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Strategy Analysis of Fresh Agricultural Enterprises in a Competitive Circumstance: The Impact of Blockchain and Consumer Traceability Preferences

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Abstract: Blockchain technology allows fresh agricultural enterprises to share records stored on the chain, and the technology can benefit information management systems, such as decentralization and transparency. This study uses game theory to examine a blockchain introduction strategy for fresh agricultural enterprises in a competitive environment, considering consumer traceability preferences. We establish a pricing decision model in traditional and blockchain traceability modes and identify optimal solutions. Additionally, we analyze the impact of the blockchain introduction strategy, consumer preferences, and blockchain influence factor on optimal pricing decisions. The results indicate that the introduction of blockchain could improve the profits of enterprises under certain conditions. Moreover, consumer traceability preferences and the blockchain influence factor could significantly affect the blockchain introduction strategy. We also discover that when the blockchain influence factor meets a certain range, introducing blockchain technique in the traceability system could shift demand from traditional enterprises to blockchain enterprises. The total market demand for blockchain enterprises under the blockchain traceability mode will increase, whereas that of traditional enterprises under the blockchain traceability mode will decrease. Both consumer traceability preferences and the blockchain influence factor could significantly affect optimal pricing. Finally, some management suggestions are provided for the traceability of fresh agricultural enterprises based on the research conclusions.

Keywords: blockchain; consumer traceability preferences; fresh agricultural products; competitive environment

MSC: 91A80

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1. Introduction

Fresh agricultural product traceability has always been a major concern for consumers. As consumers pay more attention to their health, they have higher requirements regarding the sensory quality of the products, such as taste, texture, color, and shape, and the internal quality and hygienic quality, such as ingredients, nutrients, harmful substances, pesticide residue, and mildew [1,2]. Based on experimental research, Dickinson and Bailey [3] showed that consumers are willing to pay more for the traceability and transparency of meat products. Recently, electronic trade among the supply chain members of agricultural products has become popular, which makes it more difficult to authenticate and track information in their production, processing, and distribution processes [4]. Dalian sea cucumber, Yangcheng Lake crab, Wuchang rice, and other branded agricultural products have been subject to information fraud incidents. Additionally, it is difficult for the consumer to trace accurate information about agricultural products. Food traceability is related to the behavior of all members in a supply chain, and information fraud committed by any member may reduce the authenticity and effectiveness of traceability.

In 1993, the Escherichia coli scare was the largest food crisis in the United States [5]. In 2011, bean sprouts contaminated with Escherichia coli caused many people to be infected in Germany [6]. From 2016 to 2019, many consumers complained on the Pinduoduo website because of rotting fruit. Some famous brands of agricultural products, such as Wuchang rice, Yangcheng Lake hairy crabs, Gannan navel oranges, West Lake Longjing tea, and Aksu apples, are often counterfeited [7]. Governments and enterprises have attempted to use various information technologies to solve the problems related to information opacity and authenticity in the agricultural product supply chain. For example, the European Union uses the RSS (Reduced Space Symbology) barcode system and the EAN/UCC (European Article Number/Uniform Code Council) identification system to track the quality of beef, vegetables, and other products. Some companies use the tracking system of the Internet of Things (IoT) to track the quality of products [8]. Other enterprises use the NetMES system based on a cloud platform to address information asymmetry in the supply chain. However, the above initiatives have failed because the traditional traceability systems are usually based on centralized information management systems, and information can be easily tampered with and forged [9,10]. As a result, the traditional traceability systems significantly damage consumers' trust in product authenticity. It is challenging to trace food effectively and ensure the authenticity of product traceability chain information.

Blockchain technology is feasible and has certain advantages in ensuring the traceability and authenticity of the food supply chain [11]. The traceability system based on blockchain technology is a decentralized database system with distinguishing features, such as credibility, security, and immutability [12]. In recent years, some fresh agricultural enterprises have joined the TAC platform (a traceability cloud platform based on blockchain technology) to trace agricultural products. Consumers can seek information on this platform concerning aspects such as the production date, batch, producer, and ingredients list. For example, Cainiao and Tmall Global enabled blockchain technology to trace the origin of cross-border imports in February 2018. By the end of 2019, more than 800 cooperative brands and more than 70,000 products joined JD Zhizhen Chain's anti-counterfeiting and traceability platform. According to "the report of Blockchain Traceability Service Innovation and Application in 2020," jointly released by Ceibs Supply Chain and Service Innovation Center and JD Digits, after brand owners adopted the blockchain anti-counterfeiting traceability service, the sales of nutritional health products and the visits of nutritional health products increased by 30%, while their repurchase rate increased by 44.8% and return rate decreased by 4.5%.

The traceability of fresh agricultural products is different from that of industrial products. Fresh agricultural products are perishable, and their shelf-life is considerably shorter. The value of fresh agricultural products rapidly drops to zero once the shelf-life is exceeded. It is impossible to resell these products once they have been returned. Therefore, the return loss may affect the decision of the supply chain members of fresh agricultural products. Simultaneously, the development cost of a blockchain project is hundreds of thousands up to millions, and this cost will fluctuate with the development difficulty. It is usually a huge expense for a business. The storage cost of wholly traceable data is another significant expense. Storing traceability data directly on the chain and backing up the stored data at all nodes will require a large amount of memory capacity and will increase the maintenance costs of a traceability system. The storage cost of a traceability database based on the blockchain technique is thousands of times higher than that of a traditional traceability database based on a distributed system or cloud storage technique. According to rough estimates, 1 KB of Ethereum storage costs about USD 1.58 [13]. In addition, the blockchain traceability system of the fresh products supply chain requires all nodes on the blockchain to be backed up and store data. This makes it easy to cause repetitive storage and increase memory consumption, thus increasing the maintenance cost of the traceability system. The costs related to blockchain are a colossal expense for enterprises. Additionally, Liu et al. [14] showed that consumers are more willing to pay for fresh agricultural products. The huge initial development and operating costs greatly reduce the willingness of companies in the food supply chain to adopt blockchain technology [15]. In reality, not all enterprises adopt blockchain technology; for example, Dalian sea cucumber brands such as Fortune Island and Sha Tuozi Island adopt blockchain traceability of sea cucumber products in various links, including breeding, seedling rearing, culture, and processing. Sea Star Island, Ocean Island, and other enterprises adopt the traditional traceability system to trace the origin of sea cucumber products.

In this study, we build a game model to investigate enterprise practice and the under-explored role played by blockchain in the traceability of fresh agricultural enterprises in competitive circumstances. We attempt to theoretically address the following research questions:

(1) In a competitive context, should fresh agricultural enterprises introduce blockchain technology?
(2) How does the blockchain influence factor affect the optimal pricing and profits of fresh agricultural enterprises?
(3) How would the traceability preferences of consumers affect the optimal pricing and profits of fresh agricultural enterprises?

Inspired by the observed management practice of the fresh agricultural product supply chain, this study first analyzed the optimal pricing and profits of enterprises of fresh agricultural products under a scenario where two enterprises adopt a traditional traceability mode considering consumers' traceability preferences in a competitive environment. Furthermore, we investigated the optimal pricing strategy and profits under a scenario where one enterprise adopts a blockchain traceability mode, and the other adopts a traditional traceability mode. We identify the condition of introducing blockchain traceability for the enterprise in a competitive environment and how blockchain influence factor and consumers' traceability preferences affect the optimal pricing of fresh agricultural enterprises. Unlike previous research, our study is theoretical. It explores the introduction strategy of blockchain technology to the traceability system of the agricultural product supply chain in two competitive enterprises. We examine the optimal pricing and profits of fresh agricultural enterprises under the traditional traceability mode and blockchain traceability mode with game theory. Furthermore, we examine the impact of the blockchain influence factor and consumers' traceability preferences. Novel insights and managerial implications are proposed.

Our paper is organized as follows. We review the related literature in Section 2. In Section 3, we build the basic theoretical model and explore the use of blockchain and government measures in Section 4. We formally conclude this study with suggestions for future research and management implications in Section 5. To improve readability, all technical proofs are presented in the Appendices A–F.

2. Literature Review

This study is closely related to the applications of blockchain in supply chain management, food traceability systems, and the impact of blockchain on operations management.

The literature concerning blockchain applications in supply chain management abounds. For example, Chod et al. [16] analyzed the application of blockchain in supply chain financing. Sander et al. and Tian et al. studied the feasibility of applying blockchain to operations management [17,18]. Azzi et al. [19] studied the challenges faced by the blockchain-based supply chain management ecosystem. Kshetri [20] further analyzed the impact of blockchain on supply chain objectives, such as cost, quality, speed and reliability, based on a case study. Ivanov et al. [21] studied the impact of digitalization and Industry 4.0 on supply chain reaction and disruption risk control analysis. Kamble et al. [22] developed a research model integrating the technology readiness index (TRI), technology acceptance model (TAM), and the theory of planned behavior (TPB) to examine the adoption of blockchain in the supply chain. They found that supply chain practitioners perceive BT adoption as effortless and believe it would help derive maximum benefits for improving supply chain effectiveness. Wang et al. [23] mainly used cognitive mapping and narrative analysis to evaluate people's cognitive complexity in understanding blockchain technology. They found that senior executives believe the blockchain can bring benefits such as improved tracking and traceability to the supply chain. Saberi et al. [24] studied how to use blockchain technology to design an intelligent signing mechanism in the sustainable supply chain. Duan et al., Li et al. and Pandey et al. [25–27] used content analysis to discuss the application, challenges, and future trends of blockchain in the food supply chain. Khan et al. [28] used the interview method to analyze the benefits and challenges of applying blockchain technology to agricultural supply chains during the COVID-19 pandemic and proposed solutions. Kouhizadeh et al. [29] discussed the cases and potential applications of blockchain technology in the supply chain. The above-mentioned literature discusses the feasibility, advantages, and challenges of different supply chains based on case studies, sense-making theory, and so on. We use game theory to investigate an introduction strategy for fresh agricultural enterprises in a competitive market.

The second study theme is a traceability system for fresh produce. Recently, some scholars focused on how blockchain affects the traditional traceability system. Deng et al. [30] analyzed the feasibility of using blockchain technology in food traceability. Behnke and Janssen [31] analyzed the boundary conditions when blockchain was applied to the food supply chain traceability through case analysis and interviews. Stranieri et al. and Wang et al. [32,33] found that the traceability system has a positive effect on the food market and enhances the consumer experience. Stuller and Rickard [34] investigated melon planting and processing enterprises in California, USA, and found that litigation concerns and firm reputation are the key drivers for maintaining traceability. Pouliot and Sumner [35] pointed out that food safety declines with rising numbers of farms and marketers, and imperfect traceability from consumers to marketers dampens farm liability incentives. Resende-Filho et al. [36] studied the supply chain composed of upstream and downstream food enterprises and discussed the quality improvement of upstream enterprises based on the accuracy of the traceability system. Gong and Chen [37] examined the impact of traceability on improving food safety levels in the supply chain and the profits of upstream and downstream enterprises. Aiello [38] used stochastic mathematical programming to evaluate the operational efficiency of the traceability system of the food supply chain. Cao et al. [39] designed a blockchain-based human–computer verification mechanism to strengthen consumers' trust in the traceability of the cross-border beef supply chain between Australia and China. Some scholars have studied traceability optimization decisions or incentive mechanisms under the influence of different factors. Dai et al. [40] analyzed the interactions of traceability and reliability optimization in a competitive environment with a product recall. Given the differences in the traceability of suppliers, Hastig and Sodhi [41] analyzed the need for implementing traceability systems in the cobalt mining and pharmaceutical industries and analyzed the key success factors of implementing the blockchain. This article extends the research on the traditional and blockchain traceability modes for fresh agricultural enterprises, focusing on the introduction strategy in the presence of demand competition, which is a further supplement to the above-mentioned literature.

Our third research stream relates to operational management based on the blockchain using a quantitative method model. Choi [42] assumed that the consumers' choice of products is related to the detection time of the product and the falseness of the product, and they analyzed the impact of blockchain technology on social welfare with uncertain demand. Zhang and Luo [43] proposed a traceability solution based on blockchain technology from the perspective of consumer rights. Yan et al. [44] analyzed the impact of blockchain technology on the upstream and downstream enterprises of the supply chain. Fan et al. [45] studied the optimal pricing strategies of the supply chain, considering the consumers' traceability awareness. Cao et al. [46] analyzed the impact of blockchain on the decisions of platforms in the agricultural product supply chain. He et al. [47] analyzed the impact of blockchain technology on the optimal decision for cross-order e-commerce platforms and foreign suppliers selling fresh products. As consumers pay increasing attention to product traceability, the verifiability and traceability of information are regarded as important standards for evaluating product quality, and product traceability is regarded as an important criterion for evaluating product quality. According to a report from IBM, 71% of consumers are willing to purchase traceable products at 37% higher prices. Zhou et al. [48] showed that consumers' organic preferences could affect the production and sales decisions of the fresh agricultural products supply chain. Closely related is blockchain introduction strategies for supply chains in a competitive market. Considering consumers' quality sensitivity, Feng et al. [49] analyzed the impact of blockchain technology on optimal pricing and quality decisions in the case of two competing platforms. Liu et al. [50] explore whether the E-platforms choose reselling or agency selling for fresh food in competition with different traditional retailers. They found that the competition between traditional and online channels could incentivize firms to invest more in product freshness and blockchain-enabled traceability goodwill. Assuming the consumers' traceability awareness as the sensibility to authentic and verifiable traceability information, Wu et al. [51] analyze a strategy for adopting blockchain technology in the fresh produce supply chain between two competitive supply chains. They find that when one supply chain adopts BT, the other may be a free rider. Different from the literature mentioned above, we focus on the introduction strategy of the blockchain between two competitive enterprises of fresh agricultural products. We extend the consumers' traceability preferences for fresh agricultural products to more realistic factors. We infer that consumers' traceability preferences relate to the consumers' sensitivity to the detection time of fresh agricultural products and to the falseness of the product and are also related to consumers' return loss and the probability of consumers' return. We also consider consumers' transfer cost and blockchain cost to investigate the interactive activities of enterprises in different traceability modes. Unlike Wu's conclusion, we find that under competitive circumstances, the enterprise adopting the blockchain traceability mode gains a competitive advantage, and the other enterprise adopting the traditional traceability mode is not a free rider when the blockchain influence factor is in a certain range.

In summary, the major contributions of this study lie in the following aspects. First, we identify the specific conditions needed for adopting blockchain technology to trace fresh agricultural products between two competitive enterprises, which has not been explored in previous studies. Second, we note that the blockchain influence factor has a significant impact on the introduction of blockchain technology. Third, extending the utility function of the consumers' traceability preference as information authenticity, product detection, and the falseness of the product, we prove that consumers' traceability preferences have a significant impact on the introduction of blockchain technology. Finally, we offer some important and valuable managerial insights for the literature and practice through this study. When consumers have a high preference for traceability and the blockchain influence degree is within a certain range, enterprises should adopt a blockchain traceability system. In a competitive market, enterprises that adopt the blockchain traceability system have a competitive advantage. The introduction strategy of blockchain is not only related to the consumers' traceability preference but also to the transfer cost of consumers and the input cost of blockchain. We also find that enterprises adopting blockchain traceability systems gain more customers than enterprises adopting traditional traceability systems.

3. Model Setting and Analysis

3.1. Competitive Decisions under the Traditional Traceability Mode

Suppose that two agricultural enterprises are selling similar agricultural products in a competitive market. The products provided by the two enterprises can be substituted for each other. The decision-making order of this article is that the enterprises first choose whether to introduce blockchain technology, and then consumers choose the enterprises' products. Assuming that enterprises use blockchain traceability, their entire supply chain also uses blockchain traceability.

Suppose that the market prices of enterprises 1 and 2 are p_1 and p_2, respectively, and their production costs are the same. To simplify the calculation, it can be assumed that the production cost is zero. Choi [42] assumed that the consumers' choice of products is related to the detection time of the product and the falseness of the product. Different from Choi's assumption, we suppose that consumers' traceability preference relates to the consumers' sensitivity to the detection time of fresh agricultural products and to the falseness of the product, and it is also related to consumers' return loss and the probability of consumers' return. Suppose that B represents the possibility of consumer return as a result of the disclosure of false information by traditional enterprises. ξ denotes the enterprise's return loss and τ denotes consumers' return loss. Assume that the total demand of the agricultural product market is one, and enterprises 1 and 2 cover the entire market. When neither enterprise 1 nor 2 joins the blockchain (that is, both enterprises are traditional enterprises), consumers' utilities of enterprises 1 and 2 are as follows.

$$U_1 = v - (p_1 + \beta t + (1-\alpha)\gamma - q) - kx - B\tau, \tag{1}$$

$$U_2 = v - (p_2 + \beta t + (1-\alpha)\gamma - q) - k(1-x) - B\tau, \tag{2}$$

where v represents consumers' retention value of the product, x represents the consumers' psychological position between the two enterprises, and k represents the unit transfer cost of consumers' purchases from one enterprise to the other. Here, t represents the checking time of fresh agricultural products, q represents the quality of the agricultural products, and α represents the possibility that consumers believe the information of the agricultural products is false. β and γ represent the consumers' sensitivity to the detection time of fresh agricultural products and to the falseness of the product, respectively [42].

Consumers will buy from enterprise1 only when $U_1 \geq U_2$, that is, $v - (p_1 + \beta t + (1-\alpha)\gamma - q) - kx - B\tau \geq v - (p_2 + \beta t + (1-\alpha)\gamma - q) - k(1-x) - B\tau$. We can obtain $x \leq \frac{p_2 - p_1 + k}{2k}$.

Therefore, the market demand of enterprises 1 and 2 is, respectively,

$$D_1 = \frac{p_2 - p_1 + k}{2k}, \tag{3}$$

$$D_2 = \frac{p_1 - p_2 + k}{2k}. \tag{4}$$

The profits of enterprise 1 and 2 are, respectively,

$$\pi_1 = p_1 \cdot \frac{p_2 - p_1 + k}{2k} - B\xi \cdot \frac{p_2 - p_1 + k}{2k}, \tag{5}$$

$$\pi_2 = p_2 \cdot \frac{p_1 - p_2 + k}{2k} - B\xi \cdot \frac{p_1 - p_2 + k}{2k}. \tag{6}$$

Let $\frac{\partial \pi_1}{\partial p_1} = 0$, $\frac{\partial \pi_2}{\partial p_2} = 0$, we can obtain Lemma 1.

Lemma 1. *In the traditional traceability mode, the optimal pricing for enterprises 1 and 2 is* $p_1^* = p_2^* = k + B\xi$, *the total market demand for enterprises 1 and 2 is* $D_1^* = D_2^* = \frac{1}{2}$, *and the maximum profit for enterprises 1 and 2 is* $\pi_1^* = \pi_2^* = \frac{k}{2}$.

Since $\frac{\partial p_1^*}{\partial k} = \frac{\partial p_2^*}{\partial k} = 1$, $\frac{\partial \pi_1^*}{\partial k} = \frac{\partial \pi_2^*}{\partial k} = \frac{1}{2}$, the optimal pricing and the profit of both parties increase with an increase in the unit transfer cost.

$\frac{\partial p_1^*}{\partial B} = \xi$, $\frac{\partial p_1^*}{\partial \xi} = B$, $\xi > 0$, $B > 0$, that is, the optimal pricing of both parties increases with an increase in the possibility of consumer return and the enterprise's return loss. Therefore, an optimal solution for both parties' pricing decisions exists when neither enterprise 1 nor 2 joins the blockchain. The unit transfer cost, the possibility of consumer return, and the enterprise's return loss could affect the optimal pricing and profit of both parties. The optimal pricing decision and profit of both parties increase as the switching cost increases. Additionally, the optimal pricing of both parties increases as the possibility of consumer return and the enterprise's return loss increase.

3.2. Competitive Decision-Making under the Blockchain Traceability Mode

Suppose that enterprise 1 uses blockchain technology to trace the quality of agricultural products, and enterprise 2 does not adopt blockchain technology. Compared with the traditional traceability system, the blockchain traceability system can ensure information security and maintain consumers' trust in the authenticity of product information. Therefore, when enterprise 1 uses blockchain technology to trace the source of agricultural products, consumers believe that the probability of agricultural product information fraud is zero; that is, $\alpha = 0$; the probability of consumer returns because of false information provided by enterprises is zero, that is, $B = 0$. The quality of the agricultural products becomes Q $(Q \geq q)$, and the evaluation time becomes T $(T < t)$. Enterprise $1'$s blockchain input cost is C.

Suppose that consumers have traceability preferences, such that the higher the degree of traceability preferences, the more likely consumers are willing to select products with blockchain traceability. Suppose that there are two types of consumers in the market, namely consumers with a high traceability preference (H) and those with a low traceability preference (L), where the proportion of the former in the market is θ. T and t represent the quality evaluation time for blockchain agricultural products and traditional agricultural products, respectively. Q and q denote the quality of blockchain agricultural products and traditional agricultural products, respectively. Consumers with a high traceability preference will buy agricultural products directly from enterprise 1 instead of enterprise 2. Consumers with a low traceability preference are likely to buy from enterprises 1 or 2. Enterprise 1 uses blockchain and is referred to as a blockchain enterprise, and Enterprise 2 does not use blockchain and is referred to as a traditional enterprise. The utility of consumers with a low traceability preference is, respectively,

$$U_1{}^L = v - (\overline{p}_1 + \beta T - Q) - kx, \tag{7}$$

$$U_2{}^L = v - (\overline{p}_2 + \beta t + (1-\alpha)\gamma - q) - k(1-x) - B\tau. \tag{8}$$

when $U_1{}^L > U_2{}^L$, consumers with a low traceability preference will buy agricultural products from the blockchain enterprise. The solution is $x < \frac{\overline{p}_2 - \overline{p}_1 + \beta\Delta t - \Delta q + (1-\alpha)\gamma + k + B\tau}{2k}$; therefore, the demand of consumers with a low traceability preference in the market for enterprises 1 and 2 are, respectively,

$$D_1{}^L = \frac{\overline{p}_2 - \overline{p}_1 + \beta\Delta t - \Delta q + (1-\alpha)\gamma + k + B\tau}{2k}(1-\theta), \tag{9}$$

$$D_2{}^L = \frac{\overline{p}_1 - \overline{p}_2 - \beta\Delta t + \Delta q - (1-\alpha)\gamma + k - B\tau}{2k}(1-\theta). \tag{10}$$

The total market demand of enterprises 1 and 2 are, respectively,

$$D_1^B = D_1{}^L + D^H = \frac{\overline{p}_2 - \overline{p}_1 + \beta\Delta t - \Delta q + (1-\alpha)\gamma + k + B\tau}{2k}(1-\theta) + \theta, \tag{11}$$

$$D_2^B = D_2{}^L = \frac{\overline{p}_1 - \overline{p}_2 - \beta\Delta t + \Delta q - (1-\alpha)\gamma + k - B\tau}{2k}(1-\theta). \tag{12}$$

The profit of enterprises 1 and 2 are, respectively,

$$\pi_1^B = \overline{p}_1 \cdot \left[\frac{\overline{p}_2 - \overline{p}_1 + \beta\Delta t - \Delta q + (1-\alpha)\gamma + k + B\tau}{2k}(1-\theta) + \theta\right] - C, \tag{13}$$

$$\pi_2^B = (\overline{p}_2 - B\xi)\cdot\frac{\overline{p}_1 - \overline{p}_2 - \beta\Delta t + \Delta q - (1-\alpha)\gamma + k - B\tau}{2k}(1-\theta). \quad (14)$$

Let $\frac{\partial \pi_1^B}{\partial \overline{p}_1} = 0, \frac{\partial \pi_2^B}{\partial \overline{p}_2} = 0$, we can obtain

$$\overline{p}_1 = \frac{\overline{p}_2}{2} + \frac{y + B\tau + k}{2} + \frac{k\theta}{1-\theta,} \quad (15)$$

$$\overline{p}_2 = \frac{\overline{p}_1}{2} + \frac{B(\xi - \tau) - y + k}{2}. \quad (16)$$

where $y = \beta\Delta t + (1-\alpha)\gamma + \Delta q$ represents the blockchain influence factor and reflects the comprehensive influence of blockchain technology on the quality traceability system of agricultural product supply chains. $\beta\Delta t + (1-\alpha)\gamma$ represents the unit net benefit for consumers who purchase products from enterprises using blockchain traceability technology. $\Delta q = Q - q(\Delta q \geq 0)$ represents quality improvement. In the blockchain traceability mode, the detection of fresh agricultural products belongs to multi-node detection. The reduction of detection time reduces the quality loss of fresh agricultural products [52]. In addition, the use of blockchain traceability will encourage suppliers to improve product quality [49]. The higher y is, the greater the positive effect of the blockchain traceability mode. This is because y is positively related to the unit net benefit of consumers who purchase products from enterprises using blockchain traceability technology and quality improvement.

From (15) and (16), we can obtain Lemma 2.

Lemma 2. *In a competitive environment, the optimal pricing of enterprises 1 and 2 are* $\overline{p}_1{}^* = \frac{1}{3}\left(B\xi + y + B\tau + 3k + \frac{4k\theta}{1-\theta}\right)$ *and* $\overline{p}_2{}^* = \frac{1}{3}\left(2B\xi - y - B\tau + 3k + \frac{2k\theta}{1-\theta}\right)$, *respectively.*

Substituting $\overline{p}_1{}^*$ and $\overline{p}_2{}^*$ into (11) and (12), the total market demand of enterprises 1 and 2 can be obtained as follows:

$$D_1^{B*} = \frac{1}{6k}(3k + B\xi + y + B\tau)(1-\theta) + \frac{2}{3}\theta,$$

$$D_2^{B*} = \frac{1}{6k}(3k - B\xi - y - B\tau)(1-\theta) + \frac{1}{3}\theta.$$

Substituting $\overline{p}_1{}^*$ and $\overline{p}_2{}^*$ into (13) and (14), the maximum profit of enterprises 1 and 2 are, respectively:

$$\pi_1^{B*} = \frac{1}{18k}\left(3k + \frac{4k\theta}{1-\theta} + B\xi + y + B\tau\right)^2(1-\theta) - C,$$

$$\pi_2^{B*} = \frac{1}{18k}\left(3k + \frac{2k\theta}{1-\theta} - B\xi - y - B\tau\right)^2(1-\theta).$$

Lemma 2 shows the optimal pricing decision when enterprise 1 adopts a blockchain traceability system and enterprise 2 insists on adopting a traditional traceability system. We obtained the optimal price, optimal total market demand, and maximum profit of enterprises 1 and 2 under the blockchain traceability mode.

4. Results

4.1. Analysis of the Influencing Factors of the Blockchain Introduction Strategy

Proposition 1. *In a competitive environment, the enterprise should adopt the blockchain traceability strategy when the blockchain influence factor satisfies* $y > \frac{\sqrt{18k(1-\theta)\left(C+\frac{k}{2}\right)} - 4k\theta}{1-\theta} - 3k - B\xi - B\tau$.

Proof. See Appendix A. □

Proposition 1 shows that enterprise 1 can obtain more profits than enterprise 2 when the blockchain influence factor is greater than a certain threshold. If the enterprise does not join the blockchain, it must bear the risk of losses arising from consumer returns. In this case, consumers must bear a longer quality evaluation time, a higher possibility of false quality information, and more loss of returns. If the enterprise chooses to join the blockchain, it may be subject to poor economic benefits (such as a slight reduction in consumer quality assessment time, excessive quality loss, and high costs), and consumers may be subject to an excessive loss of quality in agricultural products. Because $\frac{\partial y}{\partial \beta} = \Delta t$, $\frac{\partial y}{\partial \gamma} = 1 - \alpha$, $\Delta t > 0, 1 - \alpha > 0$, that is, the sensitivity of consumers to the detection time of the product and the sensitivity of consumers to the falseness of the product have a significant impact on the blockchain influence factor. The higher the sensitivity of consumers to the time of product detection and to the falseness of the product, the higher the blockchain influence factor.

The following numerical method is used to illustrate an introduction strategy for blockchain. Since the actual value is difficult to obtain, we assume $B = 0.14, \xi = 0.8$, $\tau = 0.4, k = 1, C = 3, \theta = 0.5$.

Figure 1 shows the impact of blockchain influence factor y on the blockchain introduction strategy.

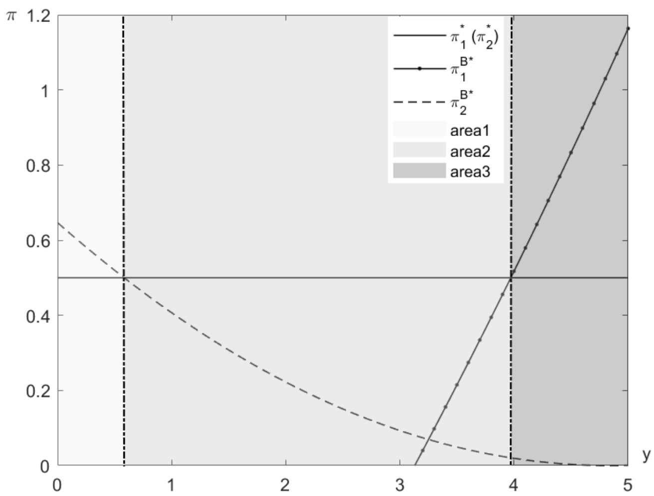

Figure 1. Impact of the blockchain influence factor y on the blockchain introduction strategy.

Figure 1 shows the influence of the blockchain influence factor on the blockchain introduction strategy. $\pi_1^*(\pi_2^*)$ represents the profit of enterprise 1 (enterprise 2) under the traditional traceability mode. Further, π_1^{B*} represents the profit of enterprise 1 under the blockchain traceability mode. π_2^{B*} represents the profit of enterprise 2 under the blockchain traceability mode. The different shaded areas in the figure represent different decisions. In a competitive environment, when the influence factor y is among [0, 3.972], enterprise 1 will not adopt blockchain. Because enterprise 1 had to invest a lot of money if enterprise 1 adopts a blockchain traceability system, its profits would be lower than that without blockchain. When the blockchain influence factor y is higher than 3.972, enterprise 1 will adopt a blockchain traceability system in a competitive environment because its profit under the blockchain traceability mode is higher than that in the traditional mode. The sensitivity of consumers to the detection time of the product and the sensitivity of consumers to the falseness of the product have a positive impact on the blockchain influence factor. As the sensitivity of consumers to the detection time of the product and the sensitivity of consumers to the falseness of the product increase, the blockchain influence factor will increase. At this time, the adoption of blockchain by enterprise 1 could significantly improve its profits, so enterprise 1 will adopt blockchain technology.

Figure 2 shows the critical conditions for introducing blockchain technology. Regional BTD (Blockchain Traceability Decision) denotes the strategy space of enterprise 1 adopting the blockchain traceability system, and regional TTD (Traditional Traceability Decision) denotes the strategy space of enterprise 1 adopting the traditional traceability system. Figure 2 shows that enterprise 1 adopting a blockchain traceability system can obtain higher profits when the blockchain influence factor is large enough and the proportion of consumers with a high traceability preference is relatively large. Therefore, when the blockchain influence factor is large enough, and the proportion of consumers with a high traceability preference is relatively large, enterprise 1 will be prompted to adopt the blockchain traceability strategy.

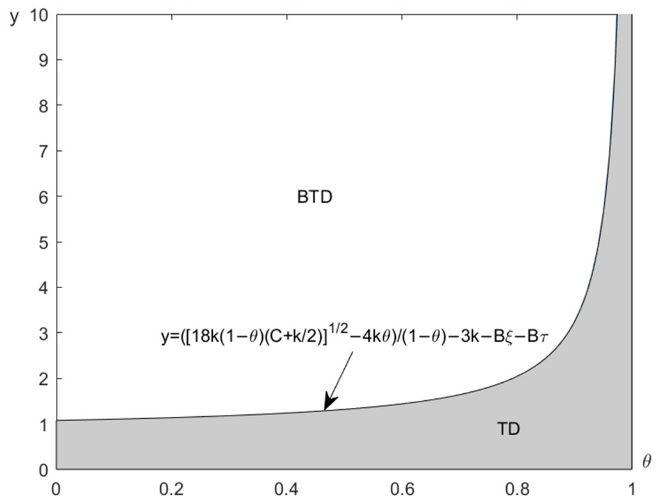

Figure 2. The impact of the proportion of consumers with a high traceability preference on the blockchain introduction strategy.

Based on proposition 1, we have $\frac{\partial \pi_1^{B*}}{\partial B} > 0$, $\frac{\partial \pi_1^{B*}}{\partial \xi} > 0$ and $\frac{\partial \pi_1^{B*}}{\partial y} > 0$, which results in Corollary 1.

Corollary 1.. *In a competitive environment, the profits of enterprise 1 increase with an increase in the possibility of consumer returns as a result of the disclosure of false information by traditional enterprises (B), the enterprise's return loss (ξ), the sensitivity of consumers to the falseness of the product (γ), the sensitivity of consumers to the detection time of the product (β), and the quality improvement of the fresh agricultural products (Δq).*

Proposition 2. *Under a competitive environment, when the blockchain influence factor satisfies $y < 3k - \frac{3k\sqrt{1-\theta}-2k\theta}{1-\theta} - B\xi - B\tau$ or $y > 3k + \frac{3k\sqrt{1-\theta}+2k\theta}{1-\theta} - B\xi - B\tau$, the profit of enterprise 2 under the blockchain traceability mode will be higher than that under the traditional traceability mode.*

Proof. See Appendix B. □

Proposition 2 shows that the maximum profit of enterprise 2 under the blockchain traceability mode will be higher than under the traditional traceability mode when blockchain influence factor y is within a certain range. In a competitive environment, only when y satisfies this range can an enterprise with a traditional traceability system under the blockchain traceability mode gain more profit.

Based on the conclusion of Proposition 2, Corollary 2 can be obtained.

Corollary 2. *In a competitive environment, the maximum profit of enterprise 2 under the blockchain traceability mode increases with an increase in y when $y > 3k + \frac{2k\theta}{1-\theta} - B\xi - B\tau$. The maximum* *profit of enterprise 2 under the blockchain traceability mode decreases with an increase in y when* $y < 3k + \frac{2k\theta}{1-\theta} - B\xi - B\tau$.

Proof. See Appendix C. □

Corollary 2 shows that when y is in a different range, the maximum profit of enterprise 2 under the blockchain traceability mode is different. $y = 3k + \frac{2k\theta}{1-\theta} - B\xi - B\tau$ is the critical point of this range. The maximum profit of enterprise 2 under the blockchain traceability mode increases with an increase in y when $y > 3k + \frac{2k\theta}{1-\theta} - B\xi - B\tau$. The maximum profit of enterprise 2 under the blockchain traceability mode decreases with an increase in y when $y < 3k + \frac{2k\theta}{1-\theta} - B\xi - B\tau$.

Proposition 3. *When the blockchain influence factor satisfies* $y \geq -B\xi - B\tau - \frac{k\theta}{1-\theta}$, *the introduction of blockchain in a competitive environment can lead to a shift of demand from the enterprise not adopting blockchain technology to the enterprise adopting blockchain technology.*

Proof. See Appendix D. □

According to proposition 3, when the blockchain influence factor satisfies $y \geq -B\xi - B\tau - \frac{k\theta}{1-\theta}$, the total market demand of enterprise 1 under the blockchain traceability mode will be higher than that of enterprise 1 under traditional traceability mode, whereas the demand of enterprise 2 under the blockchain traceability model will be lower than that of enterprise 2 under the traditional traceability mode. That means that some consumers with a high traceability preference will be willing to buy fresh agricultural products and turn from enterprises using blockchain technology.

4.2. Analysis of the Influencing Factors of the Optimal Pricing Decision

Proposition 4. *Under a competitive environment, when the blockchain influence factor satisfies* $y < \frac{B\xi}{2} - B\tau - \frac{k\theta}{1-\theta}$, *the optimal pricing of enterprise 1 under the blockchain traceability mode will be lower than that of enterprise 2 under the blockchain traceability mode.*

Proof. See Appendix E. □

Proposition 4 shows that if the optimal pricing of enterprise 1 under the blockchain traceability mode is lower than that of enterprise 2 under the blockchain traceability mode, the blockchain influence factor needs to satisfy $y < \frac{B\xi}{2} - B\tau - \frac{k\theta}{1-\theta}$. That means, in a competitive environment, when y is less than a certain value, the price of a blockchain enterprise is less than that of an enterprise that does not use blockchain technology.

Proposition 5. *Under a competitive environment, the optimal pricing of enterprises 1 and 2 increases with an increase in the enterprises' return loss, the unit transfer cost, and the proportion of consumers with a high traceability preference. The optimal pricing of enterprise 1 increases with an increase in* y, γ, β, τ, *and* Δq. *Meanwhile, the optimal pricing of enterprise 2 decreases with an increase in* y,γ, β, τ, *and* Δq.

Proof. See Appendix F. □

Proposition 5 shows that the optimal pricing is related to the enterprises' return loss, the unit transfer cost, and the proportion of consumers with a high traceability preference. In the blockchain traceability mode, consumers' sensitivity to the detection time of the product β and the falseness of the product γ, blockchain influence factor y, consumers' return loss τ, and quality improvement could affect the optimal pricing for both blockchain enterprises and traditional enterprises. The optimal pricing of enterprise 1 increases with an increase in y, γ, β, τ, and Δq. Meanwhile, the optimal pricing of enterprise 2 decreases with an increase in y, γ,β, τ, and Δq.

5. Conclusions

Increasingly, consumers pay attention to the reliability and authenticity of agricultural product information. Traditional traceability systems are usually based on centralized information management systems, and information can be easily tampered with and forged. It is difficult for customers to verify the authenticity of the information. Assuming that the consumers' traceability preference is related to the detection time of the product and to the falseness of the product, this study examines the blockchain introduction strategy of fresh agricultural enterprises with two competitive enterprises based on non-cooperative game theory. In the traditional traceability mode, we consider two enterprises that do not use blockchain technology and derive the profit functions of the two enterprises. The optimal pricing and the maximum profits of the two enterprises are obtained through theoretical analysis. In the blockchain traceability mode, we consider the scenario where one enterprise uses blockchain technology and the other enterprise does not. Then, we construct the profit functions of the two enterprises. The optimal pricing and the maximum profits of the two enterprises are obtained through theoretical analysis. By comparing the profits in two different traceability modes, we obtained the specific conditions for the enterprise to introduce blockchain technology. Subsequently, we analyzed the impact of consumer traceability preference and blockchain influence factor. The results can be summarized as follows.

First, adopting blockchain technology is not always good for enterprises in a competitive environment. This conclusion is similar to that of Wu et al. [51]. However, we find that in specific conditions, the enterprise adopting blockchain technology as a traceability system will obtain a competitive advantage, and the enterprise not adopting blockchain technology as a traceability system will not be a free rider. Because the profit of an enterprise not adopting blockchain technology when its competitor adopts the blockchain technology is lower than the profit when the two enterprises do not adopt the blockchain technology, it is different from the view of Wu et al. [51], who found that when one supply chain adopts blockchain technology, the other may be a free rider. Furthermore, we found that the introduction strategy of blockchain technology relates to the transfer cost with consumers and the investment cost of blockchain technology. When the transfer cost with consumers and the investment cost is in a certain range, it is good for the enterprise to adopt blockchain technology. Moreover, in a competitive environment, the profit of blockchain enterprises increases with an increase in the possibility of consumer returns as a result of the disclosure of false information by traditional enterprises, the enterprise's return loss, the sensitivity of consumers to the falseness of the product, the sensitivity of consumers to the detection time of the product, and the quality improvement of the agricultural products.

Second, we observe that the decision to introduce blockchain technology in a competitive environment is related to the blockchain influence factor. Enterprises will introduce blockchain technology when the blockchain influence factor is greater than a certain value. When the blockchain influence factor is less than a certain value, the optimal price of blockchain enterprises under the blockchain traceability mode is lower than that of traditional enterprises under the blockchain traceability mode. We discovered that the blockchain influence factor has a significant impact on enterprise pricing. As the blockchain influence factor increases, the optimal pricing of blockchain enterprises will increase, whereas that of traditional enterprises under the blockchain traceability mode will decrease. This study also showed that the enterprises' return loss, unit transfer costs, and proportion of consumers with a high traceability preference could influence the optimal price of enterprises. With an increase in the enterprises' return loss, unit transfer costs, and the proportion of consumers with a high traceability preference, the optimal pricing of blockchain and traditional enterprises under the blockchain traceability mode will increase.

Thirdly, we discover that the consumers' traceability preferences could affect the optimal pricing and profits of enterprises. The profits of blockchain enterprises increase with an increase in the possibility of consumer returns as a result of the disclosure of false information by traditional enterprises, the sensitivity of consumers to the falseness of the product, and the sensitivity of consumers to the detection time of the product. The optimal pricing of blockchain enterprises increases with an increase in the proportion of consumers with a high traceability preference. The optimal pricing of blockchain enterprises increases with an increase in the consumers' sensitivity to the time of product detection, consumers' sensitivity to the falseness of the product and consumers' return loss. Our results also show that introducing blockchain into a competitive environment can lead to a shift in demand. We find that, in a competitive environment, the total market demand of enterprises applying the blockchain traceability system will increase, whereas that of traditional enterprises under the traditional traceability system will decrease. This means that some consumers with a high traceability preference will be willing to buy fresh agricultural products from enterprises using blockchain technology.

Based on our research results, we provide several implications for managers of fresh product enterprises. Enterprises should focus on two aspects when considering the introduction of blockchain technology. First, enterprises should consider the consumers' preference for the detection time of the product and the falseness of the product. If the proportion of consumers with a high traceability preference reaches a certain threshold, enterprises should adopt a blockchain traceability system. For example, enterprises should introduce a blockchain traceability system if consumers in the market become more concerned about food safety issues and are skeptical about the source of food and other information. Furthermore, enterprises should focus on the blockchain influence factor. Enterprises should introduce blockchain technology when the blockchain influence factor reaches a certain value. We found that the quality improvement caused by the use of the blockchain traceability mode will positively impact the blockchain influence factor. Enterprises should pay attention to the quality loss under the traditional mode. When the quality loss of fresh agricultural products is too significant, it is beneficial for enterprises to introduce blockchain technology to improve product quality. Moreover, enterprises should focus on the blockchain influence factor. Enterprises should introduce blockchain technology when the blockchain influence factor is in a certain range. This certain value is related to many factors, such as the possibility of consumer return as a result of the disclosure of false information by traditional processors, the processor's return loss, consumers' return loss, and so on. When consumers cannot bear the cost of return of goods due to the untrue information disclosed by some enterprises and the losses caused by the return of goods are large enough, enterprises in the same industry will be more willing to adopt blockchain technology.

Finally, we note some potential directions for future research. First, we assume that the quality and return costs are both exogenous parameters in the model; the situation where both or one of them are endogenous parameters is worthy of further study. Second, this study assumed that enterprises establishing blockchain traceability would trace the production process and analyze the introduction strategy of competitive enterprises. However, the cost of building a blockchain traceability system platform is high. Some enterprises probably choose blockchain traceability services provided by third-party trading platforms. It would be interesting to investigate the impact of blockchain on the interaction mechanisms between fresh agricultural enterprises and third-party trading platforms.

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Appendix A Proof of Proposition 1

The maximum profit of enterprise 1 under the blockchain traceability mode is as follows:

$$\pi_1^{B*} = \frac{1}{18k}\left(3k + \frac{4k\theta}{1-\theta} + B\xi + y + B\tau\right)^2 (1-\theta) - C$$

In Section 2, we have $\pi_1^* = \pi_2^* = \frac{k}{2}$.

If the profit of enterprise 1 under the blockchain traceability mode is higher than that of enterprise 1 under the traditional traceability mode, it needs to meet:

$$\frac{1}{18k}\left(3k + \frac{4k\theta}{1-\theta} + B\xi + y + B\tau\right)^2 (1-\theta) - C > \frac{k}{2}$$

Let

$$Z = \frac{1}{18k}\left(3k + \frac{4k\theta}{1-\theta} + B\xi + y + B\tau\right)^2 (1-\theta) - C - \frac{k}{2}$$

Set

$$\varsigma = B\xi + y + B\tau + 3k,$$

Then

$$Z(\varsigma) = \frac{1}{18k}\left(\varsigma + \frac{4k\theta}{1-\theta}\right)^2 (1-\theta) - C - \frac{k}{2}$$

When

$$Z(\varsigma) > 0, \varsigma > \frac{\sqrt{18k(1-\theta)\left(C + \frac{k}{2}\right)} - 4k\theta}{1-\theta}$$

Substitute $\varsigma = B\xi + y + B\tau + 3k$ to obtain $y > \frac{\sqrt{18k(1-\theta)\left(C+\frac{k}{2}\right)}-4k\theta}{1-\theta} - 3k - B\xi - B\tau$.

Therefore, when $y > \frac{\sqrt{18k(1-\theta)\left(C+\frac{k}{2}\right)}-4k\theta}{1-\theta} - 3k - B\xi - B\tau$, $\frac{1}{18k}\left(3k + \frac{4k\theta}{1-\theta} + B\xi + y + B\tau\right)^2 (1-\theta) - C > \frac{k}{2}$.

Appendix B Proof of Proposition 2

The maximum profit of enterprise 2 under the blockchain traceability mode is as follows:

$$\pi_2^{B*} = \frac{1}{18k}\left(3k + \frac{2k\theta}{1-\theta} - B\xi - y - B\tau\right)^2 (1-\theta)$$

In Section 2, we have $\pi_1^* = \pi_2^* = \frac{k}{2}$.

If the profit of enterprise 2 under the blockchain traceability mode is higher than that of enterprise 2 under the traditional traceability mode, it needs to meet:

$$\frac{1}{18k}\left(3k + \frac{2k\theta}{1-\theta} - B\xi - y - B\tau\right)^2 (1-\theta) > \frac{k}{2}$$

Let

$$Z = \frac{1}{18k}\left(3k + \frac{2k\theta}{1-\theta} - B\xi - y - B\tau\right)^2 (1-\theta) - \frac{k}{2}$$

Set $\omega = 3k - B\xi - y - B\tau$, then $Z(\omega) = \frac{1}{18k}\left(\omega + \frac{2k\theta}{1-\theta}\right)^2 (1-\theta) - \frac{k}{2}$,

When $Z(\omega) > 0$, as $\omega > \frac{2k\theta}{\theta-1}$, then $\omega > \frac{3k\sqrt{1-\theta}-2k\theta}{1-\theta}$.

Substitute $\omega = 3k - B\xi - y - B\tau$ to obtain $y < 3k - \frac{3k\sqrt{1-\theta}-2k\theta}{1-\theta} - B\xi - B\tau$.

When $Z(\omega) > 0, \omega < \frac{2k\theta}{\theta-1}$, then $\omega < \frac{-3k\sqrt{1-\theta}-2k\theta}{1-\theta}$.

Substitute $\omega = 3k - B\xi - y - B\tau$ to obtain $y > 3k + \frac{3k\sqrt{1-\theta}+2k\theta}{1-\theta} - B\xi - B\tau$.

Therefore, when $y < 3k - \frac{3k\sqrt{1-\theta}-2k\theta}{1-\theta} - B\xi - B\tau$ or $y > 3k + \frac{3k\sqrt{1-\theta}+2k\theta}{1-\theta} - B\xi - B\tau, \frac{1}{18k}\left(3k + \frac{2k\theta}{1-\theta} - B\xi - y - B\tau\right)^2(1-\theta) > \frac{k}{2}$.

Appendix C Proof of Corollary 2

The maximum profit of enterprise 2 under the blockchain traceability mode is as follows:

$$\pi_2^{B*} = \frac{1}{18k}\left(3k + \frac{2k\theta}{1-\theta} - B\xi - y - B\tau\right)^2(1-\theta)$$

We have $1-\theta > 0$ and $3k + \frac{2k\theta}{1-\theta} > 0$. Thus, we have the following two cases:

$y > 3k + \frac{2k\theta}{1-\theta} - B\xi - B\tau$. In this case, π_2^{B*} increases with the increase of y

$y < 3k + \frac{2k\theta}{1-\theta} - B\xi - B\tau$. In this case, π_2^{B*} decreases with the increase of y.

Appendix D Proof of Proposition 3

The total market demand of enterprise 1 under the blockchain traceability mode is:

$$D_1^{B*} = \frac{1}{6k}(3k + B\xi + y + B\tau)(1-\theta) + \frac{2}{3}\theta$$

In Section 2, we have $D_1^* = D_2^* = \frac{1}{2}$.

If the total market demand of enterprise 1 under the blockchain traceability mode is higher than that under the traditional traceability mode, it needs to meet:

$$\frac{1}{6k}(3k + B\xi + y + B\tau)(1-\theta) + \frac{2}{3}\theta \geq \frac{1}{2}$$

Therefore, $y \geq -B\xi - B\tau - \frac{k\theta}{1-\theta}$.

When y $\geq -B\xi - B\tau - \frac{k\theta}{1-\theta}, \frac{1}{6k}(3k + B\xi + y + B\tau)(1-\theta) + \frac{2}{3}\theta \geq \frac{1}{2}$.

The total market demand of the enterprise 2 under the blockchain traceability mode is:

$$D_2^{B*} = \frac{1}{6k}(3k - B\xi - y - B\tau)(1-\theta) + \frac{1}{3}\theta$$

In Section 2, we have $D_1^* = D_2^* = \frac{1}{2}$.

If the total market demand of enterprise 2 under the blockchain traceability mode is higher than that under the traditional traceability mode, it needs to meet:

$$\frac{1}{6k}(3k - B\xi - y - B\tau)(1-\theta) + \frac{1}{3}\theta \geq \frac{1}{2}$$

Therefore, $y \leq -B\xi - B\tau - \frac{k\theta}{1-\theta}$.

When $y \leq -B\xi - B\tau - \frac{k\theta}{1-\theta}, \frac{1}{6k}(3k - B\xi - y - B\tau)(1-\theta) + \frac{1}{3}\theta \geq \frac{1}{2}$.

When $y \geq -B\xi - B\tau - \frac{k\theta}{1-\theta}, \frac{1}{6k}(3k + B\xi + y + B\tau)(1-\theta) + \frac{2}{3}\theta \geq \frac{1}{2}$.

Since $y \geq -B\xi - B\tau - \frac{k\theta}{1-\theta}$ contradicts $y \leq -B\xi - B\tau - \frac{k\theta}{1-\theta}$, so when blockchain influence factor is positive, the total market demand of enterprise 1 will increase, and the total market demand of enterprise 2 under the blockchain traceability mode will decrease.

Appendix E Proof of Proposition 4

The optimal pricing of enterprise 1 under the blockchain traceability mode is as follows:

$$\overline{p}_1{}^* = \frac{1}{3}\left(B\xi + y + B\tau + 3k + \frac{4k\theta}{1-\theta}\right)$$

The optimal pricing of enterprise 2 under the blockchain traceability mode is as follows:

$$\overline{p}_2{}^* = \frac{1}{3}\left(2B\xi - y - B\tau + 3k + \frac{2k\theta}{1-\theta}\right)$$

If the optimal pricing of enterprise 1 under the blockchain traceability mode is lower than that of enterprise 2 under the blockchain traceability mode, it needs to meet:

$$\frac{1}{3}\left(B\xi + y + B\tau + 3k + \frac{4k\theta}{1-\theta}\right) < \frac{1}{3}\left(2B\xi - y - B\tau + 3k + \frac{2k\theta}{1-\theta}\right)$$

Therefore, $y < \frac{B\xi}{2} - B\tau - \frac{k\theta}{1-\theta}$.

When $y < \frac{B\xi}{2} - B\tau - \frac{k\theta}{1-\theta}, \overline{p}_1{}^* < \overline{p}_2{}^*$.

Appendix F Proof of Proposition 5

$$\overline{p}_1{}^* = \frac{1}{3}\left(B\xi + y + B\tau + 3k + \frac{4k\theta}{1-\theta}\right)$$

$$\overline{p}_2{}^* = \frac{1}{3}\left(2B\xi - y - B\tau + 3k + \frac{2k\theta}{1-\theta}\right)$$

Easy to know $\frac{d\overline{p}_1{}^*}{d\xi} > 0, \frac{d\overline{p}_1{}^*}{dk} > 0, \frac{d\overline{p}_2{}^*}{d\xi} > 0, \frac{d\overline{p}_2{}^*}{dk} > 0$.

From $0 < \theta < 1, \frac{d\overline{p}_1{}^*}{d\theta} > 0, \frac{d\overline{p}_2{}^*}{d\theta} > 0$.

Therefore, the optimal pricing of enterprise 1 and 2 under the blockchain traceability mode increases with the increase in the enterprise's return loss, the unit transfer cost, and the proportion of consumers with a high traceability preference.

Additionally, because $\frac{dp_1{}^*}{dy} > 0, \frac{dp_2{}^*}{dy} < 0, \frac{dy}{d\gamma} > 0, \frac{dy}{d\beta} > 0, \frac{dy}{d\tau} > 0, \frac{dy}{d\Delta q} > 0$,

Thus

$$\frac{dp_1{}^*}{d\gamma} = \frac{dp_1{}^*}{dy}\cdot\frac{dy}{d\gamma} > 0, \frac{dp_1{}^*}{d\beta} = \frac{dp_1{}^*}{dy}\cdot\frac{dy}{d\beta} > 0,$$

$$\frac{dp_1{}^*}{d\tau} = \frac{dp_1{}^*}{dy}\cdot\frac{dy}{d\tau} > 0, \frac{dp_1{}^*}{d\Delta q} = \frac{dp_1{}^*}{dy}\cdot\frac{dy}{d\Delta q} > 0;$$

$$\frac{dp_2{}^*}{d\gamma} = \frac{dp_2{}^*}{dy}\cdot\frac{dy}{d\gamma} < 0, \frac{dp_2{}^*}{d\beta} = \frac{dp_2{}^*}{dy}\cdot\frac{dy}{d\beta} < 0,$$

$$\frac{dp_2{}^*}{d\tau} = \frac{dp_2{}^*}{dy}\cdot\frac{dy}{d\tau} < 0, \frac{dp_2{}^*}{d\Delta q} = \frac{dp_2{}^*}{dy}\cdot\frac{dy}{d\Delta q} < 0.$$

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