



Blockchain's role in e-commerce sellers' decision-making on information disclosure under competition

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Abstract

In e-commerce, sellers can disclose product information (such as quality, size information, function, and so on) to make consumers understand the products. However, in the process of information disclosure, consumers often fall into information distortion or information loss. Because of its immutability and traceability, blockchain can help e-commerce sellers improve information disclosure and ensure the efficiency of information transmission. We study a duopoly competitive e-commerce market in which two e-commerce sellers compete in information disclosure. According to whether to apply blockchain, we divide the sellers' decision-making into four research scenarios (NN, BN, NB, BB). Based on the above four scenarios, we get the market demand of different products depending on the consumer utility, and further establish the game model in the competitive environment. This paper explores the impact of blockchain on information disclosure and consumer surplus, and achieves the Nash equilibrium of blockchain application for both sides. In the expansion model, we study e-commerce sellers' risk aversion and capital constraints, and further explore their impact on blockchain in practice. Finally, combining with blockchain's characteristics, we also analyze the impact of the application of blockchain at other aspects on the supply chain. We find that when consumers' trust in information is low or the cost of blockchain applications is low, all e-commerce sellers in competition will adopt blockchain. In addition, when consumers have low trust in information, it will be difficult to achieve complete equilibrium in the application of blockchain as their risk aversion increases. For capital constrained sellers, when the cost of blockchain application is low, it will be difficult to achieve full equilibrium for blockchain applicants as the bank financing rate increases.

Keywords Information disclosure · Blockchain · Supply chain competition · Risk aversion · Capital constraint

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1 Introduction

1.1 Research background and motivation

1.1.1 Problems in information disclosure

In e-commerce transactions, sellers and consumers in different time and space cannot physically contact and perceive the goods that need to be purchased under offline consumption, and can only judge the goods' quality by the information from the text, pictures and videos provided by the merchants. Online sellers can increase the information disclosure (for example, product specifications, dimensions, use experience, etc.), which helps to reduce consumers' perception of risk (Montecchi et al., 2019) to improve consumers' understanding on the product, and accordingly, consolidate consumers' preference for the product to increase the sales to certain extent. Consumers consider that it is always good for online sellers to increase information disclosure, while online sellers believe that increasing information disclosure will add more burden in different ways. For example, online sellers can introduce the details in the product description to consumers through beautiful pictures, where each additional picture requires professional personnel to design and upload, thereby the cost cannot be ignored. Moreover, if the online seller acts as a middleman, he/she will review the resale products when he/she sells the products, and increasing the information disclosed means increasing the review content, which will also increase the labor and management costs. As a result, there is a tradeoff between the potential benefits of disclosing more information in increasing demand and the costs associated with it.

However, consumers are always in a passive position when receiving the information, which causes many of them to shout "fooled" after trying on the goods, and find that there is a wide gap between the real appearance of the goods and the "seller show". It should be emphasized that the false propaganda is one of the main manifestations of information asymmetry, which is more obvious in such industries as food, health products, clothing and so on. In particular, the health products industry is the hardest hit by false propaganda, especially during the COVID-19 epidemic. The relevant complaints exist from January 1, 2020 to March 6, 2020, of which 76% are from the accused enterprises concentrated on the e-commerce platform, while 24% from other purchase channels. The statistics show that water purifiers are the major health products with the most complaints at this period. The proportion of consumers' complaints against false propaganda is as high as 37.5%. In the promotion of health food, some enterprises deliberately blur the difference between functions and curative effect, and deliberately exaggerate the efficacy. The reason is related not only to the online sellers' adverse selection, but also to the lack of middlemen's strict scrutiny.

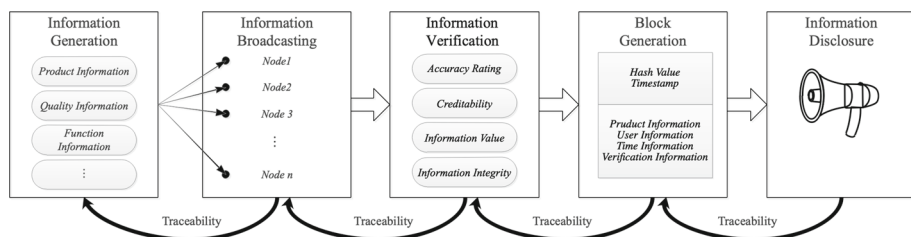
1.1.2 The role of blockchain

Fortunately, blockchain can solve information asymmetry to some extent. Information disclosure can be realized through blockchain. This means that all previously disclosed information will be permanent, and current and future users will be able to view the history of all public information. Because everything is more transparent, the product authenticity can be traced back. It is worth mentioning that if blockchain supports information disclosure, the platform must pay special attention to avoiding errors, because the information is always there. Table 1 shows the characteristics of blockchain related to product information disclosure.

Table 1 Characteristics of blockchain related to product information disclosure

Application basis	Basic features	Meeting point
Consensus mechanism	Joint maintenance	It ensures the authenticity, security and transparency of the disclosed information
Distributed ledger	Decentralization	It can be jointly maintained and get the rapid transmission and integrity of information
Digital signature Hash algorithm	Information that cannot be tampered with and self-governing	The symmetrical encryption of information is realized to avoid malicious tampering with the disclosed information by unscrupulous merchants
Time stamp	Traceability	It can trace the released time and content of the information, and increase the judgment of the information authenticity
Smart contract	Automatic execution	It avoids human interference and reduces the probability of errors in disclosure information

As for the application of blockchain, e-commerce sellers can establish alliance chain based on the whole life cycle of the supply chain. The upstream primary suppliers, secondary suppliers and downstream e-commerce platforms and consumers can constitute different nodes of the blockchain network. As shown in Fig. 1, blockchain facilitate three steps for product information from generation to disclosure: information broadcasting, information verification and block generation. Information broadcasting is convenient to broadcast the generated product information to all nodes. Information verification is to verify the accuracy and credibility of all node information. Only qualified information will be packaged and further released. When the disclosed information is written, the e-commerce seller's identity and release time are also written into the blockchain ledger and notify all the nodes in the network. Viewing the blockchain ledger can promote the verification of the seller's identity and release time. Viewing the blockchain data of the information source, consumers can judge the credit of the information disclosed by e-commerce sellers, so as to judge the credibility of the information to certain extent. Based on the traceability of blockchain, the source of false information will be easier for people to obtain. Even if speculators publish false information,

**Fig. 1** Information disclosure under blockchain

people can trace back to the source through blockchain. Therefore, blockchain can guarantee the authenticity and integrity of the disclosed information.

1.1.3 Information disclosure competition

In the aspect of e-commerce operation, in addition to the importance of product disclosure, we should also be aware of the competition among industries, the uncertainty of consumers' willingness to buy and financial constraints. Among them, the high uncertainty of industry competition and consumers' willingness to buy is more obvious in the mobile phone industry, luxury industry and other high-consumption industries. This has led to online sellers' rational sales judgment. Traditional competition is mainly reflected in two aspects: price competition and quantity competition. However, with the development of the Internet, the importance of information is self-evident, which makes e-commerce sellers have to consider the competitors' information decisions when disclosing information. Take the mobile phone market as an example, for two mobile phones with similar performance, one seller will show consumers its powerful photo function and reasonable price, while the other seller will show its beautiful appearance and powerful function on this basis. Such examples are common in e-commerce. After the application of blockchain, we need to pay attention to the impact on such information disclosure competition.

1.2 Research questions and main conclusions

Based on the industry practice of e-commerce sellers in the real world and the importance of product information disclosure in blockchain era, according to consumers' product preference, two competitive e-commerce sellers are divided into two types, e-commerce sellers with competitive advantages and e-commerce sellers with competitive disadvantages. We consider four clear situations, namely: neither of the two competitive sellers use blockchain, only the seller with competitive advantages uses blockchain, only the seller with competitive disadvantages applies blockchain, and the two competitive sellers both apply blockchain. We analyze and construct a duopoly game model of game theory separately, and discuss the product information disclosure game and blockchain application game between e-commerce sellers. We have also expanded the model and analysis in terms of risk aversion and financial constraints, and generated additional insights.

To be clear, this paper is to study the following research questions.

1. In the basic model of two competitive e-commerce sellers, what is the optimal level of product information disclosure of two competitive e-commerce sellers in four cases? And what are their characteristics? What are the consumer surplus and its characteristics after reaching the optimal level?
2. In the basic model of two competitive e-commerce sellers, what is the nature of the optimal profits of all parties in different situations? And which situation can achieve the Nash equilibrium of blockchain applications?
3. If the e-commerce seller has an aversion to risk, how do the degree of risk aversion and demand fluctuation affect the optimal product information disclosure level and consumer surplus in the four cases? Will the application of blockchain cause a change in this effect?
4. If the funds of e-commerce sellers are constrained, how does the bank's loan interest rate affect the optimal product information disclosure level and consumer surplus in the four cases? Will the application of blockchain cause a change in this effect?

With the study on the above mentioned research questions, we have the following main conclusions.

1. If only one seller uses blockchain, when the cost of blockchain application is very small, consumers' high trust will drive the high level of the seller's information disclosure. For consumer surplus, under different costs of blockchain application, the number of main bodies of applied blockchain will also have impact on the size of consumer surplus. For the applied blockchain equilibrium, we give the equilibrium region about the blockchain cost and the degree of consumer trust.
2. Risk aversion will increase the level of information disclosure and consumer surplus, but after blockchain application, information disclosure will be in lower level, while it does not increase consumer surplus. We also find that after blockchain application, its cost will increase the sensitivity of e-commerce sellers to market demand fluctuations. Both risk aversion and market volatility will change the equilibrium of the application blockchain.
3. Under the capital constraint, increasing the lending rate of banks will reduce the level of information disclosure and consumer surplus. If the cost of applying blockchain is very high, the blockchain application will reduce this impact. If the blockchain is applied, the cost of the blockchain will change the seller's sensitivity to the loan interest rate. The change of bank loan interest rate will change the equilibrium of applied blockchain.

1.3 Contribution and organizational structure

As far as we know, this paper is the first to study the impact of blockchain on the information disclosure of competitive e-commerce platforms. Combining with the characteristics of the existing e-commerce sellers, we clarify the sellers' attitude to the risk aversion and the impact of blockchain technology under financial constraints. The results are novel and reveal some crucial insights. This paper builds a foundation for the future research on the game of e-commerce operation information disclosure by using blockchain, and also provides valuable management insights for e-commerce operation practice.

The rest of this paper is organized as follows. Section 2 reviews literature related to product information disclosure, supply chain competition and blockchain. Section 3 builds four basic models for two competitive e-commerce sellers, and analyzes the role of blockchain and the equilibrium conditions of the application blockchain. Section 4 checks the robustness of the main insights generated by the basic model and analyzes various extended models. Section 5 discusses other functions and research directions of blockchain in information disclosure. Section 6 concludes the paper and indicates its implications for product information management in e-commerce.

2 Literature review

2.1 Information disclosure

In recent years, information disclosure has been widely concerned, and different types have been studied. For example, Cao et al. (2020) took quality information as the object, and examine the impact of voluntary and mandatory information disclosure on the equilibrium strategy, payment and consumer surplus of manufacturers and retailers. Jeon (2019) and Chondrakis et al. (2019) have studied technological information disclosure. The former found that in the case of technological information disclosure, innovators invest in R&D earlier, while the

latter found that increasing technological information disclosure increases M & A activities. Zhou et al. (2018) studied the impact of information disclosure on lenders' behavior in the financial market of crowdfunding supply chain. The results show that additional information disclosure can help lenders to make reasonable investment decisions. Cho et al. (2019) established a game theory model based on two-tier supply chain to study how information disclosure affects the motivation of enterprises to use different strategies to combat child labor. With the development of e-commerce, information disclosure often brings some problems in online sales. Many scholars explore its role in e-commerce through the method of game. Zhang et al. () established an analytical model to study how intermediaries and sellers manage consumers' uncertainty and returns by disclosing product information. Markopoulos and Hosanagar (2018) introduced a game theory model of the competitive market and found that the information availability of the third parties makes companies free-rider, especially low-quality enterprises, who can reduce investment more than high-quality enterprises in information disclosure. Hu et al. (2020) studied a two-phase model, where the sales volume of the first phase is disclosed, based on which the customers of the second phase will make a purchasing decision. The above studies are all focused on disclosing information by the seller to the consumer, while, there are, of course, also studies by the consumer to the seller (Feri et al., 2016; Ichihashi, 2020). Our research object is still that the seller to disclose information to consumers, because generally speaking, sellers are more likely to conceal information from consumers, so it is more meaningful to explore the role of blockchain in it. What is closest to our research is the study by Choi et al. (2019a), who established a duopoly model and analyzed the Nash game of product information disclosure between product leasing alternative service platforms. Finally, they discussed the role of blockchain, but they did not bring blockchain into the model. Our research makes up for this shortcoming. We consider that blockchain will increase consumers' trust in information, so as to establish a model based on blockchain and analyze the role of blockchain. Similarly, we mainly focus on the competitive market, and it is common to explore the issues related to information disclosure in the competitive market (Clark & Kundu, 2020; Sheth, 2019).

2.2 Competition in supply chains

Nowadays, supply chain management under competition is an attractive topic, and there are many types of competition in the supply chain, but the most classic is price competition and output competition. In terms of price competition, Xiao et al. (2014) developed a retailer-Stackelberg pricing model to study the product types and channel structure strategies of manufacturers in the annular market. Shavandi et al. () studied the problem of price competition in multinational supply chains. They focused on manufacturers' pricing strategies and unauthorized dealers' impact on prices, market share and profits. Matsui (2017) considered the price competition between manufacturers and retailers when studying the dual-channel supply chain. His biggest innovation is that manufacturers and retailers can choose not only the price level, but also the pricing timing. In the aspect of output competition, Shao et al. (2020) considered a purchasing game with opaque cost, described the equilibrium of purchasing game, and studied the influence of different parameters on purchasing strategies and profit performance. Han & Liu (2020) established an optimization model of high-quality product supply chain, in which many competing companies adopt the strategy of vertical integration and must determine the quality level of production and the quantity of production at each level. In addition, some studies also consider service competition. For example, Pi et al. (2019) studied pricing and service strategies under retailer competition and cooperation

after considering channel interruption. With the further increasing practical problems and the further deepening research, the research on supply chain competition also considers capacity competition (Yang & Hsieh 2021), social responsibility competition (Wang et al., 2020) and advertising competition (Zhang et al., 2020) and so on. Similar to the above research, our study also considers the competition between different supply chains, but unlike existing studies, our research does not consider price competition or output competition. What we are considering is the competition of the information disclosure level. In contrast, we consider the competition of information disclosure, which is easier to reflect the role and change of blockchain in the supply chain (thanks to the insurable modification of blockchain).

2.3 Blockchain application in operations management

Blockchain was originally proposed by Nakamoto (2009). It was born with Bitcoin. This peer-to-peer distributed ledger has attracted more and more attention. As a kind of information and communication technology, blockchain has been largely researched in the computer field (Ikeda, 2018; Lin & Tang, 2018; Sharma et al., 2018). However, related studies (Babich & Hilary, 2020; Gomber et al., 2018; Kumar et al., 2018; Queiroz et al., 2020) have proved that blockchain plays an irreplaceable role in improving operation management, especially in supply chain management (Chang et al., 2020; Helo & Hao, 2019; Wang et al., 2019). In recent years, blockchain has been paid more and more attention in researching operation management. De Giovanni (2020) discusses the optimal strategy of the traditional online platform and blockchain platform through the supply chain game model. Lohmer et al. (2020) used the simulation method to explore the impact of blockchain on supply chain risk management and supply chain elasticity. Choi (2019) explored different consumer utility-driven operational models and emphasizes the value of blockchain technical support platforms in diamond certification and certification. Choi et al. (2019b) discussed how to apply the mean variance (MV) method to explore the operational risk of global supply chain and air transportation logistics in the blockchain era. After that, Choi (2020) thought that blockchain can reduce the financing cost of enterprises, studies the introduction of revenue-sharing contract again, and explores the supply chain coordination before and after the use of blockchain through Nash bargaining model. Yoon et al. (2020) introduced an analytical model considering the implementation of blockchain in international trade. The results show that under the condition of blockchain, the delivery time is shortened, and the shipping cost is reduced. Choi et al. (2020) believed that blockchain helps the platform to accurately assess the proportion of risk-seeking customers, risk-neutral customers and risk-averse customers. Under the general pricing strategy and the customized pricing strategy, the significance of customized service pricing strategy mediated by blockchain technology is obtained through the optimal service price. Considering consumers' pursuit of traceability, Fan et al. (2020) also introduced a revenue-sharing contract to achieve the equilibrium of the application blockchain. Similar to the above research, our research also belongs to the application category of blockchain in operation and management. However, the difference is that in our consideration blockchain can ensure that information and data cannot be tampered with. In the traditional information disclosure, the phenomenon of information fraud is also very common, but because blockchain cannot be tampered with, we think that the information can be disclosed through blockchain system so that it can be guaranteed to be true. Obviously, there is no similar research at present. Even Choi et al. (2019a), which is most similar to our research, did not take into account that blockchain can guarantee that the information cannot be tampered with.

3 The model

3.1 Model description

We consider two e-commerce sellers who sell the same products in the same market. We define the two sellers as m , and the products they sell as m ($m = 1, 2$). The products sold by the two sellers has the same nature. Because the products are sold online, consumers cannot know the true value of the products, but the consumers' valuation of the two sellers' products is the same but uncertain. With reference to Chen & Chen (2016) and Yang et al. (2017), we assume that v is uniformly distributed between 0 and 1. We also consider consumers' preferences for products. For example, even if they sell the same products, consumers tend to think that the quality of the products on JD¹ is higher than that on Taobao.² Based on this point, the sellers on JD have more competitive advantages than the sellers on Taobao. Taking this into account, we introduce the consumer preference coefficient θ_m , i.e., the valuation of the product m purchased by the consumer is $\theta_m v$. And we assume that seller 1's product is more likely to gain consumers' trust, i.e., $\theta_1 > \theta_2$. This assumption is reflected in competitive marketing study (Chen & Bell, 2011) and competitive financing study (Yang et al., 2019).

In order to increase the product sales, seller m needs to disclose the product information to consumers through the e-commerce platform, including product quality, product specifications, user experience, etc. When consumers receive these kinds of information, they will know more about the product. For example, in the actual e-commerce market, the seller will describe the product through gorgeous pictures and personalized words on the platform. Through these methods, consumers know more about the product information, which undoubtedly leads consumers to arouse their willingness to buy. In reality, it is a pity that many sellers exaggerate their products too much and often post some false information, which may temporarily increase consumers' willingness to buy in the short term, but in the long run, this will often deal a great blow to consumers' confidence in their products. Therefore, consumers' trust in product information has become an issue that sellers need to focus on in traditional e-commerce, where we assume that consumers' trust in product information is λ , and $\lambda \in (0, 1)$. Because blockchain cannot be tampered with, it can be used to ensure the authenticity of the product information. Under this condition, the information released by the seller on the platform is so real that the consumer's recognition of the product can be guaranteed. We assume that after the blockchain application, consumers' recognition of product information is 1. For the e-commerce platform, the increasing information of the seller will also be a burden, because the e-commerce platform will have to increase the storage space for the relevant data. Although increasing sales through information disclosure will indirectly enhance the revenue of the platform (because the platform will charge the seller), considering the cost, the platform will charge for the information disclosed by the seller. We only consider the unit cost of information disclosure, which is recorded as k . Similarly, the cost of applying blockchain cannot be ignored. For each information unit disclosed by the seller, a new block is formed and connected to the previous block. During this period, power and storage consumption is obvious cost. In addition, the related labor and communication increase with information disclosure increasing. In this paper, the cost of blockchain application is defined as unit cost, which is recorded as t .

In addition, we also define the unit sales price of product m as p_m , which is exogenous, and related to the product nature. And we define the unit selling price of the product as c_m ,

¹ <https://www.jd.com>.

² <https://www.taobao.com>.

which includes the production cost, transportation cost and so on. To be simple, we make $r_m = p_m - c_m$. Seller m needs to decide the degree of product disclosure α_m and whether to apply blockchain. If seller 1 applies blockchain, we set $i = B$; otherwise $i = N$. If seller 2 applies blockchain, we define $j = B$; otherwise $j = N$. We use φ_m to indicate whether seller m applies blockchain, and define the following formula:

$$\varphi_1 = \begin{cases} 1 & \text{if } i = B \\ 0 & \text{if } i = N \end{cases}, \quad \varphi_2 = \begin{cases} 1 & \text{if } j = B \\ 0 & \text{if } j = N \end{cases}$$

The utility gained by consumers in purchasing products is U_m . For comparison, we also assume the situation where the seller has no information disclosure. In order to distinguish the consumer utility with or without information disclosure, we assume that the consumer utility without information disclosure is U_{m-NID} , while the consumer utility with information disclosure is U_{m-PID} .

3.2 Consumer's choice

First of all, we analyze the consumer utility when there is no information disclosure. Under the premise that the consumer's product valuation is v , the product utility m is $U_{m-NID} = \theta_m v - p_m$. If we consider that there is only a single seller in the market, then only when $U_{m-NID} > 0$, i.e., $v > \frac{p_m}{\theta_m}$, the consumer will buy the product. We can get the product demand m at this time is $d_m = \int_{\frac{p_m}{\theta_m}}^1 dv = 1 - \frac{p_m}{\theta_m}$.

In order to make our research more rigorous, we assume that seller 1 has an advantage over seller 2 in the e-commerce market, so we add the following assumptions.

- (1) When the product information is not disclosed by the e-commerce seller, and the consumer values product 1 and product 2, $v = 1$, $U_{1-NID} > U_{2-NID}$, i.e., $\theta_1 - p_1 > \theta_2 - p_2$.
- (2) In a single market without information disclosure, $d_1 = 1 - \frac{p_1}{\theta_1} > d_2 = 1 - \frac{p_2}{\theta_2}$.
- (3) In the absence of information disclosure, the unit sales profit of e-commerce 1 is larger than that of e-commerce 2, i.e., $p_1 - c_1 > p_2 - c_2$.

The hypothesis (1) shows that when the consumer has the information about the product, the consumer is more inclined to product 1, and the consumer only buys product 1 but not product 2. In hypothesis (2), the basic market capacity of product 1 is larger than that of product 2. In hypothesis (3), seller 1 is easier to get higher profits than seller 2.

In the market with information disclosure, under the condition that the consumer's product valuation is v , the seller's information disclosure level will increase the consumer utility after purchasing goods. What needs to know is that when there is no blockchain application, the consumers' trust degree in the information disclosure is not high enough, and for each additional information disclosure unit, consumers only get an increase in the utility of λ ($\lambda \in (0, 1)$), while after the application of blockchain, a unit of utility will be increased for consumers. Therefore, the utility that consumers get after purchasing product m is as follows:

$$U_{m-PID} = \theta_m v + (\varphi_m + (1 - \varphi_m)\lambda)\alpha_m - p_m + \varepsilon_m,$$

where ε_m is a random variable with symmetrical distribution, and $E(\varepsilon_m) = \mu_m$, $Var(\varepsilon_m) = \sigma_m^2$. The correlation coefficient between ε_1 and ε_2 is ρ . ε_m is used to reflect the uncertainty of the utility of consumers after buying products. If ε_m is very large, consumers will be more willing to buy enough products; otherwise, consumers will have little willingness. This reflects the uncertainty of the market faced by sellers indirectly.

In order to explore consumers' willingness to buy, we make it possible for $U_m = 0$ to get

$$v_m = \frac{p_m - (\varphi_m + (1 - \varphi_m)\lambda)\alpha_m - \varepsilon_m}{\theta_m}$$

Only when $U_m > 0$ (i.e., when the consumer's valuation of the product m , $v > v_m$), the consumer will buy product m .

In order to explore consumers' choice between two products, we further make $U_{1-PID} = U_{2-PID}$, the boundary of consumer valuation worthwhile:

$$v_{21} = \frac{p_1 - p_2 + (\varphi_1 + (1 - \varphi_1)\lambda)\alpha_1 - (\varphi_2 + (1 - \varphi_2)\lambda)\alpha_2 - \varepsilon_1 + \varepsilon_2}{\theta_1 - \theta_2}$$

It is obvious that $v_{21} > v_m$. The above formula shows that when $U_{1-PID} > U_{2-PID}$, i.e., $v > v_{21}$, consumers will buy product 1 instead of product 2, as shown in Fig. 2. But when $U_{1-PID} < U_{2-PID}$ and $U_{2-PID} > 0$, i.e., $v < v_{21}$ and $v > v_2$, consumers will buy product 2 instead of product 1. As shown in Fig. 2, $v_2 < v_1 < v_{21} < 1$, so when $v > v_{21}$, $v > v_1$ is bound to be established, there is no conflict between the market of product 1 and the market of product 2.

Therefore, when we do the integral, we get $D_1 = \int_{v_{21}}^1 dv = 1 - v_{21}$ and $D_2 = \int_{v_2}^{v_{21}} dv = v_{21} - v_2$, and when we expand, we get:

$$D_1 = 1 - \frac{p_1 - p_2 + (\varphi_1 + (1 - \varphi_1)\lambda)\alpha_1 - (\varphi_2 + (1 - \varphi_2)\lambda)\alpha_2}{\theta_1 - \theta_2} + \xi_1$$

$$D_2 = \frac{p_1 - p_2 + (\varphi_1 + (1 - \varphi_1)\lambda)\alpha_1 - (\varphi_2 + (1 - \varphi_2)\lambda)\alpha_2}{\theta_1 - \theta_2} - \frac{p_2 - (\varphi_2 + (1 - \varphi_2)\lambda)\alpha_2}{\theta_2} + \xi_2$$

where $\xi_1 = \frac{\varepsilon_1 - \varepsilon_2}{\theta_1 - \theta_2}$, $\xi_2 = \frac{\theta_1 \varepsilon_2 - \theta_2 \varepsilon_1}{\theta_2 (\theta_1 - \theta_2)}$.

Obviously, $E(\xi_1) = E(\xi_2) = 0$, $Var(\xi_1) = \frac{\sigma_1^2 + \sigma_1^2 - 2\rho\sigma_1\sigma_1}{(\theta_1 - \theta_1)^2}$, and $Var(\xi_2) = \frac{\theta_1\sigma_2^2 + \theta_2\sigma_1^2 - 2\theta_1\theta_2\rho\sigma_1\sigma_2}{\theta_2^2(\theta_1 - \theta_2)^2}$.

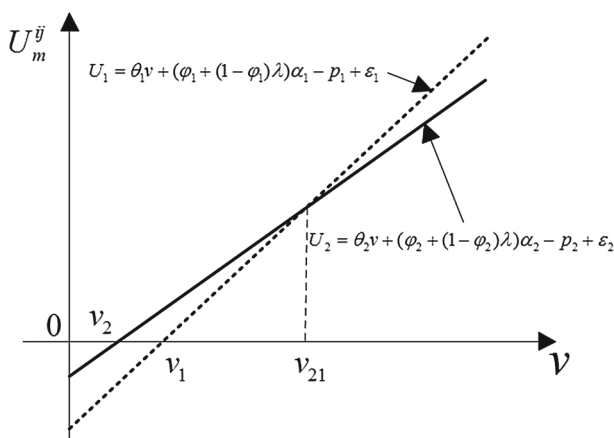


Fig. 2 The utility of consumers buying products

3.3 Analysis

In the basic model, if seller m applies blockchain, i.e., $\varphi_m = 1$, then each unit of information disclosure will have to pay more t cost; otherwise, each unit of information disclosure will only have to pay k cost. Therefore, we can get that the cost of information disclosure of seller m is $\bar{l}_m = (k + \varphi_m t)\alpha_m - PCM$. In addition to the cost of information disclosure, we need to take into account the cost of selling products, so the analysis shows that the expected profit function of seller m is:

$$\Pi_{m-PID} = (p_m - c_m - \bar{l}_m)E(D_m - PCM)$$

We define $Z_1 = \frac{-\theta_1(2\theta_1-\theta_2)d_1+\theta_1\theta_2d_2}{(4\theta_1-\theta_2)}$ and $Z_2 = \frac{-\theta_2(2\theta_1-\theta_2)d_2+\theta_1\theta_2d_1}{(4\theta_1-\theta_2)}$, which are the disclosure level of seller 1 and seller 2 in the basic market, respectively. According to our hypothesis, we can find $Z_m < 0$. And, obviously, Z_m is the decreasing function of d_m and the increasing function of d_{m-} , i.e., if the basic market demand of seller m is very large, his information disclosure level in the basic market will be even smaller. On the contrary, if the basic market demand of the other party is very large, seller m will increase the amount of information disclosure, which reflects that the basic market demand will increase the competitiveness of information disclosure between the two sides. Since d_m is the decreasing function of p_m , we can get that Z_m is the increasing function of p_m and the decreasing function of p_{m-} . Based on the above analysis, we further solve the optimal level of information disclosure, and we can get four cases according to whether seller 1 and seller 2 apply blockchain. In the four cases, their optimal information disclosure level is shown in Table 2.

Proposition 1

- (1) In the competitive product information disclosure market, there is a unique Nash equilibrium under different blockchain application scenarios. The level of balanced product information disclosure for product 1 and product 2 is shown in Table 1.
- (2) (a) For any $i = N, B$, α_{m-PCM}^{iN} is increasing function with respect to λ . (b) For any $j = N, B$, α_{m-PCM}^{Nj} is increasing function with respect to λ . (c) Only if $t < \hat{t}_m$, α_{1-PCM}^{NB} and α_{2-PCM}^{BN} are increasing function with respect to λ .
- (3) For any i and j , α_{m-PCM}^{ij} is the decreasing function of k , and for any $i = B$ or $j = B$, α_{m-PCM}^{ij} is the decreasing function of t .
- (4) $\alpha_{1-PCM}^{Nj} > \alpha_{1-PCM}^{Bj}$, $\alpha_{2-PCM}^{iN} > \alpha_{2-PCM}^{iB}$.

Table 2 Equilibrium product information disclosure level of seller 1 and seller 2

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
$\alpha_1^{ij*} - PCM$	$\frac{Z_1}{\lambda} + \frac{2\theta_1 R_1 + \theta_1 R_2}{k}$	$Z_1 + \frac{2\theta_1 R_1}{(k+t)} + \frac{\lambda\theta_1 R_2}{k}$	$\frac{Z_1}{\lambda} + \frac{2\theta_1 R_1}{k} + \frac{\theta_1 R_2}{\lambda(k+t)}$	$Z_1 + \frac{2\theta_1 R_1 + \theta_1 R_2}{(k+t)}$
$\alpha_2^{ij*} - PCM$	$\frac{Z_2}{\lambda} + \frac{\theta_2 R_1 + 2\theta_1 R_2}{k}$	$\frac{Z_2}{\lambda} + \frac{\theta_2 R_1}{\lambda(k+t)} + \frac{2\theta_1 R_2}{k}$	$Z_2 + \frac{\lambda\theta_2 R_1}{k} + \frac{2\theta_1 R_2}{(k+t)}$	$Z_2 + \frac{\theta_2 R_1 + 2\theta_1 R_2}{(k+t)}$

$$R_1 = \frac{r_1}{4\theta_1 - \theta_2}, R_2 = \frac{r_2}{4\theta_1 - \theta_2}$$

From proposition 1 (1), we can get the optimal returns of both parties in different blockchain application scenarios, as shown in “Appendix A.1”. It can be seen from proposition 1 (2) that as long as one party does not apply blockchain, the optimal information disclosure level of seller m is correlated with the consumer trust degree λ . When competitors do not apply blockchain, the greater the trust of consumers in the information, the greater the level of information disclosure of seller m . This is because when consumers have more trust in information, consumers are more willing to buy products, which leads to a larger potential market for any seller. What needs to be distinguished is that if seller m does not apply blockchain, the consumer’s trust in information λ only affects the sensitivity of the optimal level of information disclosure to the underlying market. But if seller m applies blockchain alone at this time, λ only affects the sensitivity of the optimal level of information disclosure to the unit income of competitors.

Proposition 1 (3) shows that when k and t are large, the information disclosed by seller m will decrease accordingly, because the larger k and t , the higher the marginal cost of product information disclosure. Proposition (2c) shows that only when the competitor applies blockchain, and t is small, the information disclosed by seller m will increase with the increase of λ . Combining with the conclusion of (3), we can think that when t is relatively small and λ is relatively large, competitors will increase the level of information disclosure. Therefore, in order to balance their own income, seller m will increase the level of information disclosure. In addition, it also explores the nature of consumer surplus from product information disclosure. Proposition 1 (4) shows that for either party, as long as blockchain is used, the volume of information disclosure will be reduced. With the previous analysis, it also shows that the seller is more sensitive to the cost of blockchain.

In addition, we also want to explore the impact of product information disclosure game on consumer surplus. We use CS_m to represent the consumer surplus after the product information disclosure of seller m to the consumer (i.e., the user). We use CS_m^* to represent the consumer surplus at equilibrium. When there is no information disclosure, the consumer surplus is:

$$CS_{m-N} = \int_{\frac{p_m}{\theta_m}}^{\infty} (\theta_m v - p_m) f(v) dv$$

When the information is disclosed, the consumer surplus is as follows:

$$\begin{aligned} CS_{m-PID} &= \int_{\frac{p_m - (\varphi_m + (1 - \varphi_m)\lambda)\alpha_m}{\theta_m}}^{\infty} (\theta_m v + (\varphi_m + (1 - \varphi_m)\lambda)\alpha_m - p_m) f(v) dv \\ &= \int_{\frac{p_m}{\theta_m}}^{\frac{p_m - (\varphi_m + (1 - \varphi_m)\lambda)\alpha_m}{\theta_m}} (\theta_m v - p_m) f(v) dv + \int_{\frac{p_m - (\varphi_m + (1 - \varphi_m)\lambda)\alpha_m}{\theta_m}}^{\infty} (\varphi_m + (1 - \varphi_m)\lambda)\alpha_m f(v) dv + CS_{m-N} \end{aligned}$$

It can be seen that the consumer surplus obtained by seller m through information disclosure is:

$$\delta CS_m = CS_{m-PID} - CS_{m-N} = \Lambda_m [\Lambda_m + d_m]$$

where $\Lambda_m = (\varphi_m + (1 - \varphi_m)\lambda)\alpha_m$.

In order to explore the properties of CS_m^{ij*} , we get Lemma 1.

Lemma 1 For any i and j , CS_m^{ij*} is an increasing function of Λ_{mij}^* and d_m .

Lemma 1 states that whether blockchain is applied or not, seller m will increase consumer surplus through information disclosure, and the greater the basic market demand, the more it will increase. In addition, consumer surplus is also related to the blockchain application, and

at the same level of information disclosure, after the application of blockchain, consumer surplus will become smaller.

Observing Lemma 1, we can find that the consumer surplus of seller m is only related to Λ_m , so we get the optimal Λ_{m-PCM}^{ij*} according to Proposition 1, as shown in “Appendix A.1”. Comparing their relationship, we can get Proposition 2.

Proposition 2

- (1) When $i = N$ or $j = N$, CS_{m-PCM}^{ij*} is an increasing function with respect to λ .
- (2) For any i and j , CS_{m-PCM}^{ij*} is a decreasing function with respect to k , and when $i = B$ or $j = B$, CS_{m-PCM}^{ij*} is a decreasing function with respect to t .
- (3) Under different blockchain application scenarios, the consumer surplus from information disclosure of product m has the following relationship: When

$$\begin{aligned} & \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{t}{k} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{1}{\lambda} - 1, CS_{1-PCM}^{BB*} \begin{pmatrix} < \\ = \\ > \end{pmatrix} CS_{1-PCM}^{BN*} \begin{pmatrix} < \\ = \\ > \end{pmatrix} CS_{1-PCM}^{NB*} \begin{pmatrix} < \\ = \\ > \end{pmatrix} CS_{1-PCM}^{NN*}, \\ & CS_{2-PCM}^{BB*} \begin{pmatrix} < \\ = \\ > \end{pmatrix} CS_{2-PCM}^{NB*} \begin{pmatrix} < \\ = \\ > \end{pmatrix} CS_{2-PCM}^{BN*} \begin{pmatrix} < \\ = \\ > \end{pmatrix} CS_{2-PCM}^{NN*}. \end{aligned}$$

- (4) Proposition 2 (1) states that as long as one party in the competitive market does not use blockchain, the consumer surplus of seller m is related to λ . When λ is relatively large, consumers can obtain higher consumer surplus from information disclosure. With the conclusion of Lemma 1, it is also easy to obtain the expression with the most consumer surplus, so we can also explore whether λ has an effect on consumer surplus after the blockchain application. By further derivation, it is found that $\frac{dCS_{m-PCM}^{ij*}}{d\lambda}$ has nothing to do with t , but the sensitivity of the consumer surplus of seller m to λ is positively correlated with the unit sales income of competitors. Proposition 2(2) states that with the high cost of information disclosure, the consumer surplus will be lower, because the seller will reduce the volume of information disclosure.

Proposition 2 (3) compares consumer surplus in four cases, and also illustrates two problems: (1) when t is very high, the consumer surplus with applying blockchain will be very low, and as long as one party applies blockchain, it will reduce consumer surplus; (2) with the increase of sellers who apply blockchain, the consumer surplus of either side will decrease. Of course, if the cost of quoting blockchain is relatively low, the conclusion is just the opposite. Proposition 2 (3) just shows that the consumer surplus is still very sensitive to the blockchain application cost.

From Proposition 1 (1), we can get the optimal returns of both parties in different situations, compare their benefits, and we can get the scenario of the seller applying blockchain. The specific results are represented by Proposition 3.

Proposition 3 For any $\alpha_{m-PCM}^{ij*} > 0$, ($m = 1, 2$),

- (1) When t and λ satisfy $\frac{t}{k} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$, then $\Pi_{1-PCM}^{BB*} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \Pi_{1-PCM}^{BN*}$ and $\Pi_{2-PCM}^{BB*} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \Pi_{2-PCM}^{NB*}$.

- (2) $\Pi_{1-PCM}^{NN*} < \Pi_{1-PCM}^{NB*}, \Pi_{2-PCM}^{NN*} < \Pi_{2-PCM}^{BN*}$.
- (3) When t and λ satisfy $\frac{t}{k} \begin{pmatrix} > \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$ and $\frac{\sqrt{\lambda k}(k+t)-k\sqrt{k+t}}{\sqrt{\lambda k}-\lambda\sqrt{k+t}} \begin{pmatrix} > \\ < \end{pmatrix} \frac{(2\theta_1-\theta_2)R_m-\theta_m R_m^-}{Z_m}$, then $\Pi_{m-PCM}^{NN*} > \Pi_{m-PCM}^{BB*}$, else $\Pi_{m-PCM}^{NN*} \leq \Pi_{m-PCM}^{BB*}$.

Proposition 3 (1) shows that when seller m applies blockchain, his competitors apply blockchain to his optimal return. When seller m applies blockchain, if t is relatively large or λ is relatively small, his competitors' blockchain application will increase their revenue; otherwise, his competitors will reduce their income if they apply blockchain, which also reflects that competitors' blockchain application alone will promote the transfer of competitors' income to their own side.

Proposition 3(2) shows that when seller m does not apply blockchain, his competitors apply blockchain to his income; when seller m does not use blockchain, regardless of the size of t and λ , the competitors' use of blockchain will reduce their revenue, because if seller m does not apply blockchain, while the competitor applies blockchain, consumers will rely more on the competitors' products, and the market demand will shift to the competitors. However, we must also pay attention to the influence of t . Theoretically, although seller m loses consumer information when he/she does not apply blockchain, it also avoids the cost of applying blockchain. Proposition 3 (2) fully shows that in this case, competitors using blockchain will make themselves at a disadvantage.

We regard the situation in which neither of the two perfectly competitive sellers should use blockchain or both apply blockchain as the complete equilibrium of blockchain application. Proposition 3(3) gives the condition of complete equilibrium for the blockchain application. We can find that only when their own unit return is very large, and the competitor's profit is very small, the two sellers will apply blockchain. But it should be noted that the competitor's unit return also determines the complete equilibrium. If for seller m the competitor's income is very small, then $\Pi_{m-PCM}^{BB*} > \Pi_{m-PCM}^{NN*}$, but his competitor $\Pi_{m-PCM}^{BB*} < \Pi_{m-PCM}^{NN*}$, and in this way, the complete equilibrium will not exist. Therefore, whether complete equilibrium exists depends on the relationship between the relative unit income of seller m and his competitors, and λ and t . Specifically, we have carried out the following analyses.

In order to further analyze the results of the equilibrium, we make $\theta_1 = 0.9$, $p_1 = 0.6$, $c_1 = 0.2$, $\theta_2 = 0.6$, $p_2 = 0.4$, $c_2 = 0.1$, $k = 0.3$, and then we can get the relationship between λ and t as shown in Fig. 3.

Theorem 1 When the values of λ and t are (1) in region I and region VI in Fig. 3, $\Pi_{1-PCM}^{BB*} > \Pi_{1-PCM}^{ij*}$, and $\Pi_{2-PCM}^{BB*} > \Pi_{2-PCM}^{ij*}$, there is a unique game equilibrium for the blockchain application, i.e., $(\varphi_1, \varphi_2) = (1, 1)$; (2) in region II and region V, $\Pi_{1-PCM}^{NN*} > \Pi_{1-PCM}^{ij*}$, and $\Pi_{2-PCM}^{NN*} > \Pi_{2-PCM}^{ij*}$, there is a unique game equilibrium for the blockchain application, i.e., $(\varphi_1, \varphi_2) = (0, 0)$; (3) in region III, $\Pi_{1-PCM}^{BN*} > \Pi_{1-PCM}^{NN*}$, and $\Pi_{2-PCM}^{BN*} > \Pi_{2-PCM}^{BB*}$, there is a unique game equilibrium for the blockchain application, i.e., $(\varphi_1, \varphi_2) = (1, 0)$; (4) in region IV, $\Pi_{1-PCM}^{NB*} > \Pi_{1-PCM}^{BB*}$, and $\Pi_{2-PCM}^{NB*} > \Pi_{2-PCM}^{NN*}$, there is a unique game equilibrium for the blockchain application, i.e., $(\varphi_1, \varphi_2) = (0, 1)$.

No matter what λ is, when t is very small, i.e., in region VI in Fig. 3, the two sellers in the perfectly competitive market achieve a complete equilibrium of the game, i.e., $(\varphi_1, \varphi_2) = (1, 1)$, which is easy to understand, because when t is very small, the advantages of applying blockchain outweigh the disadvantages. However, the value of t in area I in Fig. 3 is relatively

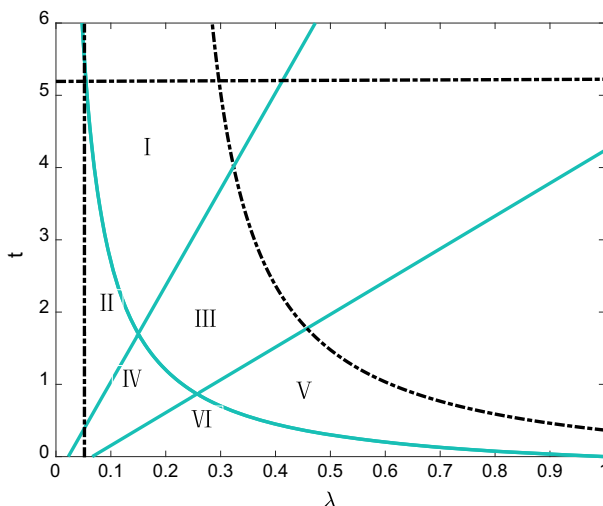


Fig. 3 Region of equilibrium for the application of blockchain

large, and the application blockchain will increase the burden on the seller. At the moment, we need to pay attention to λ , λ in region I is relatively small, and consumers' trust in product information is relatively low. From this point of view, both sides need blockchain to increase consumer confidence, so it is reasonable to achieve complete equilibrium, i.e., $(\varphi_1, \varphi_2) = (1, 1)$, in region I. When t is small, and λ is large, i.e., in region V of Fig. 3, the two sellers in the perfectly competitive market achieve a complete equilibrium of the game, i.e., $(\varphi_1, \varphi_2) = (0, 0)$, which shows that when L is relatively large, consumers have a certain degree of trust in product information, and thus it is no longer necessary to apply blockchain. However, for region II in Fig. 3, λ is very small, and this region has little relationship with t . Both sides in this region show that the competition between the two sides is more likely to achieve complete equilibrium. In addition, the value of t and λ in region III in Fig. 3 are larger than those of region IV, but in both regions, $\frac{t}{\lambda}$ is relatively small. Therefore, we can find that the equilibrium of these two regions is the result of the game between the two sellers.

4 Extended models

4.1 Considering the risk aversion behavior of E-commerce sellers

In the actual operation of the e-commerce supply chain, the risk sources are extensive, but the uncertainty of the utility obtained by consumers after purchasing products is the main source of the market risk. For example, in the electronic products industry, due to the instability of the product itself (not caused by quality), the feeling of using the product is different; thus, the utility of consumers after buying this kind of products is full of great uncertainty. In the clothing industry and the jewelry industry, consumers' feeling of using them depends not only on the nature of the products themselves, but also on the comparison with others, which will further lead to the uncertainty of the utility of the products after purchasing. Therefore, for many products, the market risk caused by the consumers' utility uncertainty is

also an issue that e-commerce supply chain decision-makers should pay attention to. In the competitive environment, when considering the application of blockchain, what impact the e-commerce sellers' risk aversion attitude will have on the optimal decision will be a problem worth discussing. Under the premise of considering the blockchain decision-making, we will explore its changes in the four situations when the e-commerce seller evades the risk, and whether the blockchain will affect the risk aversion seller's response. We also analyze the conditions for the application of blockchain equilibrium in e-commerce sellers. In this part, we choose to use the mean–variance model to describe the seller's risk.

From our basic model, we can find that the risk of seller m only comes from the market demand, so we can easily get the variance of seller m 's income as follows:

$$Var(\Pi_{m-PID}) = (p_m - c_m - (k + \varphi_m t)\alpha_{m-PID})^2 Var(\xi_m)$$

When seller m is risk-averse, the utility function of seller m is:

$$U_{m-RA} = E(\Pi_{m-PID}) - \delta_m \sqrt{Var(\Pi_{m-PID})},$$

where δ_m is the risk aversion coefficient of seller m . $\delta_m=0$ shows that seller m is risk-neutral, and $\delta_m > 0$ shows that seller m is strictly risk-averse. It is easy to see that U_{m-RA} is a strictly concave function of α_{m-RA} , from which we can get Proposition 4.

$$\text{Make } \Omega_1 = \sqrt{\sigma_1^2 + \sigma_2^2 - 2\rho\sigma_1\sigma_2} \text{ and } \Omega_2 = \sqrt{\theta_1\sigma_1^2 + \theta_2\sigma_1^2 - 2\theta_1\theta_2\rho\sigma_1\sigma_2}.$$

Define $UA_1 = \frac{2\theta_1\delta_1\Omega_1 + \delta_2\Omega_2}{4\theta_1 - \theta_2}$ and $UA_2 = \frac{\theta_2\delta_1\Omega_1 + 2\delta_2\Omega_2}{4\theta_1 - \theta_2}$. UA_m is the increasing function of δ_m and δ_{m-} respectively, and UA_m is the increasing function of σ_m and σ_{m-} .

Proposition 4 *For the case of risk aversion, the game is super modular and has a unique Nash equilibrium. The level of balanced product information disclosure of products 1 and 2 is as follows.*

- (1) For any $j = N, B$, when $i = N$, $\alpha_{1-RA}^{ij*} = \alpha_{1-PID}^{ij*} + \frac{UA_1}{\lambda}$, and when $i = B$, $\alpha_{1-RA}^{ij*} = \alpha_{1-PID}^{ij*} + UA_1$;
For any $i = N, B$, when $j = N$, $\alpha_{2-RA}^{ij*} = \alpha_{2-PID}^{ij*} + \frac{UA_2}{\lambda}$, and when $j = B$, $\alpha_{2-RA}^{ij*} = \alpha_{2-PID}^{ij*} + UA_2$.
- (2) For any i and j , $\alpha_{m-RA}^{ij*} > \alpha_{m-PID}^{ij*}$, $CS_{m-RA}^{ij*} > CS_{m-PID}^{ij*}$.
- (3) α_{m-RA}^{ij*} and CS_{m-RA}^{ij*} are increasing functions of δ_m and δ_{m-} .
- (4) α_{m-RA}^{ij*} and CS_{m-RA}^{ij*} are increasing functions of σ_m and σ_{m-} .

$\frac{UA_m}{\lambda}$ and UA_m are the residual information disclosure of risk aversion before and after the blockchain application by seller m respectively. From (1) of Proposition 4, we first observe that the optimal product information disclosure level in the case of risk aversion is higher than that in the case of risk neutral, because UA_m is always positive. If sellers are not willing to take risk, they will improve the level of product information disclosure, which is also confirmed in (2) of Proposition 4. The higher the degree of risk aversion of sellers, the higher the level of product information disclosure, not only for their own products, but also for the products of competitive platforms. From (1) and (2) of Proposition 4, it can be further found that under the condition of risk aversion of e-commerce sellers, the increased information disclosure level of e-commerce sellers has nothing to do with t application blockchain. This also shows that the cost of applying blockchain cannot affect e-commerce sellers' response to market uncertainty. Further analysis can find that when e-commerce sellers have awareness of risk aversion, the increased level of information disclosure with blockchain application will be smaller than that without blockchain application. Similarly, Proposition 4 (3) emphasizes

the impact of demand fluctuations, similar to the degree of risk aversion, because they are both risk-related.

As proved in (3) and (4) of Proposition 4, the higher the level of product information disclosure, not only for their own products, but also for the products of competitive platforms. But it should be noted that CS_{m-RA}^{ij*} is only related to Λ_{m-RA}^{ij*} . When the seller does not apply blockchain $\Lambda_{m-RA}^{ij*} = \lambda \alpha_{m-PID}^{ij*} + U A_m$, and when the seller applies blockchain $\Lambda_{m-RA}^{ij*} = \alpha_{m-PID}^{ij*} + U A_m$. Therefore, we come to a conclusion that the consumer residual added value of the seller's risk aversion has nothing to do with whether to apply blockchain.

From the conclusion of (1) of Proposition 4, we can conclude the optimal utility of each party in the seller's risk aversion, as shown in "Appendix A.4". Obviously, the utility of sellers is related to the degree of risk aversion and the demand fluctuation. According to the previous analysis, as long as one party applies blockchain, the utility of both parties will be related to t . Next, we want to explore whether t will affect the sensitivity of the optimal utility to the degree of risk aversion and the demand fluctuation. Proposition 5 can be obtained by analyzing this.

Proposition 5 *There is threshold $\overline{U A_m}^{ij}$ and threshold $\underline{U A_m}^{ij}$ respectively, as shown in Table 3, which makes the following conclusion true.*

- (1) *For any i , j unequal to N at the same time, when $0 < U A_m \leq \overline{U A_m}^{ij}$, U_m^{ij*} is the decreasing function of $U A_m$.*
- (2) *(2) For any i , j unequal to N at the same time, if $0 < U A_m \leq \underline{U A_m}^{ij}$, $\left| \frac{dU_m^{ij*}}{dU A_m} \right|$ is the increasing function of t , and when $\underline{U A_m}^{ij} < U A_m < \overline{U A_m}^{ij}$, $\left| \frac{dU_m^{ij*}}{dU A_m} \right|$ is the decreasing function of t .*

Because $U A_m$ is an increasing function of the degree of risk aversion and demand fluctuation of seller m and its competitors, we analyze the impact of $U A_m$ on U_m^{ij*} to further explore the impact of risk aversion and demand fluctuation on the optimal utility. It should be noted that the reason why we order $0 < U A_m < \overline{U A_m}^{ij}$ is to ensure that even under the condition of risk aversion, the market demand of seller m is non-negative, because if the market demand of seller m is negative, for a completely rational seller, he/she will definitely withdraw from the market. Proposition 5 (1) shows that if the seller is not willing to bear too many risks, then the utility he/she obtains through information disclosure is not high. Similarly, if there is a large uncertainty of utility (i.e., the demand fluctuation) after the consumer purchases his product, his utility will be reduced, and the impact on his competitors will be the same.

We use $\left| \frac{dU_m^{ij*}}{dU A_m} \right|$ to express to what extent $U A_m$ affects U_m^{ij*} . Proposition 5 (2) shows the influence change of $U A_m$ on U_m^{ij*} with the change of t . We find that if $U A_m$ is very small, and t is large, $U A_m$ will have a greater influence on U_m^{ij*} , and if $U A_m$ is particularly large, and t is larger, $U A_m$ will have smaller influence on U_m^{ij*} . This shows that if any party, seller m or his competitors, applies blockchain, the seller's ability to withstand risk is in a larger range, and the high cost of blockchain application will make the seller more sensitive to the market demand fluctuation. However, when seller m 's ability to bear the risk is in a relatively small range, a higher blockchain application cost means a less sensitivity for the seller m to the market demand fluctuation.

Table 3 Value of threshold $\overline{UA}_m^{ij}$ and threshold $\underline{UA}_m^{ij}$ in different situations

	$i = N, j = N$	$i = B, j = N$	$i = N, j = B$	$i = B, j = B$
$\overline{UA}_m^{ij}$	$\frac{\lambda((2\theta_1 - \theta_2)R_m - \theta_m R_m^-)}{k} - Z_m$	$\frac{(2\theta_1 - \theta_2)R_m}{k+t} - \frac{\lambda}{k}\theta_m R_m^- - Z_m$	$\frac{\lambda(2\theta_1 - \theta_2)R_m}{k} - \frac{k+t}{k^2}\theta_m R_m^- - Z_m$	$\frac{(2\theta_1 - \theta_2)R_m - \theta_m R_m^-}{k+t} - Z_m$
$\underline{UA}_m^{ij}$	-	$-\frac{\lambda}{k}\theta_m R_m^- - Z_m$	0	$-Z_m$

From Proposition 4 (1), we can get the optimal returns of both parties in different situations, we compare the benefits of both parties, and we can get the scenario of seller m applying blockchain. The specific results are represented by Proposition 6.

Proposition 6

- (1) If k and λ satisfy $\frac{t}{k} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$, then $U_{1-RA}^{*BB} \begin{pmatrix} > \\ = \\ < \end{pmatrix} U_{1-RA}^{*BN}$,
 $U_{2-PCM}^{*BB} \begin{pmatrix} > \\ = \\ < \end{pmatrix} U_{2-PCM}^{*NB}$.
- (2) There is always $U_{1-RA}^{*NN} < U_{1-RA}^{*NB}$, $U_{2-RA}^{*NN} < U_{2-RA}^{*BN}$.
- (3) If k and λ satisfy $\frac{t}{k} \begin{pmatrix} > \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$ and $\frac{\sqrt{\lambda k}(k+t)-k\sqrt{k+t}}{\sqrt{\lambda k}-\lambda\sqrt{k+t}} \begin{pmatrix} > \\ < \end{pmatrix} \frac{(2\theta_1-\theta_2)R_m-\theta_m R_m-}{Z_m+U_{Am}}$, $U_{m-RA}^{*NN} > U_{m-RA}^{*BB}$, otherwise $U_{m-RA}^{*NN} \leq U_{m-RA}^{*BB}$.

The conclusions of Proposition 6 (1) and (2) are the same as those of Proposition 3 (1) and (2), which shows that even under the condition of the seller's risk aversion, when their own blockchain decision is determined, there is no change for the competitor's decision to apply blockchain. However, when the seller is risk-averse, the complete equilibrium of the applied blockchain has changed, as illustrated in Proposition 6 (3). As mentioned in (3) of Proposition 3, when t is relatively large, the unit sales income of seller m and his competitors need to meet $\frac{(2\theta_1-\theta_2)R_m-\theta_m R_m-}{Z_m} > \frac{\sqrt{\lambda k}(k+t)-k\sqrt{k+t}}{\sqrt{\lambda k}-\lambda\sqrt{k+t}}$. When the two sides will jointly apply blockchain, and t is relatively small, this conclusion is just the opposite. However, Proposition 6 (3) expresses that when t is relatively large, the unit income of both sides needs to satisfy $\frac{(2\theta_1-\theta_2)R_m-\theta_m R_m-}{Z_m+U_{Am}} > \frac{\sqrt{\lambda k}(k+t)-k\sqrt{k+t}}{\sqrt{\lambda k}-\lambda\sqrt{k+t}}$, and because U_{Am} is always greater than 0, it can be found that when seller m is risk-averse, seller m needs a high unit income in order to achieve the complete equilibrium of blockchain applied by both sides. And if any seller is unwilling to take risks, or anyone's demand is too volatile, the great unit return is required to achieve such an equilibrium. Because the unit income we analyzed is relative, based on the above analysis, we can think that the risk tolerance of any seller is too low or the demand fluctuation is too large, it is not easy to achieve the complete equilibrium of the application blockchain.

When seller m is risk-averse, the game equilibrium of blockchain application is the same as that mentioned in Proposition 1. In order to explore the impact of risk aversion on this equilibrium, we further assign values to get the results shown in Fig. 4. Obviously, we can see Fig. 4 that with the increase of risk aversion coefficient, the area of region I and region II decrease obviously, while the area of other regions increases obviously.

As described in the analysis of proposition 1, precisely because of consumers' low trust in information, both parties apply blockchain in region I. However, we can see in Fig. 4 that with the increase of risk aversion coefficient, region I gradually decreases to the upper left corner, i.e., the complete equilibrium of using blockchain will be achieved only when consumers have lower trust in information. Similarly, region II gradually decreases to the left, but with the analysis of proposition 1, the equilibrium result of region II comes from the competition between the two sides. Therefore we can think that with the increase of risk aversion coefficient, the competition between the two sides of region II becomes greater.

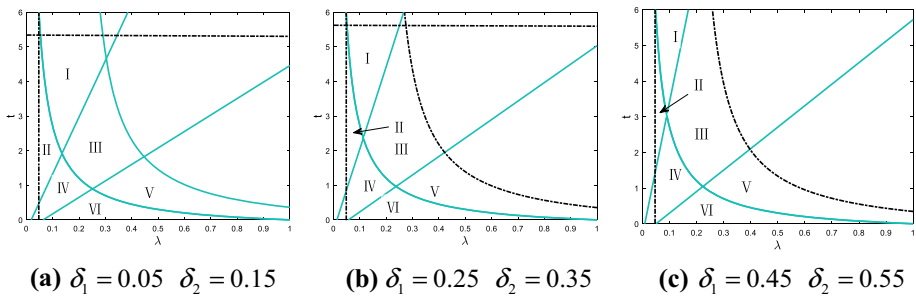


Fig. 4 Region of equilibrium for the application of blockchain under different risk aversion coefficients

4.2 Capital constraints of E-commerce sellers

E-commerce platform provides convenience for a large number of small- and medium-sized enterprises so that more individuals can run a store without physical facade. Therefore, the development of e-commerce platform has created more and more enterprises. However, due to the low threshold of e-commerce, more and more e-commerce sellers are small- and medium-sized enterprises, which are characterized by the insufficient funds. The scale of small- and medium-sized e-commerce enterprises is small, the financial system is irregular, and the branch does not make its capital flow even more optimistic at night, which is often the main reason that hinders the further development of these enterprises. In the case of bank financing, these small- and medium-sized e-commerce enterprises can get funds to support their operations in the short term, but the cost of capital brought about by loans brings operating pressure. In the application of blockchain, these enterprises will further increase their cost, but considering that blockchain can indirectly increase product sales, so comprehensively considering the shortage of funds, the application of blockchain is an issue of concern. In this part, we pay attention to the e-commerce sellers with capital constraints. On the basis of considering bank loans, we explore the changes of optimal decision-making in four scenarios, and we can also study the influence of blockchain on the e-commerce sellers' response to bank loan interest rates. Finally, the decision equilibrium of applied blockchain is analyzed.

We use NSC to denote the scenario of financial constraints. We use B_m to represent the initial capital of seller m . Usually, financial constraint refers to that the seller's initial capital is insufficient to support the sales cost, i.e., $B_m < (c_m + (k + \varphi_m t)\alpha_{m-NSC})$, but in order to simplify our model, we order $B_m = 0$. In order to obtain funds, e-commerce sellers need to borrow money from the bank. We use E to represent the interest rate of the bank loan, and we do not consider the capital cost of the bank. To sum up, we can get the return function of both parties when the financial constraints of e-commerce sellers are as follows:

$$\Pi_{m-NSC} = (p_m - (c_m + (k + \varphi_m t)\alpha_{m-NSC})(1 + \eta))E(D_{m-NSC})$$

According to the above formula, we can get Table 4 by solving the optimal level of information disclosure under financial constraints.

Proposition 7

- (1) When e-commerce sellers lack start-up funds, there is a unique Nash equilibrium in different blockchain application scenarios. The balanced product information disclosure level of product 1 and product 2 is shown in Table 2.

Table 4 Optimal level of information disclosure under financial constraints

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
α_{1-NSC}^{ij*}	$Z_1 + \frac{2\theta_1 R_{1-NSC} + \theta_1 R_{2-NSC}}{\lambda}$	$Z_1 + \frac{2\theta_1 R_{1-NSC}}{(k+t)(1+\eta)} + \frac{\lambda\theta_1 R_{2-NSC}}{k(1+\eta)}$	$\frac{Z_1}{\lambda} + \frac{2\theta_1 R_{1-NSC}}{k(1+\eta)} + \frac{\theta_1 R_{2-NSC}}{\lambda(k+t)(1+\eta)}$	$Z_1 + \frac{2\theta_1 R_{1-NSC} + \theta_1 R_{2-NSC}}{(k+t)(1+\eta)}$
α_{2-NSC}^{ij*}	$\frac{Z_2}{\lambda} + \frac{\theta_2 R_{1-NSC} + 2\theta_1 R_{2-NSC}}{k(1+\eta)}$	$\frac{Z_2}{\lambda} + \frac{\theta_2 R_{1-NSC}}{\lambda(k+t)(1+\eta)} + \frac{2\theta_1 R_{2-NSC}}{2\theta_1 R_{2-NSC} + k(1+\eta)}$	$Z_2 + \frac{\lambda\theta_2 R_{1-NSC}}{k(1+\eta)} + \frac{2\theta_1 R_{2-NSC}}{(k+t)(1+\eta)}$	$Z_2 + \frac{\theta_2 R_{1-NSC} + 2\theta_1 R_{2-NSC}}{(k+t)(1+\eta)}$

$R_{1-NSC} = \frac{r_1 - \eta c_1}{4\theta_1 - \theta_2} \quad R_{2-NSC} = \frac{r_2 - \eta c_2}{4\theta_1 - \theta_2}$

- (2) α_{m-NSC}^{ij*} and CS_{m-NSC}^{ij*} are the decreasing functions of η .
- (3) For any $i = N$, Band $j = N, B$, $\alpha_{m-NSC}^{ij*} < \alpha_{m-PID}^{ij*}$, $CS_{m-NSC}^{ij*} < CS_{m-PID}^{ij*}$.

For $\Delta\alpha_{m-NSC}^{ij*} = \alpha_{m-PID}^{ij*} - \alpha_{m-NSC}^{ij*}(a)$ When $\frac{t}{k} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$, for e-commerce

seller1, $\begin{pmatrix} \Delta\alpha_{1-NSC}^{NN*} > \Delta\alpha_{1-NSC}^{NB*} > \Delta\alpha_{1-NSC}^{BN*} > \Delta\alpha_{1-NSC}^{BB*} \\ \Delta\alpha_{1-NSC}^{NN*} = \Delta\alpha_{1-NSC}^{NB*} > \Delta\alpha_{1-NSC}^{BN*} = \Delta\alpha_{1-NSC}^{BB*} \\ \Delta\alpha_{1-NSC}^{NB*} > \Delta\alpha_{1-NSC}^{NN*} > \Delta\alpha_{1-NSC}^{BB*} > \Delta\alpha_{1-NSC}^{BN*} \end{pmatrix}$ is established, and for

e-commerce seller2, $\begin{pmatrix} \Delta\alpha_{2-NSC}^{NN*} > \Delta\alpha_{2-NSC}^{NB*} > \Delta\alpha_{2-NSC}^{BN*} > \Delta\alpha_{2-NSC}^{BB*} \\ \Delta\alpha_{2-NSC}^{NN*} = \Delta\alpha_{2-NSC}^{NB*} > \Delta\alpha_{2-NSC}^{BN*} = \Delta\alpha_{2-NSC}^{BB*} \\ \Delta\alpha_{2-NSC}^{NB*} > \Delta\alpha_{2-NSC}^{NN*} > \Delta\alpha_{2-NSC}^{BB*} > \Delta\alpha_{2-NSC}^{BN*} \end{pmatrix}$ is established;

(b) When $\frac{t}{k} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$, $\begin{pmatrix} \Delta CS_1^{NN*} > \Delta CS_1^{NB*} > \Delta CS_1^{BN*} > \Delta CS_1^{BB*} \\ \Delta CS_1^{NN*} = \Delta CS_1^{NB*} > \Delta CS_1^{BN*} = \Delta CS_1^{BB*} \\ \Delta CS_1^{NN*} < \Delta CS_1^{NB*} > \Delta CS_1^{BN*} < \Delta CS_1^{BB*} \end{pmatrix}$ and

$\begin{pmatrix} \Delta CS_2^{NN*} > \Delta CS_2^{NB*} > \Delta CS_2^{BN*} > \Delta CS_2^{BB*} \\ \Delta CS_2^{NN*} = \Delta CS_2^{NB*} > \Delta CS_2^{BN*} = \Delta CS_2^{BB*} \\ \Delta CS_2^{NN*} < \Delta CS_2^{NB*} > \Delta CS_2^{BN*} < \Delta CS_2^{BB*} \end{pmatrix}$.

From (1) of Proposition 7, we first observe that the optimal product information disclosure level under capital constraint is lower than that under risk neutral condition. If the loan interest rate of banks is very high, our results prove that sellers will reduce the product information disclosure level. Correspondingly, consumer surplus will also decrease. This is also confirmed in (2) of Proposition 7. The higher the loan interest rate of a bank, the lower the product information disclosure level, not only for its own products, but also for the products of competitive platforms.

Proposition 7 (3) shows that under the condition of capital constraint, the optimal product information disclosure level will be lower than that without capital constraint, and the consumer surplus will also be lower. Proposition 7(3) compares the optimal level of product information disclosure and consumer surplus under insufficient funds and that under sufficient funds in the blockchain application. In this way we can also see the impact of blockchain on the level of product information disclosure and consumer surplus under capital constraints. First of all, we can see that when it is relatively large, we can get that for any party, the decreased amount of product information disclosure when blockchain is not applied is more than when blockchain is applied, and the more the sellers who do not apply blockchain, the more the information disclosure reduced. This shows that if the cost of applying blockchain is relatively high, blockchain will reduce the impact of capital constraints on product information disclosure. By analogy, when it is relatively small, the corresponding conclusion should be opposite. However, what is more interesting is that if it is relatively small, for any seller, the information disclosure is in the largest reduction when he/she does not apply blockchain and his competitors apply blockchain, while information disclosure is in the smallest reduction when he/she applies blockchain and his competitors do not apply blockchain.

(b) in (3) of Proposition 7 gives the comparison of the reduction of consumer surplus under capital constraints. We find that when t is relatively large, for any party, the consumer surplus reduction without blockchain application is more than that with blockchain application, and

the more the sellers without blockchain application, the more the consumer surplus reduction. This shows that if the cost of applying blockchain is relatively high, blockchain will reduce the impact of capital constraints on consumer surplus. Of course, when t is small, we get the opposite conclusion. This shows that the impact of blockchain on consumer surplus is mainly related to t .

Now, although information disclosure will increase the market demand, the situation will be more complicated in the case of capital constraints. From the conclusion of Proposition 7, we can easily find that when α_{m-NSC}^{ij*} is large enough, α_{m-NSC}^{ij*} will continue to decrease until it becomes 0. Therefore, in the case of financial constraints on sellers, should the platform not disclose any product information? According to the conclusion of Proposition 7, we can get Corollary 2, providing answers to the question. We define threshold $\bar{\eta}_m^{ij}$ as shown in “Appendix”. In particular, when only one seller applies blockchain, in order to distinguish which seller applies blockchain, we need to make the following explanation: if $m=1$, $\bar{\eta}_m^{ij}$ means $\bar{\eta}_1^{NB}$; if $m=2$, $\bar{\eta}_m^{ij}$ means $\bar{\eta}_2^{BN}$.

Corollary 2 For $m = 1, 2$ and $i = N, B, j = N, B$, if $\eta \geq \bar{\eta}_m^{ij}$, then $\alpha_{m-NSC}^{ij*} = 0$, and if $\eta < \bar{\eta}_m^{ij}$ then $\alpha_{m-NSC}^{ij*} > 0$.

Corollary 2 shows that when the bank’s loan interest rate exceeds a certain critical value, seller m ’s optimal decision is not to disclose any information. Through our model, we can easily understand, because if the bank’s loan interest rate is too high, the cost of information disclosure will be very large. If it exceeds the seller’s affordability, the seller’s further information disclosure will increase the market demand. But from the perspective of income, it is not worth the loss.

In order to get more insight, we analyzed the sensitivity of the critical threshold. The results are summarized in Table 5.

When the basic market demand of seller m is relatively large, the bank loan interest rate that seller a can bear will be lower, and if the basic market demand of his competitors is relatively large, the bank loan interest rate that seller m can bear will be higher. In other words, if their own basic market demand is greater, there is no need to make efforts to expand the market through information disclosure. Of course, if the competitor’s basic market is large, seller m needs to seize the competitor’s market through information disclosure. If the price of their own products is relatively high, the loan interest rate of affordable banks will be higher, because the income of products can offset the increase of costs. From the point of view of consumers’ trust in information, it is natural that the greater the degree of trust, the higher interest rates seller m can bear, which is the same for himself and his competitor. In general, any cost (including sales cost, information disclosure cost and blockchain application cost) is not conducive to any seller, and any cost is too large to make two sellers be in less information disclosure level.

Table 5 Sensitivity of the critical threshold

	$d_m \uparrow$	$p_m \uparrow$	$c_m \uparrow$	$\lambda \uparrow$	$k \uparrow$	$t \uparrow$
$\bar{\eta}_m^{ij}$	↓	↑	↓	↑	↓	↓
$\bar{\eta}_{m-}^{ij}$	↑	↓	↓	↑	↓	↓

From the conclusion of Proposition 7 (1), we can conclude that the optimal returns of both parties under the seller's financial constraints are shown in "Appendix A.4". Obviously, the seller's best return is related to the bank's lending rate. Similarly, in the case of financial constraints, as long as one party applies blockchain, the income of both parties will be related to t . Next, we want to explore whether t will affect the sensitivity of the optimal return to the bank loan interest rate. Proposition 8 can be obtained.

Proposition 8 *When the e-commerce seller does not have the start-up capital, and if he/she borrows money from the bank:*

- (1) For any i, j and m , When $0 \leq \eta < \bar{\eta}_m^{ij}$, Π_{m-NSC}^{ij*} is the decreasing function of η .
- (2) $\left| d\Pi_{m-NSC}^{ij*} / d\eta \right|$ is the decreasing function of t .

Proposition 8 (1) states that under financial constraints, the higher the bank's loan interest rate, the smaller the seller's income, because if the bank's loan interest rate is very high, all the seller's cost will become higher, which will reduce the seller's income.

We use $\left| d\Pi_{m-NSC}^{ij*} / d\eta \right|$ to express the influence of η on Π_{m-NSC}^{ij*} . Proposition 8 (2) illustrates the influence of η on Π_{m-NSC}^{ij*} changes with t . We found that if any seller uses blockchain, t affects the influence of η on Π_{m-NSC}^{ij*} . If t is larger, the influence of η on Π_{m-NSC}^{ij*} will be smaller. Combining with (1) we can see that if t is larger, then Π_{m-NSC}^{ij*} will decrease more slowly with the increase of η . This phenomenon means that if a seller applies blockchain, the two sellers' ability to bear the bank loan interest rate increases.

From Proposition 7 (1), we can get the optimal returns of both parties in different situations, we compare the benefits of all parties, and we can get the scenario of seller an applying blockchain. The specific results are represented by Proposition 9.

Proposition 9

- (1) When k and λ satisfy $\begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$, $\Pi_{1-NSC}^{BB*} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \Pi_{1-NSC}^{BN*}$, and $\Pi_{2-NSC}^{BB*} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \Pi_{2-NSC}^{NB*}$.
- (2) $\Pi_{1-NSC}^{NN*} < \Pi_{1-NSC}^{NB*}$, $\Pi_{2-NSC}^{NN*} < \Pi_{2-NSC}^{BN*}$.
- (3) If k and λ satisfy $\begin{pmatrix} > \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$ and $\frac{\sqrt{\lambda k}(k+t)-k\sqrt{k+t}}{\sqrt{\lambda k}-\lambda\sqrt{k+t}} \begin{pmatrix} > \\ < \end{pmatrix} \frac{(2\theta_1-\theta_2)R_{m-NSC}-\theta_m R_{m-NSC}-}{(1+\eta)Z_m}$, $\Pi_{m-NSC}^{NN*} > \Pi_{m-NSC}^{BB*}$, otherwise $\Pi_{m-NSC}^{NN*} \leq \Pi_{m-NSC}^{BB*}$.

The conclusions of (1) and (2) of Proposition 9 are the same as those of Proposition 3, that is, even under the financial constraints of sellers, when they make blockchain decisions, competitors' decisions on the application of blockchain have no change in their own income. However, in the case of financial constraints, the complete equilibrium of the seller's application blockchain has changed, as illustrated in Proposition 9 (3). There are still many similarities between Proposition 9 (3) and Proposition 6 (3), because $1 + \eta > 1$. Under the financial constraints of seller m , the unit income of seller m needs to reach a larger value in order to achieve the complete equilibrium of blockchain applied by both sides. Moreover, if the bank's lending rate is too high, a great unit income needed to achieve such equilibrium.

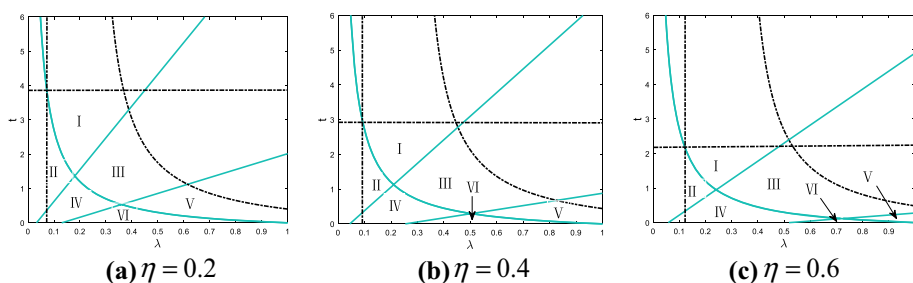


Fig. 5 Region of equilibrium for the application of blockchain under different interest rates

Therefore, we can think that the higher the loan interest rate of the bank, the more difficult it is to achieve the complete equilibrium of the application blockchain.

When the seller is risk-averse, the game equilibrium of blockchain application is the same as that mentioned in Proposition 1. In order to explore the impact of bank lending rates on the overall equilibrium, we further assign values to get the results shown in Fig. 5. Obviously, when the loan interest rate of the bank increases gradually, the area of region VI and region V decrease obviously, while the area other regions increase obviously.

5 Further analysis

The research and analyses in Sects. 3 and 4 are based on the fact that blockchain can ensure the information authenticity. But in practical application, the role of blockchain in information disclosure is far more beyond. In this part, according to the characteristics of blockchain, we focus on the significance that blockchain can contribute to e-commerce information disclosure.

5.1 Reducing σ_1 and σ_2

For a new market, e-commerce sellers will investigate and predict consumers' willingness to buy in advance, generally based on historical data or market data, no matter whether the data are distorted or unreliable. These distorted or unreliable data will lead to inaccurate predictions. The two blocks cannot be tampered with, and the traceability can increase the reliability. Transferring the required data through blockchain can ensure that the data will not be distorted in the process of transmission, and can also ensure that the data will not be tampered with. On the other hand, the traceability of blockchain can trace the source of the data, and further investigation of the historical data on the upper chain can further test its authenticity and reliability. Based on more accurate data, e-commerce sellers can predict market demand more accurately, so the application of blockchain can reduce σ_1 and σ_2 .

Theorem 2 *If blockchain is applied to predict consumers' willingness to buy, when e-commerce sellers avoid risk, compared with those not applying blockchain,*

- (1) *E-commerce sellers will reduce their information disclosure level after applying blockchain. At the same time, it will also reduce the competitors' information disclosure level.*
- (2) *It will also reduce the expected consumer surplus when consumers buy any product.*

(3) *E-commerce sellers always make a profit for their competitors after using blockchain.*

Theorem 2 shows that if e-commerce sellers use blockchain to predict consumers' purchasing intention, the market demand risk will be greatly reduced. For this reason, e-commerce sellers will not respond to the uncertain market to some extent. Meanwhile, the blockchain application by e-commerce sellers will not only have an impact on themselves, but also have an impact on their competitors. Even when competitors do not use blockchain to make predictions (the competitor's market risk is still high), competitors' response to market uncertainty will be reduced accordingly. For consumers, e-commerce sellers applying blockchain are disadvantageous to consumers, because the lower information disclosure level after the blockchain application will reduce the utility of consumers in purchasing products. If e-commerce sellers adopt blockchain, whether they can make a profit depends on the cost. But their competitors can reduce the market uncertainty without paying any price, so for any e-commerce seller, they want their competitors to adopt blockchain.

5.2 Reducing η

In fact, after receiving the loan request from the e-commerce seller, the bank will make relevant investigation. In order to get more loans, e-commerce sellers (especially some small e-commerce sellers) will package and fake their own information, resulting in that banks will spend more on fertilizer to check the authenticity of the information. If banks do not consider the amount of lending, banks will increase interest rates accordingly. However, blockchain can reduce information fraud to certain extent. If e-commerce sellers use blockchain, they will not continue to package their own information, because (1) the cost of counterfeiting is very high under the condition that blockchain is not allowed to be tampered with; (2) banks can also track the real information. For example, the loss of e-commerce sellers will outweigh the gain if they continue to counterfeit after using blockchain. In this way, the bank will not have to spend more to check the information authenticity, and the corresponding η will be reduced.

We assume that after the e-commerce seller applies the blockchain, the loan interest rate given by the bank is η' , and $\eta' < \eta$. Further analysis can get Theorem 3.

Theorem 3 *When e-commerce sellers lack start-up capital, if e-commerce sellers use blockchain to reduce bank loan interest rates, compared with those not using blockchain,*

when $\left(\frac{p_m}{(1+\eta')} - c_m\right) / \left(\frac{p_m}{(1+\eta)} - c_m\right) > \frac{k+t}{k}$, e-commerce sellers will increase the information disclosure, and consumer surplus will also increase. Its competitors will certainly increase the information disclosure, and the consumer surplus of competitors' products will also increase. E-commerce sellers always make a profit for their competitors after using blockchain.

As can be seen in Theorem 3, although the blockchain application can reduce e-commerce sellers' pressure on loans, this will indirectly lead e-commerce sellers to increase the information disclosure. However, considering that e-commerce sellers have to bear the cost after applying blockchain, if e-commerce sellers use blockchain to reduce bank loan interest rates, whether e-commerce sellers will increase the information disclosure depends on the cost of the application blockchain and the loan interest rate offered by the bank. If the loan interest rate given by banks after the applying blockchain is small enough, e-commerce sellers will naturally increase the information disclosure. At the same time, we should also note

that the key factors that determine whether the information disclosure of e-commerce sellers increases or not are the sales price and the production cost. In addition, similar to the conclusion drawn from Theorem 2, after e-commerce sellers apply blockchain, their competitors can also indirectly reduce loan costs, and the benefits gained by their competitors are cost-free. Therefore, its competitors can also make a great profit.

5.3 Increasing θ_1 and θ_2

As seen in Sects. 5.1 and 5.2, blockchain can avoid information fraud to a certain extent, which can indirectly reduce consumers' worries. As consumers gradually understand blockchain, consumers will think that the product that uses blockchain is a "high-quality product". Blockchain is gradually favored by people because of its high reliability. If blockchain is used in the process of product information disclosure, it will also increase consumers' sense of product identity. Accordingly, θ_1 and θ_2 will increase.

Theorem 4 *If e-commerce sellers use blockchain to increase consumers' preference for products, after e-commerce sellers use blockchain, their competitors will disclose more information, and the consumer surplus of buying competitors' products will also increase. At the same time, if only the e-commerce seller 1 applies blockchain, then the e-commerce seller 1 will have a greater advantage. But only the e-commerce seller 2 applies blockchain, the gap between the two sides will narrow, and the competition between the two sellers to disclose information will be fiercer.*

Theorem 4 shows that if e-commerce sellers apply blockchain, they will make themselves more competitive (from consumers' preferences), which blows their competitors. So, their competitors will increase the information disclosure to obtain the consumers' favor, so as to obtain more market demand. What we study is a market composed of e-commerce sellers with competitive advantages and e-commerce sellers with competitive disadvantages, so sellers with competitive advantages will naturally continue to increase their advantages after applying blockchain. Sellers with competitive disadvantages will continue to increase their information disclosure, which may lead to high cost, so it is quite disadvantageous to competitive inferior sellers. However, if the party with competitive disadvantages applies blockchain, it will narrow the competitive gap. If the two sides want to expand demand, they can only continuously increase the information disclosure, which leads to further competition.

6 Conclusions

Blockchain can ensure the validity and authenticity of information transmission in e-commerce supply chain. On the basis of fully considering the competitive relationship in e-commerce market (such as the competition between JD and Taobao), we regard the information disclosure as the competitive decision of two e-commerce sellers, and divide e-commerce sellers' decision-making into four research scenarios (neither of the two e-commerce sellers should use the blockchain, and the e-commerce seller applies the blockchain, e-commerce seller 2 applies blockchain, and both e-commerce sellers use blockchain). After solving the equilibrium results, the influence of blockchain is analyzed from the e-commerce sellers' and consumers' viewpoint. After that, we analyze the Nash equilibrium region of the blockchain applied by the e-commerce sellers. Considering the uncertainty of the utility of consumers buying products and the inadequate funds of e-commerce sellers, we expand these two cases

in the expansion model. Our research is only carried out on the basis of ensuring the authenticity of information in the blockchain, but the role of the blockchain is much more than that. We make a further analysis in Sect. 5 in view of the many functions of the blockchain in the information disclosure supply chain, and some conclusions are drawn.

To sum up, the main conclusions of this paper are as follows:

- (1) If only one seller uses blockchain, when the cost of blockchain application is very small, the high trust of consumers will drive the seller's, information disclosure. For consumer surplus, if the cost of blockchain application is relatively high, the results show that the blockchain application will reduce consumer surplus, and more consumer surplus will be reduced by self-application than by competitors, and the more the application subjects, the more the consumer surplus will be reduced. For the applied blockchain equilibrium, we give the equilibrium region about the blockchain cost and consumer trust.
- (2) Risk aversion will make the two competitive platforms set a high level of product information disclosure and obtain high consumer surplus. However, after the blockchain application, the level of information disclosure will be lower, but it has no effect on the increase of consumer surplus. In addition, the high cost of using blockchain will increase sellers' sensitivity to demand fluctuations. Based on the analysis of the equilibrium results, it is found that if the information is not transmitted relatively effectively before the blockchain application (the degree of trust of consumers to the product), with the increase of risk aversion, it is more difficult to achieve the Nash equilibrium of the blockchain application.
- (3) Under financial constraints, increasing lending rates will reduce the information disclosure and consumer surplus. Interestingly, if the cost of applying blockchain is high, applying blockchain will reduce this impact. If the blockchain is applied, the high cost reduces the seller's sensitivity to the loan interest rate. Based on the analysis of the equilibrium results, it is found that if the information is transmitted relatively high effectively before the blockchain application (the degree of trust of consumers to the product) is relatively high, with the increase of the bank loan interest rate, it will be more difficult to achieve the Nash equilibrium of the blockchain application.

We further analyze the other functions of blockchain: blockchain can accurately predict the utility of consumers to buy products, blockchain reduces bank lending rates, and blockchain increases consumer preference. We find that what we have in common under these three effects is that e-commerce sellers will increase the information disclosure after applying blockchain. But for themselves, whether to increase the information disclosure depends on the cost of applying blockchain.

Our study assumes that the information disclosure ability for two sellers is homogeneous. In the future, we can extend the study to the fact that it (unit information disclosure cost) is heterogeneous. And we can also consider exploring the impact of the two e-commerce sellers' information transmission efficiency and blockchain costs on their optimal decision-making.

Appendix

The optimal value of Λ_{mij}^* under different situation

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
Λ_{1-PCM}^{*ij}	$Z_1 + \frac{\lambda(2\theta_1 R_1 + \theta_1 R_2)}{k}$	$Z_1 + \frac{2\theta_1 R_1}{(k+t)} + \frac{\lambda\theta_1 R_2}{k}$	$Z_1 + \frac{2\lambda\theta_1 R_1}{k} + \frac{\theta_1 R_2}{(k+t)}$	$Z_1 + \frac{2\theta_1 R_1 + \theta_1 R_2}{(k+t)}$
Λ_{2-PCM}^{*ij}	$Z_2 + \frac{\lambda(\theta_2 R_1 + 2\theta_1 R_2)}{k}$	$Z_2 + \frac{\theta_2 R_1}{(k+t)} + \frac{2\lambda\theta_1 R_2}{k}$	$Z_2 + \frac{\lambda\theta_2 R_1}{k} + \frac{2\theta_1 R_2}{(k+t)}$	$Z_2 + \frac{\theta_2 R_1 + 2\theta_1 R_2}{(k+t)}$

The difference value of Λ_{mij}^* under different situation

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
$\Delta \Lambda_{1-NSC}^{ij*}$	$\frac{\lambda(2\theta_1\eta p_1 + \theta_1\eta p_2)}{k(1+\eta)}$	$\frac{2\theta_1\eta p_1}{(k+t)(1+\eta)} + \frac{\lambda\theta_1\eta p_2}{k(1+\eta)}$	$\frac{2\lambda\theta_1\eta p_1}{k(1+\eta)} + \frac{\theta_1\eta p_2}{(k+t)(1+\eta)}$	$\frac{2\theta_1\eta p_1 + \theta_1\eta p_2}{(k+t)(1+\eta)}$
$\Delta \Lambda_{2-NSC}^{ij*}$	$\frac{\lambda(\theta_2\eta p_1 + 2\theta_1\eta p_2)}{k(1+\eta)}$	$\frac{\theta_2\eta p_1}{(k+t)(1+\eta)} + \frac{2\lambda\theta_1\eta p_2}{k(1+\eta)}$	$\frac{\lambda\theta_2\eta p_1}{k(1+\eta)} + \frac{2\theta_1\eta p_2}{(k+t)(1+\eta)}$	$\frac{\theta_2\eta p_1 + 2\theta_1\eta p_2}{(k+t)(1+\eta)}$

Optimal profit of e-commerce sellers under different situation

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
$\Pi_1^{i,j*}$	$\frac{[kZ_1 + \lambda((2\theta_1 - \theta_2)\rho_1 R_1 - \theta_1 \rho_2 R_2)]^2}{\lambda k(\theta_1 - \theta_2)}$	$\frac{[-(k+t)Z_1 + (2\theta_1 - \theta_2)R_1 - \lambda \frac{k+t}{k} \theta_1 R_2]^2}{(k+t)(\theta_1 - \theta_2)}$	$\frac{[-kZ_1 + (2\theta_1 - \theta_2)\lambda R_1 - \frac{k}{k+t} \theta_1 R_2]^2}{\lambda k(\theta_1 - \theta_2)}$	$\frac{[-(k+t)Z_1 + (2\theta_1 - \theta_2)R_1 - \theta_1 R_2]^2}{(k+t)(\theta_1 - \theta_2)}$
$\Pi_2^{i,j*}$	$\frac{\theta_1[kZ_2 + \lambda((2\theta_1 - \theta_2)R_2 - \theta_2 R_1)]^2}{4\theta_2 \lambda k(\theta_1 - \theta_2)}$	$\frac{\theta_1[-kZ_2 + \lambda(2\theta_1 - \theta_2)R_2 - \theta_2 \frac{k}{k+t} R_1]^2}{\theta_2 \lambda k(\theta_1 - \theta_2)}$	$\frac{\theta_1[-(k+t)Z_2 + (2\theta_1 - \theta_2)R_2 - \lambda \theta_2 \frac{k+t}{k} R_1]^2}{\theta_2(k+t)(\theta_1 - \theta_2)}$	$\frac{\theta_1[-(k+t)Z_2 + (2\theta_1 - \theta_2)R_2 - \theta_2 R_1]^2}{\theta_2(k+t)(\theta_1 - \theta_2)}$

Optimal utility of e-commerce sellers with risk aversion

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$
U_1^{ij*}	$\frac{[-k(Z_1 + U A_1) + \lambda(2\theta_1 - \theta_2)R_1 - \theta_1 R_2]^2}{\lambda k(\theta_1 - \theta_2)}$	$\frac{[-(k+t)(Z_1 + U A_1) + (2\theta_1 - \theta_2)R_1 - \lambda \frac{k+t}{k} \theta_1 R_2]^2}{(k+t)(\theta_1 - \theta_2)}$
U_2^{ij*}	$\frac{\theta_1[-k(Z_2 + U A_2) + \lambda(2\theta_1 - \theta_2)R_2 - \theta_2 R_1]^2}{\theta_2 \lambda k(\theta_1 - \theta_2)}$	$\frac{\theta_1[-k(Z_2 + U A_2) + \lambda(2\theta_1 - \theta_2)R_2 - \theta_2 \frac{k+t}{k} R_1]^2}{\theta_2 \lambda k(\theta_1 - \theta_2)}$
	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
	$\frac{[-k(Z_1 + U A_1) + (2\theta_1 - \theta_2)\lambda R_1 - \frac{k+t}{k} \theta_1 R_2]^2}{\lambda k(\theta_1 - \theta_2)}$	$\frac{[-(k+t)(Z_1 + U A_1) + (2\theta_1 - \theta_2)R_1 - \theta_1 R_2]^2}{(k+t)(\theta_1 - \theta_2)}$
	$\frac{\theta_1[-(k+t)(Z_2 + U A_2) + (2\theta_1 - \theta_2)R_2 - \lambda \theta_2 \frac{k+t}{k} R_1]^2}{\theta_2(k+t)(\theta_1 - \theta_2)}$	$\frac{\theta_1[-(k+t)(Z_2 + U A_2) + (2\theta_1 - \theta_2)R_2 - \theta_2 R_1]^2}{\theta_2(k+t)(\theta_1 - \theta_2)}$

The difference value of optimal level of information disclosure under different situation

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
$\Delta\alpha_{1-NSC}^{ij*}$	$\frac{2\theta_1\eta p_1 + \theta_1\eta p_2}{k(1+\eta)}$	$\frac{2\theta_1\eta p_1}{(k+r)(1+\eta)} + \frac{\lambda\theta_1\eta p_2}{k(1+\eta)}$	$\frac{2\theta_1\eta p_1}{k(1+\eta)} + \frac{\theta_1\eta p_2}{\lambda(k+r)(1+\eta)}$	$\frac{2\theta_1\eta p_1 + \theta_1\eta p_2}{(k+r)(1+\eta)}$
$\Delta\alpha_{2-NSC}^{ij*}$	$\frac{\theta_2\eta p_1 + 2\theta_1\eta p_2}{k(1+\eta)}$	$\frac{\theta_2\eta p_1}{\lambda(k+r)(1+\eta)} + \frac{2\theta_1\eta p_2}{k(1+\eta)}$	$\frac{\lambda\theta_2\eta p_1}{k(1+\eta)} + \frac{2\theta_1\eta p_2}{(k+r)(1+\eta)}$	$\frac{\theta_2\eta p_1 + 2\theta_1\eta p_2}{(k+r)(1+\eta)}$

Optimal profit of e-commerce sellers with no start-up capital under different situation

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$
$\Pi_{1-NSC}^{i,j*}$	$\frac{[-k(1+\eta)Z_1 + \lambda((2\theta_1 - \theta_2)R_{1-NSC} - \theta_1 R_{2-NSC})]^2}{\lambda k(1+\eta)(\theta_1 - \theta_2)}$	$\frac{[-(k+t)(1+\eta)Z_1 + (2\theta_1 - \theta_2)R_{1-NSC} - \lambda \frac{k+t}{k} \theta_1 R_{2-NSC}]^2}{(k+t)(1+\eta)(\theta_1 - \theta_2)}$
$\Pi_{2-NSC}^{i,j*}$	$\frac{\theta_1[-k(1+\eta)Z_2 + \lambda((2\theta_1 - \theta_2)R_{2-NSC} - \theta_2 R_{1-NSC})]^2}{\theta_2 \lambda k(1+\eta)(\theta_1 - \theta_2)}$	$\frac{\theta_1[-k(1+\eta)Z_2 + \lambda(2\theta_1 - \theta_2)R_{2-NSC} - \theta_2 \frac{k+t}{k} R_{1-NSC}]^2}{\theta_2 \lambda k(1+\eta)(\theta_1 - \theta_2)}$
	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
	$\frac{[-k(1+\eta)Z_1 + (2\theta_1 - \theta_2)\lambda R_{1-NSC} - \frac{k+t}{k} \theta_1 R_{2-NSC}]^2}{\lambda k(1+\eta)(\theta_1 - \theta_2)}$	$\frac{[-(k+t)(1+\eta)Z_1 + (2\theta_1 - \theta_2)R_{1-NSC} - \theta_1 R_{2-NSC}]^2}{(k+t)(1+\eta)(\theta_1 - \theta_2)}$
	$\frac{\theta_1[-(k+t)(1+\eta)Z_2 + (2\theta_1 - \theta_2)R_{2-NSC} - \lambda \theta_2 \frac{k+t}{k} R_{1-NSC}]^2}{\theta_2(k+t)(1+\eta)(\theta_1 - \theta_2)}$	$\frac{\theta_1[-(k+t)(1+\eta)Z_2 + (2\theta_1 - \theta_2)R_{2-NSC} - \theta_2 R_{1-NSC}]^2}{\theta_2(k+t)(1+\eta)(\theta_1 - \theta_2)}$

The threshold of interest rate of the bank

	$\varphi_1 = 0, \varphi_2 = 0$	$\varphi_1 = 1, \varphi_2 = 0$	$\varphi_1 = 0, \varphi_2 = 1$	$\varphi_1 = 1, \varphi_2 = 1$
$\bar{\eta}_1$	$\frac{(4\theta_1 - \theta_2)(\lambda(2\theta_1 R_1 + \theta_1 R_2) + kZ_1)}{\lambda(2\theta_1 c_1 + \theta_1 c_2) - (4\theta_1 - \theta_2)kZ_1}$	$\frac{(4\theta_1 - \theta_2)(2\theta_1 k R_1 + \lambda\theta_1(k+t)R_2 + k(k+t)Z_1)}{2\theta_1 k c_1 + \lambda\theta_1(k+t)c_2 - (4\theta_1 - \theta_2)k(k+t)Z_1}$	$\frac{(4\theta_1 - \theta_2)(2\lambda\theta_1(k+t)R_1 + \theta_1 k R_2 + k(k+t)Z_1)}{2\theta_1 \lambda(k+t)c_1 + \theta_1 k c_2 - (4\theta_1 - \theta_2)k(k+t)Z_1}$	$\frac{(4\theta_1 - \theta_2)(2\theta_1 R_1 + \theta_1 R_2 + (k+t)Z_1)}{2\theta_1 c_1 + \theta_1 c_2 - (4\theta_1 - \theta_2)(k+t)Z_1}$
$\bar{\eta}_2$	$\frac{(4\theta_1 - \theta_2)(\lambda(2\theta_1 R_2 + \theta_2 R_1) + kZ_2)}{\lambda(2\theta_1 c_2 + \theta_2 c_1) - (4\theta_1 - \theta_2)kZ_2}$	$\frac{(4\theta_1 - \theta_2)(2\lambda\theta_1(k+t)R_2 + \theta_2 k R_1 + k(k+t)Z_2)}{2\theta_1 \lambda(k+t)c_2 + \theta_2 k c_1 - (4\theta_1 - \theta_2)k(k+t)Z_2}$	$\frac{(4\theta_1 - \theta_2)(2\theta_1 k R_2 + \lambda\theta_2(k+t)R_1 + k(k+t)Z_2)}{2\theta_1 k c_2 + \lambda\theta_2(k+t)c_1 - (4\theta_1 - \theta_2)k(k+t)Z_2}$	$\frac{(4\theta_1 - \theta_2)(2\theta_1 R_2 + \theta_2 R_1 + (k+t)Z_2)}{2\theta_1 c_2 + \theta_2 c_1 - (4\theta_1 - \theta_2)(k+t)Z_2}$

Proof of Proposition 1

(1) $\frac{\partial \Pi_{1-PID}^{NN}}{\partial \alpha_{1-PID}^{NN}} = \frac{(-c_1+p_1-k\alpha_{1-PID}^{NN})\lambda}{\theta_1-\theta_2} - k\left(1 - \frac{p_1-p_2+(-\alpha_{1-PID}^{NN}+\alpha_{2-PID}^{NN})\lambda}{\theta_1-\theta_2}\right)$ and $\frac{\partial^2 \Pi_{1-PID}^{NN}}{\partial \alpha_{1-PID}^{NN} \partial \alpha_{2-PID}^{NN}} = -\frac{2k\lambda}{\theta_1-\theta_2} < 0$, $\frac{\partial \Pi_{1-PID}^{NN}}{\partial \alpha_{1-CDM}^{NN}} = 0$, can be obtained $\alpha_{1-PID}^{NN} = \frac{(-c_1+p_1)\lambda+k(p_1-p_2-\theta_1+\theta_2+\alpha_{2-PID}^{NN}\lambda)}{2k\lambda}$, in the same way, $\frac{\partial \Pi_{2-PID}^{NN}}{\partial \alpha_{2-PID}^{NN}} = \frac{(-c_2+p_2)\theta_1\lambda+k(p_2\theta_1-p_1\theta_2-2\alpha_{2-PID}^{NN}\theta_1\lambda+\alpha_{1-PID}^{NN}\theta_2\lambda)}{(\theta_1-\theta_2)\theta_2}$ and $\frac{\partial^2 \Pi_{2-PID}^{NN}}{\partial \alpha_{2-PID}^{NN} \partial \alpha_{2-CDM}^{NN}} = -\frac{2k\theta_1\lambda}{(\theta_1-\theta_2)\theta_2} < 0$, then let $\frac{\partial \Pi_{2-PID}^{NN}}{\partial \alpha_{2-PID}^{NN}} = 0$, can be obtained $\alpha_{2-PID}^{NN} = \frac{(-c_2+p_2)\theta_1\lambda+k(p_2\theta_1-p_1\theta_2+\alpha_{1-PID}^{NN}\theta_2\lambda)}{2k\theta_1\lambda}$. The further solution of the values of α_{1-PID}^{NN} and α_{2-PID}^{NN} can be obtained $\alpha_{1-PID}^{NN} = \frac{Z_1}{\lambda} + \frac{2\theta_1 R_1 + \theta_1 R_2}{k}$, $\alpha_{2-PID}^{NN} = \frac{Z_2}{\lambda} + \frac{\theta_2 R_1 + 2\theta_1 R_2}{k}$. The similar methods for solving other optimal decision values in Proposition 1 are present.

Proof of Lemma 1

Because $(\varphi_m + (1 - \varphi_m)\lambda)$ is always greater than 0 and α_m is always greater than or equal to 0, Λ_m is always greater than or equal to 0, and $CS_m = \Lambda_m[\Lambda_m + d_m]$ is an increasing function about Λ_m , and in this paper, d_m is a constant, so CS_m is only positively related to Λ_m . So, the size and nature of CS_m^{ij*} is the same as that of Λ_m^{ij*} .

Proof of Proposition 2

(1) From Lemma 1, we can directly prove the properties of $\Lambda_{m^{ij}}^*$ and λ . Take $\Lambda_{m^{ij}}^*$ as an example, $\frac{d\Lambda_{m^{ij}}^*}{d\lambda} = \frac{2\theta_1 R_1 + \theta_1 R_2}{k} > 0$. Therefore, $\Lambda_{m^{ij}}^*$ is the λ increasing function, $CS_{m^{ij}}^*$ is the λ increasing function, and the properties of another consumer surplus are similar. (2) The proving process of part 2 (2) of Proposition 2 is similar to that of part (1). (3) Through the observation, it can be found that the size of $\Lambda_{m^{ij}}^*$ is related to the size of $\frac{\lambda}{k}$ and $\frac{1}{k+t}$. Through the solution, it is found that when $\frac{t}{k} > \frac{1}{\lambda} - 1$, $\Lambda_{m^{BB}}^* < \Lambda_{m^{BN}}^* < \Lambda_{m^{NB}}^* < \Lambda_{m^{NN}}^*$, then $CS_{m^{BB}}^* < CS_{m^{BN}}^* < CS_{m^{NB}}^* < CS_{m^{NN}}^*$. On the contrary, $CS_{m^{BB}}^* > CS_{m^{BN}}^* > CS_{m^{NB}}^* > CS_{m^{NN}}^*$.

Proof of Proposition 3

When the values of λ and t are in region I and region VI, $\Pi_1^{BB} > \Pi_1^{NN} > \Pi_1^{NB}$, $\Pi_2^{BB} > \Pi_2^{NN} > \Pi_2^{BN}$, $\Pi_1^{BB} > \Pi_1^{BN}$, $\Pi_2^{BB} > \Pi_2^{NB}$. Obviously, there is a unique game equilibrium $(\varphi_1, \varphi_2) = (1, 1)$ for the application of blockchain. When the values of λ and t are in region II and region V, $\Pi_1^{NN} > \Pi_1^{BB} > \Pi_1^{BN}$, $\Pi_2^{NN} > \Pi_2^{BB} > \Pi_2^{NB}$ and $\Pi_1^{NN} > \Pi_1^{NB}$, $\Pi_2^{NN} > \Pi_2^{BN}$. It is obvious that there is a unique game equilibrium $(\varphi_1, \varphi_2) = (0, 0)$ for blockchain application. When the values of λ and t are in region III, $\Pi_1^{BB} > \Pi_1^{NN} > \Pi_1^{NB}$, $\Pi_2^{NN} > \Pi_2^{BB} > \Pi_2^{NB}$ and $\Pi_1^{BN} > \Pi_1^{NN}$. The unique game equilibrium $(\varphi_1, \varphi_2) = (1, 0)$ can be obtained by underlining method. When the values of λ and t are in region IV, $\Pi_1^{NN} > \Pi_1^{BB} > \Pi_1^{BN}$, $\Pi_2^{BB} > \Pi_2^{NN} > \Pi_2^{BN}$, and $\Pi_1^{NB} > \Pi_1^{BB}$, $\Pi_2^{NB} > \Pi_2^{NN}$. The unique game equilibrium $(\varphi_1, \varphi_2) = (0, 1)$ can be obtained by underlining method.

Proof of Proposition 4

- (1). The proving process of Proposition 4 (1) is similar to that of Proposition 1 (1).
- (2). The conclusion in part 4 (2) of Proposition is obviously valid.

(1)

Proof of Proposition 5

- (1) Take the relationship between U_1^{ij*} and δ_m as an example to prove it: The derivations are obtained respectively:

$$\begin{aligned}\frac{dU_1^{NN*}}{d\delta_m} &= \frac{-2(-k(Z_1 + UA_1) + \lambda((2\theta_1 - \theta_2)R_1 - \theta_1 R_2)(dUA_1/d\delta_m))}{\lambda(\theta_1 - \theta_2)} \\ \frac{dU_1^{BN*}}{d\delta_m} &= \frac{-2(-(k+t)(Z_1 + UA_1) + (2\theta_1 - \theta_2)R_1 - \lambda\frac{k+t}{k}\theta_1 R_2)(dUA_1/d\delta_m)}{\theta_1 - \theta_2} \\ \frac{dU_1^{NB*}}{d\delta_m} &= \frac{-2(-k(Z_1 + UA_1) + \lambda(2\theta_1 - \theta_2)R_1 - \lambda\frac{k+t}{k}\theta_1 R_2)(dUA_1/d\delta_m)}{\lambda(\theta_1 - \theta_2)} \\ \frac{dU_1^{BB*}}{d\delta_m} &= \frac{-2(-(k+t)(Z_1 + UA_1) + (2\theta_1 - \theta_2)R_1 - \theta_1 R_2)(dUA_1/d\delta_m)}{\theta_1 - \theta_2}\end{aligned}$$

Obviously, under the premise that the sales volume is positive, the above formula molecules should be negative, so we can get $0 < UA_m < \overline{UA}_m^{ij}$.

- (2) The absolute value of the formula in (1) and the derivation of t can be obtained.

$\frac{d(|dU_1^{BN*}/d\delta_m|)}{dt} = \frac{2(-(Z_1 + UA_1) - \lambda\frac{\theta_1 R_2}{\theta_1 - \theta_2})(dUA_1/d\delta_m)}{\theta_1 - \theta_2}$, $\frac{d(|dU_1^{NB*}/d\delta_m|)}{dt} = \frac{-2\frac{\theta_1 R_2}{k}(dUA_1/d\delta_m)}{\lambda(\theta_1 - \theta_2)}$, $\frac{d(|dU_1^{BB*}/d\delta_m|)}{dt} = \frac{-2(Z_1 + UA_1)(dUA_1/d\delta_m)}{\theta_1 - \theta_2}$. If the above three expressions are greater than 0 respectively, $0 < UA_m < \overline{UA}_m^{ij}$ can be obtained. If the above three expressions are less than 0 respectively, $\overline{UA}_m^{ij} < UA_m < \overline{UA}_m^{ij}$ can be obtained. The methods of proving other conclusions are similar.

Proof of Proposition 6

The proving process of Proposition 6 is similar to Proposition 3.

Proof of Proposition 7

- (1) The proving process of Proposition 6 (1) is similar to that of Proposition 1 (1).

(2) The size relationship between α_{m-NSC}^{ij*} and α_{m-PID}^{ij*} can be easily compared, and accordingly, the relationship between CS_{m-NSC}^{ij*} and CS_{m-PID}^{ij*} can also be compared. After combining $\Delta\alpha_{1-NSC}^{ij*}$, it is found that $\Delta\alpha_{1-NSC}^{NN*} > \Delta\alpha_{1-NSC}^{BN*}$, $\Delta\alpha_{1-NSC}^{NN*} > \Delta\alpha_{1-NSC}^{BB*}$, $\Delta\alpha_{1-NSC}^{NB*} > \Delta\alpha_{1-NSC}^{BB*}$. We further compare the relationship between $\Delta\alpha_{1-NSC}^{BN*}$ and $\Delta\alpha_{1-NSC}^{NB*}$: if we assume $\Delta\alpha_{1-NSC}^{BN*} > \Delta\alpha_{1-NSC}^{NB*}$, we can get $\frac{t}{k} < \frac{(\lambda^2 - 1)p_1}{\lambda(2p_1 - \lambda p_2)} < 0$. This condition is obviously not true, so we can get $\Delta\alpha_{1-NSC}^{BN*} < \Delta\alpha_{1-NSC}^{NB*}$. When

$\frac{t}{k} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$, we found $n \Delta\alpha_{1-NSC}^{NN*} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \Delta\alpha_{1-NSC}^{NB*}, \Delta\alpha_{1-NSC}^{BN*} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \Delta\alpha_{1-NSC}^{BB*}$. In this

way, it is easy to compare the relationship between the variables. And $\Delta\alpha_{2-NSC}^{NN*} > \Delta\alpha_{2-NSC}^{NB*}$, $\Delta\alpha_{2-NSC}^{NN*} > \Delta\alpha_{2-NSC}^{BB*}$, $\Delta\alpha_{2-NSC}^{BN*} > \Delta\alpha_{2-NSC}^{BB*}$. We further compare the relationship between $\Delta\alpha_{2-NSC}^{BN*}$ and $\Delta\alpha_{2-NSC}^{NB*}$: if we assume that $\Delta\alpha_{2-NSC}^{BN*} > \Delta\alpha_{2-NSC}^{NB*}$, then we can solve $\frac{t}{k} > \frac{(\lambda^2-1)p_1/\theta_1}{\lambda(P_2/\theta_2-\lambda P_1/\theta_1)} < 0$. This condition is obviously true. So, we can get

$\Delta\alpha_{2-NSC}^{BN*} > \Delta\alpha_{2-NSC}^{NB*}$. When $\frac{t}{k} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{1-\lambda}{\lambda}$, we find that $\Delta\alpha_{1-NSC}^{NN*} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \Delta\alpha_{1-NSC}^{BN*}$,

$\Delta\alpha_{1-NSC}^{NB*} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \Delta\alpha_{1-NSC}^{BB*}$ so that it is easy to compare the relationship between variables.

(b) Quotes the conclusion of Lemma 1.

We only compare the size relationship of $\Delta\alpha_m^{NN*}$. When $\frac{t}{k} > \frac{1-\lambda}{\lambda}$, we can find that $\Delta\alpha_1^{NN*} > \Delta\alpha_1^{BN*} > \Delta\alpha_1^{BB*}$ and $\Delta\alpha_2^{NN*} > \Delta\alpha_2^{NB*} > \Delta\alpha_2^{BB*}$. Further compare the relationship between $\Delta\alpha_m^{BN*}$ and $\Delta\alpha_m^{NB*}$: suppose $\Delta\alpha_1^{BN*} > \Delta\alpha_1^{NB*}$, we can get $p_2 > 2p_1$. This conclusion is contradictory to our basic hypothesis, so $\Delta\alpha_1^{BN*} < \Delta\alpha_1^{NB*}$; hypothesis $\Delta\alpha_2^{BN*} > \Delta\alpha_2^{NB*}$. We can get $\frac{2p_2}{\theta_2} > \frac{p_1}{\theta_1}$, corresponding to our basic hypothesis, so $\Delta\alpha_2^{BN*} > \Delta\alpha_2^{NB*}$ holds.

Proof of Proposition 8

(1) We prove this Proposition by the relationship between Π_{1-NSC}^{ij*} and η .

$$\frac{d\Pi_{1-NSC}^{NN*}}{d\eta} = \frac{-(4\theta_1 - \theta_2)kZ_1(1 + \eta) - \lambda(2\theta_1 - \theta_2)(p_1 + (1 + \eta)c_1) + \lambda\theta_1(p_2 + (1 + \eta)c_2)}{\lambda k(1 + \eta)^2(\theta_1 - \theta_2)}$$

If $1 + \eta < \frac{\lambda(2\theta_1 - \theta_2)p_1 - \lambda\theta_1 p_2}{-kZ_1 - \lambda(2\theta_1 - \theta_2)c_1 + \lambda\theta_1 c_2} < 0$, obviously $\frac{d\Pi_{1-NSC}^{NN*}}{d\eta} < 0$. Similarly, we can prove that the other three cases are true in the same way. However, due to the limitation of η , we must ask $0 \leq \eta < \frac{1}{\eta_m}$.

(2)

$$\begin{aligned} \left| \frac{d\Pi_{1-NSC}^{BN*}}{d\eta} \right| &= \frac{(4\theta_1 - \theta_2)Z_1(1 + \eta) + \frac{(2\theta_1 - \theta_2)(p_1 + (1 + \eta)c_1)}{k+t} - \frac{\lambda}{k}\theta_1(p_2 + (1 + \eta)c_2)}{(1 + \eta)^2(\theta_1 - \theta_2)}, \\ \left| \frac{d\Pi_{1-NSC}^{NB*}}{d\eta} \right| &= \frac{(4\theta_1 - \theta_2)kZ_1(1 + \eta) + \lambda(2\theta_1 - \theta_2)(p_1 + (1 + \eta)c_1) - \frac{k+t}{k}\theta_1(p_2 + (1 + \eta)c_2)}{\lambda k(1 + \eta)^2(\theta_1 - \theta_2)}, \\ \left| \frac{d\Pi_{1-NSC}^{BB*}}{d\eta} \right| &= \frac{(4\theta_1 - \theta_2)Z_1(1 + \eta) + \frac{(2\theta_1 - \theta_2)(p_1 + (1 + \eta)c_1) - \theta_1(p_2 + (1 + \eta)c_2)}{k+t}}{(1 + \eta)^2(\theta_1 - \theta_2)}, \end{aligned}$$

Obviously, the above three expressions are t decreasing functions.

Proof of Proposition 9

The proving process of Proposition 9 is similar to Proposition 4.

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