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RETAILER'S WILLINGNESS TO ADOPT BLOCKCHAIN TECHNOLOGY BASED ON PRIVATE DEMAND INFORMATION

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Abstract. This paper considers a supply chain that includes one supplier and one retailer, in which the retailer has a more accurate demand forecast. The blockchain technology can verify the authenticity of the information, then the retailer can choose to truly share the demand information with the supplier by adopting such a costly technology. We discuss three scenarios based on signaling game: the retailer bears all the cost (no subsidy), the supplier bears part of the cost by providing direct subsidy or wholesale discount, respectively. Specifically, in a demand information asymmetric setting, we mainly focus on exploring the conditions of retailer adopting blockchain technology and the supplier's subsidy strategy choice, and further verify the robustness of the model by considering the retailer's risk aversion or multiple suppliers. In all scenarios, we find that the retailer will apply threshold strategy to adopt blockchain technology. The retailer's willingness to adopt blockchain technology is negatively correlated with the corresponding adoption cost, the supplier's profit level, and positively correlated with the number of suppliers. Additionally, we find the supplier can profit from providing subsidies when the cost of adopting blockchain technology is around a medium level, and the direct subsidy is superior to wholesale discount. More surprisingly, we find subsidies may work to the disadvantage of the subsidized party. Specifically, compared to no subsidy, we find the direct subsidy and the wholesale discount can increase the retailer's willingness to adopt blockchain technology, but hurt the retailer's as well as the supply chain's profits.

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1. **Introduction.** Demand information asymmetry in supply chain mainly refers that downstream retailer (She) is more accurate in predicting market demand than upstream supplier (He). In practice, in a retail channel which consists of one upstream supplier and one downstream retailer, the retailer is often closer to consumers and has more expertise and superior forecasting abilities in the selling process [24]. Therefore, the retailer usually holds a better knowledge about the market demand than the supplier, which is a widespread assumption in the operation management literatures [36, 1, 37]. The demand information asymmetry between the supplier and the retailer can cause a serious bullwhip effect and hurt the expected profit of supply chain [23, 34]. The supplier can only determine the component capacity based on the purchase quantity in the previous periods due to the inaccurate forecasts. For example, Hynix Semiconductor Inc., even had to sell the remaining products at a price lower than their manufacturing cost due to oversupply [47]. Hence, for the supplier, there is a risk of loss caused by insufficient inventory or excessive inventory. While for the retailer, she also faces the loss of shortages caused by the insufficient inventory of the supplier. However, since it's always beneficial for the retailer to exaggerate her private forecast information, the supplier may ignore the information provided by the retailer or reduce it. [9] discussed this process in detail and empirically showed that over time, the component capacity set by the supplier is on average 30% less than the private forecast information the retailer shares. Therefore, it's risky for both the supplier and the retailer to make decisions. Most scholars have established effective contracts through signaling and screening, such as wholesale price contract, repurchase contract, agreement contract. But many contracts of them are complicated and difficult to operate [8, 19].

The development of blockchain technology provides a new approach to solve the problem of mistrust between enterprises [32]. Technically, blockchain technology is a decentralized and distributed database where information can be securely recorded. Blockchain is cryptographically secure, distributed ledgers that can enable decentralized verifiability of digital-goods transactions. The advantages of the technology are well known as they relate to storing records of digital transactions including strong security, disintermediation, record integrity, automation [6].

For example, Alabama's Auburn University successfully completed a pilot in partnership with Nike, Macy's and Kohl's using Hyperledger to upload supply chain data onto the blockchain[14]. [45] designed and evaluated a blockchain technology architecture for sharing demand data in the supply chain to reduce bullwhip effect. The general process can be described as follows. The retailer adopts blockchain technology and uploads the relevant data of forecasting demand to the blockchain database. Because the data is encrypted in the design, the supplier needs to decrypt the data first, and then to access the data, which ensures the security of the retailer's data. When the retailer wants to share private demand information with the supplier, she can share the key of the relevant data with the supplier first, and then the supplier can access the data. The retailer will not arbitrarily tamper with the blockchain database due to the huge fee of tampering, then the supplier can verify the authenticity of the private demand information shared by the retailer.

At present, many large enterprises are working hard to invest in building blockchain platforms for various complex application scenarios, such as IBM, Tencent and Alibaba. The blockchain platform usually has developed by third party (such as IBM), which also reduces the possibility of enterprises tampering with data by the increased counterfeiting cost. For example, IBM's Food Trust platform has become popular with consumers for its traceable information. Many suppliers (e.g., Dole Food, Nestle, Tyson Foods, Unilever) and retailers (e.g., Carrefour, Walmart) in food industry have joined IBM's Food Trust platform, which is built based on the blockchain technology. However, for such a new technology that currently had few commercial applications [16], the costs are required to adopt blockchain technology in different scenarios are also different [43, 10, 7]. Carrefour adds scale and the pricing ranges from 100 a month to 10, 000 a month depending on size of the enterprise[11]. Therefore, the retailer needs to weigh the benefits of exposing private demand information and the cost of adopting blockchain technology, and maximize her expected profit to make decisions.

Therefore, this paper aims to answer: (1) under what conditions the retailer is willing to adopt blockchain technology, (2) what is the optimal subsidy for the supplier and what is the reaction of the retailer to the supplier's subsidy. With these questions, we discuss the role of private demand information sharing in a two-echelon supply chain when the blockchain technology is available. We find the supplier can update his demand forecast regardless of that the retailer adopts it or not. The main sequence of events is as follows, in the first stage, the retailer chooses whether to adopt the blockchain technology. In the second stage, based on the retailer's adopting decision, the supplier may update the demand forecast information and secure the component capacity. In the third stage, the random demand is realized and the retailer's order is constrained by the capacity. Referring to some cost-sharing settings like [46, 40, 31, 12, 50], we consider three scenarios: the retailer bears all the cost (Scenario A), the supplier provides a direct subsidy to bear part of the cost (Scenario B) and the supplier holds a wholesale discount to bear part of the cost (Scenario C). We further extend the previous model by considering the retailer's risk aversion or multiple suppliers. We find perfect Bayesian equilibrium (PBE) in all scenarios, i.e., the retailer's adopting decision is simplified to a threshold strategy. That is, the retailer adopts the blockchain technology if and only if her demand forecast information is larger than the threshold. Our findings can provide theoretical and practical guidance for the supplier and retailer.

Specifically, from exploring the retailer's strategy of adopting blockchain technology, we find that the probability of the retailer adopting blockchain technology decreases as the cost of adopting blockchain technology or the supplier's profit level increase, but increases as the number of her suppliers increases. This reflects the reality that a retailer with a larger market size, such as Walmart and Carrefour (who can correspondingly afford higher adoption cost of blockchain technology, higher negotiation power of price, and work with more suppliers), is more likely to incorporate blockchain technology. Since the development of blockchain technology is still immature and the adoption cost is relatively high, only the large retailer can profit from the adoption of blockchain technology to achieve true information sharing. However, when adopting blockchain technology is costless, we find the retailer is always willing to share her private demand information. This suggests that with the rapid development of information technology, the cost of the blockchain technology will be reduced significantly, then more and more retailers should adopt blockchain technology to solve the information asymmetry problem.

We also explored the supplier's subsidy strategy and its impact to the supply chain. We find the supplier should provide a subsidy only when the cost of adopting blockchain technology is around a medium level. For the direct subsidy and wholesale discount, our findings show that providing a direct subsidy outperforms a wholesale discount for the supplier. Hence, our finding suggests that these suppliers who subsidize the retailer to adopt blockchain technology should provide direct subsidy to gain more profit.

Additionally, an interesting finding is that, providing subsidies does not always favor the subsidized party. Specifically, the retailer is more willing to adopt blockchain technology when there is a direct subsidy or a wholesale discount, but the profits of the retailer and the supply chain system will decrease. That is, for the supplier, providing a direct subsidy outperforms a wholesale discount, whereas the retailer prefers no subsidy. This finding suggests that the supplier should seek to provide subsidies to the retailer to increase profits.

The remainder of the paper is structured as follows. In Section 2, we review the literatures. In Section 3, we describe the model parameter setting and introduce the benchmark model. In Section 4, we find the PBEs in the three scenarios, respectively. In Section 5, three proposed scenarios are numerically simulated and analyzed in detail. In Section 6, we extended the model by considering the retailer's risk aversion and multiple suppliers. The article is summarized in end of the article.

2. **Literature review.**

This article relates two streams of research, demand information asymmetry in supply chain and the model application of blockchain technology. We elaborate on them as follows.

2.1. **Demand information asymmetry.**

Demand information asymmetry has been a hot challenge in the supply chain, many scholars have proposed various scenarios to enable information sharing in supply chain. There is a lot of literatures that are similar to our setting that the retailer has advantageous demand forecast information, for example [37, 30, 27, 36, 25, 2]. The model most similar to our paper is [37], they studied the important problem of how to assure credible forecast information sharing between a supplier and a manufacturer by developing two mechanisms, i.e., a nonlinear capacity reservation contract under which the manufacturer agrees to pay a fee to reserve capacity, and an advance purchase contract under which the manufacturer is induced to place a firm order before the supplier secures the component capacity used to build the end product. However, in our article, blockchain technology can ensure a credible information sharing due to its immutability and traceability, thus we focus on whether the retailer should adopt blockchain technology, which is different with their study.

In addition, [28] adopted a screening game in the presence of the supplier encroachment, then the reseller signals private information through order quantity, while in our paper, the action of "whether a retailer adopts blockchain technology" affects the supplier's prediction of private demand information. They also used a screening game of nonlinear contract to screen the retailer's private demand information in [29]. Where a screening game mainly refer to that the supplier provides an optimized menu for the retailer to choose from, and through the retailer's choice, the supplier can have different beliefs about the private information. And in a signaling game, the decision maker who holds a private information will move at first. Such movement will reveal all or part of the private information to the following decision makers. They are two common game-theoretic approaches to resolve information asymmetry. Similar to our paper, [36] also analyzed a setting in which a manufacturer and a retailer face uncertain demand, but the retailer has an information advantage in the form of a private demand forecast. From such information asymmetry that causes the manufacturer to incur a hidden information cost, they showed that a manufacturer can leverage his timing advantage to strategically implement a temporary contract adjustment mechanism, which allows him to counter his informational disadvantage and either eliminate or reduce the hidden information cost.

There are also some other kinds of contracts that enable information to be shared credibly under the prior agreement between the parties, such as typical commitment penalty contract. This type of contract mainly through mutual punishment to achieve the reliable sharing of private information. The problem in [13] is similar to our paper, they proposed a set of commitment penalty contracts, then proved that the supplier could obtain the private demand information of the retailer by providing promise-penalty contract constraints. They found an equilibrium to maximize the expected profit, thus the retailer could truly disclose their private demand information. [15] also effectively realized the sharing of private demand information through such a contract. This type of contract may enable the information sharing truly through penalty constraints, but it is difficult to verify whether the information is truly shared, and the contract operation is relatively complex. While in our paper, the supplier can verify the authenticity of the predicted information through the tamper-proof nature of blockchain technology.

In recent studies, some scholars have explored the scenario of demand information asymmetry in some more realistic scenarios [41, 27, 25]. [41] assumed that in the presence of retail competition, sharing information can ensure adequate capability level but bringing fierce competition. Hence, the retailer needs to trade-off between the two effects of reliable information sharing. They found an incumbent retailer who observes a high demand will profit from increased level of the supplier's component capacity, thus she is willing to share information truly. On the other hand, when she observes a low demand, she is unwilling to trade high level of component capacity, then she truthfully discloses her low forecasts to curb competition. In a scenario that similar to the extended part of our paper, [27] examined a supply chain with two manufacturers in which each manufacturer implements a cross-sales strategy by selling a substitutable product through two common retailers. They found both manufacturers and retailers can benefit from a two-part tariff contract if product package substitutability is more intensive and the demand uncertainty level is relatively high, or if the product package competition is less intense. In an e-commerce scenario that an offline showroom has advantageous demand information, [25] considered a supply chain where an offline showroom provides experience service for an existing online retailer and intends to introduce a new competing online retailer to satisfy consumers' heterogeneous demand. They examined the impact of competition and the offline showroom's optimal channel cooperation strategy under asymmetric information. Similar with us, they found that optimal channel cooperation strategy depends on the trade-off between signal cost, experience service level, and creates value. [26] studied the horizontal dual source model between an integrated device manufacturer (IDM) and foundry in the semiconductor industry, and they determined the unique separation equilibrium through signaling in the case of information asymmetry. However, in their paper, IDM may need to twist up his component capacity retention decision to obtain reliable information, which differs from our paper. [24] investigated the manufacturer's contract choice (drop-shipping or batch ordering) and retailer's information sharing strategy in the presence of product quality decision. they found the retailer prefers to share demand information when the quality investment efficiency is high under batch ordering contract, while she always chooses to share information under drop-shipping contract. These above articles and our paper aim to solve the problem of demand asymmetry in the supply chain. But the difference is that our major contribution is to explore under what conditions the retailer is willing to adopt the blockchain technology based on her private demand and cost of adopting blockchain technology. We find the supplier can update his demand forecast and earn more profit even if the retailer finally does not adopt blockchain technology.

2.2. **Model and applications of blockchain technology in the supply chain.** In recent years, the relevant research on the application of blockchain technology has gradually increased [44]. However, to the best of our knowledge, there is no article that addressed the decision to adopt blockchain technology as a signal to solve the information asymmetry problem as we do. Therefore, we will review articles that explore blockchain technology in different applications by using a game-theoretic approach.

Firstly, numerous studies have explored whether firm should adopt blockchain technology. For example, [12] explored whether supply chain should adopt blockchain technology based on considering consumer traceability awareness and the cost of using blockchain technology. Their results show that the conditions for supply chain adoption of blockchain technology are closely related to consumer awareness of traceability, production costs, and the cost of using blockchain technology. Moreover, under certain conditions, revenue sharing contract can achieve Pareto improvements in supply chains when adopting blockchain technology. Their cost assumptions for adopting blockchain technology are similar to our paper, and they also consider cost sharing. The difference is that they do not consider the information asymmetry problem but the impact of traceability on whether the supply chain adopts blockchain technology or not. [5] examined the blockchain technology adoption level for Newsvendor model and its impacts on the optimal ordering decisions and the corresponding optimal profit. They found that an increased blockchain technology adoption level may reduce optimal ordering, and it is not always profitable even though there is no cost of blockchain technology. Based on the assumption that blockchain technology eliminates all risks in the supply chain and saves transaction cost, but also requires initial implementation investments and variable cost, [10] explored the service strategies of supplier and the optimal order quantity and sales price decisions of retailer. They found all cases in which the use of smart contracts makes blockchain technology applications more operationally convenient and economically appealing.

In addition, by considering the game between platforms based on blockchain technology, [7] analyzed the Nash game of product information disclosure between two rental service platforms and determined the conditions under which platforms choose to disclose or not to disclose information. They assumed that the adoption of blockchain technology can reduce the cost of information auditing, but they ignored the operational cost of the blockchain technology itself. [48] built a multi-period pricing model between a blockchain-technology-supported platform and a traditional platform under network effect. They found that platforms need to adopt the blockchain technology antecedent to the competitors. However, they also did not consider the cost of adopting blockchain technology. Some researches explored the identification of product authenticity through blockchain technology. [42] examined the use of permissioned blockchain technology for retailer to help brand name companies combat imitators and how this would affect brand name companies (i.e., incumbents) in the supply chain. [39] also examined how blockchain technology can be used by firms and government to combat counterfeiting. However, to our best knowledge, no studies have yet to discuss whether a company is willing to use blockchain technology to cooperate with other companies based on demand information asymmetry. With the development of the blockchain technology, this question is undoubtedly very meaningful.

3. **Model settings and benchmarks.** Considering a two-echelon supply chain consisting of a supplier and a retailer, and both of them are risk-neutral. Before the retailer places an order, the supplier must secure component capacity K at a unit cost c_k according to his prior information on demand D. Later, the retailer observes the demand and then places an order. The supplier tries to meet the order for unit product cost c under the capacity constraint, and then delivers the products at unit wholesale price w to the retailer. Finally, during the selling season, the retailer sells products to consumers at unit retail price r. We assume c_k, c, r are common knowledge and are exogenous parameters. We assume $r > w > c + c_k$, otherwise, the product is unprofitable. Without loss of generality, we assume that unmet demand will be lost without additional out-of-stock penalties, and unsold inventory will have a residual value of zero.

In this paper, we assume the demand is composed of three parts: $D = u + \xi + \epsilon$ [37]. In which u is common knowledge that represents the average market demand. ξ is the retailer's private demand information based on the historical data on her private blockchain, which is a more accurate part in demand forecast and is deterministically known by the retailer. On the contrary, the supplier only knows that ξ is a zero-mean continuous random variable with probability density function (PDF) $f(.)$ and cumulative distribution function (CDF) $F(.)$ supported on $[-\bar{\xi}, \bar{\xi}]$ (i.e., $f(\xi) = 0$ if $\xi \notin [-\bar{\xi}, \bar{\xi}]$). In particular, both parties learn the two parts $u + \epsilon$, where u is a positive number and ϵ is a zero-mean continuous random variable with PDF $g(.)$ and CDF $G(.)$ supported on $[-\bar{\epsilon}, \bar{\epsilon}]$ (i.e., $g(\epsilon) = 0$ if $\epsilon \notin [-\bar{\epsilon}, \bar{\epsilon}]$). We assume that the retailer is willing to share her private demand to the supplier when she adopts blockchain technology, otherwise she does not need to pay the cost of adopting the blockchain that has described in the introduction, where the cost we named as M in this paper. Then after observing the retailer's choice, the supplier can update his belief about the true private demand information ξ of the retailer, i.e., the supplier can accurately know the retailer's private demand information if the retailer adopts the blockchain technology, whereas the supplier only can update the demand distribution if the retailer does not adopt. In summary, the decision process can be characterized as follows. In the first stage, the retailer decides whether to adopt the blockchain technology based on her private demand information ξ. In the second stage, the supplier builds his component capacity K after observing the retailer's choice. In the third stage, the retailer places her order $D = u + \xi + \epsilon$ constrained by the component capacity K.

Before discussing the supplier's and the retailer's equilibriums, we first consider two benchmarks that will be used to evaluate the supply chain's expected profit: the centralized system and the decentralized system (without signaling nor any information sharing).

Benchmark 1: centralized system

In this case, there is a centralized decision maker that maximizes the total supply chain profit with full information. Hence, the total expected supply chain profit under a given demand forecast ξ is

$$(r-c)\,E\left(\min\{K, u+\xi+\epsilon\}\right) - c_k K.$$

Hence, the optimal component capacity K^{cs} is

$$K^{cs} = u + \xi + G^{-1}\left(\frac{r-c-c_k}{r-c}\right),$$

and the optimal expected supply chain profit under a given demand forecast ξ is

$$\begin{aligned}\Pi^{cs}(\xi) &= (r-c)\,E_\epsilon\left(\min\{K^{cs}, u+\xi+\epsilon\}\right) - c_k K^{cs} \\ &= (r-c)\left(\int_{-\bar{\epsilon}}^{K^{cs}-u-\xi}(u+\xi+\epsilon)g(\epsilon)\mathrm{d}\epsilon + \int_{K^{cs}-u-\xi}^{\bar{\epsilon}} K^{cs}g(\epsilon)\mathrm{d}\epsilon\right) - c_k K^{cs}.\end{aligned}$$

Thus, the optimal expected supply chain profit prior to obtaining the demand forecast is

$$\Pi^* = E_\xi(\Pi^{cs}(\xi)) =$$
$$(r-c)\int_{-\bar{\xi}}^{\bar{\xi}}\left(\int_{-\bar{\epsilon}}^{K^{cs}-u-\xi}(u+y+\epsilon)g(\epsilon)\mathrm{d}x + \int_{K^{cs}-u-\xi}^{\bar{\epsilon}} K^{cs}g(\epsilon)\mathrm{d}\epsilon\right) f(\xi)\mathrm{d}\xi - c_k K^{cs}.$$

Benchmark 2: decentralized system

In this case, the supplier does not advise the retailer to adopt blockchain technology, then he builds his component capacity K before the retailer takes any movement, then the retailer places her order $D = u + \xi + \epsilon$ constrained by the component capacity K. The supplier's expected profit is

$$(w-c)\,E_{\xi,\epsilon}\left(\min\{K, u+\xi+\epsilon\}\right) - c_k K,$$

and it's easy to see that the optimal component capacity is

$$K^{ds} = u + T^{-1}\left(\frac{w-c-c_k}{w-c}\right), \tag{1}$$

in which T is the CDF of $x = \xi + \epsilon$, i.e.,

$$T(x) = \int_{-\infty}^{\infty}\int_{-\infty}^{x-\xi} f(\xi)g(\epsilon)\mathrm{d}\epsilon\mathrm{d}\xi. \tag{2}$$

Note that, the CDF $T(.)$ should be a piecewise function due to the ξ and ϵ are generally bounded. But for simplicity, here we only write the general form. Let the PDF of x is written as $t(.)$, then as a consequence, the supplier's optimal expected profit is

$$\Pi_s^{ds} = \int_{-\bar{\xi}-\bar{\epsilon}}^{K^{ds}-u}(w-c)(u+x)t(x)\mathrm{d}x + \int_{K^{ds}-u}^{\bar{\xi}+\bar{\epsilon}}(w-c)K^{ds}t(x)\mathrm{d}x - c_k K^{ds}.$$

The retailer's and the supply chain's expected profit under the supplier's component capacity decision K^{ds} are

$$\begin{aligned}\Pi_r^{ds} &= (r-w)E_\epsilon\left(\min\left\{K^{ds}, u+\xi+\epsilon\right\}\right), \\ \Pi^{ds} &= (r-c)\,E_{\xi,\epsilon}\left(\min\left\{K^{ds}, u+\xi+\epsilon\right\}\right) - c_k K^{ds}.\end{aligned}$$

4. **Model analysis.** In this section, we solve the signaling game between the supplier and the retailer under three different scenarios: without subsidy, the supplier provides a direct subsidy and the supplier provides a wholesale discount.

4.1. **Signaling without subsidy.** According to the signaling game process that is already described in Section 3, the sequence of events is: (1) The retailer predicts the private demand information ξ based on the historical data on her private blockchain. (2) The retailer decides whether to adopt the blockchain technology based on a cost M according to the value of her private demand information ξ. (3) The supplier secures component capacity based on the behavior of the retailer. Hence, our model is an extensive signaling game with incomplete information, and we aim to find the perfect Bayesian equilibrium (PBE). The PBE of the game is $\left(z^*, K_0^{A*}, K_1^{A*}; \left(f^b, F^b\right)\right)$, in which $z^* : [-\bar{\xi}, \bar{\xi}] \rightarrow \{0,1\}$ is retailer's adopting decision based on her private demand information (1 means adopting and 0 means not adopting). We assume the retailer's decision z^* can be any Borel measurable function, i.e., $(z^*)^{-1}(1)$ is a Borel set. The supplier's component capacity decisions are K_0^{A*} if the retailer does not adopt the blockchain technology, and K_1^{A*} if the retailer adopts the blockchain technology. It should be noted that, when the retailer adopts the blockchain technology, the supplier knows the exact value of ξ, hence K_1^{A*} is a positive-valued function on domain $[-\bar{\xi}, \bar{\xi}]$. Finally, $\left(f^b, F^b\right)$ is a Bayesian posterior distribution of (f, F) on $[-\bar{\xi}, \bar{\xi}]$ that represents the supplier's belief of ξ if the retailer does not adopt the blockchain technology. The supplier will not form any uncertain belief if the retailer adopts the blockchain technology, since the exact value of ξ is known by the supplier.

Then when the retailer is willing to adopt the blockchain technology, the expected profit of the supplier and the retailer are:

$$\Pi_{s1}^A = (w-c)\, E_\epsilon \left(\min\left\{K_1^{A*}, u+\xi+\epsilon\right\}\right) - c_k K_1^{A*},$$
$$\Pi_{r1}^A = (r-w) E_\epsilon \left(\min\left\{K_1^{A*}, u+\xi+\epsilon\right\}\right) - M.$$

Similarly, when the retailer is unwilling to adopt the blockchain technology, we assume the supplier's belief about ξ's PDF $f(.)$ and CDF $F(.)$ will be updated to $f^b(.)$ and $F^b(.)$, respectively, note that $f^b(x) = 0$, if $x \notin [-\bar{\xi}, \bar{\xi}]$. Then the expected profit of the supplier and the retailer can be written as:

$$\begin{aligned} \Pi_{s0}^A &= (w-c) \int_{-\infty}^{\infty} E_\epsilon \left(\min\left\{K_0^{A*}, u+\xi+\epsilon\right\}\right) f^b(\xi) \mathrm{d}\xi - c_k K_0^{A*}, \\ \Pi_{r0}^A &= (r-w) \int_{-\infty}^{\infty} E_\epsilon \left(\min\left\{K_0^{A*}, u+\xi+\epsilon\right\}\right) f^b(\xi) \mathrm{d}\xi. \end{aligned} \tag{3}$$

To begin with, we first provide a lemma to show the retailer's decision z^* in PBE is always a threshold strategy.

Lemma 4.1. *If $\left(z^*, K_0^{A*}, K_1^{A*}(\xi); \left(f^b, F^b\right)\right)$ is a PBE, then there exists a $\xi^A \in [-\bar{\xi}, \bar{\xi}]$ such that $z^*(x) = 1$ if and only if $x \geq \xi^A$.*

Lemma 4.1 indicates structure of PBE and the optimality of the retailer's threshold strategy. The retailer adopts the blockchain technology if and only if the private demand information is larger ($x \geq \xi^A$). Since a larger private demand information of the retailer means a higher profitability of the retailer, and the retailer is more likely to signal the high demand information and bear the cost. The belief of the supplier in the PBE must be the restriction of ξ on the domain $[-\bar{\xi}, \xi^A]$ if the retailer is willing not to adopting blockchain technology. Hence, we only need to consider the threshold strategy of the retailer based on the cost of adopting blockchain technology. Before providing the characterizations of all the PBEs, we first provide some preliminary results.

Lemma 4.2. *Letting x be the restriction of ξ on $[-\bar{\xi}, \xi_y]$ for $-\bar{\xi} < \xi_y \leq \bar{\xi}$, i.e., then the PDF and CDF of x are*

$$f_{\xi_y}(x) = 1_{\{-\bar{\xi} \leq x \leq \xi_y\}} \cdot \frac{f(x)}{F(\xi_y)}, \quad F_{\xi_y}(x) = \frac{F(\min\{x, \xi_y\})}{F(\xi_y)},$$

in which $1_{\{\cdot\}}$ is the indicator function. Assume the PDF and CDF of $x+\epsilon$ to be t_{ξ_y} and T_{ξ_y} respectively. Define the following function for all $\xi_y \in (-\bar{\xi}, \bar{\xi}]$:$\Omega(\xi_y) =$

$$E_\epsilon\left(\min\left\{G^{-1}\left(\frac{w-c-c_k}{w-c}\right), \epsilon\right\}\right) - E_\epsilon\left(\min\left\{(T^b_{\xi_y})^{-1}\left(\frac{w-c-c_k}{w-c}\right) - \xi_y, \epsilon\right\}\right),$$

then $\Omega(\xi_y)$ is a bounded positive continuous function on $(-\bar{\xi}, \bar{\xi}]$, and $\lim_{\xi_y \to -\bar{\xi}} \Omega(\xi_y) = 0$. Thus, we can define $\Omega(-\bar{\xi}) = 0$, such that Ω is well-defined on $[-\bar{\xi}, \bar{\xi}]$.

In Lemma 4.2, f_{ξ_y} and F_{ξ_y} represent the supplier's belief when the retailer does not adopt blockchain technology. And $(r-w)\Omega(\xi_y)$ represents the profit gap of the retailer between adopting blockchain technology or not when her private demand information is ξ_y (see the proof of Theorem 4.3). In summary, for a given cost of adopting blockchain technology, we find the retailer's profit is equal regardless of whether blockchain technology is adopted if $(r-w)\Omega(\xi_y) - M = 0$. Then, we can now characterize all possible PBEs in the following theorem.

Theorem 4.3. *If $M > (r-w)\max_{\xi \in [-\bar{\xi}, \bar{\xi}]} \Omega(\xi)$, then*

$$\left(z^*(\xi), K_0^{A*}, K_1^{A*}(\xi); \left(f^b, F^b\right)\right) = \left(0, K^{ds}, u + \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f, F)\right)$$

is the only PBE. That is, the retailer never adopts the blockchain technology (i.e., $z^*(\xi) \equiv 0$), the supplier's belief about the demand forecast has not been updated and then the supply chain expected profit is identical to the decentralized system.

If $0 < M \leq (r-w)\max_{\xi \in [-\bar{\xi}, \bar{\xi}]} \Omega(\xi)$, letting ξ^A be a solution of the equation $M = (r-w)\Omega(\xi^A)$. Then

$$\left(z^*(\xi), K_0^{A*}, K_1^{A*}(\xi); \left(f^b, F^b\right)\right) =$$
$$\left(1_{\{\xi^A \leq \xi \leq \bar{\xi}\}}, u + (T^b_{\xi^A})^{-1}\left(\frac{w-c-c_k}{w-c}\right), u + \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f_{\xi^A}, F_{\xi^A})\right)$$

is a PBE. That is, the adopting decision of the retailer is a non-trivial threshold strategy anchoring on ξ^A. The total expected profit of the supplier, the retailer and the supply chain can be written as:

$$\begin{aligned}
\Pi_s^A &= (w-c)\, E_{\xi,\epsilon}\left(\min\left\{1_{\{\xi \leq \xi^A\}} K_0^* + 1_{\{\xi \geq \xi^A\}} K_1^{A*}(\xi), u + \xi + \epsilon\right\}\right) \\
&\quad - c_k E_\xi\left(1_{\{\xi \leq \xi^A\}} K_0^* + 1_{\{\xi \geq \xi^A\}} K_1^{A*}(\xi)\right), \\
\Pi_r^A &= (r-w)\, E_\epsilon\left(\min\left\{1_{\{\xi \leq \xi^A\}} K_0^* + 1_{\{\xi \geq \xi^A\}} K_1^{A*}(\xi), u + \xi + \epsilon\right\}\right) - E_\xi(1_{\{\xi \geq \xi^A\}} M). \\
\Pi^A &= (r-c)\, E_{\xi,\epsilon}\left(\min\left\{1_{\{\xi \leq \xi^A\}} K_0^* + 1_{\{\xi \geq \xi^A\}} K_1^{A*}(\xi), u + \xi + \epsilon\right\}\right) \\
&\quad - c_k E_\xi\left(1_{\{\xi \leq \xi^A\}} K_0^* + 1_{\{\xi \geq \xi^A\}} K_1^{A*}(\xi)\right) \\
&\qquad - E_\xi(1_{\{\xi \geq \xi^A\}} M).
\end{aligned}$$

If $M = 0$, the retailer always adopts the blockchain technology can form a PBE, i.e., $\left(z^*(\xi), K_0^{A*}, K_1^{A*}(\xi); \left(f^b, F^b\right)\right) =$

$$\left(1, u - \bar{\xi} + G^{-1}\left(\frac{w - c - c_k}{w - c}\right), u + \xi + G^{-1}\left(\frac{w - c - c_k}{w - c}\right); 1_{\{-\bar{\xi}\}}\right),$$

in which the belief of the supplier is a constant $-\bar{\xi}$ (i.e., $\left(f^b, F^b\right) = 1_{\{-\bar{\xi}\}}$) if the retailer does not adopt the blockchain technology.

Theorem 4.3 shows that when the cost of adopting blockchain technology is large, the retailer will not consider to adopt blockchain technology, which is reasonable. When the cost M is in an intermediate range, the retailer will adopt blockchain technology if and only if she predicts a high demand. When the cost M is negligible, the retailer will always adopt blockchain technology, which means the retailer is willing to share her private demand information regardless of that her private demand information is high or low. This result shows that, if a costless and reliable information sharing technology exists, the advantage of more component capacity from shared information is always larger than the loss of losing the information advantage. This is a different conclusion from the existing article, because many studies have shown that the retailer is usually unwilling to lose her information advantages, or need to meet some certain conditions before she chooses to share strategically [22, 17, 21]. The reason is that the supplier will update his belief in different ways. In our scenario, as long as the retailer's private demand information is greater than a certain threshold, then the blockchain technology will be adopted. Otherwise, the supplier will think that the retailer's private demand information is lower than the threshold and the retailer will lose more profit. In summary, the retailer's willingness of adopting blockchain technology is higher if the cost M is lower. As the blockchain technology keeps developing, the cost M may reduce and become negligible. Hence, our model predicts that, in the near future, most supply chains with private demand forecast information may build blockchain technology if the cost reduces dramatically. Further, this result also shows that the supplier may have incentives to bear part of the retailer's cost of adopting blockchain technology, such that a more accurate demand forecast can be shared. In the following subsection, we consider two types of subsidy provided by the supplier.

4.2. **Signaling with direct subsidy.** According to the above analysis, the retailer is never willing to adopt the blockchain technology if the cost M is too high. Hence, the overall efficiency of the supply chain system deteriorates due to the incomplete transparency of information. The reason may be that the retailer needs to bear all the cost M, she is less willing to adopt the blockchain technology. In addition, information transparency may also bring benefits to the supplier, thus he may have an incentive to bear part of the cost M. Hence, in this subsection, we consider that the supplier provides a direct subsidy to the retailer when she is willing to adopt the blockchain technology.

When the supplier has not yet decided on the component capacity, he selects a direct subsidy H to maximize his expected profit. The sequence of events is: (1) The supplier declares the direct subsidy H. (2) The retailer decides whether to adopt the blockchain technology according to the value of her private demand information ξ. (3) The supplier may update the demand forecast information of the retailer and secure the component capacity based on the behavior of the retailer.

(4) The random demand is realized, then the supplier tries to satisfy the retailer's order under the component capacity constraint.

When the retailer is willing to adopt the blockchain technology, the expected profit of the supplier and the retailer are:

$$\Pi_{s1}^{B} = (w-c)\, E_{\epsilon}\left(\min\left\{K_1^{B*}, u+\xi+\epsilon\right\}\right) - c_k K_1^{B*} - H,$$
$$\Pi_{r1}^{B} = (r-w) E_{\epsilon}\left(\min\left\{K_1^{B*}, u+\xi+\epsilon\right\}\right) - M + H.$$

Similarly, when the retailer is unwilling to adopt the blockchain technology, the expected profit of the supplier and the retailer can be written as Eq. (3).

For a given subsidy H determined by the supplier, the sub-game of the supplier and the retailer is extremely similar to Subsection 4.1. Therefore, for the retailer's adopting decision, we only describe them as a remark to explain and analyze. The following remark characterizes the PBE for a given fixed subsidy H provided by the supplier.

Remark 1. For a given subsidy H provided by the supplier, the PBE of the following stages are characterized as follows. If $M-H > (r-w)\max_{\xi\in[-\bar{\xi},\bar{\xi}]}\Omega(\xi)$, then

$$\left(z^*(\xi), K_0^{B*}, K_1^{B*}(\xi); \left(f^b, F^b\right)\right) = \left(0, K^{ds}, u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f, F)\right)$$

is the only PBE. That is, the retailer never adopts the blockchain technology ($z^*(\xi)\equiv 0$), then the supplier does not update the distribution of the demand forecast (i.e., $\left(f^b, F^b\right) = (f, F)$), and the supply chain expected profit is identical to the decentralized system.

If $0 < M-H \le (r-w)\max_{\xi\in[-\bar{\xi},\bar{\xi}]}\Omega(\xi)$, letting ξ^B be a solution of the equation $M-H=(r-w)\Omega(\xi^B)$. Then

$$\left(z^*(\xi), K_0^{B*}, K_1^{B*}(\xi); \left(f^b, F^b\right)\right) =$$
$$\left(1_{\{\xi^B\le\xi\le\bar{\xi}\}}, u+(T^b_{\xi^B})^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f_{\xi^B}, F_{\xi^B})\right)$$

is a PBE. That is, the adopting decision of the retailer is a non-trivial threshold strategy anchoring on ξ^B. The total expected profit of the supplier, the retailer and the supply chain can be written as:

$$\begin{aligned}
\Pi_s^B &= (w-c)\, E_{\xi,\epsilon}\left(\min\left\{1_{\{\xi\le\xi^B\}}K_0^* + 1_{\{\xi\ge\xi^B\}}K_1^{B*}(\xi), u+\xi+\epsilon\right\}\right)\\
&\quad - c_k E_{\xi}\left(1_{\{\xi\le\xi^B\}}K_0^* + 1_{\{\xi\ge\xi^B\}}K_1^{B*}(\xi)\right) \quad - E_{\xi}(1_{\{\xi\ge\xi^B\}}H),\\
\Pi_r^B &= (r-w)\, E_{\epsilon}\left(\min\left\{1_{\{\xi\le\xi^B\}}K_0^* + 1_{\{\xi\ge\xi^B\}}K_1^{B*}(\xi), u+\xi+\epsilon\right\}\right)\\
&\quad - E_{\xi}(1_{\{\xi\ge\xi^B\}}(M-H)),\\
\Pi^B &= (r-c)\left(E_{\xi,\epsilon}\left(\min\left\{1_{\{\xi\le\xi^B\}}K_0^* + 1_{\{\xi\ge\xi^B\}}K_1^{B*}(\xi), u+\xi+\epsilon\right\}\right)\right)\\
&\quad - c_k E_{\xi}\left(1_{\{\xi\le\xi^B\}}K_0^* + 1_{\{\xi\ge\xi^B\}}K_1^{B*}(\xi)\right) \quad - E_{\xi}(1_{\{\xi\ge\xi^B\}}M).
\end{aligned}$$

If $M-H=0$, then the retailer always adopts the blockchain technology can form a PBE, i.e., $\left(z^*(\xi), K_0^{B*}, K_1^{B*}(\xi); \left(f^b, F^b\right)\right) =$

$$\left(1, u-\bar{\xi}+G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); 1_{\{-\bar{\xi}\}}\right),$$

in which the belief of the supplier is a constant $-\bar{\xi}$ (i.e., $\left(f^b, F^b\right) = 1_{\{-\bar{\xi}\}}$) if the retailer does not adopt the blockchain technology.

For a given direct subsidy H by the supplier, the above Remark implies that there is also a threshold strategy of the retailer. The retailer adopts the blockchain technology if and only if $\xi \geq \xi^B$, then as a consequence, the belief of the supplier in the PBE must be the restriction of ξ on the domain $[-\bar{\xi}, \xi^B]$. Similarly, the retailer is also reluctant to adopt the blockchain technology when the cost M is too high and then supplier's subsidy is inadequate. We find if the supplier is willing to bear all the cost, it is equivalent to adopting blockchain technology without any cost for the retailer, and then the retailer will definitely be willing to adopt the blockchain technology and the reason is similar to the previous description in Subsection 4.1. However, is the best option for the supplier to provide full subsidies? Next, the supplier needs to address the following optimization problem to maximize his expected profit and find the optimal subsidy H under the equilibrium condition:

$$\begin{aligned} max_H\, (w-c)\, E_{\xi,\epsilon} & \left(\min\left\{1_{\{\xi \leq \xi^B\}} K_0^* + 1_{\{\xi \geq \xi^B\}} K_1^{B*}(\xi), u+\xi+\epsilon\right\}\right) \\ & - c_k E_\xi \left(1_{\{\xi \leq \xi^B\}} K_0^* + 1_{\{\xi \geq \xi^B\}} K_1^{B*}(\xi)\right) - E_\xi(1_{\{\xi \geq \xi^B\}} H). \\ st.\ (r-w)\, \Omega(\xi^B) - M + H = 0,\ & \xi^B \in [-\bar{\xi}, \bar{\xi}]. \end{aligned}$$

Because the supplier's optimization problem is exceedingly complicated and cannot give the optimal analytical equilibrium H, we employ the numerical method to analyze the supplier's optimal equilibrium in Section 5.

4.3. **Signaling with wholesale discount.** When the supplier is willing to bear part of the cost M, in addition to the direct subsidy, the wholesale discount may also play a similar role in subsidizing the retailer. Hence, in this subsection, we consider that the supplier provides a wholesale discount to the retailer when she is willing to adopt the blockchain technology. When the supplier has not yet decided on the component capacity, he selects a wholesale discount δ to maximize his expected profit, where $\delta w > c + c_k$ (i.e., $\delta \in ((c+c_k)/w, 1])$ otherwise the supplier is unprofitable. The sequence of events is: (1) The supplier declares the wholesale discount δ. (2) The retailer decides whether to adopt the blockchain technology according to the value of her private demand information ξ. (3) The supplier may update the information of the retailer's demand forecast information and secure the component capacity based on the retailer's behavior. (4) The random demand is realized, then the supplier tries to meet the retailer's order under the component capacity constraint.

When the retailer is willing to adopt the blockchain technology, the expected profit of the supplier and the retailer are:

$$\begin{aligned} \Pi_{s1}^C &= (\delta w - c)\, E_\epsilon \left(\min\left\{K_1^{C*}, u+\xi+\epsilon\right\}\right) - c_k K_1^{C*}, \\ \Pi_{r1}^C &= (r - \delta w)\, E_\epsilon \left(\min\left\{K_1^{C*}, u+\xi+\epsilon\right\}\right) - M. \end{aligned}$$

Similarly, when the retailer is unwilling to adopt the blockchain technology, the expected profit of the supplier and the retailer can be written as Eq. (3).

To begin with, we first provide a lemma to show that the threshold strategy is optimal for the retailer under giving a wholesale discount by the supplier. Then, the PBE of the following stages are characterized as follows.

Lemma 4.4. *For a given wholesale discount δ provided by the supplier, if $\left(z^*, K_0^{C*}, K_1^{C*}(\xi); \left(f^b, F^b\right)\right)$ is a PBE, then there exists a $\xi^C \in [-\bar{\xi}, \bar{\xi}]$ such that $z^*(x) = 1$ if and only if $x \geq \xi^C$.*

Lemma 4.4 indicates that there is also a threshold strategy of the retailer for a given wholesale discount δ. Then we only need to consider the threshold, i.e., before knowing the private demand information, the retailer chooses a corresponding threshold ξ^C based on the cost M and the wholesale discount δ provided by the supplier. The retailer adopts the blockchain technology if and only if $\xi \geq \xi^C$. As a consequence, the belief of the supplier in the PBE must be the restriction of ξ on the domain $[-\bar{\xi}, \xi^C]$. Before providing the characterizations of all the PBEs, we first define a function $\Psi(\xi_y, \delta)$, which will be used to characterize all the PBEs.

$$\begin{aligned}\Psi(\xi_y, \delta) = (r - \delta w)\, E_\epsilon \left(\min \left\{ u + \xi_y + G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right), u + \xi_y + \epsilon \right\} \right) \\ - (r - w)\, E_\epsilon \left(\min \left\{ u + (T^b_{\xi_y})^{-1}\left(\frac{w - c - c_k}{w - c}\right), u + \xi_y + \epsilon \right\} \right).\end{aligned} \tag{4}$$

Similarly, $\Psi(\xi_y, \delta) = M$ means the retailer has the same profit regardless of whether she is willing to adopt blockchain technology, then the equilibrium about ξ_y is the threshold. Next, we can characterize all possible PBEs in the following theorem,

Theorem 4.5. *For a given wholesale discount δ provided by the supplier, all PBEs can be characterized as follows:*
If $M \geq \sup_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Psi(\xi, \delta)$, then

$$\left(z^*(\xi), K_0^{C*}, K_1^{C*}(\xi); \left(f^b, F^b\right)\right) = \left(0, K^{ds}, u + \xi + G^{-1}\left(\frac{w - c - c_k}{w - c}\right); (f, F)\right)$$

is the only PBE. That is, the retailer never adopts the blockchain technology (i.e., $z^* \equiv 0$), then the supplier does not update the distribution of the demand forecast (i.e., $\left(f^b, F^b\right) = (f, F)$), and the supply chain expected profit is identical to the decentralized system.

If $\inf_{\xi \in [-\bar{\xi}, \bar{\xi}]} \Psi(\xi, \delta) < M < \sup_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Psi(\xi, \delta)$, letting ξ^C be a solution of the equation $\Psi(\xi^C, \delta) = M$, then

$$\begin{aligned}&\left(z^*(\xi), K_0^{C*}, K_1^{C*}(\xi); \left(f^b, F^b\right)\right) = \\ &\left(1_{\{\xi^C \leq \xi \leq \bar{\xi}\}}, u + (T^b_{\xi^C})^{-1}\left(\frac{w - c - c_k}{w - c}\right), u + \xi + G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right); (f_{\xi^C}, F_{\xi^C})\right)\end{aligned}$$

is a PBE. That is, the adopting decision of the retailer is a non-trivial threshold strategy anchoring on ξ^C. The total expected profit of the supplier, the retailer and the supply chain can be written as:

$$\begin{aligned}\Pi_s^C &= (\delta w - c)\, E_\epsilon \left(\min\left\{1_{\{\xi \geq \xi^C\}} K_1^{C*}(\xi), u + \xi + \epsilon\right\}\right) - c_k E_\xi \left(1_{\{\xi \leq \xi^C\}} K_0^*\right) \\ &\quad + (w - c)\, E_{\xi,\epsilon} \left(\min\left\{1_{\{\xi \leq \xi^C\}} K_0^{C*}, u + \xi + \epsilon\right\}\right) - c_k E_\xi \left(1_{\{\xi \geq \xi^C\}} K_1^{C*}(\xi)\right), \\ \Pi_r^C &= (r - \delta w)\, E_\epsilon \left(\min\left\{1_{\{\xi \geq \xi^C\}} K_1^{C*}(\xi), u + \xi + \epsilon\right\}\right) - E_\xi (1_{\{\xi \geq \xi^C\}} M) \\ &\quad + (r - w)\, E_\epsilon \left(\min\left\{1_{\{\xi \leq \xi^C\}} K_0^{C*}, u + \xi + \epsilon\right\}\right). \\ \Pi^C &= (r - c)\, E_{\xi,\epsilon} \left(\min\left\{1_{\{\xi \leq \xi^C\}} K_0^* + 1_{\{\xi \geq \xi^C\}} K_1^{C*}(\xi), u + \xi + \epsilon\right\}\right) \\ &\quad - c_k E_\xi \left(1_{\{\xi \leq \xi^C\}} K_0^* + 1_{\{\xi \geq \xi^C\}} K_1^{C*}(\xi)\right) - E_\xi (1_{\{\xi \geq \xi^C\}} M).\end{aligned}$$

If $M \leq \inf_{\xi \in [-\bar{\xi}, \bar{\xi}]} \Psi(\xi, \delta)$, the retailer always adopts the blockchain technology can *form a PBE and the supplier does not discount with him, i.e.,*

$$\left(z^*(\xi), K_0^{C*}, K_1^{C*}(\xi); \left(f^b, F^b\right)\right) =$$
$$\left(1, u-\bar{\xi}+G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); 1_{\{-\bar{\xi}\}}\right),$$

in which the belief of the supplier is a constant $-\bar{\xi}$ (i.e., $\left(f^b, F^b\right) = 1_{\{-\bar{\xi}\}}$) if the retailer does not adopt the blockchain technology.

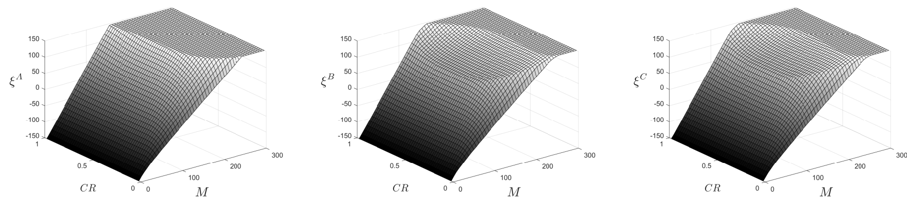
Theorem 4.5 shows that the retailer is unwilling to adopt the blockchain technology and the supplier may be unwilling to offer a wholesale discount when the cost M is too large. When the cost of adopting blockchain technology is small, the retailer is always willing to adopt the blockchain technology although the supplier does not provide a wholesale discount. Only when the cost of adopting blockchain technology is within a certain range, the supplier will provide a wholesale discount. Then all the expected profits consist of two parts, i.e., when the retailer's private demand information is larger (smaller) than the threshold, the supplier will (not) provide a discount to wholesale price and (does not) know the real private demand information. Hence, the supplier needs to address the following optimization problem to maximize his expected profit and find the optimal δ under the equilibrium condition:

$$max_\delta 1_{\{\xi\geq\xi^C\}}\left(\delta w-c\right)E_\epsilon\left(\min\left\{K_1^{C*}(\xi), u+\xi+\epsilon\right\}\right)+$$
$$1_{\{\xi\leq\xi^C\}}\left(w-c\right)E_{\xi,\epsilon}\left(\min\left\{K_0^{C*}, u+\xi+\epsilon\right\}\right)-c_kE_\xi\left(1_{\{\xi\leq\xi^C\}}K_0^*+1_{\{\xi\geq\xi^C\}}K_1^{C*}(\xi)\right)$$
$$st.\ \Psi(\xi^C,\delta)-M=0,\ \xi^C\in[-\bar{\xi},\bar{\xi}].$$

Similarly, the supplier's optimization problem is exceedingly complicated and cannot give the optimal analytical equilibrium δ, thus we employ the numerical method to analyze the supplier's optimal equilibrium in Section 5.

5. **Numerical simulation.** In this section we present a numerical simulation to find the supplier's optimal subsidy and conduct sensitivity analysis under three scenarios. We further explore the impact of risk-adjusted profit margin and degree of forecast information asymmetry on the efficiency of the supplier and the retailer. Supposing that retailer's private demand information ξ and market uncertainty ϵ are uniformly distributed over the support $[-150, 150]$. We find the final equilibrium is only dependent on the critical ratio $\left(w-c-c_k\right)/(w-c)$ and M, then it suffices to consider different values of c_k and M for fixed w and c. In addition, we note $w-c-c_k$ represents the supplier's profit margin per unit sold and the c_k represent the unit cost of component capacity, or the holding cost when there is excess inventory. The supplier hopes the holding cost is smaller and the profit is larger, according to [20], we named $CR = \left(w-c-c_k\right)/(w-c)$, which can represent the supplier's profit level, where a larger CR means the supplier has a higher margin. Hence, we let $r=4, w=3$ and $c=1$, the c_k varies from 0.04 to 0.96 and the M varies from 0 to 300. Then CR ranges from 0.02 to 0.98, which can represent the structure of the supplier from low to high margin.

5.1. **Equilibrium results.** In this subsection, we first graphically illustrate the threshold, supplier's expected profit and retailer's expected profit under different scenarios. To analyze these results more clearly, we roughly divided the cost M of adopting blockchain technology and the supplier's profit level CR into three types: small, intermediate and large.

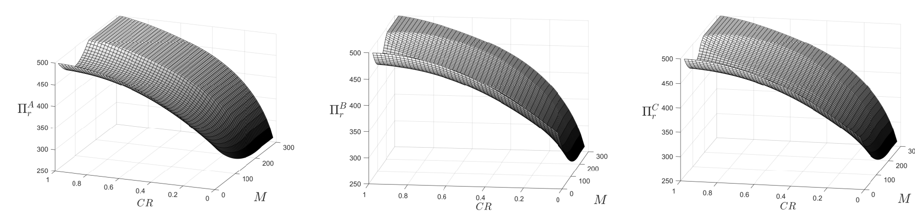


(a) (b) (c)

FIGURE 1. Equilibrium point ξ_i (where $i = 0, 1, 2$) with different values of CR and M.

Equilibrium thresholds ξ^i (where $i = A, B, C$) are illustrated in Fig. 1 with different values of CR and M, respectively. Firstly, we find the threshold is increasing in the cost of adopting blockchain technology M in the beginning. When M increases to a sufficiently high value, ξ^A tends towards the upper bound of the ξ (i.e., $\xi^A = 150$). When M is positive, ξ^A is also increasing in CR. In particular, when the supplier's profit level CR is in a small range, the slope of ξ^A with respect to the supplier's profit level is higher. That is, when the supplier's profit level gets lower, the retailer's threshold strategy is more sensitive to the supplier's profit margin. This suggests that the retailer is more willing to adopting blockchain technology to share private information when the supplier's profit level is low or the adoption cost is low. Additionally, we find the adoption cost has a greater impact on the retailer than the supplier's profit level CR does. This corresponds to the reality that a larger retailer can afford greater adoption cost and has a higher probability of sharing private information. When the market size is comparable, the retailer with higher profit level has a higher probability of adopting blockchain technology. This could reflect why Walmart, the world's largest retailer, was the first to start adopting blockchain technology in 2016[38], while many other retailers did not. On the one hand, Walmart's market size is higher than other many Supermarkets, then it she can bear a larger cost of adopting blockchain technology. On the other hand, Wal-Mart's suppliers have lower profit level than some other Supermarkets due to Wal-Mart's higher negotiating power. The reason is that[18], as the world's largest retailer, Walmart has huge bargaining power when it comes to its suppliers. Many brands depend on Walmart sales to stay in business, while even larger, established companies can little afford to be removed from Walmart's aisles or webpages.). Secondly, from the (b) and (c) of Fig. 1, the direct subsidy and the wholesale price discount have a similar impact on the retailer's adopting decision. That is, $\xi^B \le \xi^A$ (or $\xi^C \le \xi^A$) when M is lower than a certain value, i.e., the threshold is smaller when the supplier provides a subsidy, especially, when the supplier has a medium margin product. This suggests that subsidies from the supplier can increase the probability of the retailer sharing private information. That is, some other small Supermarket is more willing to adopting to share private information if its supplier can provide a subsidy.

Fig. 2 shows the retailer's expected profit in different situations. We find that all the retailer's expected profits are increasing in CR, while as the cost of adopting blockchain technology increases, the retailer's expected profits decrease at first, then increases and finally become a constant. Which can be explained as follows. From the previous theoretical analysis, the retailer's expected profit is composed of two parts, in information symmetry and semi-asymmetry, that is, the retailer is willing to adopt the blockchain technology (part one) or not (part two). Therefore, when M is in a small range, the retailer is more likely to adopt the blockchain technology, then her expected profit mainly consists of part one. ξ^i (where $i = A, B, C$) is always increasing in M, which means the retailer's probability of adopting blockchain technology will be decreased, hence as M increases, the retailer's expected profit is decreasing in M. However, when M is in an intermediate range, the retailer may be less likely to adopt the blockchain technology, then her expected profit is mainly made up of part two, hence the retailer's expected profit is increasing in M. When M is in a large range, the retailer is unwilling to adopt the blockchain technology, hence the retailer's expected profit is uncorrelated with M.

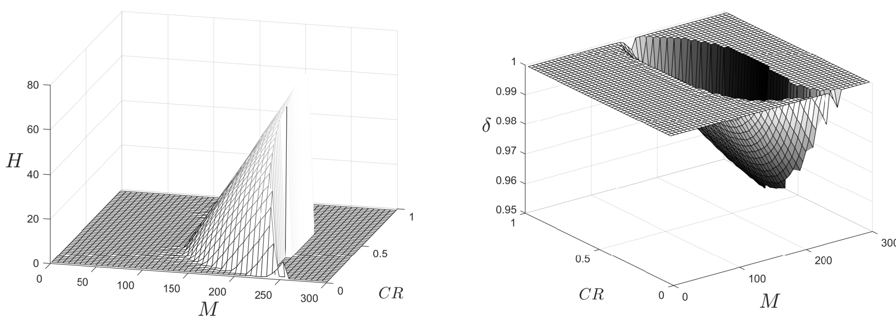


(a) (b) (c)

FIGURE 2. The retailer's expected profit Π_r under different scenarios.

In addition, by comparing the three graphs in Fig. 2, we can find the retailer's profit may be reduced when the supplier provides a subsidy and there is no big difference between direct subsidy and wholesale discount. That is, the supplier provides a subsidy will make the retailer be more likely to share private information, but hurts the retailer's profit due to the lost information advantage, thus the retailer's information advantage will be reduced by the supplier's subsidy strategy. Next, we present the supplier's optimal direct subsidy H and wholesale discount δ in Fig. 3 (Note, we find the supplier's expected profits under different situations are numerically similar and reasonable, i.e., all the supplier's expected profits are increasing in the supplier's profit level CR and decreasing in the cost M, then we omit it.)

Fig. 3 shows that the supplier is not willing to provide a subsidy (i.e., $H = 0$ and $\delta = 1$) when M is in a small range (or in a large range). However, when M takes an intermediate value, H is increasing and δ is decreasing in M. Additionally, when M is in an intermediate range, as the supplier's profit level CR increases, the direct subsidy H increases at first but decrease later, and reaches the maximum when the supplier's profit level takes an intermediate value. There are similar but opposite conclusions for δ. That is, when the supplier is in a low margin, he is reluctant to subsidize the retailer to avoid risks. When the supplier is in high margin, he is less willing to subsidize because he is not afraid of over component capacity due to a the less holding cost. This suggests that the supplier should subsidize the retailer to obtain more private information, especially when he is around a relatively moderate adoption cost or profit level. That is, the supplier will subsidize the retailer when the adoption cost reduced to a certain level due to the development of blockchain technology. However, when the blockchain technology becomes mature and then the adoption cost is costless, the supplier will stop providing the subsidy.



(a) (b)

FIGURE 3. Direct subsidy H and wholesale discount δ.

Next, the active regions between the direct subsidy and wholesale discount are compared below.

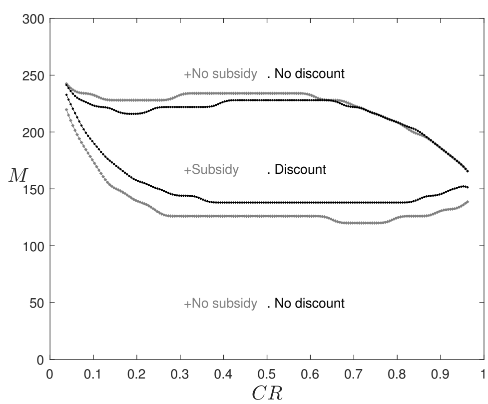


FIGURE 4. Sketch of the active region for the direct subsidy and wholesale discount.

Fig. 4 shows active region for the direct subsidy and wholesale discount, we denote them by M_S and M_D, respectively, where M_S refers to the "Subsidy" in Subsection 4.2 and M_D refer to the "Discount" in Subsection 4.3. We find $M_D \subset M_S$, which means that the direct subsidy can tolerate larger cost than the wholesale discount, thus the probability that the retailer adopts blockchain technology is larger when the supplier provides a direct subsidy. An interesting result is that the supplier is willing to provide subsidy only when M has an intermediate value. It's also a reasonable result when M is in a large range. But when M is in a small range, if the supplier provides a subsidy, it may also lower the threshold and increase the probability that the retailer adopts the blockchain technology. We find ξ^A is small (or ¡0) from above Fig. 1 for any CR, M. As an example, we assume that the supplier needs to pay for $H(\xi_{0a})$ to change the threshold from ξ_{0b} to ξ_{0a}, where $\xi_{0a} \leq \xi_{0b} \leq 0$, and $H(\xi_{0a}) \leq M$. When the private demand information $\xi \geq \xi_{0b}$, the supplier does not need to pay an extra fee $H(\xi_{0a})$. But now, due to the threshold is changed to ξ_{0a} and the difference $\xi_{0b} - \xi_{0a}$ may be smaller, the extra expected benefit brought by information sharing may not make up for the information cost $H(\xi_{0a})$, hence the supplier chooses not to subsidize the retailer when M is in a small range.

5.2. **Comparing the three scenarios.** In this subsection, we discuss the supplier's and retailer's preferences of the three scenarios. To begin with, we graphically illustrate the retailer's threshold strategy under different scenarios:

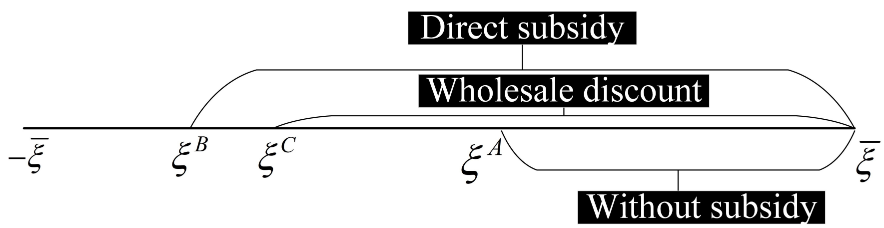
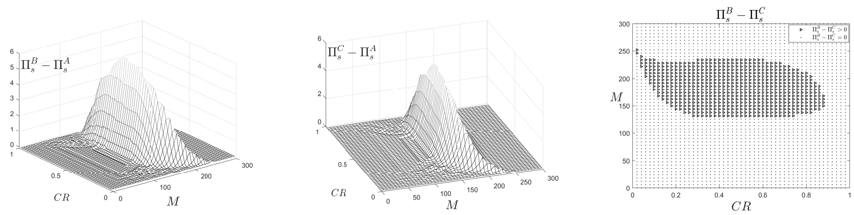


FIGURE 5. Rough sketch structure of different threshold when M is in an intermediate range.

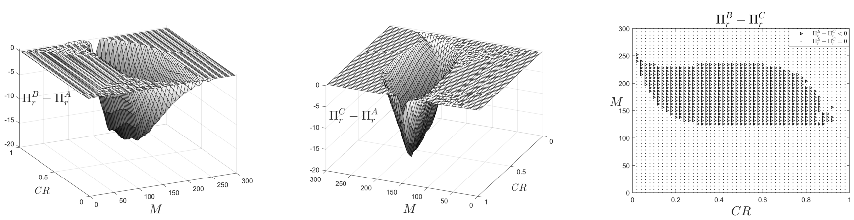
To analyze this signaling game problem and threshold strategy more clearly, when M is in an intermediate range, we graphically illustrate the threshold sketch structure in Fig. 5. The "Without subsidy", "Direct subsidy" and "Wholesale discount" show the different ranges $[\xi^i, \bar{\xi}]$ (where $i = A, B, C$) that the retailer is willing to adopt the blockchain technology based on her private demand information ξ, respectively. We find that $\xi^B \leq \xi^C \leq \xi^A$, which means providing a subsidy can motivate the retailer to share the private demand by adopting blockchain technology, especially the direct subsidy. And the retailer is more willing to share private information when the supplier offers a direct subsidy. Next, we explore the preferences of the supplier and the retailer under the two subsidy strategies.

Fig. 6 indicates the supplier's expected profit differences under the three scenarios. From the (a) and (b) of Fig. 6, when M is in an intermediate range, the differences of the supplier's expected profits ($\Pi_s^B - \Pi_s^A$ and $\Pi_s^C - \Pi_s^A$) are nonnegative. Hence, the subsidy provided by the supplier will increase his own profit. The reason is that the supplier does not need to directly bear the cost of adopting blockchain technology, thus the subsidy he is willing to pay may be much smaller than the cost M. Hence, providing a subsidy is always profitable for the supplier. Additionally, from Fig. 6(c), we find $\Pi_s^B - \Pi_s^C \geq 0$ when M is in an intermediate range, i.e., the direct subsidy performs better than wholesale discount for the supplier, thus he prefers direct subsidy. That is, for the two subsidy strategies, the supplier should provide a direct subsidy rather than wholesale discount.



(a) (b) (c)

FIGURE 6. Π_s difference between three scenarios with different values of CR and M.



(a) (b) (c)

FIGURE 7. Π_r difference between three scenarios with different values of CR and M.

Similarly, Fig. 7 is a comparison between the retailer's expected profit differences. From the (a) and (b) of Fig. 7, when M is in an intermediate range, the differences ($\Pi_r^B - \Pi_r^A$ and $\Pi_r^C - \Pi_r^A$) are negative, which verify that the retailer will be hurt when the supplier provides a subsidy, then the retailer prefers without any subsidy (i.e., scenario A). The reason may be that when $\xi^A = \bar{\xi}$, the retailer is always unwilling to adopt the blockchain technology, then she is no need to pay the cost M. But the subsidy may cause $\xi^B < \bar{\xi}$ (or $\xi^B < \xi^A$), and the extra profit from the subsidy H may be much smaller than the cost of adopting blockchain technology. From Fig. 7 (c), we find the differences ($\Pi_r^B - \Pi_r^C$) are non-positive, then the retailer prefers to be provided a wholesale discount for subsidy. The main reason is that if the supplier provides a direct subsidy, she receives a fixed subsidy H based on ξ^B. However, if the supplier chooses a wholesale discount, under the same condition, the retailer receives a subsidy that is increasing in $K_1^*(\xi)$, where $K_1^*(\xi) = u + \xi + G^{-1}\left((\delta w - c - c_k)/(\delta w - c)\right)$ and $\xi^C \leq \xi \leq \bar{\xi}$. Hence, we suggest that the supplier can provide a wholesale discount to benefit the retailer and whole supply chain.

In summary, we find that subsidizing the retailer is a wise choice for the supplier, which not only increase his own profit but also increase the probability of the retailer adopting blockchain technology. But as the cost of adopting blockchain technology increases, the retailer's profit decreases and even may be worse than decentralized system. These results are reasonable, then we omit its figure and directly explore the expected profits in the supply chain system.

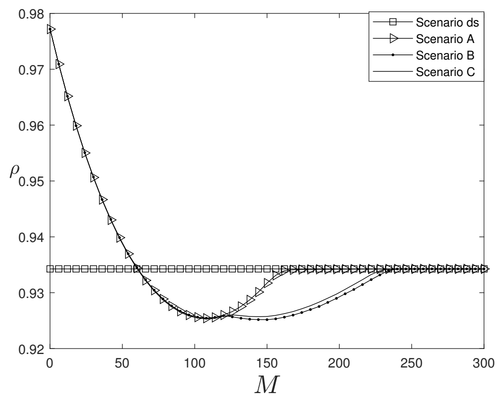


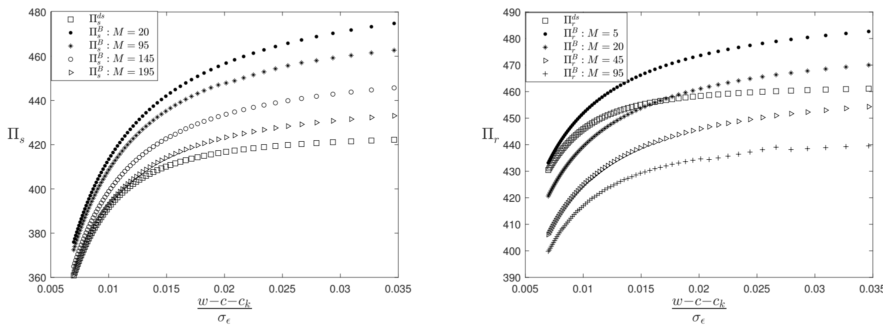
FIGURE 8. The profit ratio $\rho\left(\Pi^{ds}/\Pi^{cs}, \Pi^{A}/\Pi^{cs}, \Pi^{B}/\Pi^{cs}, \Pi^{C}/\Pi^{cs}\right)$.

Fig. 8 shows the ratio ρ of supply chain system to the centralized system of benchmark that we consider this paper. The profit of the system is more than 90% of the centralized system under the three different cost-sharing methods, which means less than 10% loss of system efficiency. Comparing with scenario ds of benchmark, we find only when the cost of adopting blockchain technology is in a relatively small range, the retailer should not adopt blockchain technology. In addition, when the value of M ranges from intermediate to large, we find the system efficiency without any subsidy is better than that with direct subsidy and wholesale discount. While for the supplier, the direct subsidy performs worse than the wholesale discount. The change of supply chain system profit mainly depends on the retailer's profit, that is, it roughly decreases at first but increases later, and finally converges to a constant. Therefore, providing a subsidy can benefit the supplier, and increase the retailer's probability of adopting blockchain technology, but both the retailer and the supply chain system will be hurt.

5.3. **The effects of risk-adjusted profit margin and degree of forecast information asymmetry.** In this subsection, we further explore the impact of dual marginalization, market uncertainty and degree of information asymmetry on the efficiency of the supplier and the retailer. Since the supplier prefers providing direct subsidy to wholesale discount and no subsidy, then we only discuss the effects of risk-adjusted profit margin and degree of forecast information asymmetry on the supply chain system when a direct subsidy is provided.

We know that compared to centralized decision-making, system losses mainly come from two aspects. One is the double marginalization, because both the supplier and the retailer make decisions to maximize their own expected profit. The other one is market uncertainty, i.e., the random variable ϵ that is modeled by a zero-mean distribution $G(.)$ in this article. According to [37], this inefficiency can be measured by risk-adjusted profit margin $(w-c-c_k)/\sigma_\epsilon$. That is the supplier's profit margin per unit sold per unit of market uncertainty, where $(w-c-c_k)$ represents the supplier's profit margin per unit sold or per unit of component capacity built.

Fig. 9 shows the profits of the supplier and the retailer with different risk-adjusted profit margin. We find both the supplier's and the retailer's profits are increasing in the risk-adjusted profit margin. This is reasonable, a larger risk-adjusted profit margin means that the supplier's profit margin per unit sold is larger or the market uncertainty is smaller, then the market become better. Comparing with the decentralized system, we find the supplier's expected profit will always become better, while the retailer's expected profit becomes better only when the cost of adopting blockchain technology is smaller or when the risk-adjusted profit margin is larger.



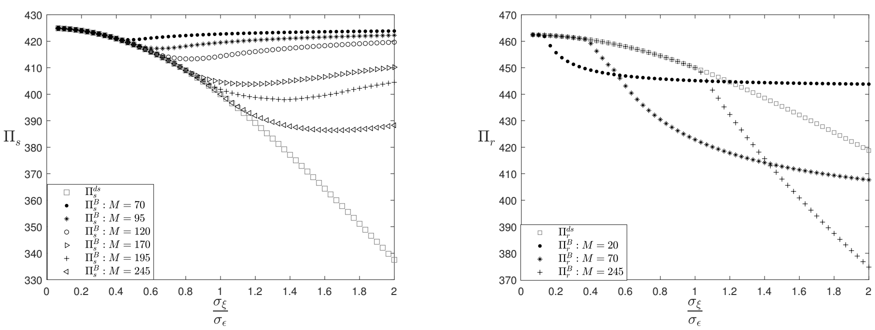
(a) (b)

FIGURE 9. Profits as a function of risk-adjusted profit margin

In addition, the degree of forecast information asymmetry is also important to the expected profit of supply chain members. The supplier may set a small component capacity to reduce the risk of oversupply due to lack of credible forecast information, which may indirectly hurt the retailer's profit. Therefore, the retailer always has an incentive to exaggerate her demand forecast, which leads to mistrust among supply chain members. At the same time, market uncertainty also plays a role, i.e., if the market uncertainty is zero, then the retailer has no incentive to share inaccurate private demand information. Then let $\sigma_\xi/\sigma_\epsilon$ represents the degree of forecast information asymmetry [37], a larger $\sigma_\xi/\sigma_\epsilon$ means that the information asymmetry becomes more significant, where σ_ξ and σ_ϵ are the standard deviations of ξ and ϵ, respectively.

Fig. 10 shows the profits of the supplier and the retailer with different degree of forecast information asymmetry. From Fig. 10 (a), as the degree of forecast information asymmetry increases, we find the supplier's profit first decreases and then increases. We know a smaller (larger) degree of forecast information asymmetry means the private demand information is smaller (larger) than market uncertainty, the impact of information asymmetry on the supplier is negligible that he can ignore it when the cost of adopting blockchain technology M is small. As the impact of information asymmetry reaches a certain level, the supplier will take actions (e.g., subsidies) to obtain the private demand information from the retailer. The motivation of the supplier to obtain the private demand information becomes larger with the impact of information asymmetry increases, which causes her profit increases. We find as the cost of adopting blockchain technology increases, the motivation of the supplier to obtain the private demand information and the supplier's profit decrease. From Fig. 10 (b), we find the retailer's profit decreases with the degree of forecast information asymmetry. Similarly, as the impact of information asymmetry increases, the retailer will begin to adopt blockchain technology. When the cost of adopting blockchain technology is larger (small), the retailer's profits will fall at a higher (lower) rate because the retailer is less (more) likely to adopt blockchain technology. Similarly, compared to the decentralized system, we find the supplier's expected profit will always become better, while the retailer's expected profit becomes better only when the degree of forecast information asymmetry is larger.

Hence, in summary, when the degree of forecast information asymmetry or the risk-adjusted profit margin is larger, the retailer prefers to adopt blockchain technology. Otherwise, she needs to prevent the supplier's demand information from being updated, for example, before observing the private demand information, notifying the supplier that she will not adopt blockchain technology regardless of her private demand information.



(a) (b)

FIGURE 10. Profits as a function of degree of forecast information asymmetry.

6. **Extensions.** To demonstrate the robustness of equilibriums, we next extend it from two perspectives in scenario A, namely, (1) Considering the retailer's risk aversion; (2) Considering multiple suppliers in the market.

6.1. **Risk averse retailer.** In fact, decision makers have risky attitudes in many cases[49, 3, 33]. To bring our model closer to reality, we consider the retailer to be risk averse and the utility function is ϕ, where $\phi' > 0, \phi'' < 0$. Whereas the supplier is assumed to be risk neutral. Such an assumption is common in literature [3, 33]. Since the supplier is risk neutral, the optimal decisions of the component capacity are the same as Section 4.1, $K_1^{D*} = K_1^{A*}$ and $K_0^{D*} = K_0^{A*}$. Then the retailer's utilities turn into $U_{r1}^D = E_\epsilon\left(\phi(\pi_{r1}^D)\right), U_{r0}^D = E_\epsilon\left(\phi(\pi_{r0}^D)\right)$, where

$$\pi_{r1}^D = \left((r-w)\min\left\{K_1^{D*}, u+\xi+\epsilon\right\} - M\right),$$

$$\pi_{r0}^D = \left((r-w)\min\left\{K_0^{D*}, u+\xi+\epsilon\right\}\right),$$

U_{r1}^D and U_{r0}^D represent the retailer's expected utilities when using or not using the blockchain, respectively. To begin with, we first provide a lemma to show that the threshold strategy is optimal for the retailer.

Remark 2. (1) If $\left(z^*, K_0^{D*}, K_1^{D*}(\xi); \left(f^b, F^b\right)\right)$ is a PBE, then there exists a $\xi^D \in [-\bar{\xi}, \bar{\xi}]$ such that $z^*(x) = 1$ if and only if $x \geq \xi^D$.

(2) Letting $\Theta_0(\xi_y, M) =$

$$E_\epsilon\left(\phi\left((r-w)\min\left\{u+\xi_y+G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi_y+\epsilon\right\}-M\right)\right.$$
$$\left.-\phi\left((r-w)\left(\min\left\{u+(T^b_{\xi_y})^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi_y+\epsilon\right\}\right)\right)\right),$$

then there exists a bounded positive continuous function Φ defined on $(-\bar{\xi}, \bar{\xi}]$, with $\lim_{\xi_y \to -\bar{\xi}} \Phi(\xi_y) = 0$. Thus, we can define $\Phi(\xi_y) = 0$, such that $\Phi(\xi_y)$ is well-defined on $[-\bar{\xi}, \bar{\xi}]$.

Next, we can characterize all possible PBEs in Remark 3, which is similar to Theorem 4.3.

Remark 3. All PBEs can be characterized as follows:
If $M \geq \sup_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Phi(\xi_y)$, then

$$\left(z^*(\xi), K_0^{D*}, K_1^{D*}(\xi); \left(f^b, F^b\right)\right) = \left(0, K^{ds}, u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f, F)\right)$$

is the only PBE.

If $0 < M < \sup_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Phi(\xi_y)$, letting ξ^D satisfies the equation $\Theta_0(\xi^D, M) = 0$, then $\left(z^*(\xi), K_0^{D*}, K_1^{D*}(\xi); \left(f^b, F^b\right)\right) =$

$$\left(1_{\{\xi^D \leq \xi \leq \bar{\xi}\}}, u+(T^b_{\xi^D})^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f_{\xi^D}, F_{\xi^D})\right)$$

is a PBE.

If $M = 0$, the retailer always adopts the blockchain technology can form a PBE, i.e., $\left(z^*(\xi), K_0^{D*}, K_1^{D*}(\xi); \left(f^b, F^b\right)\right) =$

$$\left(1, u-\bar{\xi}+G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); 1_{\{-\bar{\xi}\}}\right),$$

in which the belief of the supplier is a constant $-\bar{\xi}$ (i.e., $\left(f^b, F^b\right) = 1_{\{-\bar{\xi}\}}$) if the retailer does not adopt the blockchain technology.

Remark 3 is similar to Theorem 4.3, i.e., the retailer is only willing to adopt blockchain technology when the cost M is in a smaller range. Therefore, we verified the robustness of the PBE by considering the retailer's risk aversion when there is no subsidy. That is, the retailer's risk aversion only change the threshold of that the retailer is willing to share private information, which is closely dependent on the retailer's utility function of risk averse. Additionally, we find if the cost of adopting blockchain technology is costless, the retailer should share the private information regardless of her utility function. For some small retailers with small market size or financial constraints, it is often risk-averse due to the inability to bear higher losses. However, we suggest that they should adopt blockchain technology to facilitate information sharing to get additional expected profit if the cost of blockchain is low. We can also show that the results are similar to Sections 4.2 and 4.3 when the supplier provides direct subsidy or wholesale discount. The detailed results and proofs are omited to save space.

6.2. **Multiple suppliers.** In this subsection, according to [35], we assume one retailer in the market that sells n different types of products, supplied by n suppliers, respectively. Assuming that the n suppliers are already on the blockchain system. If the retailer adopts blockchain technology, her private information becomes a public knowledge to all suppliers. Assuming that the demand of i-th supplier can be expressed as $D_i = u_i + \lambda_i \xi + \epsilon_i$, where ξ is the retailer's private information with CDF F and PDF f, and λ_i represents the impact of the retailer's private information to i-th product's demand, u_i is a common knowledge that represents the average market demand of product i, and ϵ_i is a zero-mean continuous random variable with PDF $g_i(.)$ and CDF $G_i(.)$ supported on $[-\bar{\epsilon_i}, \bar{\epsilon_i}]$. Then the sequence of events is: (1) The retailer decides whether to adopt the blockchain technology based on the cost M and the value of her private demand information ξ. (2) All the suppliers secure component capacities based on the behavior of the retailer. Similar to Section 4.1, the optimal decisions of i-th supplier are $K_{1i}^{E*} = u_i + \lambda_i \xi + G_i^{-1}\left(\frac{w-c-c_k}{w-c}\right)$ when the retailer adopts blockchain, and $K_{0i}^{E*} = \left(u_i + (T^{bi})^{-1}\left(\frac{w-c-c_k}{w-c}\right)\right)/\lambda_i$ when the retailer does not adopt blockchain technology. Hence, the retailer's profits are, respectively,

$$\Pi_{r1}^E = \sum_{i=1}^{n} (r-w)\, E_{\epsilon_i}\left(\min\left\{K_{1i}^{E*}, u_i + \lambda_i \xi + \epsilon_i\right\}\right) - M$$
$$\Pi_{r0}^E = \sum_{i=1}^{n} (r-w)\, E_{\epsilon_i}\left(\min\left\{K_{0i}^{E*}, u_i + \lambda_i \xi + \epsilon_i\right\}\right)$$

Similarly to Lemmas 4.1 and 4.2, we have the following Remark 4.

Remark 4. (1) If $\left(z^*, K_0^{E*}, K_1^{E*}(\xi); \left(f^b, F^b\right)\right)$ is a PBE, then there exists a $\xi^E \in [-\bar{\xi}, \bar{\xi}]$ such that $z^*(x) = 1$ if and only if $x \geq \xi^E$.

(2) Letting $\Xi(\xi_y) =$

$$(r-w)\left(\sum_{i=1}^{n}\left(E_{\epsilon_i}\left(\min\left\{K_{1i}^{E*}, u_i + \lambda_i\xi + \epsilon_i\right\}\right) - E_{\epsilon_i}\left(\min\left\{K_{0i}^{E*}, u_i + \lambda_i\xi + \epsilon_i\right\}\right)\right)\right),$$

then $\Xi(\xi_y)$ is a bounded positive continuous function on $(-\bar{\xi}, \bar{\xi}]$, and $\lim_{\xi_y \to -\bar{\xi}} \Xi(\xi_y) = 0$. Thus, we can define $\Xi(-\bar{\xi}) = 0$, such that $\Xi(\xi_y)$ is well-defined on $[-\bar{\xi}, \bar{\xi}]$. Additionally, $\Xi(\xi_y)$ is increasing in n.

Next, we can characterize all possible PBEs in Remark 5, which is similar to Theorem 4.3.

Remark 5. All PBEs can be characterized as follows:
If $M \geq \sup_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Xi(\xi)$, then

$$\left(z^*(\xi), K_{0i}^{E*}, K_{1i}^{E*}(\xi); \left(f^b, F^b\right)\right) = \left(0, K^{ds}, u + \lambda_i \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f, F)\right)$$

is the only PBE.

If $0 < M < \sup_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Xi(\xi)$, letting ξ^E be a solution of the equation $\Xi(\xi^E) = M$, then $(z^*(\xi), K_{0i}^{E*}, K_{1i}^{E*}(\xi); \left(f^b, F^b\right)) =$
$\left(1_{\{\xi^E \leq \xi \leq \bar{\xi}\}}, u + (T_{\xi^E}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u + \lambda_i \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f_{\xi^E}, F_{\xi^E})\right)$
is a PBE.

If $M=0$, the retailer always adopts the blockchain technology can form a PBE, i.e., $\left(z^*(\xi), K_{0i}^{E*}, K_{1i}^{E*}(\xi); \left(f^b, F^b\right)\right) =$

$$\left(1, u-\bar{\xi}+G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\lambda_i\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); 1_{\{-\bar{\xi}\}}\right),$$

in which the belief of the supplier is a constant $-\bar{\xi}$ (i.e., $\left(f^b, F^b\right) = 1_{\{-\bar{\xi}\}}$) if the retailer does not adopt the blockchain technology.

Remark 5 is similar to Theorem 4.3, i.e., the retailer is only willing to adopt blockchain technology when the cost M is in an intermediate range when there is no subsidy. Therefore, we verified the robustness of the results when considering multiple suppliers. In addition to these, we also obtain someA new management insights. Since $\Xi(\xi_y)$ is increasing in n, $\sup_{\xi_y\in[-\bar{\xi},\bar{\xi}]}\Xi(\xi)$ is also increasing in n. That is, a retailer with larger number of suppliers is more likely to adopt blockchain technology. Whereas, retailers with fewer suppliers are less likely to adopt blockchain technology. And the result suggests that, in the current stage, the cost of adopting blockchain technology is high. Thus, only those large retailers with various of suppliers should use blockchain technology. However, as the blockchain technology goes mature in the future, the cost will be reduced significantly, and all retailers should use blockchain technology.

Table 1. Number of suppliers

The retailer	Number of suppliers from 'qcc.com'	Number of suppliers from 'tianyan-cha.com'	Average number of suppliers	Whether to use blockchain technology (using 1, not 0)
Wal-Mart	154	134	144	1
YONGHUI	47	47	47	1
Amazon	15	14	14.5	1
China Resources Vanguard Shop	18	12	15	0
Minnings	14	24	19	0
Miniso	12	9	10.5	0
Lianhua Supermarket	7	5	6	0
Watsons	5	6	5.5	0
Metro AG	33	31	32	0
RT-MART	54	54	54	0
Hyper-mart	75	57	66	0
Auchan	45	33	39	0
Wumart	7	6	6.5	0
JIAJIAYUE	43	29	36	0

To connect our conclusions with the real industry, we select 14 retailers and collect the number of their suppliers and blockchain technology adoption information.

The number of their suppliers are obtained from 'tianyancha.com' and 'qcc.com', which provide public information about suppliers' information of retailers in China. And we also checked the official website of these retailers to find out whether the blockchain technology is adopted. According to Table 1, we can see that the first three retailers have adopted blockchain technology. In addition, Carrefour also has adopted blockchain technology, and it has verified 444 suppliers in the IPE database of different industries according to [4]. However, the data collected from 'tianyancha.com' and 'qcc.com' only include those suppliers' information of retailers in China. Hence, recall our conclusion that the probability of adopting blockchain technology is higher for retailers with multiple suppliers. We verify that large retailers like Walmart, YONGHUI, Amazon and Carrefour have adopted blockchain technology. However, to the best of our knowledge, the adoption of blockchain technology may be influenced by many factors. Therefore, although the retailers like Metro AG, Metro AG, Hyper-mart, JIAJIAYUE and Auchan also have more suppliers, they have not adopted blockchain technology. The reason may be that the profit level of their suppliers is high, or the development of blockchain technology is not mature enough and then the investment cost is high.

Conclusions. This article considers a two-echelon supply chain consisting of a supplier and a retailer, where the retailer has more accurate demand forecasts. By assuming that blockchain technology can guarantee the accuracy of information delivery, this paper mainly discusses that under what conditions the retailer is willing to adopt the blockchain technology. Three different scenarios are considered: the retailer bears all the cost, the supplier bears part of the cost by providing a direct subsidy or a wholesale discount. We focus on exploring the conditions for the retailer to adopt blockchain technology and the supplier's subsidy strategy choice under information asymmetry, the obtained results contribute to both research and practice for the supplier and the retailer.

Firstly, we find PBE always exists and the retailer's optimal decision of adopting blockchain technology is a simple threshold strategy, i.e., the retailer will join the blockchain technology if and only if her private information exceeds a threshold. We find that this threshold is closely dependent on the cost of adopting blockchain technology, the supplier's profit level, and the number of suppliers. That is, the probability of the retailer to adopt blockchain technology decrease with the adoption cost and the supplier's profit level, where the adoption cost has a greater impact. On the one hand, the retailer with larger market size can afford a higher adoption cost and thus has a higher probability of adopting blockchain technology. On the other hand, the retailer with larger market size has higher bargaining power, which will lead to a lower profit level for her supplier, which also makes her be more likely to adopt blockchain technology. In addition, the number of the retailer's suppliers has a negative effect on the threshold, i.e., the retailer with the presence of more suppliers has a higher probability of adopting blockchain technology. Thus, our results reflect the reality from these three aspects, the large retailers like Wal-Mart and Carrefour will first adopt blockchain technology.

Secondly, from exploring the supplier's subsidy strategy, we find the supplier is more willing to provide a subsidy when his profit level or the cost of adopting blockchain technology is around an intermediate range. While when the cost of adopting blockchain technology is in a small (large) range, the supplier is not willing to provide subsidy. Noteworthy, providing subsidies are always profitable for the supplier, and he prefers the direct subsidy to the wholesale discount. Additionally, comparing with no subsidy, we find both the direct subsidy and wholesale discount can enhance the retailer's possibility of adopting blockchain technology and benefit the supplier, but both the retailer and the supply chain system will be hurt. Hence, this result also predicts that subsidies do not necessarily benefit the subsidized party in an information asymmetry scenarios. The supplier should always seek to provide some subsidies to the retailer to increase the probability of true sharing of private information.

Finally, from exploring the impact of dual marginalization, market uncertainty and degree of information asymmetry on the efficiency of the supplier and the retailer. We find the degree of forecast information asymmetry increases, the supplier's profit first decreases and then increases, while the retailer's profit always decreases. The retailer is more likely to adopt blockchain technology when the degree of forecast information asymmetry or the risk-adjusted profit margin is larger. Furthermore, we find that the threshold strategy is still optimal for the retailer when considering the retailer's risk aversion or multiple suppliers.

Our paper studies the problem based on some assumptions. The following is a brief summary of the shortcomings in this paper and some suggestions that can be considered in the future. All price variables considered in this paper are exogenous, which can be combined with the demand function in future research. This paper assumes that both the supplier and the retailer are completely rational. However, many researches on behavior in recent years have shown that people can only be partially rational in the actual situation.

Appendix. Proofs.

Appendix A. Proof of Lemma 4.1.

Proof. For a given belief $\left(f^b, F^b\right)$ on $[-\bar{\xi}, \bar{\xi}]$, if the retailer with private demand information ξ does not adopt the blockchain technology, the supplier solves the following problem to find K_0^{A*},

$$\begin{aligned} K_0^{A*} &= argmax_K (w-c) \int_{-\bar{\xi}}^{\bar{\xi}} \left(\int_{-\bar{\epsilon}}^{\bar{\epsilon}} \min\{K_0, u+\xi+\epsilon\} g(\epsilon) \mathrm{d}\epsilon \right) f^b(\xi) \mathrm{d}\xi - c_k K_0 \\ &= u + (T^b)^{-1} \left(\frac{w-c-c_k}{w-c} \right), \end{aligned} \tag{5}$$

where

$$T^b(x) = \int_{-\infty}^{\infty} \int_{-\infty}^{x-\xi} f^b(\xi) g(\epsilon) \mathrm{d}\epsilon \mathrm{d}\xi. \tag{6}$$

And the profit of the retailer with private demand information ξ is

$$(r-w) \int_{-\bar{\epsilon}}^{\bar{\epsilon}} \min\{K_0^{A*}, u+\xi+\epsilon\} g(\epsilon) \mathrm{d}\epsilon.$$

If the retailer with private demand information ξ adopts the blockchain technology, the supplier will solve the following problem to find K_1^{A*},

$$\begin{aligned} K_1^{A*}(\xi) &= argmax_K (w-c) \int_{-\bar{\epsilon}}^{\bar{\epsilon}} \min\{K_1, u+\xi+\epsilon\} g(\epsilon) \mathrm{d}\epsilon - c_k K_1 \\ &= u + \xi + G^{-1} \left(\frac{w-c-c_k}{w-c} \right). \end{aligned} \tag{7}$$

And the profit of the retailer with private demand information ξ is

$$\begin{aligned}&(r-w)\int_{-\bar{\epsilon}}^{\bar{\epsilon}}\min\{K_1^{A*}(\xi),u+\xi+\epsilon\}g(\epsilon)\mathrm{d}\epsilon-M\\=&(r-w)(u+\xi)+(r-w)\int_{-\bar{\epsilon}}^{\bar{\epsilon}}\min\left\{G^{-1}\left(\frac{w-c-c_k}{w-c}\right),\epsilon\right\}g(\epsilon)\mathrm{d}\epsilon-M.\end{aligned}$$

Thus, the retailer adopts the blockchain technology if and only if $DIFF(\xi)=$

$$\begin{aligned}&(r-w)(u+\xi)+(r-w)\int_{-\bar{\epsilon}}^{\bar{\epsilon}}\min\left\{G^{-1}\left(\frac{w-c-c_k}{w-c}\right),\epsilon\right\}g(\epsilon)\mathrm{d}\epsilon-M\\&-(r-w)\int_{-\bar{\epsilon}}^{\bar{\epsilon}}\min\{u+(T^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right),u+\xi+\epsilon\}g(\epsilon)\mathrm{d}\epsilon\geq 0.\end{aligned}\tag{8}$$

Note that, K_0^{A*} is independent of ξ, we have

$$\frac{dDIFF}{d\xi}(\xi)=(r-w)(1-G(K_0^{A*}-u-\xi))\geq 0,$$

i.e., $DIFF$ is an increasing function. Thus, the retailer adopts the blockchain technology if and only if ξ is larger than a certain threshold ξ^A. □

Appendix B. Proof of Lemma 4.2.

Proof. let $q_1=G^{-1}\left(\frac{w-c-c_k}{w-c}\right),q_2(y)=(T_y^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right)$,
then $G(q_1)=T_y^b(q_2(y))=P\left(\xi+\epsilon\leq q_2(y)\,|\xi\leq y\right)\geq P\left(y+\epsilon\leq q_2(y)\right)$
$=P\left(\epsilon\leq q_2(y)-y\right)=G(q_2(y)-y)$. Therefore, we have $q_1\geq q_2(y)-y$ and

$$\Omega(y)=E\left(\min\left\{q_1,\epsilon\right\}\right)-E\left(\min\left\{q_2(y)-y,\epsilon\right\}\right)\geq 0,$$

i.e., $\Omega(y)$ is a positive function.

Let $\{y_i\}$ be any sequence such that $\lim_{i\to\infty}y_i=-\bar{\xi}$. If $q_2(y_i)=(T_{y_i}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right)$ do not converge to $q_1-\bar{\xi}$, then there exists a $\lambda>0$ and a subsequence z_i of y_i such that $|q_2(z_i)-q_1+\bar{\xi}|>\lambda$ for all $i\geq_1$. Hence, either $q_2(z_i)>q_1+\lambda-\bar{\xi}$ for infinite i or $q_2(z_i)<q_1-\lambda-\bar{\xi}$ for infinite i.

If $q_2(z_i)>q_1+\lambda-\bar{\xi}$ for infinite i, there exist CR sufficiently large i such that $q_2(z_i)>q_1+\lambda-\bar{\xi}$ and $|z_i+\bar{\xi}|<\lambda/3$ (since $z_i\to-\bar{\xi}$). Thus, we have

$$\begin{aligned}\frac{w-c-c_k}{w-c}&=T_{z_i}^b(q_2(z_i))=\int_{-\infty}^{\infty}\frac{F(\min\{z_i,q_2(z_i)-s\})}{F(z_i)}g(s)\mathrm{d}s\\&\geq\int_{-\infty}^{\infty}\frac{F(\min\{z_i,q_1+\lambda-\bar{\xi}-s\})}{F(z_i)}g(s)\mathrm{d}s\\&\geq\int_{-\infty}^{q_1+\frac{2}{3}\lambda}\frac{F(\min\{z_i,q_1+\lambda-\bar{\xi}-s\})}{F(z_i)}g(s)\mathrm{d}s\\&=\int_{-\infty}^{q_1+\frac{2}{3}\lambda}g(s)\mathrm{d}s=G\left(q_1+\frac{2}{3}\lambda\right)>G(q_1)=\frac{w-c-c_k}{w-c},\end{aligned}$$

which is a contradiction.

If $q_2(z_i) < q_1 - \lambda - \bar{\xi}$ for infinite i, then

$$\begin{aligned}\frac{w-c-c_k}{w-c} &= T^b_{z_i}(q_2(z_i)) = \int_{-\infty}^{\infty} \frac{F(\min\{y_i, q_2(z_i)-s\})}{F(z_i)} g(s)\mathrm{d}s \\ &\leq \int_{-\infty}^{\infty} \frac{F(\min\{y_i, q_1-\lambda-\bar{\xi}-s\})}{F(z_i)} g(s)\mathrm{d}s \\ &= \int_{-\infty}^{q_1-\lambda-\bar{\xi}-z_i} g(s)\mathrm{d}s + \int_{q_1-\lambda-\bar{\xi}-z_i}^{\infty} \frac{F(q_1-\lambda-\bar{\xi}-s)}{F(z_i)} g(s)\mathrm{d}s \\ (i\to\infty) &\to G(q_1-\lambda) + \lim_{z_i\to-\bar{\xi}} \frac{\int_{q_1-\lambda-\bar{\xi}-z_i}^{\infty} F(q_1-\lambda-\bar{\xi}-s)g(s)\mathrm{d}s}{F(z_i)} \\ &\overset{L}{=} G(q_1-\lambda) + \lim_{z_i\to-\bar{\xi}} \frac{F(z_i)g(q_1-\lambda-\bar{\xi}-z_i)}{f(z_i)} \\ &= G(q_1-\lambda) < G(q_1) = \frac{w-c-c_k}{w-c},\end{aligned}$$

which is also a contradiction.

Therefore, $q_2(y_i) = (T^b_{y_i})^{-1}\left(\frac{w-c-c_k}{w-c}\right)$ converge to $q_1 - \bar{\xi}$, i.e.,

$$\lim_{y\to-\bar{\xi}} q_2(y) = q_1 - \bar{\xi}. \tag{9}$$

As a result, we have

$$\lim_{y\to-\bar{\xi}} \Omega(y) = E(\min\{q_1, \epsilon\}) - \lim_{y\to-\bar{\xi}} E(\min\{q_2(y)-y, \epsilon\}) = 0. \tag{10}$$

Finally, we show that $\Omega(y)$ is continuous on $(-\bar{\xi}, \bar{\xi}]$. Since $\Omega(y) = E(\min\{q_1, \epsilon\}) - E(\min\{q_2(y)-y, \epsilon\})$, it suffices to show that $q_2(y)$ is continuous on $(-\bar{\xi}, \bar{\xi}]$. For any $e \in (-\bar{\xi}, \bar{\xi}]$ and a sequence y_i that converges to e. If $q_2(y_i)$ do not converge to $q_2(e)$, there exists a $\lambda > 0$ and a subsequence z_i, such that $|q_2(z_i) - q_2(e)| > \lambda$. Since $T^b_{z_i}(q_2(z_i)) = \frac{w-c-c_k}{w-c} \in (0,1)$, $q_2(z_i)$ are all in the range $[-\bar{\xi}-\bar{\epsilon}, \bar{\xi}+\bar{\epsilon}]$. Thus, $q_2(z_i)$ have a convergence subsequence $q_2(x_i)$, and assume $q_2(x_i) \to Q \neq q_2(e)$. Then we have

$$\begin{aligned}T^b_e(q_2(e)) &= \frac{w-c-c_k}{w-c} = T^b_{x_i}(q_2(x_i)) \\ &= \int_{-\infty}^{\infty} \frac{F(\min\{x_i, q_2(x_i)-s\})}{F(x_i)} g(s)\mathrm{d}s \\ &= \lim_{i\to\infty} \int_{-\infty}^{\infty} \frac{F(\min\{x_i, q_2(x_i)-s\})}{F(x_i)} g(s)\mathrm{d}s \\ &= \int_{-\infty}^{\infty} \frac{F(\min\{e, Q-s\})}{F(e)} g(s)\mathrm{d}s = T^b_e(Q) \in (0,1).\end{aligned} \tag{11}$$

Note that T^b_e is the CDF of $\xi_e + \epsilon$, which is strictly increasing in the support $[-\bar{\xi}-\bar{\epsilon}, e+\bar{\epsilon}]$. Thus, it must hold $Q = q_2(e)$, which is a contradiction. Thus, $\Omega(y)$ is continuous on $(-\bar{\xi}, \bar{\xi}]$, and the Lemma 4.2 is proved. □

Appendix C. Proof of Theorem 4.3.

Proof. According to subsection 4.1, the decision-making process of this problem can be divided into two stages. The first stage is that the retailer decides whether to adopt the blockchain technology, and the second stage is that the supplier decides the component capacity based on the two situations of the retailer adopting or not adopting. As shown in Fig. 11 below.

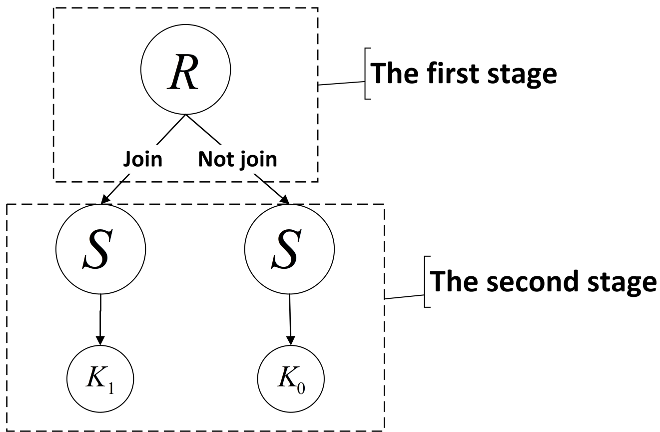


FIGURE 11. The decision-making process.

Assume $\left(z^*(\xi), K_0^{A*}, K_1^{A*}(\xi); \left(f^b, F^b\right)\right)$ to be a PBE, then according to Lemma 4.1, we know that the retailer will always adopt threshold strategy, hence the belief of the supplier (i.e., $\left(f^b, F^b\right)$) is a restriction of (f, F) on $[-\bar{\xi}, \xi_y]$ ($f(x) = 0$, if $x \notin [-\bar{\xi}, \xi_y]$) for some $\xi_y \in [-\bar{\xi}, \bar{\xi}]$. We first characterize all non-trivial PBEs such that the retailer's threshold is not $-\bar{\xi}$ or $\bar{\xi}$, i.e., $\xi_y \in (-\bar{\xi}, \bar{\xi})$.

If the retailer adopts the blockchain technology, the expected profit of the supplier is

$$\Pi_{s1}^A = (w - c)\, E_\epsilon \left(\min\left\{K_1, u + \xi + \epsilon\right\}\right) - c_k K_1,$$

then he maximizes his expected profit to obtain the optimal K_1^{A*}, i.e.,

$$K_1^{A*}(\xi) = u + \xi + G^{-1}\left(\frac{w - c - c_k}{w - c}\right). \tag{12}$$

If the retailer does not adopt the blockchain technology, the expected profit of the supplier can be written as

$$\Pi_{s0}^A = (w - c) \int_{-\infty}^{\infty} E_\epsilon \left(\min\left\{K_0, u + \xi + \epsilon\right\}\right) f^b(\xi) d\xi - c_k K_0,$$

then he maximizes his expected profit to obtain the optimal K_0^{A*}, i.e.,

$$K_0^{A*} = u + (T_{\xi_y}^b)^{-1}\left(\frac{w - c - c_k}{w - c}\right). \tag{13}$$

Now we need to solve the problem of the first stage. From Eq. (12) and (13), if the retailer does not adopt the blockchain technology, the retailer's expected profit can be expressed as

$$\Pi_{r1}^A = (r - w) E_\epsilon \left(\min\left\{K_1^{A*}(\xi), u + \xi + \epsilon\right\}\right) - M.$$

And if the retailer adopts the blockchain technology, the retailer's expected profit can be expressed as

$$\Pi_{r0}^A = (r - w) E_\epsilon \left(\min\left\{K_0^{A*}, u + \xi + \epsilon\right\}\right).$$

Hence, the retailer will adopt the blockchain technology if and only if $\Pi_{r1}^A \geq \Pi_{r0}^A$, i.e.,

$$\begin{aligned}\Pi_{r1}^A - \Pi_{r0}^A &= (r-w)E_\epsilon\left(\min\left\{K_1^{A*}(\xi), u+\xi+\epsilon\right\}\right) - M\\ &\quad - (r-w)\int_{-\infty}^{\infty} E_\epsilon\left(\min\left\{K_0^{A*}, u+\xi+\epsilon\right\}\right) f^b(\xi)\mathrm{d}\xi\\ &= (r-w)\left(E_\epsilon\left(\min\left\{G^{-1}\left(\frac{w-c-c_k}{w-c}\right), \epsilon\right\}\right)\right.\\ &\quad \left.-E_\epsilon\left(\min\left\{(T_{\xi_y}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right) - \xi, \epsilon\right\}\right)\right) - M \geq 0.\end{aligned}$$

According to Lemma 4.1, $\Pi_{r1}^A - \Pi_{r0}^A$ (Eq. (8)) is increasing in retailer's private demand information ξ. Hence, there exists a $\xi^A \in [-\bar{\xi}, \bar{\xi}]$, such that $\Pi_{r1}^A - \Pi_{r0}^A \geq 0$ is equivalent to $\xi \geq \xi^A$. Note that the belief must satisfy the Bayesian rule, thus it must hold $\xi_y = \xi^A$, i.e., $(r-w)\Omega(\xi^A) = M$.

Therefore, if $M > (r-w)\max_{\xi\in[-\bar{\xi},\bar{\xi}]}\Omega(\xi)$, there does not exist a non-trivial PBE. In this case, we know that the retailer never adopts the blockchain technology can form a PBE, i.e.,

$$\left(z^*(\xi), K_0^{A*}, K_1^{A*}(\xi); \left(f^b, F^b\right)\right) = \left(0, K^{ds}, u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f, F)\right).$$

First, it's easy to see that K_0^{A*} and $K_1^{A*}(\xi)$ are the optimal equilibrium of the supplier based on the retailer's choice and belief (f, F) (i.e., $\left(f_{\bar{\xi}}, F_{\bar{\xi}}\right)$). Hence, we only need to show that the retailer will never adopt the blockchain technology, that is $\xi^A = \bar{\xi}$ and $\Pi_{r1}^A - \Pi_{r0}^A \leq 0$ holds for all $\xi \in [-\bar{\xi}, \bar{\xi}]$. Note that Eq. (12) and (13), thus we can get

$$\begin{aligned}\frac{\Pi_{r1}^A - \Pi_{r0}^A}{(r-w)} &= E_\epsilon\left(\min\left\{K_1^{A*}(\xi), u+\xi+\epsilon\right\}\right) - \frac{M}{r-w} - E_\epsilon\left(\min\left\{K_0^{A*}, u+\bar{\xi}+\epsilon\right\}\right)\\ &= E_\epsilon\left(\min\left\{\xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right)\\ &\quad - E_\epsilon\left(\min\left\{(T_{\bar{\xi}}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right) - \frac{M}{r-w}.\end{aligned}$$

To show $(\Pi_{r1}^A - \Pi_{r0}^A)/(r-w) \leq 0$, we first prove that $q_2(x) = (T_x^b)^{-1}\left((w-c-c_k)/(w-c)\right)$ is increasing in x. According to $T(q_2(x)) = G(q_1) = (w-c-c_k)/(w-c)$ and

$$\frac{w-c-c_k}{w-c} = P\left(\xi+\epsilon \leq q_2(x)\,|\xi \leq x\right) = \int_{-\infty}^{x}\int_{-\infty}^{\infty} g(\epsilon)\frac{f(\xi)}{F(x)}1_{\{\xi+\epsilon\leq q_2(x)\}}\mathrm{d}\epsilon\mathrm{d}\xi,$$

then

$$\frac{w-c-c_k}{w-c}F(x) = \int_{-\infty}^{x} G(q_2(x)-\xi)f(\xi)\mathrm{d}\xi.$$

Taking the derivative of both sides with respect to x, we have

$$G(q_2(x)-x)f(x) + \frac{\mathrm{d}q_2(x)}{\mathrm{d}x}\int_{-\infty}^{x} g(q_2(x)-\xi)f(t)\mathrm{d}\xi - \frac{w-c-c_k}{w-c}f(x) = 0$$

then, according to $q_1 \geq q_2(y) - y$ in proving of Lemma 4.2,

$$\frac{\mathrm{d}q_2(x)}{\mathrm{d}x}\int_{-\infty}^{x} g(q_2(x)-\xi)f(t)\mathrm{d}\xi = \frac{w-c-c_k}{w-c}f(x) - G(q_2(x)-x)f(x)$$
$$= (\frac{w-c-c_k}{w-c} - G(q_2(x)-x))f(x) = (G(q_1) - G(q_2(x)-x))f(x) \geq 0.$$

Then $q_2(\xi) = (T_\xi^b)^{-1}\left((w-c-c_k)/(w-c)\right)$ is increasing in ξ, from this we can get

$$\begin{aligned}\frac{\Pi_{r1}^A - \Pi_{r0}^A}{(r-w)} &= E_\epsilon\left(\min\left\{\xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right) \\ &- E_\epsilon\left(\min\left\{(T_{\bar{\xi}}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right) - \frac{M}{r-w} \\ &\leq E_\epsilon\left(\min\left\{\xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right) \\ &- E_\epsilon\left(\min\left\{(T_{\xi}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right) - \frac{M}{r-w} \\ &= \Omega(\xi) - \frac{M}{r-w},\end{aligned}$$

then if $M > (r-w)\max_{\xi\in[-\bar{\xi},\bar{\xi}]}\Omega(\xi)$, $\Pi_{r1}^A - \Pi_{r0}^A \leq 0$, hence the retailer will never adopt the blockchain technology and the belief of the supplier is independent with the retailer's behavior, i.e., (f, F).

If $0 < M \leq (r-w)\max_{\xi\in[-\bar{\xi},\bar{\xi}]}\Omega(\xi)$, according to Lemma 4.1, then there is a ξ^A, such that $M = (r-w)\Omega(\xi^A)$, and the PBE is

$$\left(z^*(\xi), K_0^{A*}, K_1^{A*}(\xi); \left(f^b, F^b\right)\right) =$$
$$\left(1_{\{\xi^A\leq\xi\leq\bar{\xi}\}}, u + (T_{\xi^A}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u + \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f_{\xi^A}, F_{\xi^A})\right).$$

Finally, for $M = 0$, there is a PBE such that the retailer always adopts the blockchain technology, that is we check the following strategy and belief satisfy the conditions of PBE, $\left(z^*(\xi), K_0^{A*}, K_1^{A*}(\xi); \left(f^b, F^b\right)\right) =$

$$\left(1, u - \bar{\xi} + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u + \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right); 1_{\{-\bar{\xi}\}}\right).$$

First, it's easy to see that K_0^{A*} and $K_1^{A*}(\xi)$ are the optimal equilibrium of the supplier based on the retailer's choice and belief $1_{\{-\bar{\xi}\}}$ (i.e., $(f_{-\bar{\xi}}, F_{-\bar{\xi}})$). Hence, we only need to show that the retailer will always adopt the blockchain technology when the belief of the supplier is $1_{\{-\bar{\xi}\}}$. That is, $\Pi_{r1}^A - \Pi_{r0}^A \geq 0$ holds for all $\xi \in [-\bar{\xi}, \bar{\xi}]$. Note that Eq. (12) and (13), hence

$$\begin{aligned}\frac{\Pi_{r1}^A - \Pi_{r0}^A}{(r-w)} &= E_\epsilon\left(\min\left\{K_1^{A*}(\xi), u+\xi+\epsilon\right\}\right) - E_\epsilon\left(\min\left\{K_0^{A*}, u-\bar{\xi}+\epsilon\right\}\right) \\ &= E_\epsilon\left(\min\left\{\xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right) \\ &- E_\epsilon\left(\min\left\{-\bar{\xi} + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), -\bar{\xi}+\epsilon\right\}\right) = \xi + \bar{\xi} \geq 0.\end{aligned}$$

Then Theorem 4.3 is proved. $\square$

Appendix D. Proof of Lemma 4.4.

Proof. Similar result with Section 4.1 when the retailer with private demand information ξ does not adopt the blockchain technology. Hence, we only consider that the retailer with private demand information ξ adopts the blockchain technology, the supplier will solve the following problem to find K_1^{C*},

$$\begin{aligned} K_1^{C*} &= argmax_K(\delta w - c)\int_{-\bar{\epsilon}}^{\bar{\epsilon}} \min\{K, u+\xi+\epsilon\} g(\epsilon)\mathrm{d}\epsilon - c_k K \\ &= u + \xi + G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right). \end{aligned} \tag{14}$$

Else if the retailer does not adopt the blockchain technology, we have $K_0^{C*} = K_0^{A*} = u + (T^b_{\xi^C})^{-1}\left((w-c-c_k)/(w-c)\right)$ by maximizing his profit. And the profit of the retailer with private demand information ξ is

$$\begin{aligned} &(r-\delta w)\int_{-\bar{\epsilon}}^{\bar{\epsilon}} \min\{K_1^{C*}, u+\xi+\epsilon\} g(\epsilon)\mathrm{d}\epsilon - M \\ =&(r-\delta w)(u+\xi) + (r-\delta w)\int_{-\bar{\epsilon}}^{\bar{\epsilon}} \min\left\{G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right), \epsilon\right\} g(\epsilon)\mathrm{d}\epsilon - M. \end{aligned}$$

Thus, for a given δ by supplier, the retailer adopts the blockchain technology if and only if $DIFF(\xi)$

$$\begin{aligned} &= (r-\delta w)\, E_\epsilon(\min\{K_1^{C*}, u+\xi+\epsilon\}) - M - (r-w)\, E_{y,\epsilon}(\min\{K_0^{C*}, u+y+\epsilon\}) \\ &=(r-\delta w)(u+\xi) + (r-\delta w)\int_{-\bar{\epsilon}}^{\bar{\epsilon}} \min\left\{G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right), \epsilon\right\} g(\epsilon)\mathrm{d}\epsilon - M \\ &\quad - (r-w)\int_{-\bar{\epsilon}}^{\bar{\epsilon}} \min\{u + (T^b_{\xi_y})^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\} g(\epsilon)\mathrm{d}\epsilon \geq 0. \end{aligned} \tag{15}$$

Note that, K_0^{C*} is independent of ξ, we have

$$\begin{aligned} \frac{dDIFF}{d\xi}(\xi) =&(r-\delta w) - (r-w)(G(K_0^{C*} - u - \xi)) \\ \geq&(r-w) - (r-w)(G(K_0^{C*} - u - \xi)) \\ \geq&0. \end{aligned}$$

i.e., $DIFF$ is an increasing function in ξ. Hence, for a given δ by supplier, the retailer will find a certain threshold ξ^C, and adopt the blockchain technology if and only if ξ is larger than a certain threshold ξ^C.

□

Appendix E. Proof of Theorem 4.5.

Proof. According to Subsection 4.3, the decision-making process of this problem can be divided into three stages. The first stage is that the supplier chooses an optimal wholesale discount δ to the retailer, the second stage is that the retailer decides whether to adopt the blockchain technology, and the third stage is that the supplier decides the component capacity based on the two situations of the retailer adopting or not adopting.

Assume $\left(z^*(\xi), K_0^{C*}, K_1^{C*}(\xi); \left(f^b, F^b\right)\right)$ to be a PBE, then according to Lemma 4.4, we know that the retailer will always adopt threshold strategy, hence the belief of the supplier (i.e., $\left(f^b, F^b\right)$) is a restriction of (f, F) on $[-\bar{\xi}, \xi_y]$ for some $\xi_y \in$

$(-\bar{\xi}, \bar{\xi}]$. We first characterize all non-trivial PBEs such that the retailer's threshold is not $-\bar{\xi}$ or $\bar{\xi}$, i.e., $\xi_y \in (-\bar{\xi}, \bar{\xi})$.

If the retailer adopts the blockchain technology, the expected profit of the supplier is

$$\Pi_{s1}^C = (\delta w - c)\, E_\epsilon \left(\min\left\{K_1, u + \xi + \epsilon\right\}\right) - c_k K_1,$$

then he maximizes his expected profit to obtain the optimal K_1^{C*} as Eq (14) Similarly, if the retailer does not adopt the blockchain technology, the optimal K_0^{C*} is equal to the Eq. (13).

Now we need to solve the problem of the second stage that when the retailer is willing to adopt the blockchain technology. From Eq. (12) and (13), if the retailer does not adopt the blockchain technology, the retailer's expected profit can be expressed as

$$\Pi_{r1}^C = (r - \delta w)\, E_\epsilon \left(\min\left\{K_1^{C*}(\xi), u + \xi + \epsilon\right\}\right) - M.$$

And if the retailer adopts the blockchain technology, the retailer's expected profit can be expressed as

$$\Pi_{r0}^C = (r - w) E_\epsilon \left(\min\left\{K_0^{C*}, u + \xi + \epsilon\right\}\right).$$

Hence, the retailer is willing to adopt the blockchain technology if and only if $\Pi_{r1}^C \geq \Pi_{r0}^C$, i.e., $\Pi_{r1}^C - \Pi_{r0}^C =$

$$\begin{aligned}
&(r - \delta w)\, E_\epsilon \left(\min\left\{K_1^{C*}(\xi), u + \xi + \epsilon\right\}\right) - M - (r - w) E_\epsilon \left(\min\left\{K_0^{C*}, u + \xi + \epsilon\right\}\right) \\
&= (r - \delta w)\, E_\epsilon \left(\min\left\{u + \xi + G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right), u + \xi + \epsilon\right\}\right) \\
&\qquad - (r - w)\, E_\epsilon \left(\min\left\{u + (T_{\xi_y}^b)^{-1}\left(\frac{w - c - c_k}{w - c}\right), u + \xi + \epsilon\right\}\right) - M \\
&\geq 0,
\end{aligned}$$

According to Lemma 4.4, $\Pi_{r1}^C - \Pi_{r0}^C$ (Eq. (G)) is increasing in retailer's private demand information ξ. Hence, there exists a $\xi^C \in [-\bar{\xi}, \bar{\xi}]$, such that $\Pi_{r1}^C - \Pi_{r0}^C \geq 0$ is equivalent to $\xi \geq \xi^C$. Note that the belief must satisfy the Bayesian rule, thus it must hold $\xi_y = \xi^C$, i.e., $\Psi(\xi^C, \delta) = M$.

Therefore, if $M \geq \sup_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Psi(\xi, \delta)$, there does not exist a non-trivial PBE. In this case, we know that the retailer never adopts the blockchain technology can form a PBE, i.e.,

$$\left(z^*(\xi), K_0^{C*}, K_1^{C*}(\xi); \left(f^b, F^b\right)\right) = \left(0, K^{ds}, u + \xi + G^{-1}\left(\frac{w - c - c_k}{w - c}\right); (f, F)\right).$$

First, it's easy to see that K_0^{C*} and $K_1^{C*}(\xi)$ are the optimal equilibrium of the supplier based on the retailer's choice and belief (f, F), i.e., $\left(f_{\bar{\xi}}, F_{\bar{\xi}}\right)$. Hence, we only need to show that the retailer will never adopt the blockchain technology, that is $\xi^C = \bar{\xi}$ and $\Pi_{r1}^C - \Pi_{r0}^C \leq 0$ holds for all $\xi \in [-\bar{\xi}, \bar{\xi}]$. Note that Eq. (14) and (13). From the proof of Theorem 4.3, $(T_\xi^b)^{-1}\left((w - c - c_k)/(w - c)\right)$ is increasing in

ξ, then $\Pi_{r1}^C - \Pi_{r0}^C =$

$$
\begin{aligned}
&(r-\delta w)\, E_\epsilon \left(\min\left\{K_1^{C*}(\xi), u+\xi+\epsilon\right\}\right) - M - (r-w)\, E_\epsilon \left(\min\left\{K_0^{C*}, u+\bar{\xi}+\epsilon\right\}\right) \\
&= (r-\delta w)\, E_\epsilon \left(\min\left\{\xi + G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right), \xi+\epsilon\right\}\right) \\
&\quad - (r-w) E_\epsilon \left(\min\left\{(T_{\bar{\xi}}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right) - M, \\
&\leq (r-\delta w)\, E_\epsilon \left(\min\left\{\xi + G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right), \xi+\epsilon\right\}\right) \\
&\quad - (r-w) E_\epsilon \left(\min\left\{(T_{\xi}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), \xi+\epsilon\right\}\right) - M \\
&= \Psi(\xi,\delta) - M.
\end{aligned}
$$

If $M \geq \sup_{\xi\in[-\bar{\xi},\bar{\xi}]} \Psi(\xi,\delta)$, then $\Pi_{r1}^C - \Pi_{r0}^C \leq 0$ and the retailer will never adopt the blockchain technology, thus the belief of the supplier is $\left(f_{\bar{\xi}}, F_{\bar{\xi}}\right) = (f, F)$.

If $\inf_{\xi\in[-\bar{\xi},\bar{\xi}]} \Psi(\xi,\delta) < M < \sup_{\xi\in[-\bar{\xi},\bar{\xi}]} \Psi(\xi,\delta)$, according to Lemma 4.4, then there is a ξ^C, such that $M = \Psi(\xi^C,\delta)$, and the PBE is

$$
\begin{aligned}
&\left(z^*(\xi), K_0^{C*}, K_1^{C*}(\xi); \left(f^b, F^b\right)\right) = \\
&\left(1_{\{\xi^C \leq \xi \leq \bar{\xi}\}}, u + (T_{\xi^C}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right); (f_{\xi^C}, F_{\xi^C})\right).
\end{aligned}
$$

Finally, for $M \leq \inf_{\xi\in[-\bar{\xi},\bar{\xi}]} \Psi(\xi,\delta)$, there is a PBE such that the retailer always adopts the blockchain technology, that is we check the following decisions and belief satisfy the conditions of PBE, $\left(z^*(\xi), K_0^{C*}, K_1^{C*}(\xi); \left(f^b, F^b\right)\right) =$

$$
\left(1, u - \bar{\xi} + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); 1_{\{-\bar{\xi}\}}\right),
$$

First, it's easy to see that K_0^{C*} and $K_1^{C*}(\xi)$ are the optimal equilibrium of the supplier based on the retailer's choice and belief $1_{\{-\bar{\xi}\}}$. Hence, we only need to show that the retailer will always adopt the blockchain technology when the belief of the supplier is $1_{\{-\bar{\xi}\}}$. That is, $\Pi_{r1}^C - \Pi_{r0}^C \geq 0$ holds for all $\xi \in [-\bar{\xi},\bar{\xi}]$. Note that Eq. (14) and (13), then according to the proof of Theorem 4.3, $(T_x^b)^{-1}\left((w-c-c_k)/(w-c)\right)$ is increasing in x, $\Pi_{r1}^C - \Pi_{r0}^C =$

$$
\begin{aligned}
&(r-\delta w)\, E_\epsilon \left(\min\left\{K_1^{C*}(\xi), u+\xi+\epsilon\right\}\right) - M - (r-w)\, E_\epsilon \left(\min\left\{K_0^{C*}, u+\bar{\xi}+\epsilon\right\}\right) \\
&= (r-\delta w)\, E_\epsilon \left(\min\left\{u+\xi + G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right), u+\xi+\epsilon\right\}\right) \\
&\quad - (r-w) E_\epsilon \left(\min\left\{u+(T_{-\bar{\xi}}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\right\}\right) - M, \\
&\geq (r-\delta w)\, E_\epsilon \left(\min\left\{u+\xi + G^{-1}\left(\frac{\delta w - c - c_k}{\delta w - c}\right), u+\xi+\epsilon\right\}\right) \\
&\quad - (r-w) E_\epsilon \left(\min\left\{u+(T_{\xi}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\right\}\right) - M \\
&= \Psi(\xi,\delta) - M.
\end{aligned}
$$

Hence, if $M \leq \inf_{\xi\in[-\bar{\xi},\bar{\xi}]} \Psi(\xi,\delta)$, then $\Pi_{r1}^C - \Pi_{r0}^C \geq 0$ and the Theorem 4.5 is proved. ∎

Appendix F. Proof of Remark 2.

Proof. We will it prove in two steps. (1) Firstly, we have the supplier's decision are similar to that in the proof of 4.3, i.e., $K_1^{D*} = K_1^{A*}$ and $K_0^{D*} = K_0^{A*}$.

And the utilities of the retailer with private demand information ξ are $U_{r1}^D = E_\epsilon\left(\phi(\pi_{r1}^D)\right), U_{r0}^D = E_\epsilon\left(\phi(\pi_{r1}^D)\right)$. Thus, the retailer adopts the blockchain technology if and only if

$$\begin{aligned} E_\epsilon\left(\phi\left(\pi_{r1}^D\right) - \phi\left(\pi_{r0}^D\right)\right) = E_\epsilon\left(\phi\left((r-w)\min\left\{K_1^{D*}, u+\xi+\epsilon\right\} - M\right)\right) \\ - E_\epsilon\left(\phi\left((r-w)\min\left\{K_0^{D*}, u+\xi+\epsilon\right\}\right)\right) \geq 0. \end{aligned} \tag{16}$$

Note that, K_0^{D*} is independent of ξ, we have $E_\epsilon\left((\partial(\phi\left(\pi_{r1}^D\right) - \phi\left(\pi_{r0}^D\right)))/\partial\xi\right)$

$$\begin{aligned} &= E_\epsilon\left(\frac{\partial\phi\left(\pi_{r1}^D\right)}{\partial\xi}1_{\{\epsilon<K_0^{D*}-u-\xi\}} + (\frac{\partial\phi\left(\pi_{r1}^D\right)}{\partial\xi} - \frac{\partial\phi\left(\pi_{r0}^D\right)}{\partial\xi})1_{\{\epsilon>K_0^{D*}-u-\xi\}}\right) \\ &= E_\epsilon\left(1_{\{\epsilon<K_0^{D*}-u-\xi\}}\phi(\pi_{r1}^D)'(r-w) + 1_{\{\epsilon>K_0^{D*}-u-\xi\}}(\phi(\pi_{r1}^D)' - \phi(\Pi_{r1}^B)')(r-w)\right) \\ &= E_\epsilon\Big(1_{\{\epsilon<K_0^{D*}-u-\xi\}}\phi'(\pi_{r1}^D)(r-w) \\ &+ 1_{\{\epsilon>K_0^{D*}-u-\xi\}}(\phi'((r-w)(u+\xi+\epsilon)-M) - \phi'\left((r-w)(u+\xi+\epsilon)\right)(r-w))\Big) \end{aligned}$$

Firstly, we know $\phi'((r-w)(u+\xi+\epsilon)-M) - \phi'\left((r-w)(u+\xi+\epsilon)\right) > 0$ due to $\phi' > 0$ and $\phi'' < 0$. Hence, we have $\partial(\phi\left(\pi_{r1}^D\right) - \phi\left(\pi_{r0}^D\right))/\partial\xi > 0$ always holds, then i.e., $\phi\left(\pi_{r1}^D\right) - \phi\left(\pi_{r0}^D\right)$ is an increasing function. Thus, the retailer adopts the blockchain technology if and only if ξ is larger than a certain threshold ξ^D.

(2) Letting $\Theta_0(\xi_y, M)$

$$\begin{aligned} &= E_\epsilon\left(\phi\left((r-w)\min\left\{u+\xi_y+G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi_y+\epsilon\right\} - M\right)\right. \\ &\left. - \phi\left((r-w)\min\left\{u+(T_{\xi_y}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi_y+\epsilon\right\}\right)\right), \\ &= E_\epsilon\left(\phi\left((r-w)\left[(u+\xi_y)+\min\left\{q_1,\epsilon\right\}\right]-M\right)\right. \\ &\left.-\phi\left((r-w)\left[(u+\xi_y)+\min\left\{q2-\xi_y,\epsilon\right\}\right]\right)\right), \end{aligned} \tag{17}$$

where $q_1 = G^{-1}\left(\frac{w-c-c_k}{w-c}\right), q_2 = (T_{\xi_y}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right)$.

According to the proof of Theorem 4.1, we have $\lim_{\xi\to-\bar{\xi}} q_2(y) = q_1 - \bar{\xi}$. Hence, we have $q1 > q2(y) - y$, therefore $\Theta_0(\xi_y, 0) \geq 0$. While $\lim_{M\to\infty}\Theta_0(\xi_y, M) \leq 0$ due to $\partial\Theta_0(\xi_y, M)/\partial M < 0$ holds. Then there is a continuous $\Phi(\xi_y)$ on $(-\bar{\xi}, \bar{\xi}]$, where $\Theta_0(\xi_y, \Phi(\xi_y)) = 0$ holds. That is, $\Theta_0(\xi_y, M) = 0$ has a unique solution $M = \Phi(\xi_y)$.

Next, we need prove that $\Phi(\xi_y)$ is positive, we note $\Theta_0(\xi_y, 0) \geq 0$ and $\Theta_0(\xi_y, \Phi(\xi_y)) = 0$ hold, then $\Phi(\xi_y) \geq 0$ due to $\partial\Theta_0(\xi_y, M)/\partial M < 0$.

Finally, we need prove $\lim_{\xi_y\to-\bar{\xi}}\Phi(\xi_y) = 0$. If $\lim_{\xi_y\to-\bar{\xi}}\Phi(\xi_y) \neq 0$, then there exists a sequence $\{y_i\}_{i=1}^\infty$, such that $\lim_{n\to\infty} y_i \to -\bar{\xi}$ and $\lim_{n\to\infty}\Theta(y_i) \to \kappa$, where $\kappa > 0$. We have $0 = \lim_{n\to\infty}\Theta_0(y_i, \Theta(y_i)) < \lim_{n\to\infty}\Theta_0(y_i, 0) = 0$, which is a contradiction. Hence, $\lim_{\xi_y\to-\bar{\xi}}\Phi(\xi_y) = 0$ must be hold. ☐

Appendix G. Proof of Remark 3.

Proof. Assume $\left(z^*(\xi), K_0^{D*}, K_1^{D*}(\xi); \left(f^b, F^b\right)\right)$ to be a PBE, then according to Remark 2, we know that the retailer will always adopt threshold strategy, hence the belief of the supplier (i.e., $\left(f^b, F^b\right)$) is a restriction of (f, F) on $[-\bar{\xi}, \xi_y]$ ($f(x) = 0$, if

$x \notin [-\bar{\xi}, \xi_y]$) for some $\xi_y \in [-\bar{\xi}, \bar{\xi}]$. We first characterize all non-trivial PBEs such that the retailer's threshold is not $-\bar{\xi}$ or $\bar{\xi}$, i.e., $\xi_y \in (-\bar{\xi}, \bar{\xi})$.

For the supplier, his decision is similar with scenario A, i.e., the optimal decisions of the component capacity are the same as Section 4.1, $K_1^{D*} = K_1^{A*}$ and $K_0^{D*} = K_0^{A*}$. Now we need to solve the problem of the first stage. From Eq. (12) and (13), the retailer's utilities can be expressed as

$$\Pi_{r1}^D = E_\epsilon \left(\phi\left((r-w)\min\left\{K_1^{D*}, u+\xi+\epsilon\right\} - M\right)\right),$$
$$\Pi_{r0}^D = E_\epsilon \left(\phi\left((r-w)\min\left\{K_0^{D*}, u+\xi+\epsilon\right\} f^b(\xi)\right)\right).$$

Hence, the retailer will adopt the blockchain technology if and only if $\Pi_{r1}^D \geq \Pi_{r0}^D$, i.e., Thus, the retailer adopts the blockchain technology if and only if

$$\begin{aligned}\phi\left(\Pi_{r1}^D\right) - \phi\left(\Pi_{r0}^D\right) = & E_\epsilon \left(\phi\left((r-w)\min\left\{K_1^{D*}, u+\xi+\epsilon\right\} - M\right)\right) \\ & - E_\epsilon \left(\phi\left((r-w)\min\left\{K_0^{D*}, u+\xi+\epsilon\right\}\right)\right) \geq 0.\end{aligned}$$

According to Remark 2, $\Pi_{r1}^D - \Pi_{r0}^D$ (Eq. (16)) is increasing in retailer's private demand information ξ. Hence, there exists a $\xi^D \in [-\bar{\xi}, \bar{\xi}]$, such that $\Pi_{r1}^D - \Pi_{r0}^D \geq 0$ is equivalent to $\xi \geq \xi^D$. Note that the belief must satisfy the Bayesian rule, thus it must hold $\xi_y = \xi^D$, i.e., $M = \Theta(\xi_y)$. Therefore, if $M > \max_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Phi(\xi_y)$, there does not exist a non-trivial PBE. In this case, we know that the retailer never adopts the blockchain technology can form a PBE, i.e.,

$$\left(z^*(\xi), K_0^{D*}, K_1^{D*}(\xi); \left(f^b, F^b\right)\right) = \left(0, K^{ds}, u+\xi+G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f, F)\right).$$

First, it's easy to see that K_0^{D*} and $K_1^{D*}(\xi)$ are the optimal equilibrium of the supplier based on the retailer's choice and belief (f, F) (i.e., $\left(f_{\bar{\xi}}, F_{\bar{\xi}}\right)$). Hence, we only need to show that the retailer will never adopt the blockchain technology, that is $\xi^A = \bar{\xi}$ and $\Pi_{r1}^D - \Pi_{r0}^D \leq 0$ holds for all $\xi \in [-\bar{\xi}, \bar{\xi}]$. Note that Eq. (12) and (13), thus we can get $\left(\phi\left(\Pi_{r1}^D\right) - \phi\left(\Pi_{r0}^D\right)\right)$

$$\begin{aligned}&= E_\epsilon \left(\phi\left((r-w)\min\left\{G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\right\} - M\right)\right) \\ &- E_\epsilon \left(\phi\left((r-w)\min\left\{(T_{\bar{\xi}}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\right\}\right)\right).\end{aligned}$$

From $(T_{\xi}^b)^{-1}\left((w-c-c_k)/(w-c)\right)$ is increasing in ξ, we can get

$$\begin{aligned}&E_\epsilon \left(\phi\left(\pi_{r1}^D\right) - \phi\left(\pi_{r0}^D\right)\right) \\ &= E_\epsilon \left(\phi\left((r-w)\min\left\{G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\right\} - M\right)\right) \\ &- E_\epsilon \left(\phi\left((r-w)\min\left\{(T_{\bar{\xi}}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\right\}\right)\right) \\ &\leq E_\epsilon \left(\phi\left((r-w)\min\left\{G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\right\} - M\right)\right) \\ &- E_\epsilon \left(\phi\left((r-w)\min\left\{(T_{\xi}^b)^{-1}\left(\frac{w-c-c_k}{w-c}\right), u+\xi+\epsilon\right\}\right)\right) \\ &= \Theta(\xi, M).\end{aligned}$$

then if $M > \max_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Phi(\xi_y)$, $\Pi_{r1}^D - \Pi_{r0}^D \leq 0$, hence the retailer will never adopt the blockchain technology and the belief of the supplier is independent with the retailer's behavior, i.e., (f, F). If $0 < M \leq \max_{\xi_y \in [-\bar{\xi}, \bar{\xi}]} \Phi(\xi_y)$, according to Remark 2, then there is a ξ^D, such that $M = \Phi(\xi_y)$, and the PBE is

$$\left(z^*(\xi), K_0^{D*}, K_1^{D*}(\xi); \left(f^b, F^b\right)\right) =$$
$$\left(1_{\{\xi^D \leq \xi \leq \bar{\xi}\}}, u + (T^b_{\xi^D})^{-1}\left(\frac{w-c-c_k}{w-c}\right), u + \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right); (f_{\xi^D}, F_{\xi^D})\right).$$

Finally, for $M = 0$, there is a PBE such that the retailer always adopts the blockchain technology, that is we check the following decisions and belief satisfy the conditions of PBE, $\left(z^*(\xi), K_0^{D*}, K_1^{D*}(\xi); \left(f^b, F^b\right)\right) =$

$$\left(1, u - \bar{\xi} + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u + \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right); 1_{\{-\bar{\xi}\}}\right).$$

First, it's easy to see that K_0^{D*} and $K_1^{D*}(\xi)$ are the optimal equilibrium of the supplier based on the retailer's choice and belief $1_{\{-\bar{\xi}\}}$ (i.e., $(f_{-\bar{\xi}}, F_{-\bar{\xi}})$). Hence, we only need to show that the retailer will always adopt the blockchain technology when the belief of the supplier is $1_{\{-\bar{\xi}\}}$. That is, $\Pi_{r1}^A - \Pi_{r0}^A \geq 0$ holds for all $\xi_y \in [-\bar{\xi}, \bar{\xi}]$. Hence, according to $R' > 0$, we have $E_\epsilon\left(\phi\left(\Pi_{r1}^D\right) - \phi\left(\Pi_{r0}^D\right)\right)$

$$= E_\epsilon\left(\phi\left((r-w)\min\left\{u + \xi + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u + \xi + \epsilon\right\}\right)\right.$$
$$\left.- \phi\left((r-w)\min\left\{u - \bar{\xi} + G^{-1}\left(\frac{w-c-c_k}{w-c}\right), u - \bar{\xi} + \epsilon\right\}\right)\right) \geq 0$$

Then Remark 3 is proved. □

Appendix H. Proof of Remark 4.

Proof. The i-th supplier decision the optmal component capacity K_{1i}^{E*} and K_{0i}^{E*} by maximizing his profit, then we can obtain the optimal
$K_{1i}^{E*} = u_i + \lambda_i \xi + G_i^{-1}\left(\frac{w-c-c_k}{w-c}\right)$, $K_{0i}^{E*} = \left(u_i + (T^{bi})^{-1}\left(\frac{w-c-c_k}{w-c}\right)\right)/\lambda_i$.

And the profit of the retailer with private demand information ξ is

$$\Pi_{r1}^E = \sum_{i=1}^n (r-w) E_{\epsilon_i}\left(\min\left\{K_{1i}^{E*}, u_i + \lambda_i\xi + \epsilon_i\right\}\right) - M,$$
$$\Pi_{r0}^E = \sum_{i=1}^n (r-w) E_{\epsilon_i}\left(\min\left\{K_{0i}^{E*}, u_i + \lambda_i\xi + \epsilon_i\right\}\right)\xi.$$

Thus, the retailer adopts the blockchain technology if and only if

$$\Pi_{r1}^E - \Pi_{r0}^E = \sum_{i=1}^n (r-w) E_{\epsilon_i}\left(\min\left\{K_{1i}^{E*}, u_i + \lambda_i\xi + \epsilon_i\right\}\right) - M$$
$$- \sum_{i=1}^n (r-w) E_{\epsilon_i}\left(\min\left\{K_{0i}^{E*}, u_i + \lambda_i\xi + \epsilon_i\right\}\right).$$

Note that, K_{0i}^* is independent of ξ, we have

$$\frac{\partial(\Pi_{r1}^E - \Pi_{r0}^E)}{\partial\xi} = (r-w)\left(n - \sum_{i=1}^n G_i\left(K_{0i}^{E*} - u_i - \lambda_i\xi\right)\right) > 0$$

Then $\Pi_{r1}^E - \Pi_{r0}^E$ is an increasing function. Thus, the retailer adopts the blockchain technology if and only if ξ is larger than a certain threshold ξ^E.

Letting

$$
\begin{aligned}
\Xi(\xi_y) = & \sum_{i=1}^{n} (r-w)\, E_{\epsilon_i}\left(\min\left\{K_{1i}^{E*}, u_i+\lambda_i\xi+\epsilon_i\right\}\right) \\
& - \sum_{i=1}^{n} (r-w)\, E_{\epsilon_i}\left(\min\left\{K_{0i}^{E*}, u_i+\lambda_i\xi+\epsilon_i\right\}\right) \\
& = (r-w)\left(\sum_{i=1}^{n} E_{\epsilon_i}\left(\min\left\{K_{1i}^{E*}, u_i+\lambda_i\xi+\epsilon_i\right\}\right)\right. \\
& \left. - \sum_{i=1}^{n} E_{\epsilon_i}\left(\min\left\{K_{0i}^{E*}, u_i+\lambda_i\xi+\epsilon_i\right\}\right)\right) \\
& = (r-w)\left(\sum_{i=1}^{n}\left(E_{\epsilon_i}\left(\min\left\{K_{1i}^{E*}, u_i+\lambda_i\xi+\epsilon_i\right\}\right)\right.\right. \\
& \left.\left. -E_{\epsilon_i}\left(\min\left\{K_{0i}^{E*}, u_i+\lambda_i\xi+\epsilon_i\right\}\right)\right)\right).
\end{aligned}
$$

Similar with the Proof of Lemma 4.2, we can prove that $\Xi(\xi_y)$ is a positive function and continuous on $(-\bar{\xi}, \bar{\xi}]$. Therefore, the proof of Remark 5 is similar with Remark 4.3, then we omit them. □

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