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INFORMATION SHARING DECISION OF RETAIL PLATFORM: PLATFORM'S RISK AVERSION AND COMPETING SUPPLIERS

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Abstract. An increasing number of retail platforms are adopting blockchain technology to mitigate information asymmetries and share data with upstream suppliers, thereby reducing demand uncertainty. However, these platforms often engage with multiple upstream suppliers of varying product quality. This study constructs a game-theoretic model within a supply chain framework, featuring a risk-averse retail platform and two upstream suppliers of different quality levels. As the core leader of the game, the retail platform decides whether to share demand information with the two competing suppliers after implementing the technology. Using mean-variance theory, this study addresses a key question: Which types of suppliers should be included in information sharing on a retail platform? The results show that when the unit cost of information sharing is low, allowing both suppliers to share demand information is most beneficial. Conversely, when the unit cost is high, only high-quality suppliers should be included. Notably, as the unit cost of information sharing and the intensity of competition between high-quality and low-quality products increase, low-quality suppliers are excluded from information sharing. Additionally, the model indicates that the greatest social welfare can be achieved whether both high-quality and low-quality suppliers are authorized to join the information sharing network, or only high-quality suppliers are included.

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1. Introduction

With the rapid advancement of digital technologies such as big data, blockchain, and artificial intelligence, the e-commerce industry has experienced significant growth in sales. Among various modes of shopping, online retail platforms have emerged as one of the most popular. According to data from the China Internet Network Information Center (CNNIC), the scale of online shopping users continued to expand in 2021, reaching 842 million by the end of December 2021, which accounted for 81.6% of the total Internet users in the country. Online retail platforms operate under three primary sales models: resale, agency, and mixed models, each catering to different market needs. The retail industry is characterized by significant demand fluctuations. Scholars have suggested that in scenarios of high demand uncertainty, platforms should adopt competitive pure resale contracts [1]. Prominent examples of the resale model in e-commerce include platforms such as NetEase

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Koala, NetEase Yanxuan, and JD.com's self-operated mall. These platforms often deal with multiple suppliers offering similar products, leading to information asymmetry between upstream and downstream enterprises, which in turn affects decision-making processes.

In December 2022, Ebrun published the "Future Retail Development Report 2023" highlighting the increasing market demands for enhanced inter-organizational collaboration. The report emphasizes that by establishing efficient information transmission mechanisms among organizations, enterprises can stimulate their innovation capabilities and improve operational efficiency, thereby facilitating upgrades in management and business models. In the era of Web 3.0, e-commerce platforms operating under the paradigm of Internet autonomy will have greater development potential. This paper investigates a critical topic: under the resale model, how can retail platforms establish efficient information-sharing mechanisms with upstream suppliers? Specifically, when a retail platform engages with multiple upstream suppliers simultaneously, what strategies should it employ to leverage blockchain technology for developing robust information-sharing mechanisms?

Fluctuations in market demand within the retail industry have resulted in heightened uncertainty regarding product sales. In response to this challenge, the e-commerce sector is increasingly focusing on the integration of emerging technologies to bolster its competitive advantage. This strategic initiative aims to mitigate the uncertainties associated with supply chain demand and to enhance overall profitability. Specifically, the adoption of advanced solutions such as artificial intelligence (AI), big data analytics, and blockchain technology is being prioritized to optimize various aspects of the supply chain. Ensuring the secure, effective, and efficient sharing of information is crucial for the smooth operation of supply chains. An optimal supply chain necessitates efficiency and transparency at every tier, along with trust among all stakeholders [2]. Blockchain technology further enhances the supply chain by providing a secure and transparent method for tracking products from origin to consumer. This transparency not only builds trust among stakeholders but also ensures the integrity of the supply chain, reducing the likelihood of fraud and counterfeiting [3]. Additionally, blockchain's decentralized nature allows for more efficient and secure transactions, eliminating the need for intermediaries and thereby reducing costs [1, 4, 5]. This technology facilitates secure transactions among multiple parties without the need for intermediaries. When data is appropriately shared among supply chain members, it can significantly reduce operational costs, such as inventory redundancy, benefiting all parties involved. Additionally, the technology enhances information sharing and addresses information asymmetry [6]. Increasingly, retailers and retail platforms are adopting blockchain technology. For instance, Walmart utilizes IBM's blockchain service for food traceability, while major e-commerce companies like JD.com and Alibaba are leading the way in applying blockchain for the traceability of fresh food, luxury goods, and other products, thereby achieving transparency in demand information within the supply chain. By effectively leveraging these technologies, online retailers can significantly improve their market position. They can create a more resilient and efficient supply chain ecosystem that is capable of adapting to dynamic market conditions and evolving consumer preferences.

However, introducing a new technology often comes at a cost. Hence, it is essential to carefully evaluate the impact of implementing blockchain technology on the decision-making processes of supply chain stakeholders. The integration of this technology into the supply chain ecosystem brings about various cost considerations, including initial setup expenses, maintenance costs, and training investments. These financial implications can influence the willingness of participants to adopt blockchain technology solutions and the overall feasibility of such implementations. Moreover, the potential benefits of enhanced transparency, security, and efficiency must be weighed against the associated costs to ensure that the decision aligns with the strategic objectives of all involved parties.

Furthermore, online retail platforms are increasingly adopting blockchain technology to share demand information with upstream suppliers to mitigate supply chain demand uncertainty, although concerns remain about the best implementation time and strategy. Building upon this foundation, the key focus of this study is that after the retail platform decides to introduce blockchain technology, it can use the characteristics of this technology (such as traceability, transparency) to achieve real-time information sharing with upstream suppliers to reduce the demand uncertainty in the process of product sale. Our objective is to tackle the following two crucial research inquiries:

(1) Which types of suppliers should be included to information sharing in a retail platform after blockchain is introduced?
(2) Which game mode of the efficiency of demand information sharing profit is best for high- or low-quality suppliers respectively?
(3) Which game mode achieves the largest social welfare?

In response to these challenges, a comprehensive supply chain framework was established, incorporating a high-quality supplier, a low-quality supplier, and a retail platform. Both suppliers distribute their products to the same retail platform for further sale to consumers. Retail platforms, positioned as strategic leaders, possess intricate knowledge of market dynamics. The pivotal decision regarding the integration of blockchain technology rests with the retail platform, which subsequently determines the eligibility of high-quality and low-quality suppliers to partake in the technology ecosystem to information sharing. This decision-making process results in four distinct scenarios: (1) NN-model (There is no blockchain in the supply chain, that's to say the retail platform does not share demand information), (2) BN-model (The retail platform empowers high-quality suppliers to share demand information), (3) NB-model (The retail platform empowers low-quality suppliers to share demand information), and (4) BB-model (The retail platform empowers both high-quality and low-quality suppliers to share demand information). Through our investigation, we have uncovered a significant trend: For retail platform, when the expense of information sharing in retail platform is low, there is a strategic advantage in proactively onboarding two suppliers onto the information sharing network to sharing information; otherwise, it is an advantageous strategy for the retail platform to allow only high-quality suppliers to join the information sharing. Furthermore, premium suppliers consistently demonstrate a readiness to participate in the information sharing network, whereas lower-tier suppliers may choose not to join under certain circumstances. The choice of the largest social welfare model is influenced by both the intensity of competition for high- and low-quality products and the costs associated with implementing information sharing. In addition, this study validates the resilience of the model put forth by examining variations in the fixed costs associated with information sharing implementation and the risk aversion tendencies of retail platforms.

The contribution of this paper is to describe a risk-averse retail platform by means of mean-variance method. The platform stores information on product demand and determines whether to permit upstream suppliers to join the blockchain technologies' information sharing network for sharing consumer demand specifics for products. Moreover, this paper assumes that upstream suppliers of the supply chain have product quality differences, which are reflected in two aspects, the level of product transaction cost and the size of product market potential. This paper aims to make recommendations for operational management of implementing blockchain technology and demand information sharing decisions on retail platforms operating in a resale mode. In particular, after the retail platform has introduced blockchain technology, decide when and how best to share demand information with upstream competing vendors?

The structure of this paper is as follows: the second section presents a literature review focusing on three main areas – Competitive game under uncertainty and information sharing, the use of blockchain in supply chain management, and mean variance analysis in supply chain operations. The third section delves into model description and analytical calculations, where four models are examined along with a sensitivity analysis of key decision-making parameters. In the fourth section, a comparative analysis is conducted to determine the optimal profit strategy for participants in the supply chain game and the most efficient profit strategy. Section 5 covers social welfare analysis, while Section 6 serves as an extension to validate the model's robustness concerning fixed costs and varying levels of risk aversion on retail platforms. Section 7 is the numerical analysis part of this paper, which intends to use empirical data to test to confirm the accuracy of the model results and assumptions. Finally, Section 8 provides a summary of the paper's conclusions, managerial implications, and outlines areas for future research.

2. Literature review

The research in this paper is closely intertwined with the application of competitive game under uncertainty and information sharing in supply chain, blockchain technology in the context of supply chain management, and the study of mean variance theory as applied to supply chain operations.

2.1. Competitive game under uncertainty and information sharing

In the contemporary business landscape, supply chains are increasingly subjected to various sources of uncertainty, including fluctuating demand, supply disruptions, and market volatility [7, 8]. These uncertainties pose significant challenges for firms operating within the supply chain, necessitating robust strategies to maintain competitiveness and efficiency. Information sharing is regarded as the most straightforward and efficacious method for mitigating information uncertainty [9]. In the scientific research of competitive game in supply chain, information sharing has become a key research field and is being studied by scholars. Platform economy is becoming more and more prosperous. As the core enterprise of platform economy, retail platform often occupies all the demand information. Among this, based on the research background of chain to chain competition in the supply chain, the value of information sharing by retailers/retail platforms is studied by many scholars [10–14]. Guo *et al.* [11] studies two competing supply chains and finds that the intensity of competition is negatively correlated with the amount of information shared by retailers. Shang *et al.* [10] highlighting the significant impact of retailer-shared information on production costs and product competitiveness. With regard to the competitive game between enterprises in the supply chain, Li *et al.* [15] examine a supply chain comprising a retailer and two competing manufacturers, where the retailer engages in vertical information sharing with one manufacturer (the large manufacturer) and consistently discloses production information to the other manufacturer (the small manufacturer). Their findings indicate that the implementation of blockchain technology has minimal impact on the production decisions of the manufacturers. In addition, Cong *et al.* [16] studies the competition between two types of suppliers, green and traditional. Wang and Hao [17] focuses on the sales model selection between two competing suppliers. Tsunoda and Zennyo [18] studies the influence of platform information sharing on supplier sales model selection. Liu *et al.* [19] finds that retail platforms have an incentive to share information. Different from the above literature studies that focus on whether retail platforms share information and how information sharing affects sales models, this paper focuses on the behavioral decision-making problem of a retail platform that reduces product demand uncertainty by introducing blockchain technology and actively authorizes upstream suppliers with product quality differences to join blockchain technology' network in sharing demand information. As far as we know, this is rarely studied by scholars.

2.2. Blockchain technology in supply chain

A growing cohort of scholars is focusing their research efforts on delving into the extensive implications of blockchain technology on various facets of supply chain management, including but not limited to transparency [1], traceability [20–23], security [24], and trust levels [25–27]. This burgeoning interest underscores the recognition of blockchain as a transformative tool with the potential to revolutionize traditional supply chain practices. Within this realm, a subset of scholars has embarked on pioneering research endeavors that delve into the intersection of the channel selection predicament within competitive supply chains [28] and the transformative potential of blockchain technology [29]. In addition, in addition to the study of blockchain technology + supply chain channels, there are some scholars who use the traceability characteristics of blockchain to study the blockchain in combating counterfeit goods [30, 31]. Some scholars also have pointed out that blockchain technology play an important role in reducing the costs related to supply chains. De Giovanni [5] posits that the integration of blockchain technology has offering substantial cost-saving benefits. The authors emphasize in their article the transformative impact of blockchain technology in significantly lowering transaction costs and enhancing market predictability by diminishing uncertainties. Wu *et al.* [1] also pointed out that blockchain can reduce transaction costs. They also looked at the role of blockchain technology in sharing demand information. Li *et al.* [15] also studied the impact of blockchain on information sharing behavior. In contrast to the research conducted by Li *et al.* [15], which primarily delves into the competitive dynamics within the downstream segment of the supply chain, this study shifts its focus towards analyzing the competitive landscape among upstream product suppliers within the supply chain network. Upstream suppliers are divided into high-quality suppliers and low-quality suppliers, both of which sell products to the same retail platform. The retail platform closest to the consumer has the decision-making power of information sharing to determine which type of suppliers to share the demand information with.

2.3. Mean-variance theory in supply chain

The mean-variance theory is often used by scholars to study risk preference in behavioral operation management, considering that decision makers have risk avoidance behaviors. In recent years, some scholars have tried to introduce this theory into the supply chain to conduct scientific research [32–37]. Yan *et al.* [38] studies the influence of risk aversion attitude of supply chain members, channel structure of supply chain and scale of product demand disruption on supply chain decision-making. Ray and Jenamani [39] considers the mean-variance (MV) model framework, which includes the risk of supply chain disruption of risk-averse buyers and multiple unreliable suppliers. The MV objective function maximizes the buyer's expected profit while minimizing its variance. Most scholars use mean-variance method to study supply chain pricing, dual-channel supply chain optimal strategy, inventory decision, supply chain disruption risk and other supply chain scientific issues. However, as far as we know, few scholars use mean-variance method to study the platform supply chain strategy embedded in blockchain for information sharing. Zhang *et al.* [40] studied blockchain adoption in a dual-channel supply chain consisting of a retailer and a manufacturer. To the best of our knowledge, they are the first to use mean-variance methods to study articles in which blockchain is embedded in supply chain operations. However, Zhang *et al.* [40] does not consider the adoption of blockchain in a competitive supply chain environment. And, unlike [40], in this study, we focus on the central enterprise within the platform supply chain – the retail platform – which holds a dominant position and opts for blockchain implementation over traditional retailer. Moreover, upstream competing suppliers have product quality differences. This research positions a risk-averse retail platform as a leader in the supply chain ecosystem, highlighting its crucial role in driving the adoption of blockchain technology for information sharing and strategically integrating upstream suppliers into the information sharing network.

2.4. Summary of literature review

In addition to the literature review, Table 1 summarizes relevant work and highlights the research gap addressed by this study. Unlike previous literature on similar themes, this paper focuses on upstream supply chain competition, including high quality and low quality suppliers. Among them, two types of competing products wholesale products to retail platforms, and retail platforms sell products to consumers. Retail platforms are risk-averse, and they decide which types of suppliers to share information with. This study focuses on the role after the use of blockchain technology, that is, supply chain information sharing, rather than this technology itself. This study aims to determine which type of supplier should be authorized to join the information sharing network for information sharing by retail platforms. In summary, through an in-depth analysis of the information sharing decisions catalyzed by the adoption of blockchain technology in retail platforms, this paper provides a new perspective on how key players in the industry will make decisions about information sharing and improve operational efficiency after adopting the technology.

3. Model description, assumptions and equilibrium

Consider two suppliers with product quality differences selling their products through a single retail platform. As previously stated, the retail sector is progressively integrating blockchain technology into its operations to facilitate the sharing of demand-related information with upstream suppliers. This integration is aimed at mitigating the uncertainty associated with demand within the supply chain. So, in order to reduce demand uncertainty, the retail platform chooses whether to share demand information with upstream suppliers. In short,

TABLE 1. Literature comparison.

Paper	Competition	Product quality variance	Information sharing	Using of blockchain	Mean-variance theory	Demand uncertainty
Guo *et al.* [11]	Two competing channels	×	✓	×	×	✓
Shang *et al.* [10]	Two competing manufacturers	✓	✓	×	×	✓
De Giovanni [5]	Platform competition	×	×	✓	×	×
Bian *et al.* [13]	Two competing supply chains	×	✓	×	×	✓
Li *et al.* [15]	Two competing manufacturers	×	✓	✓	×	×
Chen *et al.* [12]	Two competing products	×	✓	×	×	✓
Liu *et al.* [19]	Multiple sellers	×	✓	×	×	✓
Tsunoda *et al.* [18]	Two competing channels	×	✓	×	×	✓
Zhou *et al.* [9]	×	×	✓	✓	×	✓
Biswas *et al.* [20]	×	✓	×	✓	×	×
Cui *et al.* [21]	×	✓	×	✓	×	×
Dong *et al.* [22]	Multiple upstream suppliers	×	×	✓	×	×
Wu *et al.* [1]	Two competing suppliers in different channels	×	✓	✓	×	✓
Tao *et al.* [41]	Two competing platforms	✓	×	✓	×	×
Zhang *et al.* [40]	Two competing channels	×	✓	✓	✓	✓
Ray and Jenamani [39]	×	✓	×	×	✓	×
Yan *et al.* [38]	×	×	×	×	✓	✓
Our paper	Two competing suppliers	✓	✓	✓	✓	✓

there are two scenarios in the design of this model: the retail platform does not share the demand information and the retail platform shares the demand information. When the retail platform intends to share demand information, there will be a choice between sharing it only with upstream high-quality suppliers or low-quality suppliers, or sharing it with two upstream suppliers. Table 2 shows all the symbols and descriptions. Figure C.6 shows the model logic for this article. We describe the model assumptions in terms of demand and cost.

Demand function: inverse demand function are as follows:

$$p_H^\chi = a_H + \varepsilon - q_H^\chi - \gamma q_L^\chi, p_L^\chi = a_L + \varepsilon - q_L^\chi - \gamma q_H^\chi \tag{1}$$

where refer to [42, 43]. We assumes that the market potential of high and low quality products is different, $a_H > a_L$. There are demand uncertainty ε, assuming that $\varepsilon \sim N(0, \sigma^2)$, where $\sigma \in [0, 1]$. Because of poor data quality. (When retail platforms decide to information sharing with a supplier, it is assumed that information sharing can reduce demand uncertainty.) The uncertainty of demand $\varepsilon \sim N(\frac{h}{2}, \sigma^2)$, where $h \in [0, 1]$.

Cost: the transaction cost of low-quality product is c_L. The transaction cost of high-quality product is c_H, $0 < c_L < c_H$. Blockchain technology helps reduce product costs by improving the transparency of the supply chain, reducing intermediate links, and optimizing the transaction process. In practice, companies in various industries have adopted this technology to reduce the cost of products during the transaction process[1,2]. Based on these practical examples, and refer to [4, 5], this article considers the introduction of blockchain technology into retail platforms with the aim of eliminating product transaction costs in the supply chain. In the model setup of this paper, if the upstream supplier is allowed to join the information sharing network, then the transaction cost of the upstream supplier's product will be eliminated. In previous articles studied by scholars

[1] https://onlynaturaldiamonds.com.cn/inside-diamond-world/20230829-1/ (De Beers' Tracr platform, for example, ensures that diamonds are transparent and traceable every step of the way, from mining to sale, through blockchain technology. This not only improves consumer trust, but also reduces costs associated with counterfeit and illegal transactions, while optimizing supply chain management and reducing operational costs.)

[2] https://china.everledger.io/ (Everledger uses blockchain technology to track the provenance and authenticity of luxury goods and jewelry, helping manufacturers and consumers identify counterfeit products. This system reduces the investment of brand owners in the fight against fakes, while providing consumers with higher purchase confidence and reducing the cost of fraud in the market.)

TABLE 2. Parameters and decision variables.

Symbol	Description
Sign	
Superscript $\chi =$ NN, BN, NB, BB	Four strategy scenarios
Parameter	
a_H, a_L	Market potential of high and low quality products
c_H	Transaction cost of high-quality product
c_L	Transaction cost of low-quality product
ε	Demand uncertainty
$\frac{h}{2}$	Expectations of demand uncertainty parameters when retail platform decide to information sharing
σ^2	Variance of the demand uncertainty parameter
γ	Competitive Intensity
b	The information sharing cost of retail platform
F	Fixed costs of blockchain' information sharing
k	The level of risk aversion for retail platform
Decision variables	
w_H	Wholesale prices for high-quality suppliers
w_L	Wholesale prices for low-quality suppliers
q_H	Sales volume from high-quality suppliers
q_L	Sales volume from low-quality suppliers
Function expressions and symbols	
$U_R^\chi = E(\pi_R) - k\sqrt{\mathrm{SD}(\pi_R)}$	The expected utility function expressions for retail Platform, $E(\pi_R)$ represents the expected profit of the retail platform $\mathrm{SD}(\pi_R)$ represents the variance of retail platform profits
$U_{S_H}^\chi$	The expected utility function expressions for high-quality supplier
$U_{S_L}^\chi$	The expected utility function expressions for low-quality supplier
Profits	
π_R^χ	Profit of retail Platform
$\pi_{S_H}^\chi$	Profit of high-quality supplier
$\pi_{S_L}^\chi$	Profit of low-quality supplier

[4,5,42], this parameter b is often regarded as the unit operating cost of introducing new technologies into retail platforms, and this parameter setting is also introduced in this paper. However, this paper takes the introduction of new technologies into retail platforms to share information with upstream suppliers and reduce the demand uncertainty of upstream competitive suppliers as a research perspective. Therefore, this cost is more prominent as the information sharing cost of retail platform in this paper.

3.1. NN-model: The retail platform does not share demand information

Using the mean-variance approach, we establish a supply chain model comprising two rival suppliers and a retail platform, with the expected utility function expressions outlined as follows:

$$U_R^{\mathrm{NN}} = E(\pi_R) - k\sqrt{\mathrm{SD}(\pi_R)} \tag{2}$$

where $\pi_R^{\mathrm{NN}} = (p_H^{\mathrm{NN}} - w_H^{\mathrm{NN}})q_H^{\mathrm{NN}} + (p_L^{\mathrm{NN}} - w_L^{\mathrm{NN}})q_L^{\mathrm{NN}}$. We consider the level of risk aversion of retail platforms $k = 1$ (same in the BN, NB and BB model), and in the extension of the sixth section of this paper, the influence of the change of risk avoidance level on the model is considered, that is, the robustness of the model is verified.

$$U_{S_H}^{\mathrm{NN}}(\pi_{S_H}^{\mathrm{NN}}) = (w_H^{\mathrm{NN}} - c_H^{\mathrm{NN}})q_H^{\mathrm{NN}} \tag{3}$$

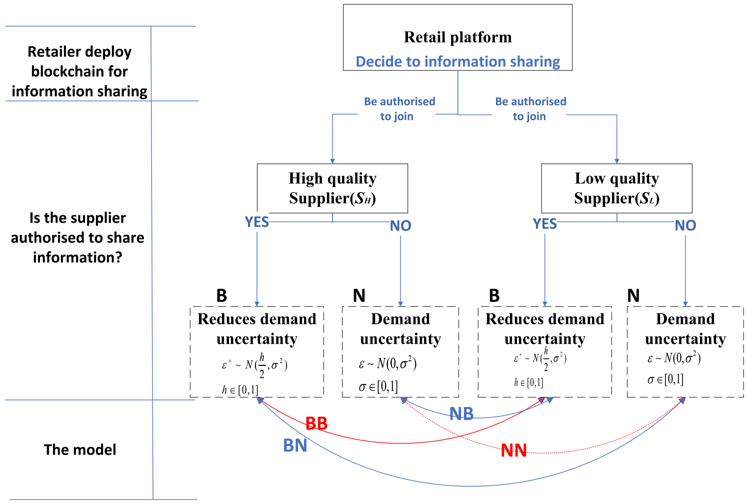


FIGURE 1. The model logic.

$$U_{S_L}^{\mathrm{NN}}(\pi_{S_L}^{\mathrm{NN}}) = (w_L^{\mathrm{NN}} - c_L^{\mathrm{NN}})q_L^{\mathrm{NN}}. \tag{4}$$

Lemma 1. *In Model NN, the optimal equilibrium solution for the wholesale prices of the high-quality supplier and the low-quality supplier is as follows:*

$$w_H^{\mathrm{NN}^*} = \frac{(a_H - \sigma)\gamma^2 + (a_L - \sigma - c_L)\gamma + 2\sigma - 2a_H - 2c_H}{\gamma^2 - 4},$$
$$w_L^{\mathrm{NN}^*} = \frac{(a_L - \sigma)\gamma^2 + (a_H - \sigma - c_H)\gamma + 2\sigma - 2a_L - 2c_L}{\gamma^2 - 4}.$$

The ordering quantities are:

$$q_H^{\mathrm{NN}^*} = \frac{(\sigma - a_H + c_H)\gamma^2 + (\sigma - a_L + c_L)\gamma - 2(\sigma + a_H - c_H)}{2\gamma^4 - 10\gamma^2 + 8},$$
$$q_L^{\mathrm{NN}^*} = \frac{(\sigma - a_L + c_L)\gamma^2 + (\sigma - a_H + c_H)\gamma - 2(\sigma - a_L + c_L)}{2\gamma^4 - 10\gamma^2 + 8}.$$

The validity condition of the equilibrium solution is $a_H - c_H < a_L - c_L, 0 < \gamma < \gamma_1$.

Proposition 1. $w_H^{\mathrm{NN}^*} > w_L^{\mathrm{NN}^*}, q_H^{\mathrm{NN}^*} < q_L^{\mathrm{NN}^*}, p_H^{\mathrm{NN}^*} > p_L^{\mathrm{NN}^*}$. *(The proofs of all propositions, corollaries, etc. of this paper are presented in the appendix.)*

Corollary 1. $\frac{\partial w_H^{\mathrm{NN}^*}}{\partial \gamma} < 0, \frac{\partial w_L^{\mathrm{NN}^*}}{\partial \gamma} < 0; \frac{\partial q_L^{\mathrm{NN}^*}}{\partial c_L} = \frac{\partial q_H^{\mathrm{NN}^*}}{\partial c_H} < 0, \frac{\partial q_L^{\mathrm{NN}^*}}{\partial a_L} = \frac{\partial q_H^{\mathrm{NN}^*}}{\partial a_H} > 0.$

The appendix contains the proof of Proposition 1 and Corollary 1. Proposition 1 demonstrates that, in the NN model, the wholesale price of products from the high-quality supplier exceeds that of the low-quality supplier. At the same time, when $a_H - c_H < a_L - c_L$, high-quality supplier sells fewer products than low-quality supplier. Furthermore, the wholesale price variable of high- and low-quality suppliers exhibits a negative correlation with the product competition intensity coefficient. Furthermore, a negative correlation has been observed between product sales and costs across two suppliers alike. Conversely, a positive correlation has been identified between product sales and the market potential of the product, irrespective of the quality of the suppliers. This suggests that while cost management plays a critical role in sales performance for suppliers of varying quality levels, the market potential of the product exerts a consistent influence on sales outcomes. The findings underscore the importance of balancing cost efficiency with market positioning in optimizing sales performance across supplier categories. These observations are consistent with real-world conditions. This shows that regardless of the quality level of the supplier, product sales are closely related to market potential, while costs can negatively impact sales. The discovery of this correlation provides an important reference for enterprises to make supply chain strategy and product pricing strategy, and also emphasizes the importance of market potential for product sales.

3.2. The retail platform share demand information

3.2.1. BN-model (only share demand information with high-quality suppliers)

In model BN, the expected utility functions of the BN-model are outlined as follows:

$$U_R^{\mathrm{BN}} = E(\pi_R) - k\sqrt{\mathrm{SD}(\pi_R)} \tag{5}$$

where $\pi_R^{\mathrm{BN}} = (p_H^{\mathrm{BN}} - w_H^{\mathrm{BN}} - b)q_H^{\mathrm{BN}} + (p_L^{\mathrm{BN}} - w_L^{\mathrm{BN}})q_L^{\mathrm{BN}}$.

$$U_{S_H}^{\mathrm{BN}}(\pi_{S_H}^{\mathrm{BN}}) = w_H^{\mathrm{BN}} q_H^{\mathrm{BN}} \tag{6}$$

$$U_{S_L}^{\mathrm{BN}}(\pi_{S_L}^{\mathrm{BN}}) = (w_L^{\mathrm{BN}} - c_L^{\mathrm{BN}})q_L^{\mathrm{BN}}. \tag{7}$$

Lemma 2. *The optimal equilibrium solution wholesale price is,*

$$w_L^{\mathrm{BN}^*} = \frac{(2a_L - 2\sigma)\gamma^2 + (-2b + h - 2\sigma + 2a_H)\gamma + 4\sigma - 4a_L - 4c_L}{2\gamma^2 - 8},$$

$$w_H^{\mathrm{BN}^*} = \frac{(-2b + h + 2a_H - 2\sigma)\gamma^2 + (-2c_L - 2\sigma + 2a_L)\gamma + 4b - 2h + 4\sigma - 4a_H}{2\gamma^2 - 8}.$$

The ordering quantities are,

$$q_H^{\mathrm{BN}^*} = \frac{(2\sigma - 2a_H + 2b - h)\gamma^2 + (2\sigma - 2a_L + 2c_L)\gamma - 4b + 2h - 4\sigma + 4a_H}{4\gamma^4 - 20\gamma^2 + 16},$$

$$q_L^{\mathrm{BN}^*} = \frac{(2\sigma - 2a_L + 2c_L)\gamma^2 + (2b - h + 2\sigma - 2a_H)\gamma - 4(\sigma - a_L + c_L)}{4\gamma^4 - 20\gamma^2 + 16}.$$

The validity condition of the equilibrium solution is $\frac{h}{2} + a_H - a_L - 2c_L < b < \min\{\frac{h}{2} + a_H - \sigma, \frac{h}{2} + a_H - a_L + c_L\}$ *and* $0 < \gamma < \gamma_2$.

Proposition 2. $w_H^{\mathrm{BN}^*} > w_L^{\mathrm{BN}^*}, p_H^{\mathrm{BN}^*} > p_L^{\mathrm{BN}^*}, q_H^{\mathrm{BN}^*} > q_L^{\mathrm{BN}^*}$.

In BN mode, the wholesale and retail prices of high-quality suppliers are higher than those of low-quality suppliers, and the sales volume of high-quality suppliers exceeds that of low-quality suppliers.

Corollary 2. $\frac{\partial w_L^{\mathrm{BN}^*}}{\partial \gamma} < 0, \frac{\partial w_H^{\mathrm{BN}^*}}{\partial \gamma} < 0, \frac{\partial w_L^{\mathrm{BN}^*}}{\partial b} > 0, \frac{\partial w_H^{\mathrm{BN}^*}}{\partial b} < 0, \frac{\partial q_H^{\mathrm{BN}^*}}{\partial a_H} = \frac{\partial q_L^{\mathrm{BN}^*}}{\partial a_L} > 0, \frac{\partial q_H^{\mathrm{BN}^*}}{\partial b} < 0, \frac{\partial q_L^{\mathrm{BN}^*}}{\partial b} > 0.$

In the BN-model, there is an observed negative association between the wholesale prices of suppliers categorized as high and low and the coefficient of product competition intensity. The wholesale prices for goods procured from suppliers of inferior quality are positively correlated with the information sharing cost of retail platform. In contrast, the wholesale prices of goods supplied by high-quality suppliers are negatively correlated with the information sharing cost of retail platform. Additionally, the sales performance of products sourced from low-quality suppliers is positively correlated with the information sharing cost of retail platform, whereas the sales of products from high-quality suppliers are inversely correlated with these integration costs. Furthermore, akin to the NN model, within the BN model, the sales figures of both high-quality and low-quality suppliers are positively correlated with the market potential of the product. This suggests that the market potential has a substantial impact on the sales outcomes for products from suppliers of varying quality, irrespective of the information sharing cost of retail platform settings. These findings underscore the complex interplay among pricing strategies, product quality, technological investments, and market dynamics in shaping sales performance across different supplier categories.

3.2.2. NB-model (only share demand information with low-quality suppliers)

In Model NB, the expected utility functions as follows:

$$U_R^{\mathrm{NB}} = E(\pi_R) - k\sqrt{\mathrm{SD}(\pi_R)} \tag{8}$$

where $\pi_R^{\mathrm{NB}} = (p_H^{\mathrm{NB}} - w_H^{\mathrm{NB}})q_H^{\mathrm{NB}} + (p_L^{\mathrm{NB}} - w_L^{\mathrm{NB}} - b)q_L^{\mathrm{NB}}$.

$$U_{S_H}^{\mathrm{NB}}(\pi_{S_H}^{\mathrm{NB}}) = (w_H^{\mathrm{NB}} - c_H^{\mathrm{NB}})q_H^{\mathrm{NB}} \tag{9}$$

$$U_{S_L}^{\mathrm{NB}}(\pi_{S_L}^{\mathrm{NB}}) = w_L^{\mathrm{NB}}q_L^{\mathrm{NB}}. \tag{10}$$

Lemma 3. *The optimal equilibrium solution wholesale price is:*

$$w_L^{\mathrm{NB}^*} = \frac{(2a_L - 2\sigma - 2b + h)\gamma^2 + (-2\sigma + 2a_H - 2c_H)\gamma + 4b - 2h + 4\sigma - 4a_L}{2\gamma^2 - 8},$$

$$w_H^{\mathrm{NB}^*} = \frac{(2a_H - 2\sigma)\gamma^2 + (-2b + h - 2\sigma + 2a_L)\gamma + 4\sigma - 4a_H - 4c_H}{2\gamma^2 - 8}.$$

The ordering quantities are:

$$q_H^{\mathrm{NB}^*} = \frac{(2\sigma - 2a_H + 2c_H)\gamma^2 + (2b - h + 2\sigma - 2a_L)\gamma - 4\sigma + 4a_H - 4c_H}{4\gamma^4 - 20\gamma^2 + 16},$$

$$q_L^{\mathrm{NB}^*} = \frac{(2b - h + 2\sigma - 2a_L)\gamma^2 + (2\sigma - 2a_H + 2c_H)\gamma - 4b + 2h - 4\sigma + 4a_L}{4\gamma^4 - 20\gamma^2 + 16}.$$

The validity condition of the equilibrium solution is $\max\{0, \frac{h}{2} - a_H + a_L - 2c_H\} < b < \min\{\frac{h}{2} - \sigma + a_L, \frac{h}{2} - a_H + a_L + c_H\}$ *and* $0 < \gamma < \min\{\gamma_3, \gamma_3''\}$.

Proposition 3. $w_H^{\mathrm{NB}^*} < w_L^{\mathrm{NB}^*}, q_H^{\mathrm{NB}^*} < q_L^{\mathrm{NB}^*}$.

In the NB mode, unlike the BN mode, the wholesale price of high-quality suppliers is lower than that of low-quality suppliers, and the sales volume of high-quality suppliers is lower than that of low-quality suppliers.

Corollary 3. $\frac{\partial w_L^{\mathrm{NB}^*}}{\partial \gamma} < 0, \frac{\partial w_H^{\mathrm{NB}^*}}{\partial \gamma} < 0, \frac{\partial w_L^{\mathrm{NB}^*}}{\partial b} < 0, \frac{\partial w_H^{\mathrm{NB}^*}}{\partial b} > 0, \frac{\partial q_H^{\mathrm{NB}^*}}{\partial a_H} = \frac{\partial q_L^{\mathrm{NB}^*}}{\partial a_L} > 0, \frac{\partial q_L^{\mathrm{NB}^*}}{\partial b} < 0, \frac{\partial q_H^{\mathrm{NB}^*}}{\partial b} > 0$.

In the NB model, the variables governing the wholesale pricing decisions for suppliers classified as high and low-quality exhibit a negative correlation with the coefficient of product competition intensity. And, the wholesale prices of goods sourced from low-quality suppliers are found to have a negative correlation with the costs associated with the information sharing on retail platforms. Conversely, the wholesale prices of products from high-quality suppliers are positively correlated with these implementation costs. This pattern extends to the sales performance of the products, where the sales of low-quality suppliers' products show a negative correlation with the costs of information sharing on retail platforms, whereas the sales of high-quality suppliers' products are positively correlated with these costs.

This correlation pattern in the NB model is consistent with that observed in both the NN and BN models. In line with these models, the NB model reveals a positive correlation between the sales of products from both high- and low-quality suppliers and the market potential of the product. This suggests that the market potential plays a pivotal role in influencing sales outcomes for products from suppliers across the quality spectrum, regardless of the costs involved in the adoption of information sharing in retail settings.

The findings from the NB model contribute to the understanding of the intricate relationships within the retail industry, highlighting the significance of product quality, competition dynamics, and information sharing in shaping pricing strategies and sales performance. The negative correlation between low-quality supplier wholesale prices and the cost of information sharing, as well as the positive correlation between high-quality supplier wholesale prices and the same cost, underscores the potential trade-offs between quality and the investment tracking systems.

3.2.3. BB-model (share demand information with both high- and low-quality suppliers)

In Model BB, the expected utility functions as follows:

$$U_R^{\mathrm{BB}} = E(\pi_R) - k\sqrt{\mathrm{SD}(\pi_R)} \tag{11}$$

where $\pi_R^{\mathrm{BB}} = (p_H^{\mathrm{BB}} - w_H^{\mathrm{BB}} - b)q_H^{\mathrm{BB}} + (p_L^{\mathrm{BB}} - w_L^{\mathrm{BB}} - b)q_L^{\mathrm{BB}}$.

$$U_{S_H}^{\mathrm{BB}}(\pi_{S_H}^{\mathrm{BB}}) = w_H^{\mathrm{NB}} q_H^{\mathrm{NB}} \tag{12}$$

$$U_{S_L}^{\mathrm{BB}}(\pi_{S_L}^{\mathrm{BB}}) = w_L^{\mathrm{NB}} q_L^{\mathrm{BB}}. \tag{13}$$

Lemma 4. *The optimal equilibrium solution wholesale price is:*

$$w_L^{\mathrm{BB}^*} = \frac{(2a_L - 2\sigma - 2b + h)\gamma^2 + (h - 2b - 2\sigma + 2a_H)\gamma + 4(b + \sigma - a_L) - 2h}{2\gamma^2 - 8},$$

$$w_H^{\mathrm{BB}^*} = \frac{(2a_H - 2\sigma - 2b + h)\gamma^2 + (h - 2b - 2\sigma + 2a_L)\gamma + 4(b + \sigma - a_H) - 2h}{2\gamma^2 - 8}.$$

The ordering quantities are:

$$q_H^{\mathrm{BB}^*} = \frac{(2b - h + 2\sigma - 2a_H)\gamma^2 + (2b - h + 2\sigma - 2a_L)\gamma - 4b + 2h - 4\sigma + 4a_H}{4\gamma^4 - 20\gamma^2 + 16},$$

$$q_L^{\mathrm{BB}^*} = \frac{(2b - h + 2\sigma - 2a_L)\gamma^2 + (2b - h + 2\sigma - 2a_H)\gamma - 4b + 2h - 4\sigma + 4a_L}{4\gamma^4 - 20\gamma^2 + 16}.$$

The validity condition of the equilibrium solution is $0 < b < \min\{\frac{h}{2} - \sigma + a_L, \frac{h}{2} - \sigma + a_H\}$, $0 < \gamma < \gamma_4$.

Proposition 4. $w_H^{\mathrm{BB}^*} > w_L^{\mathrm{BB}^*}, q_H^{\mathrm{BB}^*} > q_L^{\mathrm{BB}^*}$.

In the context of the BB model, akin to the BN model, the wholesale pricing dynamics between high-quality and low-quality suppliers exhibit a pronounced disparity. Specifically, the wholesale prices of products sourced from high-quality suppliers are observed to surpass those of their low-quality counterparts, thereby stimulating a higher sales volume for the former. This pricing strategy is reflective of the market's appreciation for the superior quality of goods offered by high-quality suppliers, which in turn leads to increased demand and sales, underscoring the premium value placed on quality by consumers.

The BB model's strategic approach to pricing high-quality products at a premium is designed to leverage consumer preferences for quality and, consequently, to enhance profitability for both the suppliers and the retail platform. By establishing a pricing differential based on product quality, the BB model aims to create a competitive advantage within the retail ecosystem. This differentiation not only attracts a clientele that values quality but also serves to differentiate the retail platform from its competitors, thereby potentially increasing customer loyalty and market share.

Moreover, the higher wholesale prices for high-quality products facilitate a more efficient allocation of resources within the supply chain, as high-quality suppliers are incentivized to invest in the production of superior goods, which are then rewarded with higher returns. This dynamic encourages a virtuous cycle of quality improvement and market recognition, ultimately contributing to the overall enhancement of the retail ecosystem's performance. The competitive landscape within the BB model is characterized by a strategic interplay between high-quality and low-quality suppliers. High-quality suppliers, through their commitment to quality, are able to command higher prices and secure a larger market share. In contrast, low-quality suppliers may struggle to compete on price or quality, leading to a potential erosion of their market position. This competitive tension drives both suppliers and the retail platform to continuously innovate and improve, fostering a dynamic and evolving retail environment that benefits all stakeholders involved.

Corollary 4. $\frac{\partial w_L^{\mathrm{BB}*}}{\partial \gamma} < 0, \frac{\partial w_H^{\mathrm{BB}*}}{\partial \gamma} < 0, \frac{\partial w_L^{\mathrm{BB}*}}{\partial b} = \frac{\partial w_H^{\mathrm{BB}*}}{\partial b} < 0, \frac{\partial q_H^{\mathrm{BB}*}}{\partial a_H} = \frac{\partial q_L^{\mathrm{BB}*}}{\partial a_L} > 0, \frac{\partial q_H^{\mathrm{BB}*}}{\partial b} = \frac{\partial q_L^{\mathrm{BB}*}}{\partial b} < 0.$

In the BB model, the wholesale price decisions of high-quality and low-quality suppliers are intricately linked to the intensity of product competition, manifesting as an inverse relationship with the coefficient of competition. This relationship implies that as the competition among suppliers intensifies, high-quality suppliers tend to set higher wholesale prices, while low-quality suppliers may be compelled to offer lower prices to remain competitive. This dynamic reflects the strategic positioning of suppliers within the market, where high-quality suppliers leverage their superior product offerings to command premium prices, thereby influencing the overall pricing landscape. Moreover, the wholesale pricing parameters for both high- and low-quality suppliers are negatively correlated with the expenses associated with information sharing into retail platforms. This correlation suggests that the higher the costs of information sharing, the more likely suppliers are to adjust their pricing strategies to offset these additional expenses. The adoption of information sharing aims to enhance product transparency, consumer trust, and operational efficiency, but the associated costs can significantly impact supplier profitability, necessitating careful consideration of pricing strategies.

Similarly, the sales figures of products sourced from high- and low-quality suppliers are inversely connected to the costs of information sharing. These findings collectively emphasize the significant impact of information sharing costs on pricing dynamics and sales performance across different supplier tiers. The intricate interplay between supplier pricing strategies, product sales, and the adoption of information sharing in retail settings is crucial for businesses aiming to navigate the complexities of information sharing while considering the implications for supplier pricing strategies and product sales across varying quality levels. Recognizing these interdependencies is essential for businesses seeking to optimize their pricing strategies and technology investments. The BB model, akin to the NN, BN, and NB models, reveals that product sales of high- and low-quality suppliers are positively correlated with product market potential. This positive correlation indicates that the market's acceptance and demand for products are influenced by both the quality of the supplier and the potential of the product to meet market needs.

Corollary 5. $\frac{\partial q_H^{\mathrm{NN}*}}{\partial \gamma} - \frac{\partial q_L^{\mathrm{NN}*}}{\partial \gamma} < 0, \frac{\partial q_H^{\mathrm{NB}*}}{\partial \gamma} - \frac{\partial q_L^{\mathrm{NB}*}}{\partial \gamma} < 0, \frac{\partial q_H^{\mathrm{BN}*}}{\partial \gamma} - \frac{\partial q_L^{\mathrm{BN}*}}{\partial \gamma} > 0, \frac{\partial q_H^{\mathrm{BB}*}}{\partial \gamma} - \frac{\partial q_L^{\mathrm{BB}*}}{\partial \gamma} > 0.$

In the context of heightened competition, the sales performance of high-quality and low-quality products on retail platforms exhibits divergent patterns across various models. Specifically, within the NN and NB models, the sales of low-quality products tend to escalate in conjunction with increasing competition intensity. In contrast, the BN and BB models demonstrate a surge in sales of high-quality products as product competition intensity rises, suggesting a positive correlation between product quality and sales performance under these conditions. Moreover, when retail platforms decide to information sharing, an escalation in the unit cost of information sharing leads to a widening numerical disparity between high-quality and low-quality products across the four models in terms of their sensitivity to competition intensity (as shown in Figs. 2 and 3). This observation highlights the intricate relationship between competition intensity, product quality, and the adoption of information sharing, underscoring the need for businesses to strategically navigate these dynamics to optimize sales performance and maintain competitiveness in the evolving retail landscape. This lays the foundation for retail platforms to determine the price of products under different information sharing models.

Table 3 succinctly summarizes the sensitivity trends of decision variables in relation to key parameters. When evaluating the impact of the cost of information sharing, the restriction of information sharing access to

TABLE 3. sensitivity trends of decision variables.

Decision variables	Key parameters			
	γ	b	a_H	a_L
w_H^{U*}	$\frac{\partial w_H^{U*}}{\partial\gamma}\downarrow$	$\frac{\partial w_H^{\mathrm{BN}^*}}{\partial b}\downarrow, \frac{\partial w_H^{\mathrm{NB}^*}}{\partial b}\uparrow, \frac{\partial w_H^{\mathrm{BB}^*}}{\partial b}\downarrow$	$\frac{\partial w_H^{U*}}{\partial a_H}\uparrow$	$\frac{\partial w_H^{U*}}{\partial a_L}\downarrow$
w_L^{U*}	$\frac{\partial w_L^{U*}}{\partial\gamma}\downarrow$	$\frac{\partial w_L^{\mathrm{BN}^*}}{\partial b}\uparrow, \frac{\partial w_L^{\mathrm{NB}^*}}{\partial b}\downarrow, \frac{\partial w_L^{\mathrm{BB}^*}}{\partial b}\downarrow$	$\frac{\partial w_L^{U*}}{\partial a_H}\downarrow$	$\frac{\partial w_L^{U*}}{\partial a_L}\uparrow$
q_H^{U*}	$\frac{\partial q_H^{\mathrm{NN}^*}}{\partial\gamma}\downarrow, \frac{\partial q_H^{\mathrm{NB}^*}}{\partial\gamma}\downarrow, \frac{\partial q_H^{\mathrm{BN}^*}}{\partial\gamma}\uparrow, \frac{\partial q_H^{\mathrm{BB}^*}}{\partial\gamma}\uparrow$	$\frac{\partial q_H^{\mathrm{BN}^*}}{\partial b}\downarrow, \frac{\partial q_H^{\mathrm{NB}^*}}{\partial b}\uparrow, \frac{\partial q_H^{\mathrm{BB}^*}}{\partial b}\downarrow$	$\frac{\partial q_H^{U*}}{\partial a_H}\uparrow$	$\frac{\partial q_H^{U*}}{\partial a_L}\uparrow$
q_L^{U*}	$\frac{\partial q_L^{\mathrm{NN}^*}}{\partial\gamma}\uparrow, \frac{\partial q_L^{\mathrm{NB}^*}}{\partial\gamma}\uparrow, \frac{\partial q_L^{\mathrm{BN}^*}}{\partial\gamma}\downarrow, \frac{\partial q_L^{\mathrm{BB}^*}}{\partial\gamma}\downarrow$	$\frac{\partial q_L^{\mathrm{BN}^*}}{\partial b}\uparrow, \frac{\partial q_L^{\mathrm{NB}^*}}{\partial b}\downarrow, \frac{\partial q_L^{\mathrm{BB}^*}}{\partial b}\downarrow$	$\frac{\partial q_L^{U*}}{\partial a_H}\uparrow$	$\frac{\partial q_L^{U*}}{\partial a_L}\uparrow$

either high-quality or low-quality suppliers can result in a decline in sales volume for the corresponding quality category. This is due to the increased costs associated with the utilization of information sharing.

In terms of wholesale price sensitivity analysis, when a retail platform decides to share demand information only with high quality (or low quality) suppliers, as the cost increases, so does the price of low (or high) quality products of wholesale quality. Conversely, when retail platforms share demand information with both high- and low-quality suppliers, the wholesale price of the product will fall as the cost of the associated information sharing rises. It is worth noting that increasing wholesale prices does not yield favorable outcomes as competition intensifies. Sensitivity analysis regarding market potential reveals that a higher market potential correlates with increased sales of products, aligning with the conventional wisdom that elevated consumer demand drives product sales and overall sales volume. Analyzing the effect of market potential on product sales aids businesses in acquiring a deeper understanding of consumer demand's impact on sales, thereby providing critical insights for pricing and marketing strategies.

4. Comparison

By conducting a thorough comparative analysis, we evaluated the profitability of supply chain game players, ultimately deriving the most advantageous strategy that considers various factors. This comprehensive approach involved assessing the financial performance of different types of suppliers and the retailer to identify the optimal course of action. This strategic decision-making process aims to enhance overall profitability and efficiency while maintaining a balance between quality, cost, and operational effectiveness. $0 < b < \frac{h}{2} - a_H + a_L + c_H, a_H - c_H < a_L - c_L, 0 < \gamma < \gamma_4$.

4.1. Equilibrium profit solution comparison between high- and low-quality supplier

Proposition 5. $\pi_{S_H}^{\mathrm{NN}^*} < \pi_{S_L}^{\mathrm{NN}^*}, \pi_{S_H}^{\mathrm{BN}^*} > \pi_{S_L}^{\mathrm{BN}^*}, \pi_{S_H}^{\mathrm{NB}^*} < \pi_{S_L}^{\mathrm{NB}^*}, \pi_{S_H}^{\mathrm{BB}^*} > \pi_{S_L}^{\mathrm{BB}^*}$.

In cases where the retail platform decides not to share demand information with upstream suppliers, the margins of high-quality suppliers are consistently lower than those of low-quality suppliers. However, once the decision was made on the retail platform to share product demand information with upstream suppliers, and only with high-quality suppliers, the results showed that high-quality suppliers had a clear competitive advantage in terms of profitability. Before the retail platform shares demand information with low-quality suppliers, low-quality suppliers show a sustained profit advantage over high-quality suppliers. This discrepancy persists even after retail platforms share demand information with lower-quality suppliers. Curiously, a paradigm shift occurs when retail platforms share information about product demand with both high- and low-quality suppliers, resulting in a reversal of profitability trends. In this configuration, the profit of high-quality suppliers exceeds

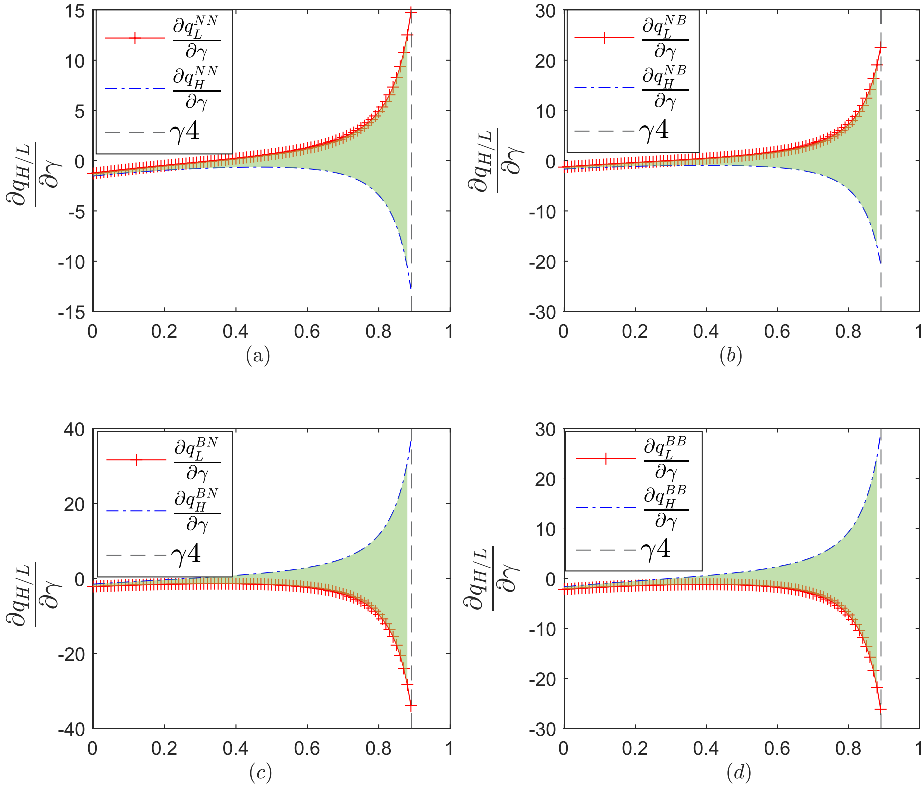


FIGURE 2. $0 < b < \frac{h}{2} + c_L$. (a) $\gamma(0 < b < h/2 + c_L)$. (b) $\gamma(0 < b < h/2 + c_L)$. (c) $\gamma(0 < b < h/2 + c_L)$. (d) $\gamma(0 < b < h/2 + c_L)$.

that of low-quality suppliers, which highlights the transformative effect of demand information sharing on supply chain dynamics.

4.2. Equilibrium solution comparison of four modes of game participants

Within this segment, we conduct an in-depth examination of the model's decision variables to establish the following propositions:

Proposition 6. *When* $0 < b < \frac{h}{2} + c_L$*, there are* $q_H^{\mathrm{NB}^*} < q_H^{\mathrm{NN}^*} < q_H^{\mathrm{BB}^*} < q_H^{\mathrm{BN}^*}$, $p_H^{\mathrm{BB}^*} < p_H^{\mathrm{BN}^*} < p_H^{\mathrm{NB}^*} < p_H^{\mathrm{NN}^*}$, $w_H^{\mathrm{NB}^*} < w_H^{\mathrm{NN}^*} < w_H^{\mathrm{BB}^*} < w_H^{\mathrm{BN}^*}$. *When* $\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H$*, there are* $q_H^{\mathrm{NN}^*} < q_H^{\mathrm{NB}^*} < q_H^{\mathrm{BN}^*} < q_H^{\mathrm{BB}^*}$, $p_H^{\mathrm{BN}^*} < p_H^{\mathrm{BB}^*} < p_H^{\mathrm{NN}^*} < p_H^{\mathrm{NB}^*}$, $w_H^{\mathrm{NN}^*} < w_H^{\mathrm{NB}^*} < w_H^{\mathrm{BB}^*} < w_H^{\mathrm{BN}^*}$.

Proposition 7. *When* $0 < b < \frac{h}{2} - a_H + a_L + c_H$*, there are* $p_L^{\mathrm{BB}^*} < p_L^{\mathrm{BN}^*} < p_L^{\mathrm{NB}^*} < p_L^{\mathrm{NN}^*}$, $w_L^{\mathrm{BN}^*} < w_L^{\mathrm{NN}^*} < w_L^{\mathrm{BB}^*} < w_L^{\mathrm{NB}^*}$.

$$0 < b < \frac{h}{2} + c_L \begin{cases} 0 < \gamma < \gamma *+, q_L^{\mathrm{BN}^*} < q_L^{\mathrm{NN}^*} < q_L^{\mathrm{BB}^*} < q_L^{\mathrm{NB}^*} \\ \gamma *+ < \gamma < \gamma 4, q_L^{\mathrm{BN}^*} < q_L^{\mathrm{BB}^*} < q_L^{\mathrm{NN}^*} < q_L^{\mathrm{NB}^*} \end{cases}$$
$$\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H \begin{cases} 0 < \gamma < \gamma *+, q_L^{\mathrm{BB}^*} < q_L^{\mathrm{NB}^*} < q_L^{\mathrm{BN}^*} < q_L^{\mathrm{NN}^*} \\ \gamma *+ < \gamma < \gamma 4, q_L^{\mathrm{BB}^*} < q_L^{\mathrm{BN}^*} < q_L^{\mathrm{NB}^*} < q_L^{\mathrm{NN}^*}. \end{cases}$$

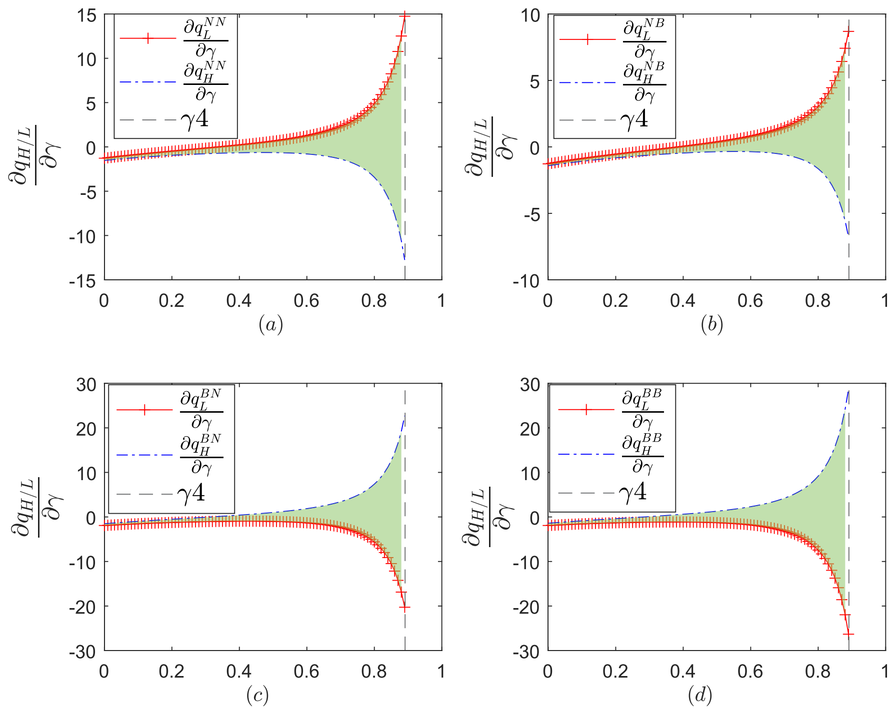


FIGURE 3. $\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H$. (a) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$. (c) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$. (d) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$.

Figures 4 and 5 vividly illustrate Propositions 6 and 7 through numerical simulations. In conclusion, the strategic decision of a retail platform to disclose product demand information to upstream suppliers is empirically demonstrated to facilitate the reduction of product prices. This insight underscores the pivotal role that information sharing plays in the supply chain dynamics, enabling more efficient market responses and cost optimizations. This observation is consonant with the findings presented by Tao *et al.* [41], Wu *et al.* [1] and Pun *et al.* [30]'s studies, which highlight the integration of blockchain technology in the supply chain to facilitate information sharing. In our study further elucidates the nuanced impacts of such information sharing on product sales, particularly highlighting its positive correlation with the sales of high-quality goods. However, an intriguing finding emerges in the context of retail platforms that predominantly sell low-quality products: under the scenario where the cost of information sharing is escalating, NN-model exhibit the highest sales performance. This anomaly suggests that the strategic deployment of information sharing might not uniformly benefit all types of retail platforms, particularly those characterized by the sale of inferior goods. The implications of these findings underscore the importance of considering the specific characteristics and market dynamics of different retail segments when evaluating the potential benefits and costs associated with information sharing integration.

4.3. Equilibrium profit solution comparison of four modes of game participants

This section performs a comparative evaluation of the profitability of high-quality and low-quality suppliers, along with retail platforms, across four distinct scenarios. The objective is to identify the most advantageous profit model for every participant in the supply chain ecosystem. Through this analysis, the study aims to establish some propositions that can guide decision-making processes and strategic planning within the supply chain industry.

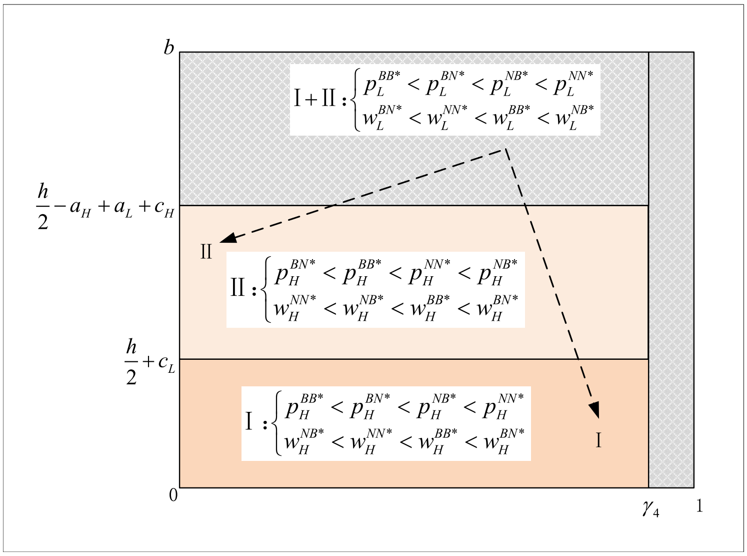


Figure 4. Price.

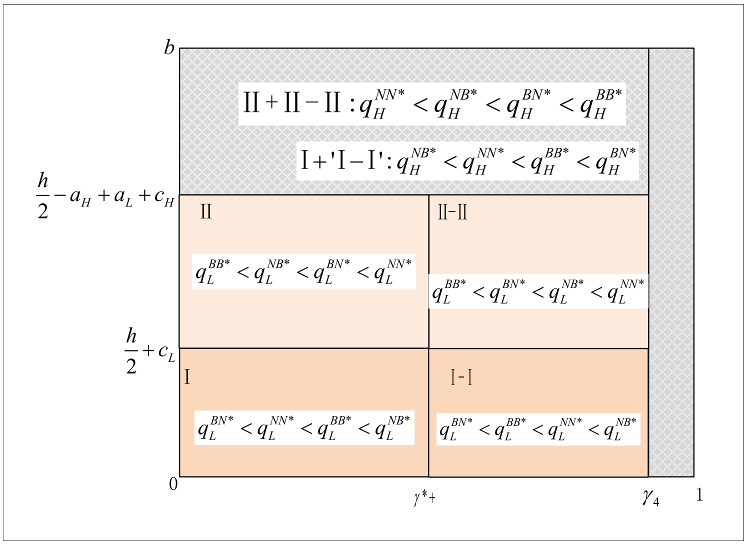


Figure 5. Quantity.

Proposition 8. *High-quality suppliers, when* $0 < b < \frac{h}{2} + c_L$, *there are* $\pi_{S_H}^{\mathrm{NB}^*} < \pi_{S_H}^{\mathrm{NN}^*} < \pi_{S_H}^{\mathrm{BB}^*} < \pi_{S_H}^{\mathrm{BN}^*}$. *When* $\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H$, *there are* $\pi_{S_H}^{\mathrm{NN}^*} < \pi_{S_H}^{\mathrm{NB}^*} < \pi_{S_H}^{\mathrm{BN}^*} < \pi_{S_H}^{\mathrm{BB}^*}$.

Proposition 9. *Low-quality suppliers, when* $0 < b < \frac{h}{2} + c_L$, *there are*

$$\begin{cases} 0 < \gamma < \gamma * +, \pi_{S_L}^{\mathrm{BN}^*} < \pi_{S_L}^{\mathrm{NN}^*} < \pi_{S_L}^{\mathrm{BB}^*} < \pi_{S_L}^{\mathrm{NB}^*} \\ \gamma * + < \gamma < \gamma_4, \pi_{S_L}^{\mathrm{BN}^*} < \pi_{S_L}^{\mathrm{BB}^*} < \pi_{S_L}^{\mathrm{NN}^*} < \pi_{S_L}^{\mathrm{NB}^*}; \end{cases}$$

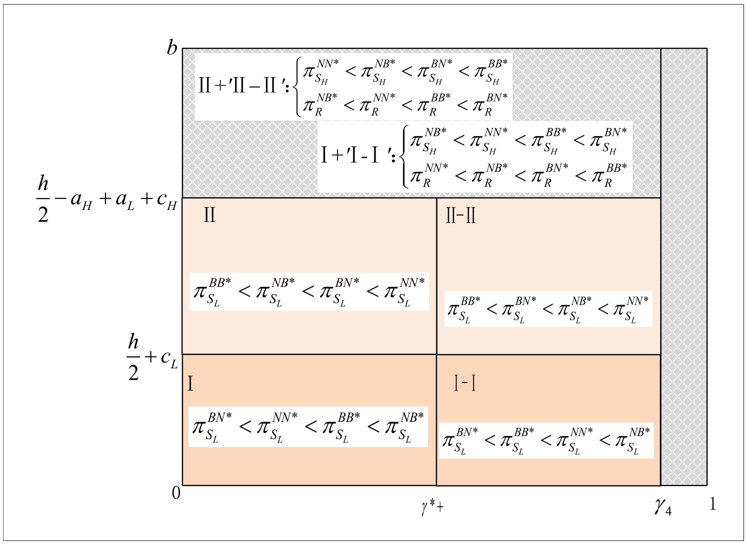


FIGURE 6. Profit.

when $\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H$, *there are*

$$\begin{cases} 0 < \gamma < \gamma * +, \pi_{S_L}^{\mathrm{BB}^*} < \pi_{S_L}^{\mathrm{NB}^*} < \pi_{S_L}^{\mathrm{BN}^*} < \pi_{S_L}^{\mathrm{NN}^*} \\ \gamma * + < \gamma < \gamma_4, \pi_{S_L}^{\mathrm{BB}^*} < \pi_{S_L}^{\mathrm{BN}^*} < \pi_{S_L}^{\mathrm{NB}^*} < \pi_{S_L}^{\mathrm{NN}^*}. \end{cases}$$

Proposition 10. *Retailers, when* $0 < b < \frac{h}{2} + c_L$, *there are* $\pi_R^{\mathrm{NN}^*} < \pi_R^{\mathrm{NB}^*} < \pi_R^{\mathrm{BN}^*} < \pi_R^{\mathrm{BB}^*}$. *When* $\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H$, *there are* $\pi_R^{\mathrm{NB}^*} < \pi_R^{\mathrm{NN}^*} < \pi_R^{\mathrm{BB}^*} < \pi_R^{\mathrm{BN}^*}$.

Propositions 8–10 demonstrate that the deployment cost of information sharing on retail platforms impacts the optimal profit model of participants in the supply chain game. Figure 6 clearly shows the results for Propositions 8–10. The profit-dominant strategies employed by the participants in the supply chain game are intricately moulded by the dynamic interaction between the unit cost related to the integration of information sharing into retail platforms and the degree of competition intensity within the product market. Particularly, the intensity of product competition has the most significant impact on low-quality suppliers. Figure 6 shows the optimal supply chain such as the size region under the common change of information sharing cost and product competition intensity.

In scenarios where the cost of information sharing on retail platforms is negligible, high-quality suppliers predominantly adopt the BN profit dominance strategy, whereas low-quality suppliers prefer the NB strategy. In this context, the retail platform deems the BB strategy as optimal. Conversely, when the unit cost of information sharing on retail platforms is considerable, high-quality suppliers tend to opt for the BB profit dominance model. In contrast, low-quality suppliers are more inclined to follow the NN strategy, and retail platforms are anticipated to adopt the BN profit dominance model. The transition between profit dominance models, contingent upon the cost of information sharing implementation, illuminates the strategic decision-making processes of each participant within the supply chain ecosystem. This underscores the dynamic nature of profit optimization strategies in response to differing cost structures.

In the case of low unit cost for information sharing, the retail platform opts for the BB model. Although this model is not the profit-dominant model of high-quality suppliers, the BB model is the second-dominant model choice of high-quality suppliers' profits, and high-quality suppliers will not lose too much. For low-quality suppliers, if and only if the product competition intensity is within a certain threshold range ($0 < \gamma < \gamma * +$),

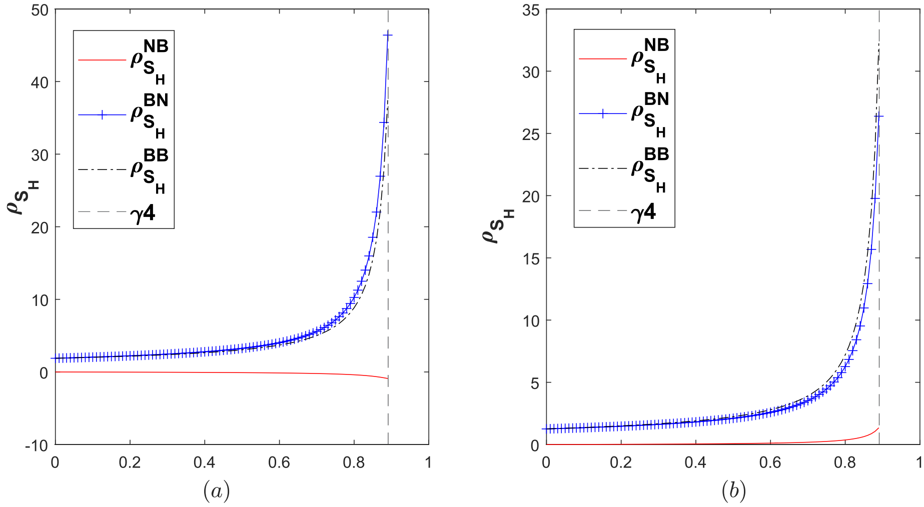


FIGURE 7. Efficiency of demand information sharing profit of high-quality supplier. (a) $\gamma(0 < b < h/2 + c_L)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$.

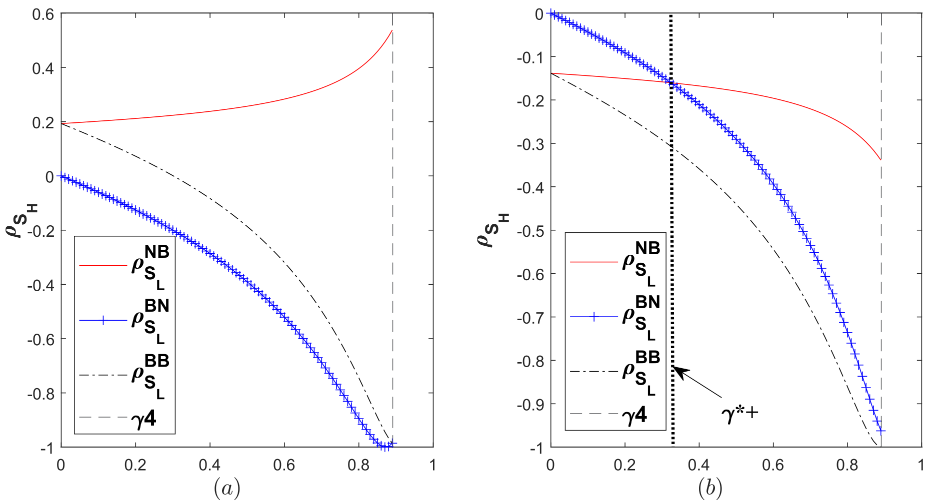


FIGURE 8. Efficiency of demand information sharing profit of low-quality supplier. (a) $\gamma(0 < b < h/2 + c_L)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$.

the BB model will be the second-dominant profit model of low-quality suppliers. In cases where the unit cost associated with information sharing is substantial, the retail platform is inclined to opt for the BN model. This model entails exclusively permitting authorized high-quality suppliers to participate in the information sharing network while facilitating the sharing of demand information. The BN model emerges as the second most favorable choice for enhancing the profitability of high-quality suppliers, ensuring that they do not incur significant losses. This strategic selection not only safeguards the interests of high-quality suppliers but also underscores the retail platform's commitment to fostering transparency and efficiency in supply chain operations. By prioritizing the BN model under conditions of high implementation costs, retail platforms can strike a balance between cost-effectiveness and supplier profitability, thereby laying the foundation for sustainable and mutually

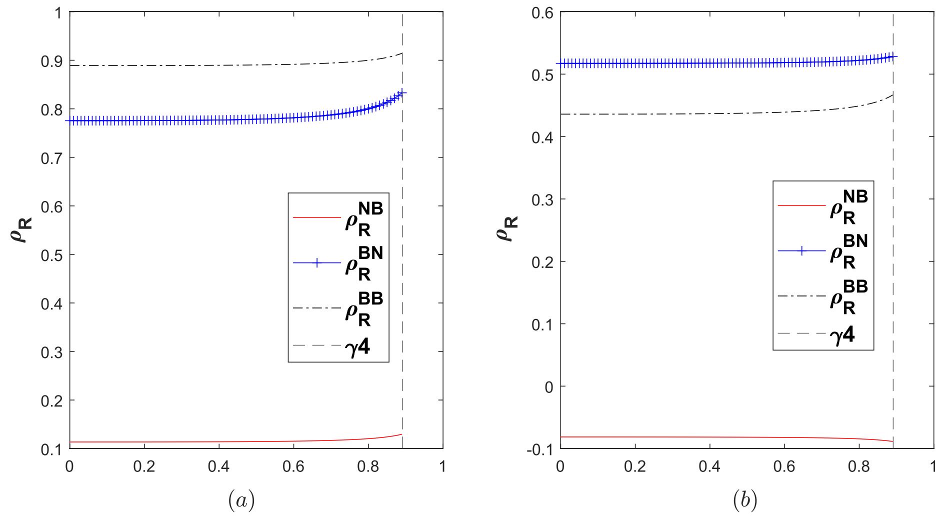


FIGURE 9. Efficiency of demand information sharing profit of retail platform. (a) $\gamma(0 < b < h/2 + c_L)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$.

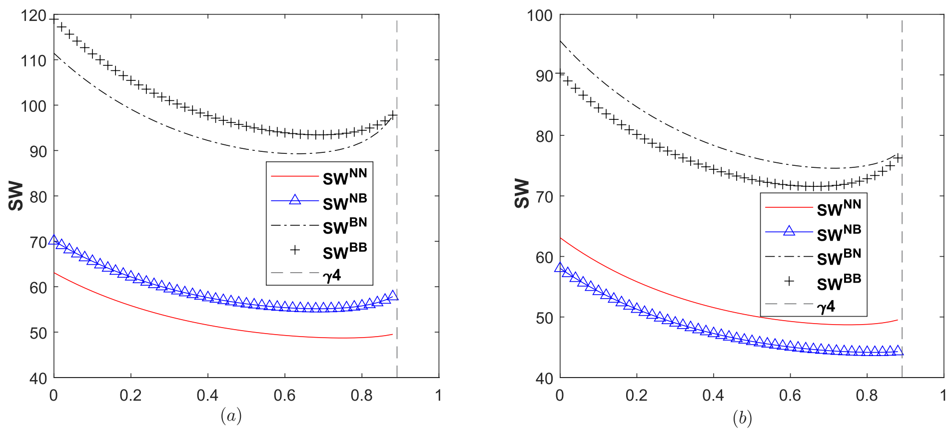


FIGURE 10. Social welfare for four models. (a) $\gamma(0 < b < h/2 + c_L)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$.

beneficial supplier relationships. For low-quality suppliers, if and only if the product competition intensity is within a certain threshold range $(0 < \gamma < \gamma * +)$, the BB model will be the second-dominant profit model of low-quality suppliers. Additionally, it is evident that irrespective of the unit cost associated with the information sharing on retail platforms, when the BN or BB model emerges as the most lucrative option for high-quality suppliers, it invariably becomes the least profitable alternative for low-quality suppliers.

The core of this phenomenon is rooted in the cost-benefit analysis of information sharing attributes among suppliers with differing quality levels, including factors such as transparency, traceability, and secure information exchange. High-quality suppliers leverage information sharing to bolster their brand reputation by guaranteeing product authenticity and supply chain integrity. Conversely, low-quality suppliers may suffer competitive setbacks due to transparency that reveals their shortcomings. At low deployment costs, the advantages of exclusive access to demand information can offset costs for all suppliers, allowing manipulation of data without revealing quality levels. However, rising deployment costs alter this balance.

4.4. Comparison of demand information sharing efficiency gains

This section compares the equilibrium results of the paper to obtain the optimal demand information sharing model for each participant in the supply chain game. In order to facilitate comparative analysis, we define $\rho_{\Psi}^{i} = \frac{U_{\Psi}^{i} - U_{\Psi}^{\mathrm{NN}}}{U_{\Psi}^{\mathrm{NN}}}$ as the efficiency of demand information sharing profit for retail platforms and high- and low-quality suppliers, where $i = \mathrm{NB}, \mathrm{BN}, \mathrm{BB}; \Psi = R, S_H, S_L$.

Proposition 11. *When* $0 < b < \frac{h}{2} + c_L$*, there are* $\rho_{S_H}^{\mathrm{NB}} < \rho_{S_H}^{\mathrm{BB}} < \rho_{S_H}^{\mathrm{BN}}$, $\rho_{S_L}^{\mathrm{BN}} < \rho_{S_L}^{\mathrm{BB}} < \rho_{S_L}^{\mathrm{NB}}$, $\rho_{R}^{\mathrm{NB}} < \rho_{R}^{\mathrm{BN}} < \rho_{R}^{\mathrm{BB}}$. *When* $\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H$*: there are* $\rho_{S_H}^{\mathrm{NB}} < \rho_{S_H}^{\mathrm{BN}} < \rho_{S_H}^{\mathrm{BB}}$, $\rho_{R}^{\mathrm{NB}} < \rho_{R}^{\mathrm{BB}} < \rho_{R}^{\mathrm{BN}}$.
$$\begin{cases} 0 < \gamma < \gamma *+, \rho_{S_L}^{\mathrm{BB}} < \rho_{S_L}^{\mathrm{NB}} < \rho_{S_L}^{\mathrm{BN}} \\ \gamma *+ < \gamma < \gamma_4, \rho_{S_L}^{\mathrm{BB}} < \rho_{S_L}^{\mathrm{BN}} < \rho_{S_L}^{\mathrm{NB}} \end{cases}.$$

From the perspective of high-quality suppliers (see Fig. 7), quality suppliers are the most profitable at this time when it is cheaper for retail platforms only share demand information with high-quality suppliers. In contrast, when the information sharing costs are high and the retail platform shares demand information with both high and low quality suppliers, the profit improvement efficiency of high quality suppliers is greatest. This strategic approach emphasizes the importance of vendor participation in information sharing.

From the perspective of low-quality suppliers (see Fig. 8). When the cost of information sharing is low and the demand information is only shared with low-quality suppliers (NB-model), the efficiency of demand information sharing profit for low-quality suppliers is the highest.

When the cost of deploying information sharing for retail platforms is high, there are competitive intensity threshold conditions that maximize the efficiency of demand information sharing profit for low-quality suppliers in different models. Specifically, in the case of low competition intensity, that is, $0 < \gamma < \gamma *+$, low-quality suppliers are not shared demand information, only high-quality suppliers are shared demand information (NB-mode), low-quality suppliers have the highest profit improvement efficiency; In the case of high competitive intensity, *i.e.*, $\gamma *+ < \gamma < \gamma_4$, only low-quality suppliers are shared demand information (BN-model), and low-quality suppliers have the highest profit improvement efficiency. If the costs associated with implementing information sharing within a retail platform are large, then low-quality suppliers may be excluded from the network of information sharing. This selective approach aims to maintain the integrity and efficiency of the information sharing ecosystem by ensuring that only reputable and reliable vendors gain access. By limiting access to high-quality suppliers, retail platforms can enhance transparency, traceability, and overall quality standards in their supply chains. This exclusivity strategy not only protects the reputation of the platform, but also creates a competitive environment that incentivizes high-quality vendors to maintain their standards and actively contribute to the information-sharing network of information sharing.

From the perspective of retail platform (see Fig. 9), in scenarios where the expense of information sharing into a retail platform is minimal and allows for the participation of all suppliers in the information sharing network, the retail platform can achieve maximize the efficiency of demand information sharing profit. This inclusive approach not only promotes transparency and collaboration among all suppliers but also facilitates seamless transactions and data sharing, leading to improved operational efficiency and increased profitability for the retail platform. On the contrary, in the case of the high cost of information sharing for retail platforms, the efficiency of profits will be maximized only by empowering high-quality suppliers to join in the information sharing. By prioritizing the participation of high-quality suppliers based on stringent criteria, the retail platform can leverage information sharing to streamline operations, enhance customer trust, and drive sustainable growth.

So that the results are consistent with the research of [44], which emphasizes that high-quality products should introduce blockchain technology. But there are also differences, and they focus on the fact that if the manufacturer in the supply chain has a high-quality product, the manufacturer should use blockchain technology. This paper is more inclined to deploy blockchain technology for information sharing on retail platforms and allow high-quality suppliers for information sharing. This paper is also different from the study by Guo *et al.* [11] (they found that the greater the intensity of competition, the less retailers share information). We added the factor of blockchain technology, considered the deployment of the technology by retail platforms and authorized upstream suppliers to join the technology for demand information sharing, and came to a different conclusion. We found that the greater the intensity of competition, the higher the efficiency of profit improvement of demand information sharing on retail platforms. Therefore, we believe that retail platforms empowering upstream suppliers to join the demand information sharing are positively correlated with the intensity of competition.

5. Social welfare

We will study the information sharing strategy of supply chain from the perspective of social welfare. The introduction of blockchain technology to retail platforms and strategies for sharing demand information with what types of suppliers. Social welfare consists of consumer surplus and firm profits.

Proposition 12. *When the cost of information sharing for retail platforms is small, i.e.,* $0 < b < \frac{h}{2} + c_L$*, the BB model is the dominant strategy for social welfare. When the cost of information sharing for retail platforms is large, i.e.,* $\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H$*, BN model is a dominant strategy for social welfare.*

Proposition 12 shows that the optimal choice for social welfare is closely related to the cost of deploying information sharing on a retail platform. The optimal choice for social welfare is the same as the dominant strategy for retail platforms and the optimal strategy for demand information sharing efficiency gains (see Fig. 10).

The ability of retail platforms to deploy information sharing for demand information sharing can increase social welfare is consistent with research by Shen *et al.* [31] and Choi and Luo [45]. However, it is important to highlight that due to the growing competitiveness in product markets and the rising expenses associated with information sharing in retail platforms, the most beneficial option for societal well-being transitions from the BB model to the BN model (see Figs. 10a and 10b). When the cost and competitive intensity are relatively low, retail platforms deploy blockchain to share demand information and are willing to authorize high and low quality suppliers to information sharing at the same time; When costs and competitive intensity are high, retail platforms prefer to share demand information only with high-quality suppliers. Since high-quality suppliers can generate greater profits, unnecessary costs may be incurred if a retail platform allows low-quality suppliers access to demand information. This can lead to retail platforms bearing the information sharing costs associated with low-quality products in the supply chain, resulting in unnecessary losses.

6. Model extension

In the previous model in this article, we consider the unit cost of the optimal information sharing pattern for retailers. We also consider the situation that the level of risk aversion is $k = 1$.

In this section expansion, consider the impact of the fixed costs of to information sharing and different levels of risk aversion on retailers' information sharing. Section 6.1 considers the fixed cost F [45] of deploying blockchain to information sharing for retail platforms, and the corresponding fixed cost B for two suppliers. Section 6.2 considers the impact of different risk avoidance levels on the profit enhancement efficiency of retail platforms' demand information sharing.

6.1. Fixed costs of blockchain' information sharing

When retail platforms authorize high- and low-quality suppliers to information sharing, there are three information sharing modes, namely BN, NB, BB. This section considers the impact of information sharing fixed

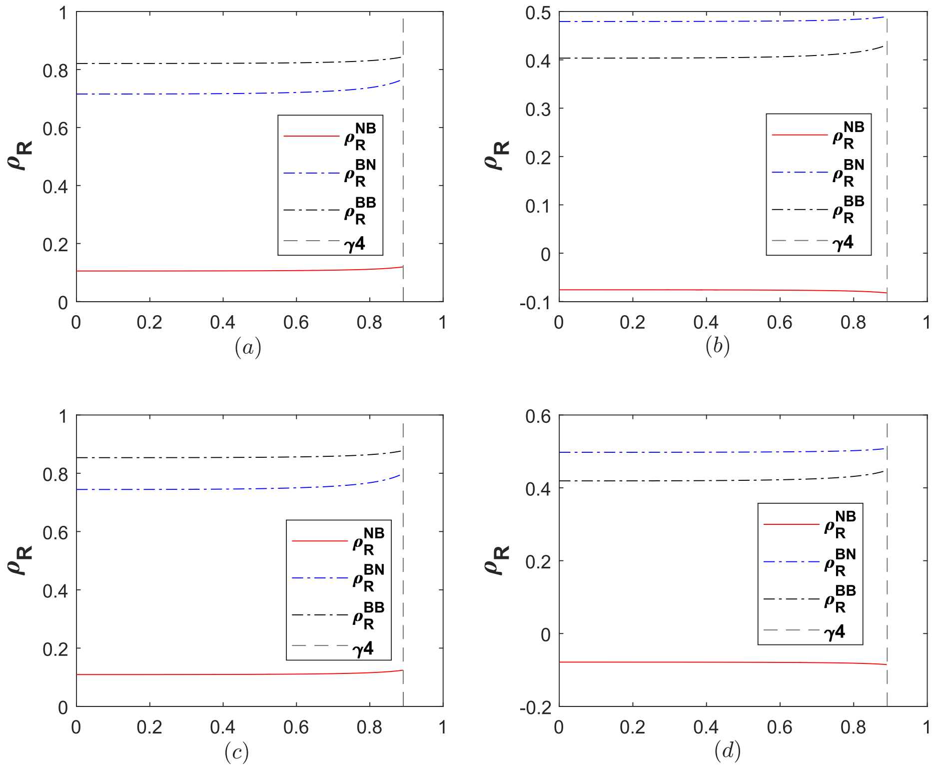


FIGURE 11. The impact of the level of risk aversion. (a) $\gamma(0 < b < h/2 + c_L)(k_1 = 0)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)(k_1 = 0)$. (c) $\gamma(0 < b < h/2 + c_L)(k_2 = 0.5)$. (d) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)(k_2 = 0.5)$.

costs on the profit enhancement efficiency of demand information sharing for supply chain participants on the basis of three information sharing models. This section uses the superscript $\chi+$ to represent the model.

$$U_R^{\chi+} = U_R^{\chi} - F \tag{14}$$

$$U_{S_H}^{\chi+} = U_{S_H}^{\chi} - B \tag{15}$$

$$U_{S_L}^{\chi+} = U_{S_L}^{\chi} - B \tag{16}$$

where $\chi \in (\text{BN, NB, BB}), F < U_R^{\chi}, B < \min\{U_{S_H}^{\chi}, U_{S_L}^{\chi}\}$.

Through calculation, we can find that the model conclusion is basically unchanged, which shows that our model is robust. Please refer to appendix for detailed calculation steps and simulation results.

6.2. Risk-averse level

In this section, we consider the level of risk aversion for retail platforms. The function expression is $U_R^{\chi} = E(\pi_R) - k\sqrt{\text{SD}(\pi_R)}$, where $k_1 = 0, k_2 = 0.5$.

The optimal solution is obtained according to the principle of profit maximization. See appendix for detailed solution and results.

When comparing the efficiency of demand information sharing in retail platforms, we observe a consistent trend in efficiency changes: When the cost of information sharing in retail platforms is low, the BB model demonstrates the most significant improvement in profits. This observation further validates the reliability of

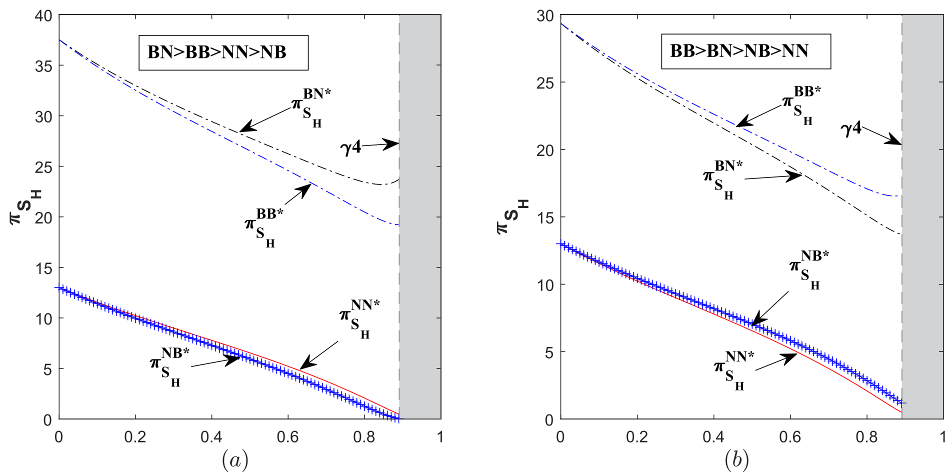


FIGURE 12. Numerical simulation of high-quality supplier's profits. (a) $\gamma(0 < b < h/2 + c_L)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$.

the proposed model. Additionally, it is important to highlight that retail platforms with higher levels of risk aversion experience greater efficiency in profit enhancement through blockchain deployment for information sharing (see Fig. 11).

7. Numerical analysis

In this section, we will conduct a numerical analysis of the principal outcomes. To ensure the authenticity and objectivity of the data, we reference pertinent literature [46–48]. Furthermore, appropriate parameter adjustments will be made in accordance with the scenario established in this paper for numerical analysis, with the aim of formulating management recommendations for practical application.

7.1. Analysis of the impact of γ and b on the profits of suppliers and retail platforms

This section primarily focuses on the impact of product competitive intensity and information sharing unit operational costs on the profit decisions of supply chain game participants. The parameters are set as follows: $c_L = 3$; $c_H = 9$; $a_L = 16$; $a_H = 20$; $\sigma = 0.8$; $h = 0.25$; $\gamma \in (0, 0.8911)$. $b = 2$ $(0 < b < \frac{h}{2} + c_L)$, $b = 4$ $(\frac{h}{2} + c_L < b < \frac{h}{2} - a_H + a_L + c_H)$.

From Figures 12 to 14, it can be observed that the optimal profit trends of supply chain game participants align with the theoretical analysis results previously discussed, thereby demonstrating the robustness of the model presented in this paper. Furthermore, it can be noted that as the information sharing operational costs borne by the retail platform increase, the profits of both upstream suppliers exhibit a declining trend across all four scenarios. However, the profit of the retail platform gradually increases.

The underlying reason for this phenomenon lies in the distribution and absorption of information sharing operational costs within the supply chain. The retail platform may leverage the blockchain's capabilities for enhancing operational efficiency, information sharing, and transparency, which can lead to increased sales and, ultimately, higher profits.

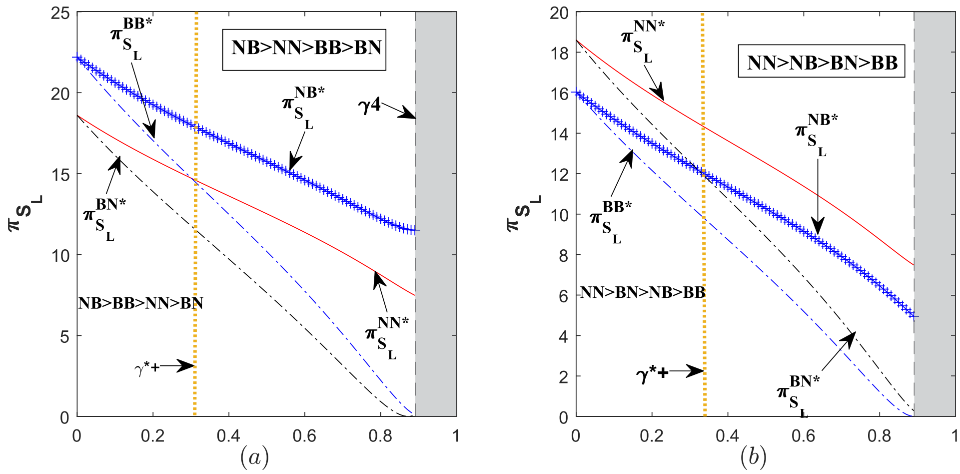


FIGURE 13. Numerical simulation of low-quality supplier's profits. (a) $\gamma(0 < b < h/2 + c_L)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$.

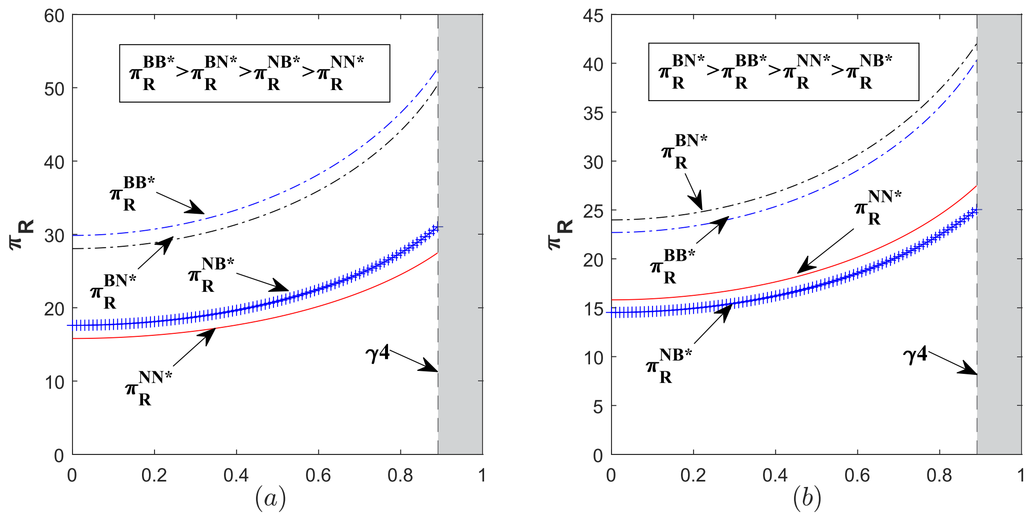


FIGURE 14. Numerical simulation of retail platform's profits. (a) $\gamma(0 < b < h/2 + c_L)$. (b) $\gamma(h/2 + c_L < b < h/2 - a_H + a_L + c_H)$.

7.2. Analysis of the impact of γ and σ on the profits of suppliers and retail platforms

This section mainly addresses the impact of competitive intensity γ and the variance of demand uncertainty σ on the profit decisions of supply chain game participants. The parameters are set as follows: $\sigma = 0.8$ & $\sigma = 0.2$; $b = 0$; $c_L = 3$; $c_H = 9$; $a_L = 16$; $a_H = 20$; $h = 0.25$; $\gamma \in (0, 0.8911)$.

Comparing Figures 15–17 with Figures 12–14, it is readily apparent that the optimal profit trends of supply chain game participants are consistent with the profit trends discussed in Section 7.1. It is noteworthy that when information sharing operational costs are not considered ($b = 0$), the overall profits of supply chain game participants increase. Moreover, lower variances in product demand uncertainty correlate with higher profits for all supply chain participants.

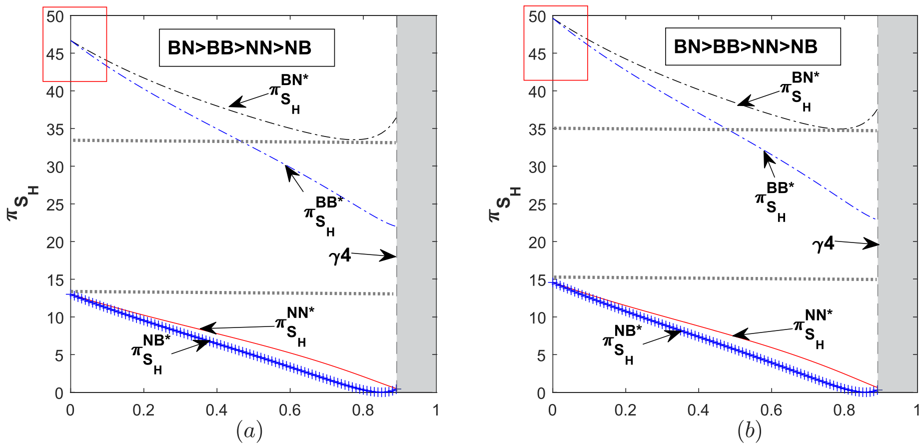


FIGURE 15. Numerical simulation of high-quality supplier's profits ($b = 0$). (a) $\gamma(b = 0, \sigma = 0.8)$. (b) $\gamma(b = 0, \sigma = 0.2)$.

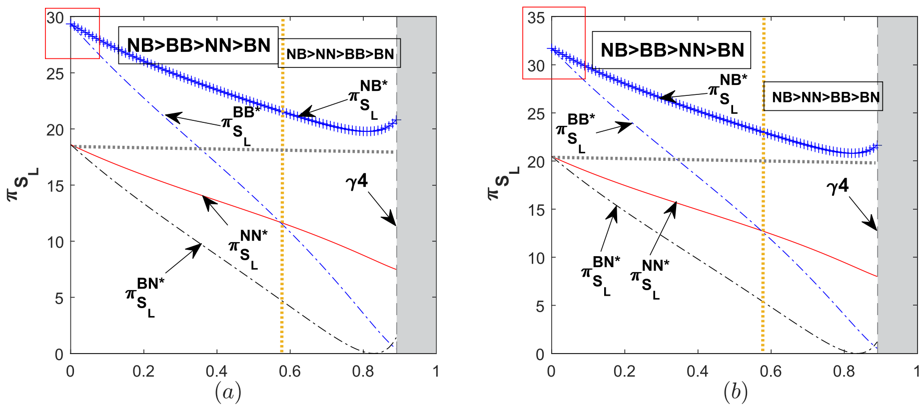


FIGURE 16. Numerical simulation of low-quality supplier's profits ($b = 0$). (a) $\gamma(b = 0, \sigma = 0.8)$. (b) $\gamma(b = 0, \sigma = 0.2)$.

The reason behind this phenomenon can be attributed to the impact of information sharing operational costs and demand uncertainty on supply chain efficiency and risk management. When the operational costs are excluded, the financial burden on supply chain participants decreases, naturally leading to an increase in their overall profits. This is because the cost savings can either be reinvested into the business or passed down to consumers in the form of lower prices, potentially increasing sales volume and profit margins.

Furthermore, lower variances in product demand uncertainty mean that supply chain participants can more accurately forecast demand, allowing for more efficient inventory management and production planning. Together, these factors contribute to higher profitability for supply chain participants, illustrating the critical role of demand forecasting accuracy and cost management in supply chain operations.

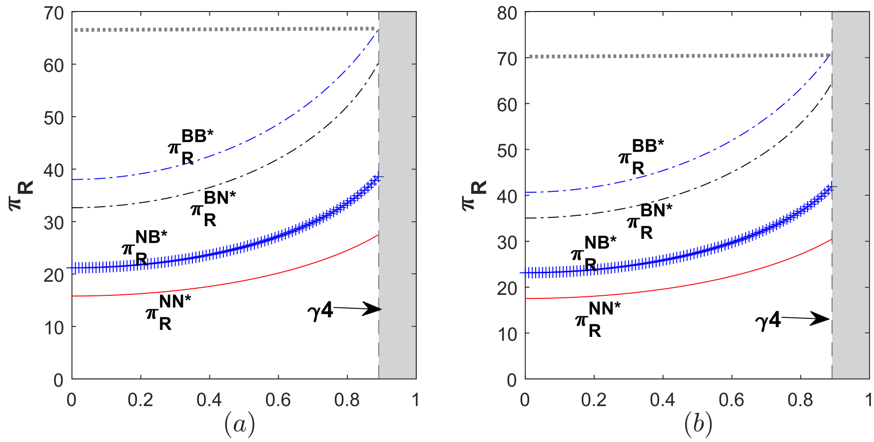


FIGURE 17. Numerical simulation of retail platform's profits ($b = 0$). (a) $\gamma(b = 0, \sigma = 0.8)$. (b) $\gamma(b = 0, \sigma = 0.2)$.

8. Conclusion

8.1. Concluding remarks

Many research findings indicate that the adoption of blockchain technology can enhance supply chain efficiency, boost transparency and traceability, and potentially reduce enterprise back-office costs by up to 30%. Presently, blockchain has emerged as a sought-after digital solution being rapidly integrated by numerous e-commerce platforms, with its disruptive influence extending across various industries and penetrating the retail sector. Companies like Walmart and Alibaba are beginning to experiment with how distributed ledger technology can help them become better and serve customers more effectively. For example, "Ant Chain – the representative technology brand of Ant Group, is committed to building a new infrastructure of trust in the era of digital economy, building the world's largest value network, and making blockchain change production and life like mobile payment". The role of blockchain is becoming increasingly prominent. This paper presents a supply chain framework incorporating supply chain information sharing, featuring a high-quality supplier, a low-quality supplier, and a risk-averse retail platform. The upstream supplier supplies products to the downstream retail platform, which then distributes the products to customers. The retail platform has the discretion to share product demand information with upstream suppliers. Acting as the game model leader, the retail platform strategically selects suppliers to join the information sharing network for facilitated information sharing, improved product sales and enhanced clarity in conveying product demand information to upstream suppliers.

We summarized the following findings:

First, for the first research question of this paper, which types of suppliers should be included to information sharing in a retail platform after blockchain is introduced? Our assertion is that:

- When the information sharing cost and competitive intensity are low, the retail platform decides to share demand information and is willing to share it with both quality and poor quality suppliers (BB-model);
- When the information sharing cost and competitive intensity are high, retail platforms tend to share demand information only with high-quality suppliers (BN-model).

Second, for the second research question of this paper, which game mode of the efficiency of demand information sharing profit is best for high- or low-quality suppliers respectively? We hold the view that for maximizing profits:

- When it is cheaper for retail platforms to implement information sharing, the BN-model is best for high-quality suppliers. In contrast, when information sharing costs are high, BB-model is best for high-quality suppliers.
- Conversely, when it is cheaper for retail platforms to implement information sharing, the NB-model is best for low-quality suppliers. When the cost of deploying information sharing for retail platforms is high, there are competitive intensity threshold conditions that maximize the efficiency of demand information sharing profit for low-quality suppliers indifferent models.

Third, for the third research question of this paper, Which game mode achieves the largest social welfare? The result of this paper is:

- Due to the increasingly competitive product market and the rising costs associated with implementing information sharing in retail platforms, the most beneficial option for social welfare is to shift from the BB-model to the BN-model.

Fourth, furthermore, we enhance the model by incorporating the fixed cost of blockchain (in order to information sharing) and the risk aversion level of retail platforms, confirming the model's robustness as outlined in this paper. Moreover, our research indicates that a retail platform with a higher level of risk aversion experiences increased efficiency in information sharing profit. We also make numerical example analysis. It is important to highlight that in scenarios where information sharing operational costs are negligible ($b = 0$), the total profits experienced by participants in the supply chain game see an uplift. Additionally, a lower variability in product demand uncertainty is associated with increased profits for all entities involved in the supply chain.

8.2. Conclusion comparison

First, this paper compares with the previous literature, summarizes the conclusion and draws the inheritance and development of this paper, see Table 4.

Secondly, based on a specific perspective – blockchain and information asymmetry, the research conclusions of this paper are compared with the following literature.

- *For the comparison of research perspectives on blockchain*: Saxena and Sarkar [49] believe that blockchain plays the role of transparency and traceability in the supply chain. In their model, using RFID technology on the physical surface combined with blockchain on the network surface to deal with Inventory discrepancy and supplement issues. Their findings prove that blockchain-based RFID is profitable for the system in any case, but the incremental profit increases as the cost of ownership increases. The results of the study by Amankou *et al.* [50] also show that the total profits of manufacturing companies with Iot-based blockchain basic consumer services increased by 29.12% compared to the situation without blockchain. Saxena *et al.* [51], on the other hand, addresses the use of advanced technologies and data-driven approaches to optimize production processes, noting that full traceability increases transparency and promotes effective quality control and accountability. *Our findings echo those of Saxena and Sarkar [49], Amankou et al. [50], and Saxena et al. [51]* (*i.e.*, we also argue that the use of blockchain technology in the supply chain is intended to increase supply chain transparency and facilitate supply chain information sharing. And we demonstrate that the use of blockchain technology is profitable for supply chain systems), the difference is that we focus on the cost of information sharing on retail platforms (b) rather than the cost of product ownership. We also consider the effect of product competition intensity parameters between two competing suppliers. Specifically, *from the perspective of retail platform, Figs. 9, 11, 14, 17 are shown* (Fig. 9 shows the demand information sharing efficiency of retail platform profits, Figure 11 includes the demand information sharing efficiency of retail platform profits under the influence of retailers' risk level parameters, and Figure 14 is the numerical simulation of the optimal profit of retail platforms. Figure 17 is the numerical simulation of retail platform profit when $b = 0$). The interaction between the product competition intensity parameters of two competing suppliers and the information sharing cost parameters of the retail platform affects the selection of the optimal strategy of the retail platform (as in Figs. 14 and 17, the NN-model is always

TABLE 4. Summarize the inheritance and development of the conclusions of this paper.

Item	Previous literature	Inheritance of our paper	Development of our paper
Prices	[1, 30, 41]	Integrating blockchain into supply chain results in lower product prices.	Examining blockchain application in retail platforms and enhancing upstream supplier engagement.
Quality	[44]	Emphasizes that high-quality products should introduce blockchain. But they focus on the fact that if the manufacturer in the supply chain has a high-quality product, the manufacturer should use blockchain.	Our paper is more inclined to retail platforms deploy blockchain and sharing demand information with high-quality suppliers.
Information sharing	[11]	Product competition strength to share information has a very close relationship. But they found that the greater the intensity of competition, the less retailers share information.	We incorporated blockchain technology, focusing on its adoption by retail platforms and enabling upstream suppliers to participate in blockchain for demand information sharing, and believe that a positive correlation between such deployment and competitive intensity.
Social welfare	[31, 45]	The introduction of blockchain has a positive effect on increasing social welfare	It is important to highlight that due to the growing competitiveness in product markets and the rising expenses associated with implementing information sharing in retail platforms, the most beneficial option for societal well-being transitions from the BB model to the BN model.

below the blockchain information sharing policy). *From the perspective of high-quality suppliers, as shown in Figs. 7, 12 and 15,* similarly, we can see that the blockchain information sharing strategy pattern is always superior to the situation where there is no blockchain technology in the supply chain system (for example, in Figs. 12 and 15, NN-model is always below the blockchain information sharing strategy). However, as the competition intensity parameter increases, the profit of high-quality suppliers gradually decreases. (The comparison of optimal strategies of low-quality suppliers is shown in Figs. 8, 13 and 16. In Fig. 16, the analysis of optimal strategy choice of low-quality suppliers is similar to that of high-quality suppliers.) Interestingly, both high and low quality suppliers only want to be selected by the retail platform to join the blockchain network for information sharing, which is due to the pursuit of maximum profits by supply chain participants.

– *For the comparison of research perspectives on information asymmetry*: asymmetric information sharing among supply chain participants affects the profits of the supply chain. Such information asymmetry may be profitable for some supply chain participants, but not for the whole supply chain, and may lead to internal discoordination among them [52]. Sarkar and Guchhait [52] findings demonstrate the role of blockchain technology in dealing with information asymmetry. The numerical analysis shows that unreliability can be controlled in two ways: blockchain transparency can eliminate information asymmetry, and the use of RFID can guarantee inventory security. The study by Hota *et al.* [53] focuses more on information asymmetry in the context of random demand and unreliable manufacturers, in which the results of the study find the optimal retail strategy. The research shows that the single-setup-multi-unequal-increasing-delivery policy is 1.14% more profitable than the single-setup-multi-delivery policy, and 8.53% more profitable than the single-setup-single-delivery policy. *Our research also focuses on information asymmetry in the supply chain, demonstrating the role of blockchain technology in reducing information asymmetry and facilitating information sharing. However, we did not consider inventory [52] and retail strategy [53].* Our study considers supply chain decision variables as wholesale price and quantity of products sold. Our research uses the transparency of blockchain technology to eliminate information asymmetry, and also embedded the perspective of risk avoidance characteristics of retail platforms, that is, considering the degree of risk avoidance of retail platforms to obtain the optimal information sharing mode (that is, in the supply chain, the retail platform with blockchain technology is better than the situation without blockchain technology).

8.3. Managerial insights

Firstly, suppliers at the upstream end of the supply chain prioritize enhancing product quality. Regardless of the cost implications of information sharing, retail platforms consistently opt to authorize high-quality suppliers to participate in information sharing networks, indicating a preference for sharing demand information with suppliers of superior products. This decision underscores a pronounced preference for exchanging demand information exclusively with suppliers that provide superior quality products. In light of this, it is advisable for suppliers aiming to thrive in such an ecosystem to focus on elevating the quality of their offerings. High-quality suppliers not only gain the opportunity to participate in information sharing networks but also benefit from enhanced visibility and trust among retail platforms and consumers alike. Additionally, staying abreast of technological advancements and integrating them into their operations can further solidify their position as preferred suppliers within the supply chain. By prioritizing product quality and embracing technological innovations, suppliers can better align themselves with the strategic objectives of retail platforms and secure a competitive edge in the marketplace.

Second, retail platforms/retailers, being strategically located nearest to the end consumers in the supply chain, are tasked with efficiently capturing and interpreting demand signals originating from the end of the chain, while also conducting thorough evaluations of the quality standards maintained by their upstream suppliers. The integration of blockchain technology (in order information sharing) consistently proves advantageous for downstream entities within the supply chain, particularly for Retailers and Retail Platforms, underscoring the critical significance of identifying and addressing any discrepancies in quality among suppliers. As key decision-makers, retailers assume a central role in determining the suppliers they choose to engage with, thereby promoting heightened transparency throughout the supply chain and fostering a mutually beneficial environment for all involved stakeholders.

8.4. The prospect of future research

In the realm of blockchain information sharing research within the supply chain domain, there exists ample opportunity to further delve into various aspects highlighted in this article. The article examines scenarios where retail platforms actively share information with upstream suppliers, who passively accept integration. However, a notable gap exists in understanding how upstream suppliers actively decide whether to embrace retail platform authorization. Subsequent research could investigate the influence of proactive decision-making by upstream suppliers on the successful deployment of information sharing within the supply chain [15]. The research can also be conducted from the perspective of the production end of the supply chain, and the technology embedding mode of "blockchain + Internet of Things or RFID technology [49]" can be established to solve the problem of product quality and quantity decision-making at the production end of the supply chain. This paper emphasizes that two types of suppliers with quality differences wholesale products to retail platforms through resale mode. In the future, this study can also be studied from the perspective of dual-channel supply chain research [50,54,55].

Appendix A.

The calculation process of NN-model

In formula (1), $E(\pi_R) = (a_H - q_H^{NN} - \gamma q_L^{NN} - w_H^{NN})q_H^{NN} + (a_L - q_L^{NN} - \gamma q_H^{NN} - w_L^{NN})q_L^{NN}$, $SD(\pi_R) = \sigma q_H^{NN} + \sigma q_L^{NN}$. So $U_R^{NN} = (a_H - q_H^{NN} - \gamma q_L^{NN} - w_H^{NN})q_H^{NN} + (a_L - q_L^{NN} - \gamma q_H^{NN} - w_L^{NN})q_L^{NN} - \sigma(q_H^{NN} + q_L^{NN})$.

The first order condition of formula (1) for q_H^{NN}, q_L^{NN} is, $q_H^{NN}(w_H, q_L) = \frac{a_H - \sigma - w_H}{2} - \gamma q_L$, $q_L^{NN}(w_L, q_H) = \frac{a_L - \sigma - w_L}{2} - \gamma q_H$. Then, the two forms are obtained simultaneously: $q_H^{NN}(w_H) = \frac{(a_L - w_L - \sigma)\gamma + \sigma - a_H + w_H}{2\gamma^2 - 2}$, $q_L^{NN}(w_L) = \frac{(a_H - w_H - \sigma)\gamma + \sigma - a_L + w_L}{2\gamma^2 - 2}$.

Substituting $q_H^{NN}(w_H)$ into (2), we can obtain $w_H^{NN}(w_L) = \frac{a_H + c_H - \sigma - \gamma(a_L - w_L)}{2}$. Substituting $q_L^{NN}(w_L)$ into (3), we can obtain $w_L^{NN}(w_H) = \frac{a_L + c_L - \sigma - \gamma(a_H - w_H)}{2}$. Then, the two forms are obtained simultaneously: $w_H^{NN^*} = \frac{(a_H - \sigma)\gamma^2 + (a_L - \sigma - c_L)\gamma + 2\sigma - 2a_H - 2c_H}{\gamma^2 - 4}$, $w_L^{NN^*} = \frac{(a_L - \sigma)\gamma^2 + (a_H - \sigma - c_H)\gamma + 2\sigma - 2a_L - 2c_L}{\gamma^2 - 4}$. Substituting $w_H^{NN^*}, w_L^{NN^*}$ into $q_H^{NN}(w_H) = \frac{(a_L - w_L - \sigma)\gamma + \sigma - a_H + w_H}{2\gamma^2 - 2}$, $q_L^{NN}(w_L) = \frac{(a_H - w_H - \sigma)\gamma + \sigma - a_L + w_L}{2\gamma^2 - 2}$, we can get $q_H^{NN^*} = \frac{(\sigma - a_H + c_H)\gamma^2 + (\sigma - a_L + c_L)\gamma - 2(\sigma + a_H - c_H)}{2\gamma^4 - 10\gamma^2 + 8}$, $q_L^{NN^*} = \frac{(\sigma - a_L + c_L)\gamma^2 + (\sigma - a_H + c_H)\gamma - 2(\sigma - a_L + c_L)}{2\gamma^4 - 10\gamma^2 + 8}$. Then we can get $p_H^{NN^*} = \frac{2\gamma^2 a_H + (a_L - \sigma - c_L)\gamma - 2(\sigma + 3a_H + c_H)}{2\gamma^2 - 8}$, $p_L^{NN^*} = \frac{2\gamma^2 a_L + (-\sigma + a_H - c_H)\gamma - 2(\sigma + 3a_L + c_L)}{2\gamma^2 - 8}$.

Proof of preconditions for the validity of Lemma 1. The wholesale prices $w_L^{NN^*}$ are positive only if $a_H - c_H < a_L + 2c_L$ or $(a_H - c_H > a_L + 2c_L) \cup 0 < \gamma < \gamma_1^{\vartheta}$, $\gamma_1^{\vartheta} = -\frac{\sigma - a_H + c_H + \sqrt{9\sigma^2 - 2\sigma a_H - 16\sigma a_L + 2\sigma c_H - 8\sigma c_L + a_H^2 - 2a_H c_H + 8a_L^2 + 8a_L c_L + c_H^2}}{2(\sigma - a_L)}$.

The wholesale prices $w_H^{NN^*}$ re positive only if $a_L - c_L < a_H + 2c_H$. The ordering quantities $q_L^{NN^*}$ are positive only if $a_H - c_H < a_L - c_L$. The ordering quantities $q_H^{NN^*}$ are positive only if $a_H - c_H < a_L - c_L \cup 0 < \gamma < \gamma_1$, $\gamma_1 = -\frac{\sigma - a_L + c_L + \sqrt{9\sigma^2 - 2\sigma a_L - 16\sigma a_H + 2\sigma c_L + 16\sigma c_H + a_L^2 - 2a_L c_L + 8a_H^2 - 16a_H c_H + c_L^2 + 8c_H^2}}{2(\sigma - a_H + c_H)}$. So, finally, the wholesale prices and the ordering quantities are positive only if $a_H - c_H < a_L - c_L, 0 < \gamma < \gamma_1$. □

Proof of Proposition 1. $w_H^{NN^*} - w_L^{NN^*} = \frac{\gamma(a_L - a_H) - a_H + a_L - c_H + c_L}{\gamma + 2} < 0$, $q_H^{NN^*} - q_L^{NN^*} = \frac{-a_H + c_H + a_L - c_L}{2\gamma^2 + 2\gamma - 4}$. □

Proof of Corollary 1.
$\frac{\partial w_H^{NN^*}}{\partial \gamma} = \frac{(\sigma - a_H + c_H)\gamma^2 + (4\sigma - 4a_L + 4c_L)\gamma + 4\sigma - 4a_H + 4c_H}{(\gamma^2 - 4)^2} < 0$, $\frac{\partial w_L^{NN^*}}{\partial \gamma} = \frac{(\sigma - a_L + c_L)\gamma^2 + (4\sigma - 4a_H + 4c_H)\gamma + 4\sigma - 4a_L + 4c_L}{(\gamma^2 - 4)^2} < 0$, $\frac{\partial q_L^{NN^*}}{\partial a_L} = \frac{\partial q_H^{NN^*}}{\partial a_H} = \frac{-\gamma^2 + 2}{2\gamma^4 - 10\gamma^2 + 8} > 0$, $\frac{\partial q_L^{NN^*}}{\partial c_L} = \frac{\partial q_H^{NN^*}}{\partial c_H} = \frac{\gamma^2 - 2}{2\gamma^4 - 10\gamma^2 + 8} < 0$. □

Proof of preconditions for the validity of Lemma 2 is similarly to Lemma 1, among them.
$\gamma_2 = -\frac{A - 2a_H + \sqrt{4b^2 - 4bh + 8b\sigma - 8ba_H + h^2 - 4h\sigma + 4ha_H + 36\sigma^2 - 8\sigma a_H - 64\sigma a_L + 64\sigma c_L + 4a_H^2 + 32a_L^2 - 64a_L c_L + 32c_L^2}}{4(\sigma - a_L + c_L)}$. □

Proof of Proposition 2.
$w_H^{BN^*} - w_L^{BN^*} = \frac{(-2b + h + 2a_H - 2a_L)\gamma - 2b + h + 2a_H - 2a_L - 2c_L}{2\gamma + 4} > 0$, $q_H^{BN^*} - q_L^{BN^*} = \frac{2b - h - 2a_H + 2a_L - 2c_L}{4\gamma^2 + 4\gamma - 8} > 0$. □

Proof of Corollary 2. $\frac{\partial w_L^{BN^*}}{\partial \gamma} = \frac{(2b - h + 2\sigma - 2a_H)\gamma^2 + (8\sigma - 8a_L + 8c_L)\gamma + 8b - 4h + 8\sigma - 8a_H}{2(\gamma^2 - 4)^2} < 0$, $\frac{\partial w_H^{BN^*}}{\partial \gamma} = \frac{(\sigma - a_L + c_L)\gamma^2 + (4b - 2h + 4\sigma - 4a_H)\gamma + 4\sigma - 4a_L + 4c_L}{(\gamma^2 - 4)^2} < 0$, $\frac{\partial w_L^{BN^*}}{\partial b} = -\frac{2\gamma}{2\gamma^2 - 8} > 0$, $\frac{\partial w_H^{BN^*}}{\partial b} = \frac{-2\gamma^2 + 4}{2\gamma^2 - 8} < 0$, $\frac{\partial q_H^{BN^*}}{\partial a_H} = \frac{\partial q_L^{BN^*}}{\partial a_L} = \frac{-2\gamma^2 + 4}{4\gamma^4 - 20\gamma^2 + 16} > 0$, $\frac{\partial q_H^{BN^*}}{\partial b} = \frac{2\gamma^2 - 4}{4\gamma^4 - 20\gamma^2 + 16} < 0$, $\frac{\partial q_L^{BN^*}}{\partial b} = \frac{2\gamma}{4\gamma^4 - 20\gamma^2 + 16} > 0$. □

Proof of preconditions for the validity of Lemma 3 is similarly to Lemma 1.
$\gamma_3 = -\frac{A - 2a_L + \sqrt{4b^2 - 4bh + 8b\sigma - 8ba_L + h^2 - 4h\sigma + 4ha_L + 36\sigma^2 - 8\sigma a_L - 64\sigma a_H + 64\sigma c_H + 4a_L^2 + 32a_H^2 - 64a_H c_H + 32c_H^2}}{4(\sigma - a_H + c_H)}$.
$\gamma_3^{\vartheta} = -\frac{\sigma - a_H + c_H + \sqrt{8b^2 - 8bh + 16b\sigma - 16ba_L + 2h^2 - 8h\sigma + 8ha_L + 9\sigma^2 - 2\sigma a_H - 16\sigma a_L + 2\sigma c_H + a_H^2 + 8a_L^2 - 2a_H c_H + c_H^2}}{2b - h + 2\sigma - 2a_L}$. □

Proof of Proposition 3.
$w_H^{\mathrm{NB}^*} - w_L^{\mathrm{NB}^*} = \frac{(2b-h+2a_H-2a_L)\gamma+2b-h+2a_H-2a_L+2c_H}{2\gamma+4} < 0,\ q_H^{\mathrm{NB}^*} - q_L^{\mathrm{NB}^*} = \frac{-2b+h-2a_H+2a_L+2c_H}{4\gamma^2+4\gamma-8} < 0.$ □

Proof of Corollary 3. $\frac{\partial w_L^{\mathrm{NB}^*}}{\partial\gamma} = \frac{(\sigma-a_H+c_H)\gamma^2+(4b-2h+4\sigma-4a_L)\gamma+4b-2h+4\sigma-4a_L}{(\gamma^2-4)^2} < 0,\ \frac{\partial w_H^{\mathrm{NB}^*}}{\partial\gamma} = \frac{(2b-h+2\sigma-2a_L)\gamma^2+(8\sigma-8a_H+8c_H)\gamma+8b-4h+8\sigma-8a_L}{(\gamma^2-4)^2} < 0,\ \frac{\partial w_L^{\mathrm{NB}^*}}{\partial b} = \frac{-2\gamma^2+4}{2\gamma^2-8} < 0,\ \frac{\partial w_H^{\mathrm{NB}^*}}{\partial b} = -\frac{2\gamma}{2\gamma^2-8} > 0,$ $\frac{\partial q_H^{\mathrm{NB}^*}}{\partial a_H} = \frac{\partial q_L^{\mathrm{NB}^*}}{\partial a_L} = \frac{-2\gamma^2+4}{4\gamma^4-20\gamma^2+16} > 0,\ \frac{\partial q_H^{\mathrm{NB}^*}}{\partial b} = \frac{2\gamma^2}{4\gamma^4-20\gamma^2+16} > 0,\ \frac{\partial q_L^{\mathrm{NB}^*}}{\partial b} = \frac{2\gamma^2-4}{4\gamma^4-20\gamma^2+16} < 0.$ □

Proof of preconditions for the validity of Lemma 4 is similarly to Lemma 1.
$\gamma_4 = -\frac{2b-h+2\sigma-2a_H+\sqrt{36b^2-36bh+72b\sigma-8ba_H-64ba_L+9h^2-36h\sigma+4ha_H+32ha_L+36\sigma^2-8\sigma a_H-64\sigma a_L+4a_H^2+32a_L^2}}{2(2b-h+2\sigma-2a_L)}.$ □

Proof of Proposition 4. $w_H^{\mathrm{BB}^*} - w_L^{\mathrm{BB}^*} = \frac{(a_H-a_L)(1+\gamma)}{\gamma+2} > 0,\ q_H^{\mathrm{BB}^*} - q_L^{\mathrm{BB}^*} = \frac{-a_H+a_L}{2\gamma^2+2\gamma-4} > 0.$ □

Proof of Corollary 4. $\frac{\partial w_L^{\mathrm{BB}^*}}{\partial\gamma} = \frac{(2b-h+2\sigma-2a_H)\gamma^2+(8b-4h+8\sigma-8a_L)\gamma+8b-4h+8\sigma-8a_H}{2(\gamma^2-4)^2} < 0,\ \frac{\partial w_H^{\mathrm{BB}^*}}{\partial\gamma} = \frac{(2b-h+2\sigma-2a_L)\gamma^2+(8b-4h+8\sigma-8a_H)\gamma+8b-4h+8\sigma-8a_L}{2(\gamma^2-4)^2} < 0,\ \frac{\partial w_L^{\mathrm{BB}^*}}{\partial b} = \frac{\partial w_H^{\mathrm{BB}^*}}{\partial b} = \frac{-2\gamma^2-2\gamma+4}{2\gamma^2-8} < 0,\ \frac{\partial q_H^{\mathrm{BB}^*}}{\partial a_H} = \frac{\partial q_L^{\mathrm{BB}^*}}{\partial a_L} = \frac{-2\gamma^2+4}{4\gamma^4-20\gamma^2+16} > 0,\ \frac{\partial q_H^{\mathrm{BB}^*}}{\partial b} = \frac{\partial q_L^{\mathrm{BB}^*}}{\partial b} = \frac{2\gamma^2+2\gamma-4}{4\gamma^4-20\gamma^2+16} < 0.$ □

Proof of Proposition 5. $\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_L}^{\mathrm{NN}^*} = \frac{(c_L-c_H+a_H-a_L)(-a_H+2\sigma+c_H-a_L+c_L)}{2\gamma^2-8} < 0,\ \pi_{S_H}^{\mathrm{BN}^*} - \pi_{S_L}^{\mathrm{BN}^*} = -\frac{(2b-h+4\sigma-2a_H-2a_L+2c_L)(2b-h-2a_H+2a_L-2c_L)}{8\gamma^2-32} > 0,\ \pi_{S_H}^{\mathrm{NB}^*} - \pi_{S_L}^{\mathrm{NB}^*} = \frac{(2a_H-2a_L-2c_H+2b-h)(2b-h+4\sigma-2a_H-2a_L+2c_H)}{8\gamma^2-32} < 0,\ \pi_{S_H}^{\mathrm{BB}^*} - \pi_{S_L}^{\mathrm{BB}^*} = \frac{(-a_H+2b-h+2\sigma-a_L)(a_H-a_L)}{2\gamma^2-8} > 0.$ □

Proof of Proposition 6. $w_H^{\mathrm{NN}^*} - w_H^{\mathrm{BN}^*} = \frac{(2b-h)\gamma^2-4b+2h-4c_H}{2\gamma^2-8} < 0,\ w_H^{\mathrm{NN}^*} - w_H^{\mathrm{NB}^*} = \frac{\gamma(2b-h-2c_L)}{2\gamma^2-8}$, among them $0 < b < \frac{h}{2}+c_L, w_H^{\mathrm{NN}^*} - w_H^{\mathrm{NB}^*} > 0;\ \frac{h}{2}+c_L < b < \frac{h}{2}-a_H+a_L+c_H, w_H^{\mathrm{NN}^*} - w_H^{\mathrm{NB}^*} < 0$. $w_H^{\mathrm{NN}^*} - w_H^{\mathrm{BB}^*} = \frac{\gamma^2(2b-h)+\gamma(2b-h-2c_L)-4b+2h-4c_H}{2\gamma^2-8} < 0,\ w_H^{\mathrm{BN}^*} - w_H^{\mathrm{NB}^*} = \frac{\gamma^2(-2b+h)+\gamma(2b-h-2c_L)+4b-2h+4c_H}{2\gamma^2-8} > 0,\ w_H^{\mathrm{BN}^*} - w_H^{\mathrm{BB}^*} = \frac{\gamma(2b-h-2c_L)}{2\gamma^2-8}$, among them $0 < b < \frac{h}{2}+c_L, w_H^{\mathrm{BN}^*} - w_H^{\mathrm{BB}^*} > 0;\ \frac{h}{2}+c_L < b < \frac{h}{2}-a_H+a_L+c_H, w_H^{\mathrm{BN}^*} - w_H^{\mathrm{BB}^*} < 0$. $w_H^{\mathrm{NB}^*} - w_H^{\mathrm{BB}^*} = \frac{\gamma^2(2b-h)-4b+2h-4c_H}{2\gamma^2-8} < 0.$

The proof for w_L^* is similar to that for w_H^*, omitted.

$q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BN}^*} = \frac{(-2b+h+2c_H)\gamma}{4\gamma^4-20\gamma^2+16}.b < \frac{h}{2}+c_H, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BN}^*} > 0.$

$q_L^{\mathrm{NN}^*} - q_L^{\mathrm{NB}^*} = -\frac{2(\gamma^2-2)(-c_L+b-\frac{h}{2})}{4\gamma^4-20\gamma^2+16}.\begin{cases} b < \frac{h}{2}+c_L, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{NB}^*} < 0 \\ b > \frac{h}{2}+c_L, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{NB}^*} > 0 \end{cases}.$

$q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BB}^*} = \frac{\gamma^2(2c_L-2b+h)+(-2b+h+2c_H)+4b-2h-4c_L}{4\gamma^4-20\gamma^2+16}$, among them $F(\gamma) = \gamma^2(2c_L-2b+h)+(-2b+h+2c_H)+4b-2h-4c_L$. $F(1) = 2c_H-2c_L > 0, F(0) = 4b-2h-4c_L$, when $F(0) = 4b-2h-4c_L > 0, \Rightarrow b > \frac{h}{2}+2c_L \Rightarrow F(\gamma) > 0, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BB}^*} > 0$. When $F(0) = 4b-2h-4c_L < 0, \Rightarrow b < \frac{h}{2}+2c_L$, $F(\gamma)$ has only one solution in the interval $0 < \gamma < \gamma 4$. Now, there are $0 < \gamma < \gamma *+, F < 0, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BB}^*} < 0; \gamma *+ < \gamma < \gamma 4, F > 0, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BB}^*} > 0$. So $b < \frac{h}{2}+2c_L\begin{cases} 0 < \gamma < \gamma *+, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BB}^*} < 0 \\ \gamma *+ < \gamma < \gamma 4, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BB}^*} > 0 \end{cases}; b > \frac{h}{2}+2c_L, q_L^{\mathrm{NN}^*} - q_L^{\mathrm{BB}^*} > 0.$

$q_L^{\mathrm{NB}^*} - q_L^{\mathrm{BN}^*} = \frac{\gamma^2(-2c_L+2b-h)+(-2b+h+2c_H)-4b+2h+4c_L}{4\gamma^4-20\gamma^2+16}$, among them $F(\gamma) = \gamma^2(-2c_L+2b-h)+(-2b+h+2c_H)-4b+2h+4c_L$, $F(1) = 2c_L+2c_H-4b+2h > 0, F(0) = -4b+2h+4c_L$, when $F(0) = -4b+2h+4c_L > 0, \Rightarrow b < \frac{h}{2}+2c_L \Rightarrow F(\gamma) > 0 \Rightarrow q_L^{\mathrm{NB}^*} - q_L^{\mathrm{BN}^*} > 0$. When $F(0) = -4b+2h+4c_L < 0, \Rightarrow b > \frac{h}{2}+2c_L$, $F(\gamma)$ has only one solution in the interval $0 < \gamma < \gamma 4$. $0 < \gamma < \gamma *+, F < 0, q_L^{\mathrm{NB}^*} - q_L^{\mathrm{BN}^*} < 0; \gamma *+ < \gamma < \gamma 4, F > 0, q_L^{\mathrm{NB}^*} - q_L^{\mathrm{BN}^*} > 0$, $\gamma *+ = -\frac{2b-h-2c_H+\sqrt{36b^2-36bh-8bc_H-64bc_L+9h^2+4hc_H+32hc_L+4c_H^2+32c_L^2}}{2(2b-h-2c_L)}$. So $b < \frac{h}{2}+2c_L, q_L^{\mathrm{NB}^*} - q_L^{\mathrm{BN}^*} > 0; b > \frac{h}{2}+2c_L\begin{cases} 0 < \gamma < \gamma *+, q_L^{\mathrm{NB}^*} - q_L^{\mathrm{BN}^*} < 0 \\ \gamma *+ < \gamma < \gamma 4, q_L^{\mathrm{NB}^*} - q_L^{\mathrm{BN}^*} > 0 \end{cases}.$

$$q_L^{\mathrm{NB}^*} - q_L^{\mathrm{BB}^*} = \frac{(-2b+h+2c_H)\gamma}{4\gamma^4-20\gamma^2+16} > 0,\ q_L^{\mathrm{BN}^*} - q_L^{\mathrm{BB}^*} = -\frac{2(\gamma^2-2)(-c_L+b-\frac{h}{2})}{4\gamma^4-20\gamma^2+16}.\begin{cases} b < \frac{h}{2}+c_L, q_L^{\mathrm{BN}^*} - q_L^{\mathrm{BB}^*} < 0 \\ b > \frac{h}{2}+c_L, q_L^{\mathrm{BN}^*} - q_L^{\mathrm{BB}^*} > 0 \end{cases}.$$

$$q_H^{\mathrm{NN}^*} - q_H^{\mathrm{BN}^*} = -\frac{2(-c_H+b-\frac{h}{2})(\gamma^2-2)}{4\gamma^4-20\gamma^2+16}. b < \frac{h}{2}+c_H, q_H^{\mathrm{NN}^*} - q_H^{\mathrm{BN}^*} < 0.$$

$$q_H^{\mathrm{NN}^*} - q_H^{\mathrm{NB}^*} = \frac{(2c_L-2b+h)\gamma}{4\gamma^4-20\gamma^2+16}.\begin{cases} b < \frac{h}{2}+c_L, q_H^{\mathrm{NN}^*} - q_H^{\mathrm{NB}^*} > 0 \\ b > \frac{h}{2}+c_L, q_H^{\mathrm{NN}^*} - q_H^{\mathrm{NB}^*} < 0 \end{cases}.$$

$$q_H^{\mathrm{NN}^*} - q_H^{\mathrm{BB}^*} = \frac{(2c_H-2b+h)\gamma^2+(2c_L-2b+h)\gamma+4b-2h-4c_H}{4\gamma^4-20\gamma^2+16} < 0.$$

$$q_H^{\mathrm{NB}^*} - q_H^{\mathrm{BN}^*} = \frac{(2c_H-2b+h)\gamma^2+(-2c_L+2b-h)\gamma+4b-2h-4c_H}{4\gamma^4-20\gamma^2+16} < 0.$$

$$q_H^{\mathrm{NB}^*} - q_H^{\mathrm{BB}^*} = -\frac{2(-c_H+b-\frac{h}{2})(\gamma^2-2)}{4\gamma^4-20\gamma^2+16} < 0.$$

$$q_H^{\mathrm{BN}^*} - q_H^{\mathrm{BB}^*} = \frac{2(c_L-2b+h)\gamma}{4\gamma^4-20\gamma^2+16}\begin{cases} b < \frac{h}{2}+c_L, q_H^{\mathrm{BN}^*} - q_H^{\mathrm{BB}^*} > 0 \\ b > \frac{h}{2}+c_L, q_H^{\mathrm{BN}^*} - q_H^{\mathrm{BB}^*} < 0 \end{cases}.$$ □

Proof of Proposition 8. $\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_H}^{\mathrm{NB}^*} = \frac{4\gamma((2\sigma-2a_H+2c_H)\gamma^2+(b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma-4\sigma+4a_H-4c_H)(b-\frac{h}{2}-c_L)}{8\gamma^6-72\gamma^4+192\gamma^2-128}$, among them $8\gamma^6-72\gamma^4+192\gamma^2-128 < 0$, $F(\gamma) = (2\sigma-2a_H+2c_H)\gamma^2+(b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma-4\sigma+4a_H-4c_H$, $F(\gamma)$ is positive in the interval $\gamma \in (0,1)$, that is $F(\gamma) > 0$. So when $b < \frac{h}{2}+c_L$, there are $\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_H}^{\mathrm{NB}^*} > 0$. When $b > \frac{h}{2}+c_L$, there are $\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_H}^{\mathrm{NB}^*} < 0$.

$\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_H}^{\mathrm{BN}^*} = \frac{4(\gamma^2-2)((b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma^2+(2\sigma-2a_L+2c_L)\gamma-4\sigma+4a_H-2c_H-2b+h)(b-\frac{h}{2}-c_H)}{8\gamma^6-72\gamma^4+192\gamma^2-128}$, among them $8\gamma^6-72\gamma^4+192\gamma^2-128 < 0$. So, when $b < \frac{h}{2}+c_H$, there are $\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_H}^{\mathrm{BN}^*} < 0$. When $b > \frac{h}{2}+c_H$, there are $\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_H}^{\mathrm{BN}^*} > 0$.

$\pi_{S_H}^{\mathrm{NB}^*} - \pi_{S_H}^{\mathrm{BN}^*} = \frac{4((b-\frac{h}{2}-c_H)\gamma^2+(-b+\frac{h}{2}+c_L)\gamma-2b+h+2c_H)((b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma^2+(b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma-2b+h-4\sigma+4a_H-2c_H)}{8\gamma^6-72\gamma^4+192\gamma^2-128}$, among them $F(\gamma) = (b-\frac{h}{2}-c_H)\gamma^2+(-b+\frac{h}{2}+c_L)\gamma-2b+h+2c_H$, $F(0) = -2b+h+2c_H$. If $F(0) = -2b+h+2c_H > 0$, $b < \frac{h}{2}+c_H$, $F(1) = -2b+h+c_H+c_L > 0$. $F(\gamma)$ is an open downward convex function and all functional solutions in the $\gamma \in (0,1)$ interval are greater than 0, $F(\gamma) > 0$, so there are $b < \frac{h}{2}+c_H$, $\pi_{S_H}^{\mathrm{NB}^*} - \pi_{S_H}^{\mathrm{BN}^*} < 0$. If $F(0) = -2b+h+2c_H < 0$, $b > \frac{h}{2}+c_H$, $F(1) = -2b+h+c_H+c_L < 0$, $F(\lambda)$ is an open downward convex function and all functional solutions in the $\gamma \in (0,1)$ interval are less than 0, $F(\gamma) < 0$, so there are $b > \frac{h}{2}+c_H$, $\pi_{S_H}^{\mathrm{NB}^*} - \pi_{S_H}^{\mathrm{BN}^*} > 0$.

$\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_H}^{\mathrm{BB}^*} = \frac{4((b-\frac{h}{2}-c_H)\gamma^2+(b-\frac{h}{2}-c_L)\gamma-2b+h+2c_H)((b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma^2+(b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma-2b+h-4\sigma+4a_H-2c_H)}{8\gamma^6-72\gamma^4+192\gamma^2-128}$, similarly $b < \frac{h}{2}+c_H$, $\pi_{S_H}^{\mathrm{NN}^*} - \pi_{S_H}^{\mathrm{BB}^*} < 0$.

$\pi_{S_H}^{\mathrm{BN}^*} - \pi_{S_H}^{\mathrm{BB}^*} = \frac{8\gamma(b-\frac{h}{2}-c_L)((b-\frac{h}{2}+\sigma-a_H)\gamma^2+(\frac{b}{2}-\frac{h}{4}+\sigma-a_L+\frac{c_L}{2})\gamma-2b+h-2\sigma+2a_H)}{8\gamma^6-72\gamma^4+192\gamma^2-128}$, similarly when $b < \frac{h}{2}+c_L$, $\pi_{S_H}^{\mathrm{BN}^*} - \pi_{S_H}^{\mathrm{BB}^*} > 0$. When $b > \frac{h}{2}+c_L$, $\pi_{S_H}^{\mathrm{BN}^*} - \pi_{S_H}^{\mathrm{BB}^*} < 0$.

$\pi_{S_H}^{\mathrm{NB}^*} - \pi_{S_H}^{\mathrm{BB}^*} = \frac{4(b-\frac{h}{2}-c_H)(\gamma^2-2)((b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma^2+(2b-h+2\sigma-2a_L)\gamma-2b+h-4\sigma+4a_H-2c_H)}{8\gamma^6-72\gamma^4+192\gamma^2-128}$, $b < \frac{h}{2}+c_H$, $\pi_{S_H}^{\mathrm{NB}^*} - \pi_{S_H}^{\mathrm{BB}^*} < 0$. □

The proof of Propositions 9 and 10 is similar to Proposition 8.

Proposition A.1.

$$\rho_R^{\mathrm{NB}} = \frac{12((\frac{2\sigma}{3}-\frac{2a_H}{3}+\frac{2c_H}{3})\gamma^3+(b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma^2-\frac{4b}{3}+\frac{2h}{3}-\frac{8\sigma}{3}+\frac{8a_L}{3}-\frac{4c_L}{3})(b-\frac{h}{2}-c_L)}{\begin{array}{l}8(\sigma-a_L+c_L)(\sigma-a_H+c_H)\gamma^3+(24\sigma^2+(-24a_H-24a_L+24c_H+24c_L)\sigma \\ +12c_L^2-24a_Lc_L+12a_L^2+12(a_H-c_H)^2)\gamma^2-32\sigma^2 \\ +(32a_H+32a_L-32c_H-32c_L)\sigma-16c_L^2+32a_Lc_L-16a_L^2 \\ -16(a_H-c_H)^2\end{array}}$$

$$\rho_R^{\mathrm{BN}} = \frac{12((\frac{2\sigma}{3}-\frac{2a_L}{3}+\frac{2c_L}{3})\gamma^3+(b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma^2-\frac{4b}{3}+\frac{2h}{3}-\frac{8\sigma}{3}+\frac{8a_H}{3}-\frac{4c_H}{3})(b-\frac{h}{2}-c_H)}{\begin{array}{l}8(\sigma-a_L+c_L)(\sigma-a_H+c_H)\gamma^3+(24\sigma^2+(-24a_H-24a_L+24c_H+24c_L)\sigma \\ +12c_H^2-24a_Hc_H+12a_H^2+12(a_L-c_L)^2)\gamma^2-32\sigma^2 \\ +(32a_H+32a_L-32c_H-32c_L)\sigma-16c_H^2+32a_Hc_H-16a_H^2-16(a_L-c_L)^2\end{array}}$$

$$\rho_R^{\mathrm{BB}} = \frac{\begin{array}{l}((8b-4h-4c_H-4c_L)\sigma+(-4b+2h+4c_L)a_H+(-4b+2h+4c_H)a_L\\ -4c_Lc_H+4(b-\frac{h}{2})^2)\gamma^3+((24b-12h-12c_H-12c_L)\sigma+(-12b+\\ 6h+12c_H)a_H+(-12b+6h+12c_L)a_L-6c_H^2-6c_L^2+12(b-\frac{h}{2})^2)\gamma^2\\ +(-32b+16h+16c_H+16c_L)\sigma+(16b-8h-16c_H)a_H+\\ (16b-8h-16c_L)a_L+8c_H^2+8c_L^2-16(b-\frac{h}{2})^2\end{array}}{\begin{array}{l}4(\sigma-a_L+c_L)(\sigma-a_H+c_H)\gamma^3+(12\sigma^2+(-12a_H-12a_L+12c_H+12c_L)\sigma\\ +6a_H^2-12a_Hc_H+6a_L^2-12a_Lc_L+6c_H^2+6c_L^2)\gamma^2-16\sigma^2+(16a_H+16a_L-\\ 16c_H-16c_L)\sigma-8a_H^2+16a_Hc_H-8a_L^2+16a_Lc_L-8c_H^2-8c_L^2\end{array}}$$

$$\rho_{S_H}^{\mathrm{NB}} = \frac{((2\sigma-2a_H+2c_H)\gamma^2+(b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma-4\sigma+4a_H-4c_H)\gamma(b-\frac{h}{2}-c_L)}{((\sigma-a_H+c_H)\gamma^2+(\sigma-a_L+c_L)\gamma-2\sigma+2a_H-2c_H)^2}$$

$$\rho_{S_H}^{\mathrm{BN}} = \frac{((b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma^2+(2\sigma-2a_L+2c_L)\gamma-2b+h-4\sigma+4a_H-2c_H)(\gamma^2-2)(b-\frac{h}{2}-c_H)}{((\sigma-a_H+c_H)\gamma^2+(\sigma-a_L+c_L)\gamma-2\sigma+2a_H-2c_H)^2}$$

$$\rho_{S_H}^{\mathrm{BB}} = \frac{\begin{array}{l}((b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma^2+(b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma-2b+h-4\sigma\\ +4a_H-2c_H)((b-\frac{h}{2}-c_H)\gamma^2+(b-\frac{h}{2}-c_L)\gamma-2b+h+2c_H)\end{array}}{((\sigma-a_H+c_H)\gamma^2+(\sigma-a_L+c_L)\gamma-2\sigma+2a_H-2c_H)^2}$$

$$\rho_{S_L}^{\mathrm{NB}} = \frac{((b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma^2+(2\sigma-2a_H+2c_H)\gamma-2b+h-4\sigma+4a_L-4c_L)(\gamma^2-2)(b-\frac{h}{2}-c_L)}{((\sigma-a_L+c_L)\gamma^2+(\sigma-a_H+c_H)\gamma-2\sigma+2a_L-2c_L)^2}$$

$$\rho_{S_L}^{\mathrm{BN}} = \frac{((2\sigma-2a_L+2c_L)\gamma^2+(b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma-4\sigma+4a_L-4c_L)\gamma(b-\frac{h}{2}-c_H)}{((\sigma-a_L+c_L)\gamma^2+(\sigma-a_H+c_H)\gamma-2\sigma+2a_L-2c_L)^2}$$

$$\rho_{S_L}^{\mathrm{BB}} = \frac{\begin{array}{l}((b-\frac{h}{2}+2\sigma-2a_L+c_L)\gamma^2+(b-\frac{h}{2}+2\sigma-2a_H+c_H)\gamma-2b+h-4\sigma\\ +4a_L-2c_L)((b-\frac{h}{2}-c_L)\gamma^2+(b-\frac{h}{2}-c_H)\gamma-2b+h+2c_L)\end{array}}{((\sigma-a_L+c_L)\gamma^2+(\sigma-a_H+c_H)\gamma-2\sigma+2a_L-2c_L)^2}.$$

Appendix B. Social welfare

NN-model

$$SW^{\mathrm{NN}} = CS^{\mathrm{NN}} + \pi_R^{\mathrm{NN}^*} + \pi_{S_H}^{\mathrm{NN}^*} + \pi_{S_L}^{\mathrm{NN}^*}, \quad CS^{\mathrm{NN}} = \frac{(2\sigma-a_H-a_L+c_H+c_L)^2}{8(\gamma^2-\gamma-2)^2}.$$

BN-model

$$SW^{\mathrm{BN}} = CS^{\mathrm{BN}} + \pi_R^{\mathrm{BN}^*} + \pi_{S_H}^{\mathrm{BN}^*} + \pi_{S_L}^{\mathrm{BN}^*}, \quad CS^{\mathrm{BN}} = \frac{(2b-h+4\sigma-2a_H-2a_L+2c_L)^2}{32(\gamma^2-\gamma-2)^2}.$$

NB-model

$$SW^{\mathrm{NB}} = CS^{\mathrm{NB}} + \pi_R^{\mathrm{NB}^*} + \pi_{S_H}^{\mathrm{NB}^*} + \pi_{S_L}^{\mathrm{NB}^*}, \quad CS^{\mathrm{NB}} = \frac{(2b-h+4\sigma-2a_H-2a_L+2c_H)^2}{32(\gamma^2-\gamma-2)^2}.$$

BB-model

$$SW^{\mathrm{BB}} = CS^{\mathrm{BB}} + \pi_R^{\mathrm{BB}^*} + \pi_{S_H}^{\mathrm{BB}^*} + \pi_{S_L}^{\mathrm{BB}^*}, \quad CS^{\mathrm{BB}} = \frac{(2b-h+2\sigma-a_H-a_L)^2}{8(\gamma^2-\gamma-2)^2}.$$

Appendix C. Extension

C.1. Fixed costs of Blockchain' information sharing

Through calculation, we find that the optimal equilibrium of decision variables in $J+$ model is the same as that in the basic model, only the profit of supply chain participants in $J+$ model changes. Through MATLAB2022a numerical simulation, we obtained the changes in the optimal demand information sharing model for each participant, intending to verify the robustness of the model. As shown in the Figures C.1–C.6, it can be seen that the efficiency trend of demand information sharing model profit enhancement of supply chain participants is consistent with the basic model, and the model in this paper has strong robustness

C.2. Risk-averse level

NN-model ($k = 0$)

$w_H^{\mathrm{NN}^*}(k = 0) = \frac{a_H\gamma^2+(a_L-c_L)\gamma-2a_H-2c_H}{\gamma^2-4}$, $w_L^{\mathrm{NN}^*}(k = 0) = \frac{a_L\gamma^2+(a_H-c_H)\gamma-2a_L-2c_L}{\gamma^2-4}$, $p_H^{\mathrm{NN}^*}(k = 0) = \frac{2\gamma^2a_H+(a_L-c_L)\gamma-2(3a_H+c_H)}{2\gamma^2-8}$, $p_L^{\mathrm{NN}^*}(k = 0) = \frac{2\gamma^2a_L+(a_H-c_H)\gamma-2(3a_L+c_L)}{2\gamma^2-8}$, $q_H^{\mathrm{NN}^*}(k = 0) = \frac{(-a_H+c_H)\gamma^2+(-a_L+c_L)\gamma+2(a_H-c_H)}{2\gamma^4-10\gamma^2+8}$, $q_L^{\mathrm{NN}^*}(k = 0) = \frac{(-a_L+c_L)\gamma^2+(-a_H+c_H)\gamma-2(-a_L+c_L)}{2\gamma^4-10\gamma^2+8}$.

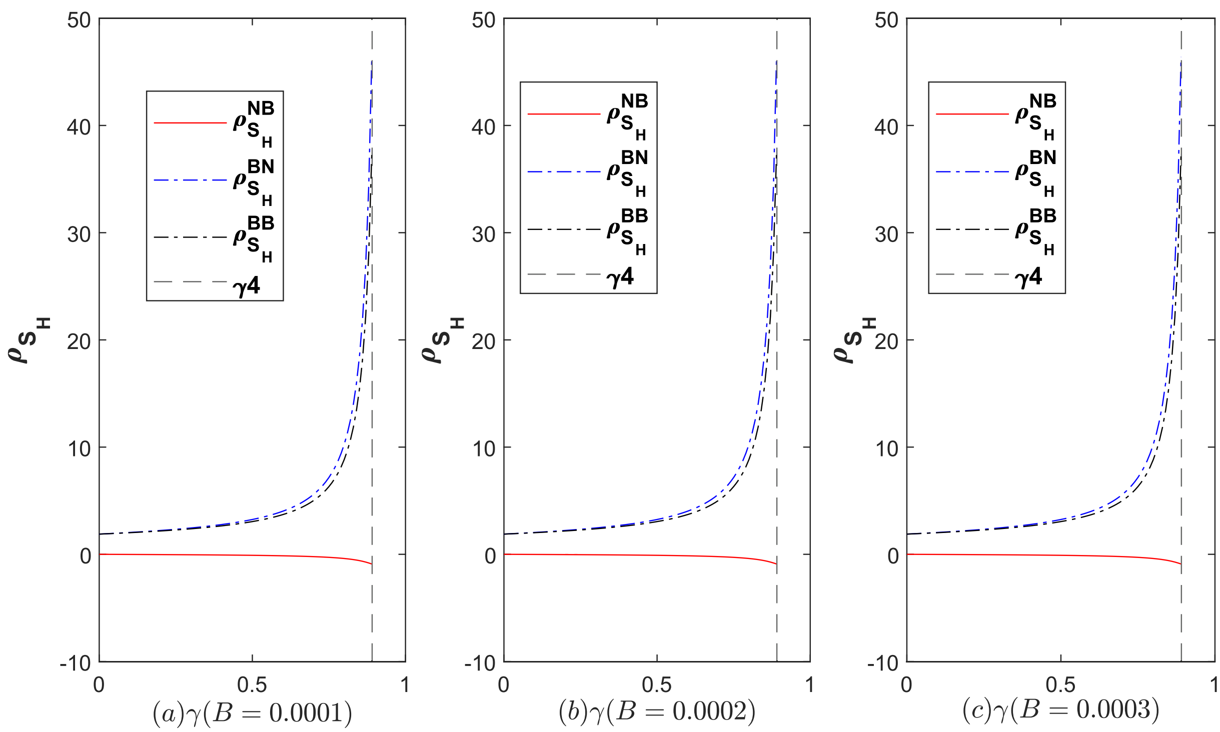


Figure C.1. High quality suppliers' information sharing profit efficiency under low information sharing cost.

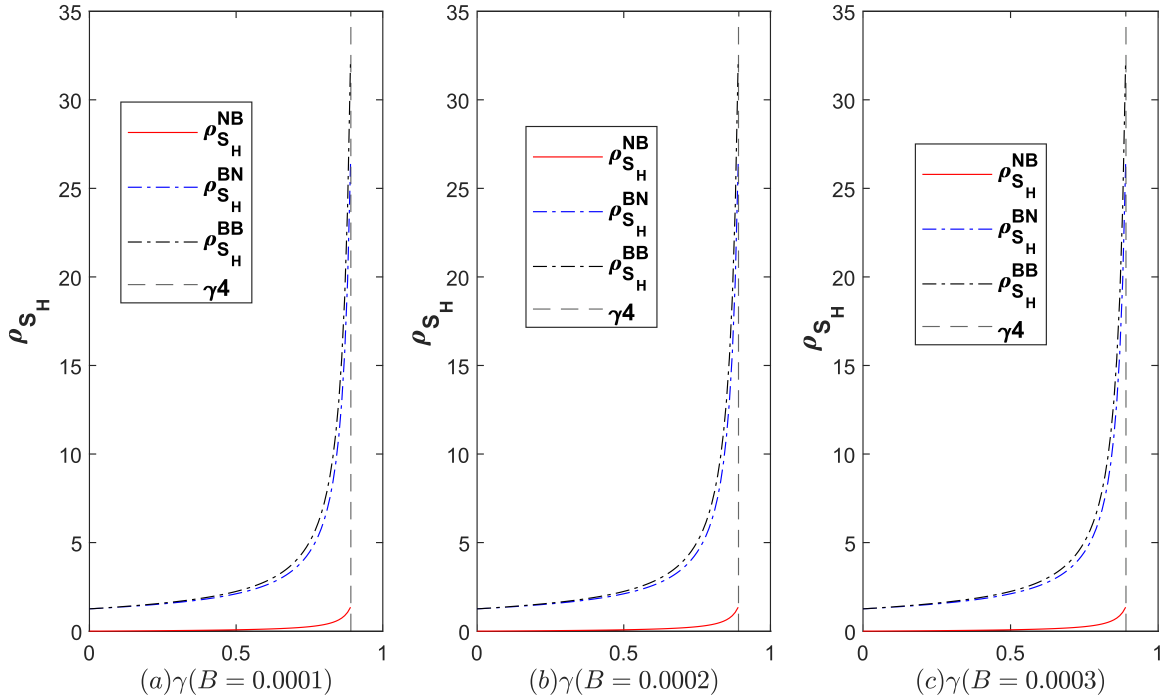


FIGURE C.2. High quality suppliers' information sharing profit efficiency under high information sharing cost.

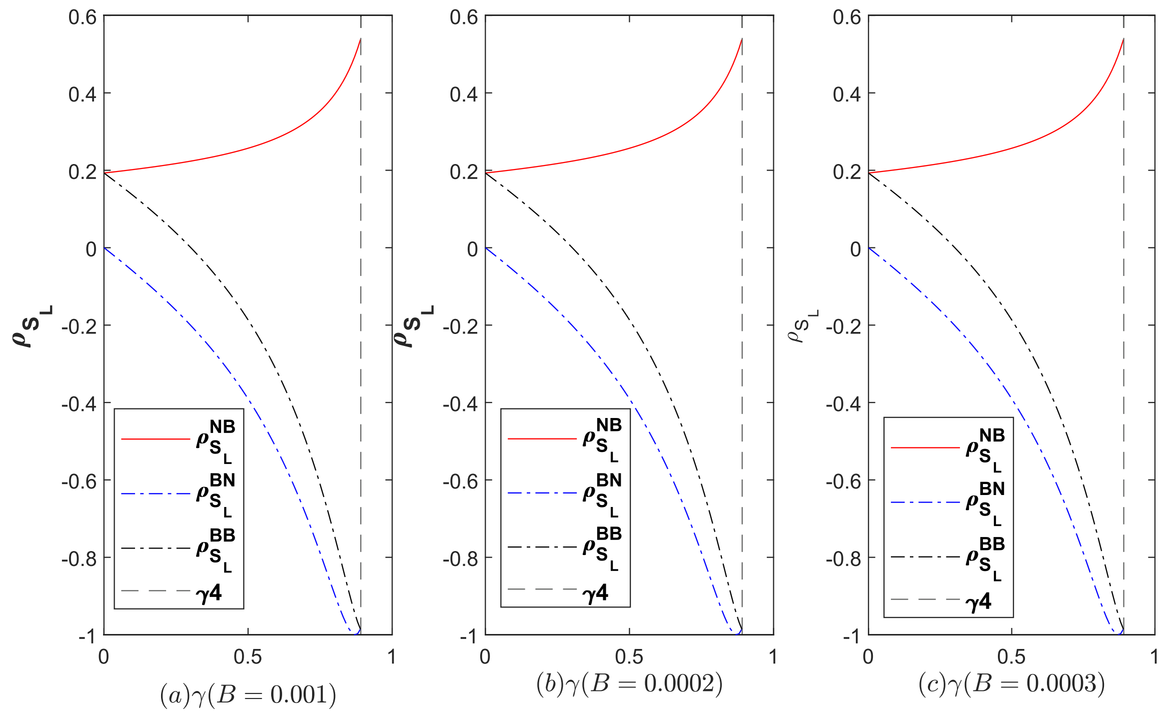


FIGURE C.3. Low quality suppliers' information sharing profit efficiency under low information sharing cost.

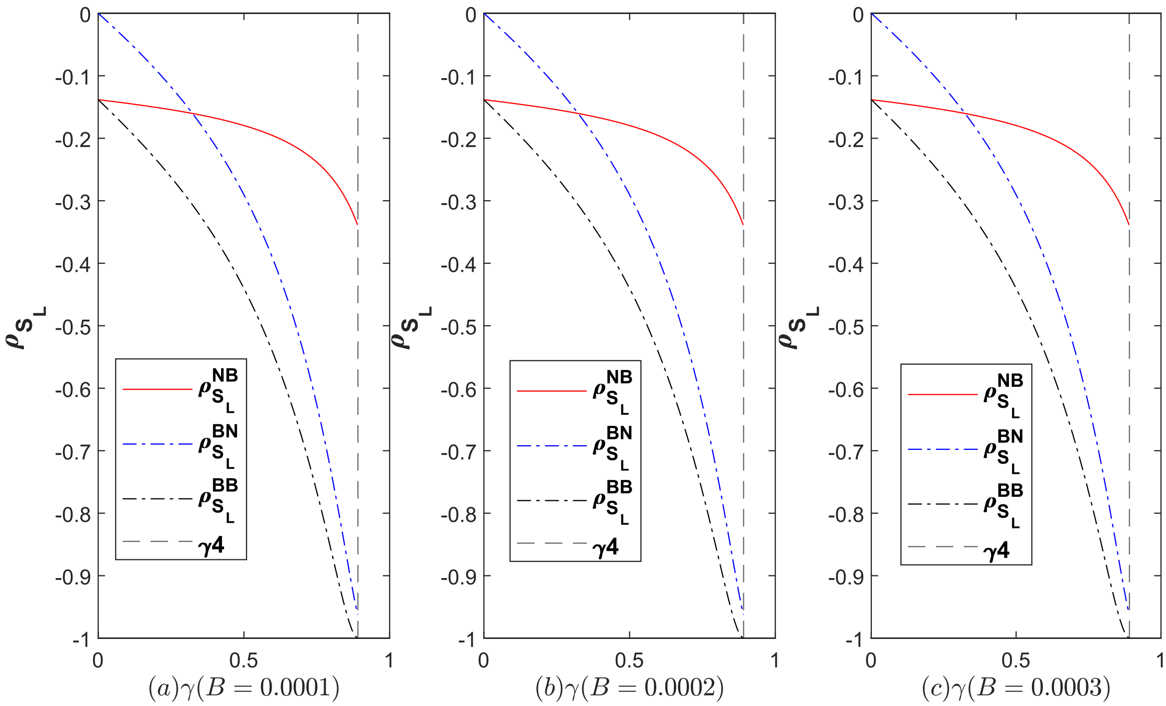


FIGURE C.4. Low quality suppliers' information sharing profit efficiency under high information sharing cost.

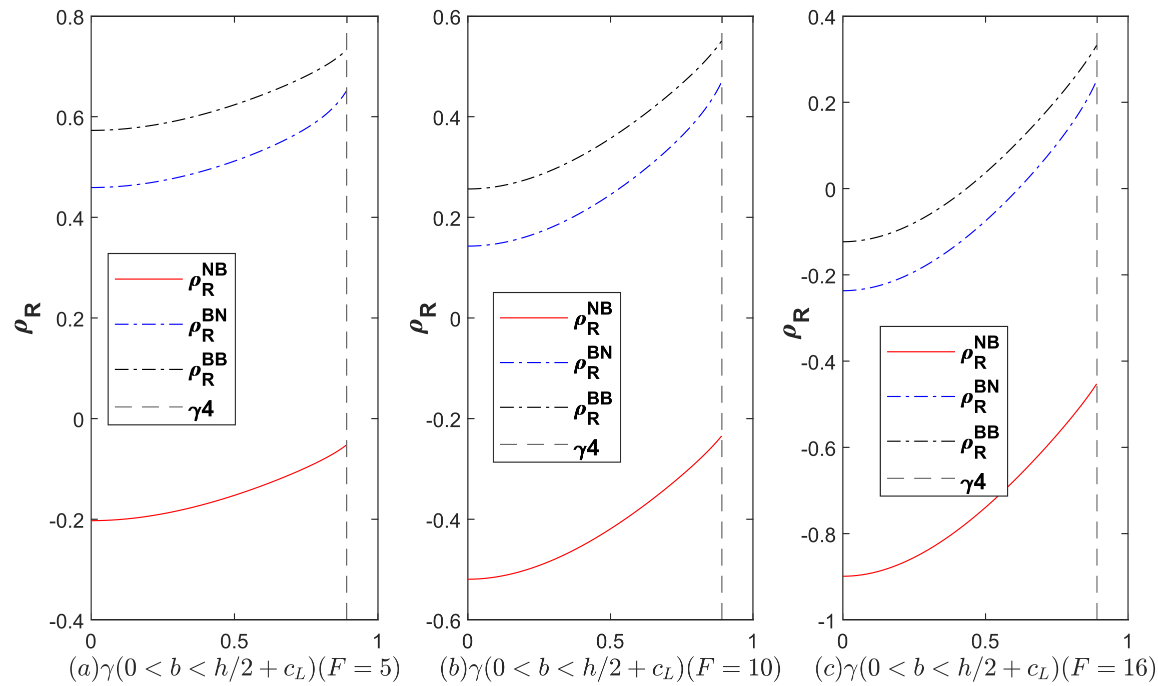
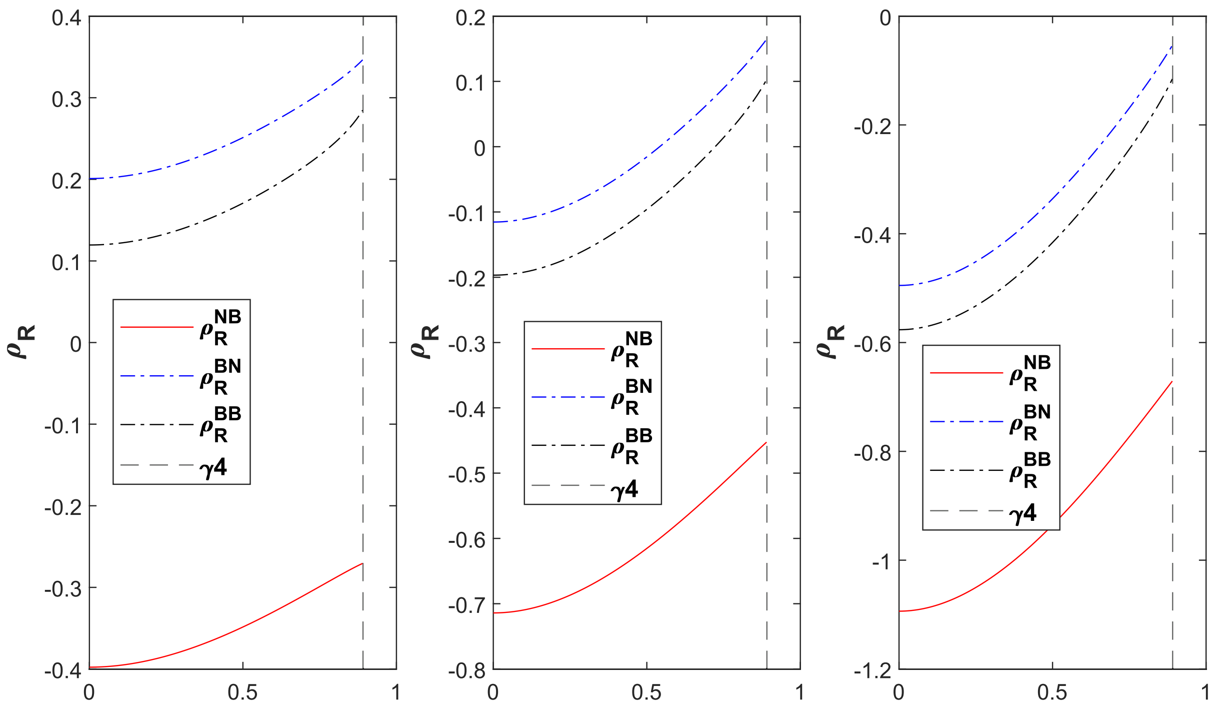


FIGURE C.5. Retail platforms' information sharing profit efficiency under low information sharing cost.



$(a)\gamma(F=5)$ $(b)\gamma(F=10)$ $(c)\gamma(F=16)$

FIGURE C.6. Retail platforms' information sharing profit efficiency under high information sharing cost.

NB-model $(k=0)$

$w_H^{\mathrm{NB}^*}(k=0)=\frac{2a_H\gamma^2+(-2b+h+2a_L)\gamma-4a_H-4c_H}{2\gamma^2-8}$, $w_L^{\mathrm{NB}^*}(k=0)=\frac{(-2b+h+2a_L)\gamma^2+(2a_H-2c_H)\gamma+4b-4a_L-2h}{2\gamma^2-8}$, $p_H^{\mathrm{NB}^*}(k=0)=\frac{4\gamma^2a_H+(-2b+h+2a_L)\gamma-12a_H-4c_H}{4\gamma^2-16}$, $p_L^{\mathrm{NB}^*}(k=0)=\frac{\gamma^2(h+2a_L)+(a_H-c_H)\gamma-6a_L-3h}{2\gamma^2-8}$, $q_H^{\mathrm{NB}^*}(k=0)=\frac{(-2a_H+2c_H)\gamma^2+(2b-h-2a_L)\gamma-4\sigma+4a_H-4c_H}{4\gamma^4-20\gamma^2+16}$, $q_L^{\mathrm{NB}^*}(k=0)=\frac{(2b-h-2a_L)\gamma^2+(-2a_H+2c_H)\gamma-4b+2h+4a_L}{4\gamma^4-20\gamma^2+16}$.

BN-model $(k=0)$

$w_H^{\mathrm{BN}^*}(k=0)=\frac{(-2b+h+2a_H)\gamma^2+(2a_L-2c_L)\gamma-4a_H-4b-2h}{2\gamma^2-8}$, $w_L^{\mathrm{BN}^*}(k=0)=\frac{2a_L\gamma^2+(-2b+h+2a_H)\gamma-4a_L-4c_L}{2\gamma^2-8}$, $p_H^{\mathrm{BN}^*}(k=0)=\frac{(h+2a_H)\gamma^2+(a_L-c_L)\gamma-6a_H-2b-3h}{2\gamma^2-8}$, $p_L^{\mathrm{BN}^*}(k=0)=\frac{4a_L\gamma^2+(-2b+h+2a_H)\gamma-12a_L-4c_L}{4\gamma^2-16}$, $q_H^{\mathrm{BN}^*}(k=0)=\frac{(-2a_H+2b-h)\gamma^2+(-2a_L+2c_L)\gamma-4b+2h+4a_H}{4\gamma^4-20\gamma^2+16}$, $q_L^{\mathrm{BN}^*}(k=0)=\frac{(-2a_L+2c_L)\gamma^2+(2b-h-2a_H)\gamma-4(-a_L+c_L)}{4\gamma^4-20\gamma^2+16}$.

BB-model $(k=0)$

$$w_H^{\mathrm{BB}^*}(k=0)=\frac{(-2b+h+2a_H)\gamma^2+(-2b+h+2a_L)\gamma+4b-4a_H-2h}{2\gamma^2-8},$$
$$w_L^{\mathrm{BB}^*}(k=0)=\frac{(-2b+h+2a_L)\gamma^2+(-2b+h+2a_H)\gamma+4b-2h-4a_L}{2\gamma^2-8},$$
$$p_H^{\mathrm{BB}^*}(k=0)=\frac{(2h+4a_H)\gamma^2+(-2b+h+2a_L)\gamma-12a_H-4b-6h}{4\gamma^2-6},$$

$$p_L^{\mathrm{BB}^*}(k=0) = \frac{(2h+4a_L)\gamma^2 + (-2b+h+2a_H)\gamma - 4b - 6h - 12a_L}{4\gamma^2 - 16},$$

$$q_H^{\mathrm{BB}^*}(k=0) = \frac{(2b-h-2a_H)\gamma^2 + (2b-h-2a_L)\gamma - 4b + 2h + 4a_H}{4\gamma^4 - 20\gamma^2 + 16},$$

$$q_L^{\mathrm{BB}^*}(k=0) = \frac{(2b-h-2a_L)\gamma^2 + (2b-h-2a_H)\gamma - 4b + 2h + 4a_L}{4\gamma^4 - 20\gamma^2 + 16},$$

$$\rho_R^{\mathrm{NB}}(k=0) = \frac{\begin{array}{l} 12(\frac{2\sigma\gamma^4}{3} + (\frac{4\sigma}{3} - \frac{2a_H}{3} + \frac{2c_H}{3})\gamma^3 + (b - \frac{h}{2} - 2\sigma - 2a_L + c_L)\gamma^2 - \frac{8\sigma\gamma}{3} - \frac{4b}{3} + \frac{2h}{3} + \frac{8\sigma}{3} \\ + \frac{8a_L}{3} - \frac{4c_L}{3})(b - \frac{h}{2} - c_L) \end{array}}{\begin{array}{l} 16(\sigma - \frac{a_H}{2} - \frac{a_L}{2} + \frac{c_H}{2} + \frac{c_L}{2})\sigma\gamma^4 + (24\sigma^2 + (-16a_H - 16a_L + 16c_H + 16c_L)\sigma + \\ 8(a_L - c_L)(a_H - c_H))\gamma^3 + (-72\sigma^2 + (24a_H + 24a_L - 24c_H - 24c_L)\sigma \\ + 12c_L^2 - 24a_Lc_L + 12a_L^2 + 12(a_H - c_H)^2)\gamma^2 - 64(\sigma - \frac{a_H}{2} - \frac{a_L}{2} + \frac{c_H}{2} + \frac{c_L}{2})\sigma\gamma + 96\sigma^2 \\ + (-32a_H - 32a_L + 32c_H + 32c_L)\sigma - 16c_L^2 + 32a_Lc_L - 16a_L^2 - 16(a_H - c_H)^2 \end{array}},$$

$$\rho_R^{\mathrm{BN}}(k=0) = \frac{\begin{array}{l} 12(b - \frac{h}{2} - c_H)(\frac{2\sigma\gamma^4}{3} + (\frac{4\sigma}{3} - \frac{2a_L}{3} + \frac{2c_L}{3})\gamma^3 + (b - \frac{h}{2} - 2\sigma - 2a_H + c_H)\gamma^2 \\ - \frac{8\sigma\gamma}{3} - \frac{4b}{3} + \frac{8\sigma}{3} + \frac{2h}{3} + \frac{8a_H}{3} - \frac{4c_H}{3}) \end{array}}{\begin{array}{l} 16(\sigma - \frac{a_H}{2} - \frac{a_L}{2} + \frac{c_H}{2} + \frac{c_L}{2})\sigma\gamma^4 + (24\sigma^2 + (-16a_H - 16a_L + 16c_H + 16c_L)\sigma \\ + 8(a_L - c_L)(a_H - c_H))\gamma^3 + (-72\sigma^2 + (24a_H + 24a_L - 24c_H - 24c_L)\sigma \\ + 12c_H^2 - 24a_Hc_H + 12a_H^2 + 12(a_L - c_L)^2)\gamma^2 - 64(\sigma - \frac{a_H}{2} - \frac{a_L}{2} + \frac{c_H}{2} + \frac{c_L}{2})\sigma\gamma \\ + 96\sigma^2 + (-32a_H - 32a_L + 32c_H + 32c_L)\sigma - 16c_H^2 + 32a_Hc_H - 16a_H^2 - 16(a_L - c_L)^2 \end{array}},$$

$$\rho_R^{\mathrm{BB}}(k=0) = \frac{\begin{array}{l} ((8b - 4h - 4c_H - 4c_L)\sigma\gamma^4 + ((16b - 8h - 8c_H - 8c_L)\sigma + (4a_L - 4c_L)c_H + 4c_La_H \\ + 4(b - \frac{h}{2})(b - \frac{h}{2} - a_H - a_L))\gamma^3 + ((-24b + 12h + 12c_H + 12c_L)\sigma - 6c_H^2 + 12a_Hc_H - 6c_L^2 \\ + 12a_Lc_L + 12(b - \frac{h}{2})(b - \frac{h}{2} - a_H - a_L))\gamma^2 + (32b - 16h - 16c_H - 16c_L)\sigma + 8c_H^2 \\ - 16a_Hc_H + 8c_L^2 - 16a_Lc_L - 16(b - \frac{h}{2})(b - \frac{h}{2} - a_H - a_L) \end{array}}{\begin{array}{l} 8(\sigma - \frac{a_H}{2} - \frac{a_L}{2} + \frac{c_L}{2} + \frac{c_H}{2})\sigma^4 + (12\sigma^2 + (-8a_H - 8a_L + 8c_H + 8c_L)\sigma \\ + 4(a_L - c_L)(a_H - c_H))\gamma^3 + (-36\sigma^2 + (12a_H + 12a_L - 12c_H - 12c_L)\sigma \\ + 6a_H^2 - 12a_Hc_H + 6a_L^2 - 12a_Lc_L + 6c_H^2 + 6c_L^2)\gamma^2 - 32(\sigma - \frac{a_H}{2} - \frac{a_L}{2} + \frac{c_L}{2} + \frac{c_H}{2})\sigma\gamma \\ + 48\sigma^2 + (-16a_H - 16a_L + 16c_H + 16c_L)\sigma - 8a_H^2 + 16a_Hc_H - 8a_L^2 \\ + 16a_Lc_L - 8c_H^2 - 8c_L^2 \end{array}}.$$

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Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, author- ship, and/or publication of this article.

Data availability statement

The data used to support the findings of this study are available from the corresponding author upon request.

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