturer tends to reduce wholesale prices and require the dealer to make prompt payments through bank financing, thereby accelerating capital turnover and improving fund utilization efficiency. This strategy yields higher comprehensive benefits in a low interest rate environment compared to the interest and higher revenues from offering trade credit. On the other hand, dealers prefer seller financing. Despite the higher purchase cost, the lower financing expense allows him to raise retail prices to increase unit profits, often resulting in higher overall profits than those achievable through bank financing. To mitigate such conflicts, the manufacturer can introduce a "cash discount" contract, offering price incentives for immediate payment. This encourages dealers to opt for bank financing and expedite payment, creating a win-win situation for both parties.

Finally, when interest rates fall within a specific range ($r^* < r_{ij}^{CF} < \frac{16}{9}r^*$), no financing conflict arises between the manufacturer and the dealer. By offering a more competitive trade credit price, the manufacturer provides the dealer with greater flexibility in setting prices. The dealer adopts a volume-based strategy, stimulating market demand by moderately reducing selling price. Although unit profit decreases, the significant increase in sales volume ultimately drives growth in total profit.

6. The effect of asymmetric information on optimal financing decision

Proposition 2 shows that the manufacturer prefers providing seller financing, favoring trade credit contracts over wholesale price contracts under symmetric demand information. At this time, the dealer's financing strategy is influenced by his initial capital level B: with smaller capital, he prefers seller financing, whereas larger capital leads him to opt for bank financing. Under asymmetric demand information, Proposition 6 concludes that the manufacturer's strategy is influenced by the level of market interest rates. In detail, when the market interest rate r_{ij}^{CF} is high, providing seller financing through trade credit contract is the manufacturer's optimal strategy; conversely, at low interest rates, the manufacturer is less inclined to offer financing support and instead uses wholesale price contracts. At this time, a distinct financing conflict exists between the two parties in terms of financing choices. We find that there are significant changes in the strategies of both the manufacturer and the dealer in an environment of demand information asymmetry. This change in behavioral patterns mainly stems from the effect of inference, that is, the information asymmetry in the signaling game leads to strategic adjustments by both parties in pricing and financing choices. This conclusion once again confirms the profound impact of the inference effect on the decision-making processes within supply chains.

In signaling games, scholars have conducted in-depth research on the inference effect under costly separating scenarios. Specifically, [45] observed that the inference effect is characterized by the signal sender distorting its pricing behavior so that the receiver can infer relevant information based on this distorted pricing. [46] further analyzed the inference effect of wholesale price contracts, and this study also arrived at the same conclusion as prior research. Building on this, we focus on the inference effect of trade credit contracts and derive Proposition 7 based on this.

Proposition 7. *The inference effect has contrasting impacts on supply chain:*

1. *The inference effect negatively impacts the manufacturer's situation.*
2. *The inference effect positively impacts the dealer's situation.*

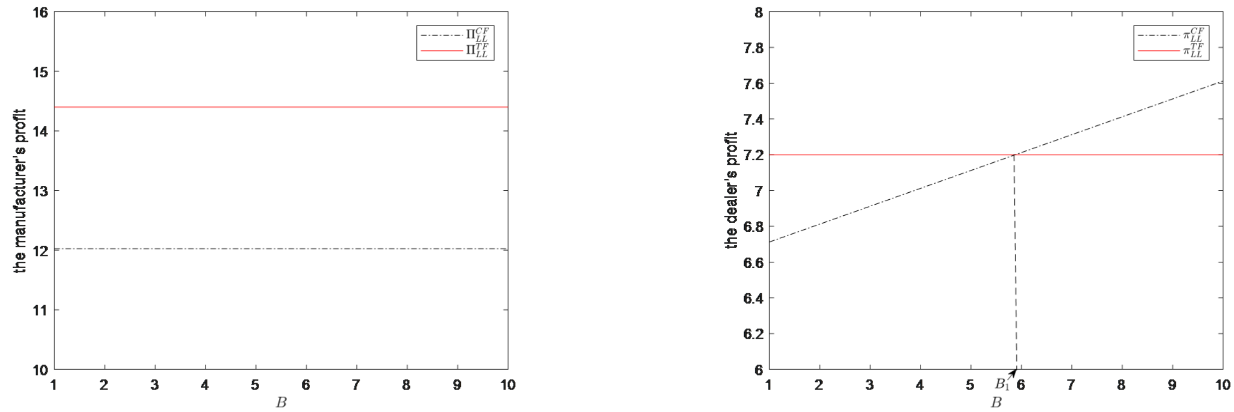
Proposition 7 reveals the influence of information asymmetry on both parties. The inference effect tends to adversely impact the signal sender's benefit, which has been clearly elaborated in game theory. According to Proposition 1, under symmetric demand information, the manufacturer sets the wholesale price at a level consistently below that of the trade credit price. However, the manufacturer has to distort prices downward and interest rates upward to achieve separating under asymmetric information. This distortion of prices and interest rate deviates from its optimal decision-making path, and the distortion under the trade credit contract is more significant. Therefore, the emergence of the inference effect will always cause damage to the manufacturer's interests. By lowering the trade credit price, the manufacturer enables the uninformed dealer to infer the market demand and thereby set a reduced selling price, which ultimately benefits the dealer.

7. Numerical analysis

7.1. Example 1

In the following analysis, we verify the propositions and lemmas mentioned above through numerical analysis. Following the parameter settings in [47,48] while ensuring interior solutions and graphical clarity, we use: $A_L = 34$, $c = 2$, and $\alpha = 5$. When analyzing the optimal choices of both parties in a symmetric information setting, we set $A_i = A_L = 34$ to facilitate a comparative analysis with the asymmetric information scenario.

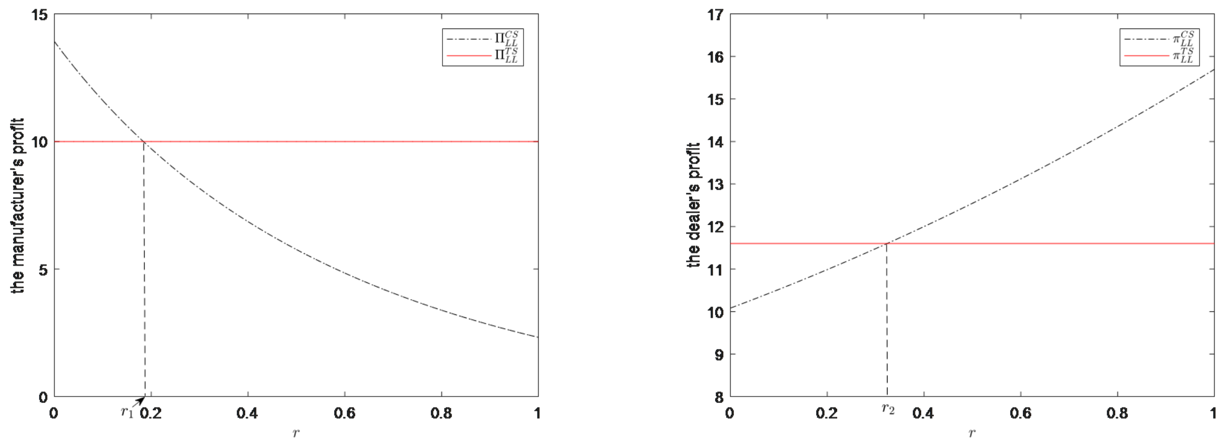
Figure 3a demonstrates the manufacturer's profitability under symmetric information. The study finds that the manufacturer's profit level under the trade credit contract consistently surpasses that under the wholesale price contract. The dealer's profit level, on the other hand, is significantly positively affected by the initial capital B, as shown in Figure 3b. Further analysis indicates that the dealer's choice is primarily influenced by the initial capital B: When B is small, the profit level of choosing seller financing is higher; whereas as B increases, the bank financing method yields higher profit benefits. A specific financial disagreement arises, supported by Proposition 2.



(a) Manufacturer's profit under symmetric information. **(b)** Dealer's profit under symmetric information.

Figure 3. The impact of B on profit.

We also examined the profits of both two parties under asymmetric information. In this case, we set $B = 12$ to examine how the market interest rate level affects profits. Figure 4a shows that when $r < r_1$, the manufacturer strategically employs wholesale price contracts to signal, thereby maximizing her profits. However, when $r > r_1$, the manufacturer adopts a trade credit contract, effectively signaling demand. Figure 4b shows that the dealer's financing choice also exhibits sensitivity to the market interest rate. Specifically, when $r < r_2$, the dealer prefers seller financing; when $r > r_2$, the dealer prefers bank financing. In both scenarios, the manufacturer and the dealer face a financing conflict. Particularly, within the interest rate range $r_1 < r < r_2$, the manufacturer opts for a trade credit contract to signal, whereas the dealer favors seller financing, resulting in no financial conflict in this case.



(a) Manufacturer's profit under asymmetric information. **(b)** Dealer's profit under asymmetric information.

Figure 4. The impact of r on profit.

7.2. *Example 2*

As indicated by the preceding analysis, market interest rates, dealer's own capital, and market demand volatility all influence the financing choices of supply chain members. Using the same baseline parameter values ($A_L = 34$, $c = 2$, and $\alpha = 5$) as above, we focus on examining the impact of market interest rates and dealer's capital on financing decisions when demand volatility falls within the separating equilibrium interval ($\tau < \phi < 3$). Taking into account the intrinsic relationship between the market demand volatility and interest rates, we further calculate the profit levels of the manufacturer and the dealer across different interest rate intervals and dealer-owned capital levels. The specific analytical results are presented in Table 3 .

Table 3. Supply chain profit for $\tau < \phi < 3$.

B	r	Manufacturer's Profits		Dealer's Profits		Manufacturer's Profit Loss	
		Bank Financing	Seller Financing	Bank Financing	Seller Financing	Bank Financing	Seller Financing
0	0.1	$11.601^{\dagger}$	10	9.321	$11.6^{\dagger}$	0.422	4.4
	0.2	9.714	$10^{\dagger}$	8.587	$11.6^{\dagger}$	0.369	4.4
	0.4	6.857	$10^{\dagger}$	7.2	$11.6^{\dagger}$	0.286	4.4
	0.6	4.841	$10^{\dagger}$	5.921	$11.6^{\dagger}$	0.221	4.4
	0.8	3.385	$10^{\dagger}$	4.753	$11.6^{\dagger}$	0.171	4.4
	1	2.322	$10^{\dagger}$	3.698	$11.6^{\dagger}$	0.128	4.4
6	0.1	$11.601^{\dagger}$	10	9.921	$11.6^{\dagger}$	0.422	4.4
	0.2	9.714	$10^{\dagger}$	9.787	$11.6^{\dagger}$	0.369	4.4
	0.4	6.857	$10^{\dagger}$	9.6	$11.6^{\dagger}$	0.286	4.4
	0.6	4.841	$10^{\dagger}$	9.521	$11.6^{\dagger}$	0.221	4.4
	0.8	3.385	$10^{\dagger}$	9.553	$11.6^{\dagger}$	0.171	4.4
	1	2.322	$10^{\dagger}$	9.698	$11.6^{\dagger}$	0.128	4.4
12	0.1	$11.601^{\dagger}$	10	10.521	$11.6^{\dagger}$	0.422	4.4
	0.2	9.714	$10^{\dagger}$	10.987	$11.6^{\dagger}$	0.369	4.4
	0.4	6.857	$10^{\dagger}$	$12^{\dagger}$	11.6	0.286	4.4
	0.6	4.841	$10^{\dagger}$	$13.121^{\dagger}$	11.6	0.221	4.4
	0.8	3.385	$10^{\dagger}$	$14.353^{\dagger}$	11.6	0.171	4.4
	1	2.322	$10^{\dagger}$	$15.698^{\dagger}$	11.6	0.128	4.4

*Note: The superscript † denotes the optimal financing choice of the manufacturer and the dealer.

The results in Table 3 show that under seller financing, the profit levels of both the manufacturer and the dealer are independent of the interest rate and depend primarily on actual demand, whereas under bank financing, the profits of both parties are jointly affected by the interest rate and demand volatility. Further analysis indicates that under conditions of low interest rates ($r \leq 0.1$) and low demand fluctuation, the manufacturer consistently prefers wholesale price contracts regardless of the dealer's capital. This is because, in such scenarios, the profit loss from using wholesale price contracts to signal demand is significantly lower than with trade credit contracts, making them more suitable as a signaling tool. In contrast, under the same conditions, the dealer persistently favors seller financing. However, when interest rates rise ($r > 0.1$), the manufacturer also tends to adopt trade credit contracts; although signaling demand with such contracts incurs a larger profit loss than with wholesale price contracts, the overall profit is significantly higher, so trade credit remains the favored choice. It follows that in an environment of low interest rates and low demand volatility, the applicable interest rate range within which the manufacturer chooses trade credit contracts will expand accordingly.

Nevertheless, the dealer's own capital level significantly influences his profit performance under bank financing, an effect that is particularly pronounced when interest rates are high ($r > 0.4$). When interest rates are relatively high and demand fluctuation is substantial, the dealer's financing preference shifts from seller financing to bank financing. Therefore, as his own capital increases, the applicable interest rate range for the dealer to choose bank financing also expands accordingly. This outcome further validates the conclusions of Proposition 6.

8. Conclusion

Automotive dealers encounter financial limitations and unequal access to information. Consequently, our research investigates the supply chain involving one manufacturer and a dealer facing financial limitations, focusing on the manufacture's and the dealer's financial strategies under asymmetric demand information. The manufacturer employs wholesale price contracts and trade credit contracts signaling demand information. To identify the dealer's potential financing options, this paper analyzes bank financing and seller financing.

(1) A widely accepted conclusion in the existing supply chain finance literature is that the manufacturer has an inherent benefit when employing trade credit contracts under symmetric demand information [13]. We have reached a similar conclusion. Our findings also indicate that the initial capital B of a capital-constrained party impacts their financing decisions under symmetric demand information. A dealer is more likely to opt for seller financing when B is low; conversely, when B is high, bank financing is preferred.

(2) Existing literature offers scarce research on the strategies adopted by capital-constrained supply chains in an environment of asymmetric demand information. This study finds that the manufacturer's contract strategy is also dependent on the market interest rate level r in an asymmetric demand information setting. At lower r levels, the manufacturer signals market conditions via wholesale price contracts; in contrast, for higher r levels, the manufacturer is more likely to offer financing through trade credit contracts. Meanwhile, the dealer demonstrates a stronger preference for seller financing options under low interest rates and bank financing under high interest rates. This extends the research of Jing et al. [22].

(3) Research reveals that the inference effect negatively impacts the profits of the signal sender, thereby changing the manufacturer's contract decisions within an environment of asymmetric demand information. However, the signal receiver may benefit or suffer from the inference effect, and thus it affects the dealer's decision-making under asymmetric demand information. These findings are supported by earlier works from Cao and Chen [46].

Finally, this paper proposes several potential extensions to the current model. First, the study does not incorporate dealer bankruptcy risk, thereby overlooking the potential impact of dealer default under extreme market conditions on financing strategies. Future research could relax this assumption to examine how the financing decisions of supply chain members may differ in the presence of default risk. Second, treating the bank interest rate as an exogenous variable fails to capture the two-way risk transmission between the bank and the supply chain. Future studies could endogenize the interest rate and develop models that incorporate banking decisions to better reflect the actual financing decision-making process. Lastly, the current model is built on a single manufacturer, single dealer framework, while real world scenarios often involve multiple manufacturers competing for the same dealer or a single manufacturer distributing products through multiple dealers. Extending the model to such competitive market structures represents another valuable direction for future research.

Author contributions

Shanshan Xie: conceptualization, methodology, formal analysis, validation, writing–original draft; Jiamuyan Xie: conceptualization, methodology, supervision, writing–review and editing; Zhixian Zeng: investigation, supervision, writing–review and editing.

Use of Generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare no conflict of interest.

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