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Research Article

Optimal Decision and Coordination of Organic Food Supply Chain from the Perspective of Blockchain

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Driven by the pain points of the organic food supply chain, which has been plagued by counterfeiting and difficulties in pursuing accountability, this paper investigates a secondary organic food supply chain consisting of suppliers and retailers and establishes two supply chain models under the traditional model and in the blockchain traceability context. In order to effectively solve the problem of unrealized Pareto improvement in organic food supply chain after applying blockchain, a new hybrid contract based on benefit-sharing and cost-sharing is designed to coordinate the supply chain and realize Pareto improvement, and this solution is gradually applied to organic food enterprises. Based on the fact that blockchain can improve trust in the supply chain and eliminate counterfeiting of organic food, the relationship between the rate of genuine products and market demand and the cost of blockchain is established, and then the analysis is developed using the Stackelberg game. We compare the traditional model with the model in the blockchain context and analyze the optimal profit of each supply chain entity, comparing the change in optimal profit before and after the blockchain implementation, and clarifying the cost threshold of the blockchain technology input application. We find that: (i) The adoption of blockchain can not only improve the authenticity of products and combat counterfeit and shoddy organic food, but at the same time, the improvement of organic level in the context of blockchain will also attract some consumers to buy organic food, which will increase the main body of the supply chain and the overall profit. (ii) Blockchain-adopted supply chains are consistently more profitable for all parties and overall than traditional supply chains. The main contribution of this study is that in the organic food supply chain under the application of blockchain technology model, by introducing revenue-sharing and cost-sharing contracts, the profit between each member of the organic food supply chain is further improved than the traditional model, and also, all of them are optimized, which further improves the stability of the supply chain and brings the supply chain to a coordinated state. Finally, in this context, the obtained results show the effectiveness and realistic operational efficiency of the proposed approach for companies compared to traditional single revenue-sharing covenants. A combination of revenue-sharing and cost-sharing covenants is the best approach to solve such problems. In conclusion, it should be noted that the analysis presented in this study will help decision makers choose the most appropriate option among the possible solutions according to their criteria. This proposed framework can also be extended in various cases where profits are out of balance in the organic food supply chain, such as safety and value gain.

1. Introduction

According to Blueweave Consulting & Research Pvt. Ltd., the global organic food market is expected to grow at a compound annual growth rate (CAGR) of over 15% from 2018 to 2026, driving consumers to purchase organic food. The main reason for purchasing organic food is health, and customers with healthy eating habits are more likely to buy organic food [1]. Organic food is now one of the fastest growing segments of the food market, with significant increases in production and sales in many developing countries. The consumer demand in China's organic food market is gradually becoming larger, and the number of consumers buying organic food is increasing, involving organic food products such as dairy products and vegetables [2, 3].

The organic food supply chain has always had the pain point of counterfeiting and accountability [4]. The current traceability technology cannot prevent organic food information from being tampered with, resulting in general mistrust between the upstream and downstream of the organic food supply chain, uncoordinated supply chain management, and low efficiency [5, 6]. Since the Japanese scholar Satoshi Nakamoto proposed the blockchain in 2008, blockchain technology has entered the public's field of vision as the underlying technology of Bitcoin. Due to the unique characteristics of the blockchain, people soon began to realize the block chain. The application prospect of blockchain technology has caused a frenzy of research on blockchain in the world [4]. One of the cores of the blockchain is to increase trust. It establishes mutual trust relationship through peer-to-peer network, encryption algorithm, time stamp, and other technologies, which plays an important role in enhancing the trust cooperation relationship between supply chains and improving supply chain coordination [7]. After years of development, blockchain has begun to extend to finance, supply chain management, logistics, traceability, and other important areas, of which anti-counterfeiting traceability of agricultural products is one of the main applications in traceability. Organic food is quite popular among global consumers because its healthy and green. In the past five years, the production of organic food in China has been rising and the market scale has been expanding, but the painful problem of counterfeiting in the distribution process has not been solved. The traditional organic food supply chain distribution system is prone to information tampering and low data security, coupled with information asymmetry and difficulty in accurate traceability, resulting in unscrupulous organic food manufacturers in the supply chain making use of substandard products and adulterating them [8]. In the circulation process of organic food, confusing labels and counterfeiting of trademarks occur from time to time, and the tampering of organic food information is even more difficult to prevent [9]. In the upstream of the supply chain, it is still genuine organic food, but when it reaches downstream distributors and retailers, it is discarded by low-quality and shoddy organic food. The supply chain is filled with a large number of fake and shoddy organic foods that cannot be accurately identified the organic food supply chain. The trust between them has long existed in name only, which has seriously affected the cooperation and coordination among the members of the supply chain and hindered the development of the organic food industry [10]. Although many large organic food companies spend a lot of operating cost every year to fight counterfeiting and anti-counterfeiting and maintain their own brand products, the results are minimal, and it is still difficult to solve the problems of trust and counterfeiting in the organic food supply chain. The immutable nature of the blockchain has brought opportunities to combat counterfeit and shoddy organic food and establish a traceability system that can be traced throughout the entire process. Its encryption algorithm, peer-to-peer network, consensus mechanism, and other technologies have created conditions for the establishment of trust between supply chains [11]. With the continuous development of blockchain technology, many companies have begun to study blockchain-based traceability management systems [12]. In the past two years, more and more enterprises have used blockchain technology to trace the whole process of organic food, combat the phenomenon of counterfeiting and shoddy organic food in the supply chain, protect the real organic food, and reshape the relationship between the upstream and downstream of the organic food supply chain. Trust can improve the collaboration efficiency between supply chains and achieve supply chain coordination. With the continuous development of blockchain technology, many countries are aware of the application prospects of blockchain in traceability [13, 14]. Based on the fact that the information on the blockchain cannot be tampered with, the authenticity of the product can be guaranteed when the blockchain is used for traceability. Therefore, in recent years, some large enterprises in China have begun to seize the opportunity to enter the blockchain traceability market [5]. At present, the development of blockchain is in a period of rapid development, and the application of blockchain is no longer limited to the financial field. During this period, a large number of entrepreneurs began to create blockchain companies, and people began to explore the application of blockchain technology in other fields. The value and prospect are, respectively, applied to logistics, supply chain management, medical care, and education. Currently, there are more applications in the field of supply chain finance [15–17].

Lotfi et al. [18] considered a closed-loop supply chain by taking into account sustainability, resilience, robustness, and risk aversion for the first time. Lotfi et al. [19] proposed that the use of blockchain Technology (BCT) is growing faster in each country. Blockchain can improve transparency, trust, information sharing, security, and ensure information is not tampered with in the organic food supply chain [20]. By using blockchain technology, it helps to share information between members and reduce transaction costs between companies in the organic food supply chain [21]. The supply chain information system built using blockchain effectively connects all supply chain entities and facilitates the exchange of information in the supply chain [22]. The technical characteristics of blockchain, such as nontampering of information, open and transparent information, and time stamp, provide new ideas for solving the problem of counterfeiting and counterfeiting of organic food and reshaping the trust between organic food supply chains. The whole process of anti-counterfeiting traceability system of food can prevent counterfeit and shoddy organic food from flowing into the supply chain, enhance trust between the upstream of the organic food supply chain, and promote the supply chain to achieve a coordinated state. Although the blockchain is still in the initial stage of development, it is believed that under the promotion of national policies, in the context of the urgent needs of the organic food industry, and the unique advantages of blockchain in anti-counterfeiting and traceability, and establishing trust in the supply chain, future applications blockchain traceability of organic food will become a norm, so it is of practical significance for us to study the coordination of the organic food supply chain based on blockchain technology.

Based on this, in the context of blockchain technology, this paper studies the coordination of organic food supply chain, and introduces appropriate supply chain contracts to coordinate the profits of supply chain members. The following questions are mainly investigated:

(1) Under decentralized decision-making, which model is more profitable for retailers compared to the traditional model and the blockchain model?

(2) Under decentralized decision-making, does the supply chain in the context of blockchain reach the optimal state?

(3) In the traditional supply chain, how does the genuine rate of organic food affect the profit of the supply chain?

(4) Are supply chains that adopt blockchain more profitable than traditional supply chains? Can supply chain adoption of blockchain improve efficiency?

(5) How do cost-sharing and revenue-sharing factors affect supply chain profitability?

(6) How to encourage organic food manufacturers to actively adopt blockchain technology, trace the source of the whole process, maintain the brand image of organic food, and put it into the supply chain to achieve supply chain collaboration and improve supply chain performance?

We consider a secondary supply chain model consisting of an organic food producer and a retailer. We take the serious phenomenon of organic food counterfeiting and the distrust between the supply chain subjects as the research background, and use the characteristics of blockchain on-chain information being tamperproof and traceable as the basis. Introducing blockchain can eliminate the counterfeiting of organic food, improve the organic degree between the supply chain subjects, and make the organic food supply chain achieve coordination as the goal, and on this basis, we study the contractual coordination problem of the organic food supply chain. We construct a supply chain game model based on two scenarios: the blockchain model and the traditional model, and compare and analyze the optimal profit of each supply chain subject. Comparing the change in optimal profit before and after the implementation of blockchain, we further study the cost threshold of blockchain technology input application.

The main contribution and motivation of this study are as follows:

(1) Under the traditional model, the increase in organic food authenticity will bring higher profits to the supply chain.

(2) The adoption of blockchain can increase the rate of organic food authenticity and combat counterfeit organic food, while the increase in trust in the blockchain context will attract some consumers to buy organic food and bring additional revenue to the supply chain.

(3) As there is no counterfeiting and trust is improved in the blockchain context, the profit of the supply chain is always higher than that of the traditional supply chain, which also shows that the adoption of blockchain can improve the efficiency of the supply chain.

We organized this paper as follows. In Section 2, we study on related work and show gap research within the organic food supply chain in the context of blockchain technology. In Section 3, we determine the blockchain model of organic food and the mathematical model of the traditional model. In Section 4, we detail management insights from the industrial case. In Section 5, the findings and results of the proposed model with sensitivity analysis are explained. In Sections 6 and 7, the managerial insights and conclusion and outlook are determined. All proofs are relegated to Appendix.

2. Literature Review

Based on the topics we discuss, our work involves the following three aspects. This section briefly reviews related concepts, including blockchain, organic food supply chains, and supply chain contracts to provide some background information based on our research. Therefore, we will summarize the literature from the above three aspects.

2.1. Blockchain. The blockchain is now more and more valued by the country and all walks of life. By sorting out the blockchain traceability and the research status of our paper, there are mainly the following two aspects: on the one hand, blockchain can improve the transparency and trust of supply chain information degree, information sharing, and security to ensure that information is not tampered with. Bodkhe et al. [23] found that the application of blockchain technology helps to realize information sharing among members and reduce transaction costs among supply chain enterprises. Berdik et al. [24] used the supply chain information system constructed by the blockchain to effectively connect the main bodies of the supply chain and promote the exchange of information in the supply chain. Lu [25] proposed an agricultural product system architecture model based on the consortium blockchain based on the decentralization characteristics of blockchain technology, thereby preventing network attacks and ensuring the security and reliability of agricultural product data. Monrat et al. [26] proposed to use blockchain technology to build a consortium chain to solve the problem of trust between cross-border e-commerce and domestic e-commerce and the quality and safety of goods. Zhou et al. [27] concluded that the application of blockchain will solve the problem of information asymmetry in financial institutions and reduce risks through theoretical analysis. Morkunas et al. [28] used the newsboy model to analyze that the blockchain debt swap platform has high trust, high efficiency, easy operation, low cost, and higher financing efficiency. Singh et al. [29] showed that blockchain technology can overcome collaboration and trust issues in supply chains and minimize the negative consequences of eliminating information asymmetry in supply chain echelons. To make the agricultural supply chain more transparent, Chang et al. [30] proposed a dual-chain storage structure characterized by a chained data structure for storing blockchain transaction hashes, with the aim of ensuring that agricultural product data is not tampered with or destroyed. On the other hand, the record information of the blockchain cannot be calculated and traced, which is suitable for solving the problem of counterfeiting and shoddy, and can carry out product information traceability and anti-counterfeiting, which has a good effect on solving the long-standing pain point of counterfeiting.

In recent years, many experts and scholars have used blockchain as a tool to study and solve the problems of product traceability and anti-counterfeiting. Feng et al. [31] proposed that the integration of blockchain technology and IoT technology can solve the problems of easy calculation, modification, and counterfeiting of cross-border e-commerce product information. Andoni et al. [32] believe that the immutable characteristics of blockchain and timestamp technology can be used to solve the problems of data tracking and information anti-counterfeiting. Dutta et al. [33] proposed that because blockchain technology information cannot be tampered with, and information is updated and stored in real-time, it has great advantages for supply chain cost control, and information is difficult to tamper with, which is conducive to supply chain anti-counterfeiting traceability. Deepa et al. [34] built a blockchain-based agricultural product traceability system, which helped solve the problem of insecure agricultural product data and information, protected consumers' rights and interests, and improved consumers' confidence in products. Other scholars have also conducted in-depth discussions on blockchain traceability, and began to study the construction of blockchain-based traceability systems and frameworks and applied them to different subjects. Upadhyay [35] proposed a blockchain-based framework that can successfully handle the critical recovery problem, preventing cloning attacks, counterfeit labels, and counterfeit products. Gai et al. [36] constructed a blockchain-based logistics monitoring system to provide a solution for package tracking in supply chains. Xu et al. [37] described the integration of blockchain into supply chain architecture to solve the problems of corruption, fraud, and tampering faced by supply chains in centralized supply chain management systems. Zhang and Lee [38] discussed the tracking and traceability of soybean supply chain using the potential of blockchain and smart contracts.

After summarizing the domestic and foreign research status of the above blockchain, it can be concluded that the application of blockchain to improve the overall trust in the supply chain and combating counterfeit and shoddy products has become a consensus in the industry. There are also many ideas for blockchain traceability. It has been implemented, and these theoretical and practical foundations have brought better help to our research.

2.2. Organic Food Supply Chain. Among the existing research results, the coordination between enterprises in the food supply chain and the green supply chain is most similar to the coordination of the organic food supply chain. Many scholars have conducted related research. Most of the coordination methods proposed by scholars mainly includes incentive coordination, cost coordination, and contract coordination. Rana and Paul [3] advocate an incentive mechanism. He believes that there will inevitably be some risks in the cooperative enterprises in the food supply chain. Therefore, some risks that may appear should be prevented and avoided. Among them, the use of incentive mechanisms is an excellent way to avoid risks. One of the means. Perlman et al. [39] conducted a theoretical and empirical analysis of the contractual cooperation between upstream and downstream suppliers and retailers in the food supply chain.

A large number of articles have studied the problem of profit coordination between manufacturers and retailers in the supply chain, and have designed a variety of coordination mechanisms to maximize the profits of the supply chain, but only a small number of articles have included the consumers who determine product sales in the model and considered the influence of consumer mentality factors even less. Segura et al. [40] found that bargaining power is the most important determinant of the relationship between core and upstream and downstream firms in the food supply chain, and the researchers studied the bargaining process between firms in the food supply chain by applying game bargaining theory. Denver et al. [41] studied 149 companies at the core of the supply chain, and pointed out that companies in large industries with high uncertainty have begun to pay attention to and implement guidance, education, evaluation, and guidance on green suppliers. Supervise activities to achieve vertical and horizontal expansion of the enterprise and improve the performance level of the enterprise. Paciarotti and Torregiani [42] proposed that the effect of pollution prevention in supply chain operation is closely related to the degree of cooperation between upstream and downstream enterprises in the supply chain. Carino et al. [43] believe that the bullwhip effect in the supply chain is obvious, and propose that if information sharing is used as a coordination incentive mechanism, the phenomenon of bullwhip effect in the supply chain can be effectively reduced, and the safety and quality problems in the food supply chain can be well solved and control. Torretta et al. [44] first discovered the different ways of undertaking supply chain enterprises, and on this basis, proposed two methods to achieve sustainable development of the supply chain, and proposed a method in which all members share environmental-related responsibilities. A large number of articles simplify the supply chain coordination problem to a two-player game model of a supplier and a retailer, and few articles study the game between the two groups of suppliers and retailers. In view of the deficiencies in the above studies, our paper will conduct further in-depth research. Haleem et al. [45] conducted an actual survey of a few manufacturing companies in the United States, and on this basis, proposed some supply chain systems to help companies establish how to coordinate with the environment within the system. Nakandala and Lau [46] put forward a specific method on how to use a reliable accountability system to improve the food safety factor. The research results show that contract management can improve the food safety factor in the food supply chain very well.

2.3. Supply Chain Contract. We will use cost-sharing and revenue-sharing contracts, so the research review will be more inclined to the relevant research status in this area. There are still many studies on the use of cost-sharing and revenue-sharing contracts to coordinate supply chains, which is suitable for the supply chain model that solves the uneven sharing of supply chain costs and the uncoordinated distribution of benefits, which is consistent with our research content. The introduction of blockchain technology will increase some additional costs, so we believe that revenue-sharing and cost-sharing contracts should be one of the preferred contracts for coordination of organic food supply chain contracts, and are also more suitable for solving problems in organic food supply chains and coordination issues.

The research on cost-sharing and revenue-sharing contracts is in-depth and extensive, and they are basically the coordination research applied to two-level and three-level supply chain models, including single contract coordination, as well as joint and improved contract coordination. For example, Dubey et al. [47] studied the contract coordination problem of the two-level supply chain of banks and e-commerce platforms, by introducing parameters such as effort level and cost, reputation information price and cost, and used game theory to analyze the final use of revenue-sharing and cost-sharing contracts to achieve supply chain coordination.

In addition, there are a number of top scholars who have made substantial contributions in their respective fields. Goli et al. [48] address a robust multiobjective multi-period aggregate production planning (APP) problem based on different scenarios under uncertain seasonal demand. According to the survey conducted by Ghoreishi et al. [49], optimal pricing strategy is one of the major policies for sellers or retailers to obtain its maximum profit. Goli et al. [50] address the multiobjective, multiproduct, and multi-period closed-loop supply chain network design with uncertain parameters, whose aim is to incorporate the financial flow as the cash flow and debts' constraints and labor employment under fuzzy uncertainty. Savku and Weber [51] study a stochastic optimal control problem for a delayed Markov regime-switching jump-diffusion model. Lotfi et al. [52] suggested a hybrid fuzzy and data-driven robust optimization for Resilience and Sustainable Health Care Supply Chain (RSHCSC) with VMI approach is appropriate for improving the inventory management system and tackling uncertainty and disruption in this situation. Tirkolaee et al. [53] identified the contributions of ML techniques in selecting and segmenting suppliers, predicting supply chain risks, and estimating demand and sales, production, inventory management, transportation and distribution, sustainable development (SD), and circular economy (CE). Kropat et al. [54] proposed a novel framework of semi-algebraic gene-environment networks. Khalilpourazari and Doulabi [55] showed that the offered robust model handles uncertainties more efficiently and finds solutions that have significantly lower costs and delivery time. Midya et al. [56] mainly focus on presenting an innovative study of a multi-stage multi-objective fixed-charge solid transportation problem (MMFSTP) with a green supply chain network system under an intuitionistic fuzzy environment.

Lin and He [57] studied the master-slave problem of the two-level supply chain of suppliers and e-commerce platforms by introducing several parameters, fresh-keeping effort level, and cost. The mixed contract of revenue-sharing and cost-sharing realizes the coordination of the supply chain. Jiang and Liu [58] studied the supply chain coordination problem of the three-level fresh food e-commerce supply chain of suppliers, distributors, and retailers through two variables of loss value and confidence level, and finally realized the supply chain through revenue-sharing contracts and discount contracts and coordination. Chang et al. [59] studied the supply chain coordination among the three stakeholders of e-commerce suppliers, third-party logistics companies, and community retail fresh stores, and introduced two variables, freshness preservation effort level and freshness, to define fresh food products. Finally, through game theory analysis, it can be seen that the supply chain is not coordinated, and the supply chain coordination is realized through revenue-sharing and preservation cost-sharing contracts. Dolgui et al. [60] study the coordination problem of two-level fresh food supply chain including suppliers and retailers, and use Stackberg game to analyze, and use cost universal contract to study whether it can make the supply chain coordinated, and finally, the numerical analysis verifies its effectiveness. Xiao et al. [61] proposed to add a reverse revenue-sharing contract to the closed-loop supply chain for coordination in view of the inconsistency in the closed-loop supply chain.

The research on cost-sharing and revenue-sharing contracts is still relatively abundant. Among them, cost-sharing contracts are mostly used when there are common costs in the supply chain, while revenue-sharing contracts are mostly used in conjunction with cost-sharing contracts which can achieve supply chain coordination.

In conclusion, first of all, we consider the method of quantitative analysis and research, and respectively, construct the game model under the blockchain and the traditional mode. We study the profit changes under the blockchain and the traditional mode, respectively. Each subject and the total profit are higher than the traditional model, and the cost threshold of applying the blockchain is found. Second, we describe the relationship between the authenticity rate of organic food and supply chain profit, and decentralized decision-making can lead to a decline in total supply chain profit. Finally, we design a cost-sharing and benefit-sharing contract, and conclude that the benefit-sharing and cost-sharing coefficients are within a certain range, which can facilitate coordination between organic food producers and retailers.

Table 1: Classification and survey of organic food supply chain.

Reference	Supply chain	Method	Contract	Objectives	Blockchain	Case study
[28]	Two-stage	Revenue-sharing	Single	Economic	—	Numerical Example (NE)
[24]	Two-stage	Cost-sharing	Single	Economic and IT costs enterprise	—	NE
[26]	Two-stage	Cost-sharing	Single	Economic and IT costs	—	NE
[30]	Two-stage	Return	Single	Economic	—	Offline supermarket
[27]	Two-stage	Quantity discount	Multi	Social enterprise	—	NE
[33]	Two-stage	Price subsidy	Single	Economic	—	NE
[37]	Two-stage	Quantity flexibility	Single	Economic	—	Offline supermarket
[29]	Two-stage	Return	Single	Environmental	—	NE
[25]	Two-stage	Return	Single	Social enterprise	-	NE
[36]	Two-stage	Revenue-sharing	Single	Economic	—	NE
[42]	Two-stage	Cost-sharing	Single	Environmental	—	NE
[38]	Two-stage	Return	Single	Social enterprise	—	NE
[45]	Two-stage	Quantity discount	Single	Economic	—	NE
[40]	Two-stage	Cost-sharing	Single	Economic and IT costs	—	NE
[47]	Two-stage	Price subsidy	Single	Economic	—	NE
This research	Two-stage + Two modes	Revenue-sharing + cost-sharing	Multi	Economy, organic field, society, and information technology	Application of blockchain	Enterprise chain

A more detail classification of the literature is presented in Table 1 with respect to six features including supply chain, method, contract, objectives, blockchain, and case study. The features related to the problem in the present study are presented in the last row of the table.

3. Problem Statement

We consider that many organic food manufacturers are both producers and distributors, and in the context of blockchain, the organic food supply chain does not need so many links to complete transactions. In order to facilitate analysis, we are considering including organic food. A two-tier supply chain model including food producers and retailers, where organic food producers are the leaders of this supply chain model, and retailers are followers, so our study is suitable for analysis by the Stackelberg game, where retailers decide the optimal price based on the wholesale price of organic food producers' selling price.

3.1. Assumptions and Notation List

(i) Organic food producers need to invest in additional costs to process and produce organic food, where $e\,(0 < e < 1)$ is the organic degree of the food [62].

(ii) We assume that the market demand function is of the form $Q^B = a - bp + \lambda e$, where a is the potential organic food market demand, b is the price sensitivity coefficient of organic food, p is the market price of organic food, and λe is the consumption [63].

(iii) The demand under the traditional and blockchain models is the retailer's order quantity D, so $Q = D$, our mathematical model use Q directly to analyze the order quantity, and no longer use D.

(iv) We assume that the application cost c_B and organic effort cost $ke^2/2$ of the blockchain are borne by the organic food manufacturer, the leader of the supply chain [64, 65].

Figure 1 describes the supply chain structure.

First, parameters and decision variables are defined in Table 2 as follows:

The supply chain decision-making problem is usually looked at from the perspectives of centralized and decentralized organization settings. In the following, we first study the decentralized decision model in the traditional model and compare it with the decentralized decision model in the blockchain model. We then study the centralized decision model in the blockchain model and find that the supply chain in the blockchain model is not optimal, arguing for the need to construct a coordination model.

3.2. Decentralized Decision-Making Model in Traditional Mode. First, we consider that, in the context of the traditional traceability model, the manufacturer is the leader of the supply chain and the retailer is the follower. In the traditional case, the consumer's demand function is of the form $Q^N = a - bp^N$. The organic food retailer purchases unit Q^N of organic food from the organic food manufacturer after clarifying the market demand. In the traditional traceability mode, there is a phenomenon of fake and inferior products, and the rate of genuine products is $\mu\,(0 < \mu < 1)$.

Then the profits of organic food producers and retailers can be obtained as follows:

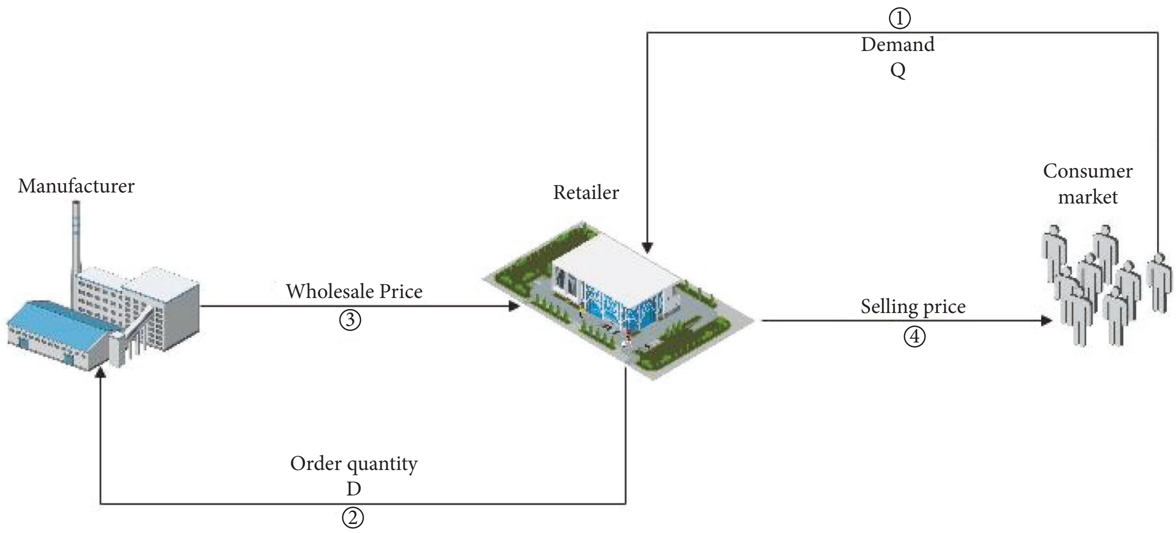

Figure 1: Model decision process.

Table 2: Notation list.

Variable	Description
Parameters	
k	Organic effort cost factor
p	Market price of organic food
w	Wholesale price per unit of organic food
μ	Authenticity rate of organic food
e	Degree of organic
λ	Organic preference
c_B	Application cost of blockchain technology
π_m	Organic food producer profit
π_r	Organic food retailer profit
π	Total supply chain profit
a	Potential organic food market demand
b	Price sensitivity of organic foods
c	Production cost per unit of organic food
Q	Consumer demand function
N	Traditional model
B	Blockchain model
Decision variables	
σ	Cost-sharing factor
ε	Revenue-sharing factor

$$\pi_m^N = \left(w^N - c\right)Q^N - \frac{k}{2}e^2, \tag{1}$$

$$\pi_r^N = \mu Q^N p^N - Q^N w^N. \tag{2}$$

Lemma 1. *Since $\partial^2 \pi_r^N / \partial (p^N)^2 = -2\mu b < 0$, $\partial^2 \pi_m^N / \partial (w^N)^2 = -b/\mu < 0$, there is an equilibrium decision, (p^{N*}, w^{N^*}, $\pi_m^{N^*}$, $\pi_r^{N^*}$, π^{N^*}) as follows:*

$$\begin{aligned} p^{N*} &= \frac{\mu a + b w^N}{2b\mu}, \\ w^{N^*} &= \frac{\mu a + bc}{2b}, \\ \pi_m^{N^*} &= \frac{(\mu a - bc)^2}{8\mu b}, \\ \pi_r^{N^*} &= \frac{(\mu a - bc)^2}{16\mu b}, \\ \pi^{N^*} &= \frac{3(\mu a - bc)^2}{16\mu b} \end{aligned} \tag{3}$$

the specific certification process is in Appendix.

3.3. Decentralized Decision-Making Model in the Context of Blockchain. We will analyze that in the context of blockchain, manufacturers and retailers are separate individuals under decentralized decision-making, and both manufacturers and retailers pursue the maximization of their own interests. At this point, the retailer wants to buy Q units of organic food from the producer, and the producer's wholesale price is w. Under the blockchain traceability mode, all information cannot be changed once it is on the chain, the information is symmetrical, and there is no counterfeiting. From here we will use the superscript B, which stands for the blockchain model. At this time $Q^B = a - bp^B + \lambda e$, the blockchain application cost c_B is borne by the organic food producer.

Then, the profits of organic food producers and retailers at this time can be obtained as follows:

$$\pi_m^B = \left(w^B - c\right)\left(a - bp^B + \lambda e\right) - c_B - \frac{k}{2}e^2, \quad (4)$$

$$\pi_r^B = \left(p^B - w^B\right)\left(a - bp^B + \lambda e\right). \quad (5)$$

The specific certification process is in Appendix.

Lemma 2. *Since $\partial^2\pi_r^B/\partial(p^B)^2 = -2b < 0$, $\partial^2\pi_m^B/\partial(w^B)^2 = -b < 0$, there is an equilibrium decision, (p^{B*}, w^{B*}, π_m^{B*}, π_r^{B*}, π^{B*}) as follows:*

$$\begin{aligned}
p^{B*} &= \frac{a + \lambda e + bw^B}{2b}, \\
w^{B*} &= \frac{a + \lambda e + bc}{2b}, \\
\pi_m^{B*} &= \frac{(a + \lambda e - bc)^2}{8b} - c_B - \frac{k}{2}e^2, \\
\pi_r^{B*} &= \frac{(a + \lambda e - bc)^2}{16b}, \\
\pi^{B*} &= \frac{3(a + \lambda e - bc)^2}{16b} - c_B - \frac{k}{2}e^2.
\end{aligned} \quad (6)$$

The specific certification process is in Appendix.

3.4. Comparison of Traditional Models and Models in the Context of Blockchain. We compare the retailer's profit, the supplier's profit, and the overall profit of the supply chain between the traditional model and the blockchain scenario, and draw the following propositions:

Proposition 1. *The profit of the retailer under the blockchain model is higher than that of the retailer under the traditional model.*

From Proposition 1, for organic food retailers, the adoption of blockchain is beneficial, at least more profitable than the traditional model.

The specific certification process is in Appendix.

Proposition 2. *To meet certain conditions, the profit of producers under the blockchain model can be higher than that of the traditional model.*

See Appendix for the specific certification process.

Proposition 3. *The application of blockchain can effectively eliminate the fake and shoddy organic food, improve the trust of organic food, and at the same time attract a part of consumer demand to buy organic food, which directly brings about an increase in revenue, from the overall profit of the supply chain. From a perspective, if the cost of blockchain is too high, it is not recommended for the supply chain to adopt blockchain for anti-counterfeiting traceability of organic food.*

The specific certification process is in Appendix.

Corollary 1. *When $0 \le c_B \le c_B^E$, after the application of blockchain technology, the total profit of the supply chain can be improved, where $c_B^E = 3[\mu(a + \lambda e - bc)^2 - (\mu a - bc)^2]/16\mu b - k/2e^2$.*

The specific certification process is in Appendix.

Corollary 1 finds the cost threshold of blockchain application, that is, within this threshold range, blockchain can improve the total profit of the supply chain and increase the stability of the organic food supply chain.

Corollary 2. *When $c_B \ge c_B^E$, after the blockchain is put into application, the total profit of the supply chain is less than that of the traditional model, where $c_B^E = 3[\mu(a + \lambda e - bc)^2 - (\mu a - bc)^2]/16\mu b - k/2e^2$.*

The specific certification process is in Appendix.

Corollary 2 states that when the cost of blockchain application is higher than this threshold, the overall profit of the supply chain will decline and will be lower than the traditional model. Therefore, the application of blockchain technology is not recommended at this time.

3.5. Centralized Decision-Making Model in the Context of Blockchain. Under centralized decision-making, the supply chain as a whole, organic food producers, and retailers will decide pricing for the entire supply chain to achieve the optimal profit level without the cost of ordering products.

Then the profit of the supply chain system can be obtained as follows:

$$\pi^B = \left(p^B - c\right)\left(a - bp^B + \lambda e\right) - c_B - \frac{k}{2}e^2. \quad (7)$$

Lemma 3. *Since $\partial^2\pi^B/\partial(p^B)^2 = -2b < 0$, there is an equilibrium decision, (p^{B**}, π^{B**}) as follows:*

$$\begin{aligned}
p^{B**} &= \frac{a + bc + \lambda e}{2b}, \\
\pi^{B**} &= \frac{(a - bc + \lambda e)^2}{4b} - c_B - \frac{k}{2}e^2.
\end{aligned} \quad (8)$$

The specific certification process is in Appendix.

Obtained by comparison: $p^{B*} > p^{B**} = w^{B*}$. In other words, the sales price of organic food under decentralized decision-making is greater than that under centralized decision-making, and the sales price under centralized decision-making is equal to the wholesale price under decentralized decision-making.

Also in the context of blockchain, from the perspective of the total profit of the supply chain, when π^{B*} is compared in decentralized decision-making and π^{B**} in centralized decision-making, we get $\pi^{B*} < \pi^{B**}$. In other words, the total profit of the supply chain in decentralized decision-making is lower than that in centralized decision-making, which indicates that the supply chain profit does not reach the optimal state and Pareto efficiency when decentralized decision-making is used. At this time, the supply chain is not in the optimal state, so we consider using cost-sharing contracts for coordination.

3.6. Coordinating the Supply Chain

3.6.1. Cost-Sharing Contract Coordination under Decentralized Decision-Making in the Context of Blockchain. The blockchain-based organic food supply chain does not achieve Pareto efficiency in decentralized decision-making, and the supply chain is not optimal. Since the cost of blockchain is borne by the manufacturer, for retailers, they prefer to apply blockchain technology to eliminate fake and shoddy organic food, while retailers do not bear the cost of blockchain application and organic efforts costs, which in turn lead to supply chain imbalances. Therefore, we first adopt a cost-sharing contract to coordinate the organic food supply chain in the blockchain context, optimized as follows: organic food producers wholesale to retailers at a lower price w than the wholesale price in decentralized decision-making; at the same time, the retailer commits to bear a proportion σ of the blockchain cost c_B and the organic effort cost $ke^2/2$, which is the proportion that the producer bears $(1-\sigma)$. Producers and retailers share the cost of blockchain and organic efforts. The introduction of the subscript–CS indicates the state under the cost-sharing contract.

At this point, the profits of organic food producers and retailers under the cost-sharing contract can be obtained as follows:

$$\pi_{m-CS}^{B} = \left(w^{B}-c\right)\left(a-bp^{B}+\lambda e\right)-(1-\sigma)\left(c_{B}+\frac{k}{2}e^{2}\right), \quad (9)$$

$$\pi_{r-CS}^{B} = \left(p^{B}-w^{B}\right)\left(a-bp^{B}+\lambda e\right)-\sigma\left(c_{B}+\frac{k}{2}e^{2}\right). \quad (10)$$

Lemma 4. *Since $\partial^2\pi_{r-CS}^{B}/\partial(p^B)^2 = -2b<0$, there is an equilibrium decision, (p^{B***}, π_{m-CS}^{B***}, π_{r-CS}^{B***}, π_{CS}^{B***}) as follows:*

$$\begin{aligned}
p^{B***} &= \frac{a+\lambda e+bw^{B}}{2b},\\
\pi_{m-CS}^{B***} &= (\sigma-1)\left(c_{B}+\frac{k}{2}e^{2}\right)\leq 0,\\
\pi_{r-CS}^{B***} &= \frac{(a+\lambda e-bc)^{2}}{4b}-\sigma\left(c_{B}+\frac{k}{2}e^{2}\right),\\
\pi_{CS}^{B***} &= \frac{(a+\lambda e-bc)^{2}}{4b}-c_{B}-\frac{k}{2}e^{2}=\pi^{B**}.
\end{aligned} \quad (11)$$

The specific certification process is in Appendix.

In order to realize the coordination of supply chain, the necessary condition of cost-sharing contract is that the optimal sales price p^{B***} under the coordination of cost-sharing contract is equal to the optimal sales price p^{B**} under centralized decision-making, namely, $a+\lambda e+bw^B/2b = a+bc+\lambda e/2b$, which can be obtained through algebraic analysis. When $w^B = c$, $p^{B**} = p^{B***}$. At this time, the maximization of the profit of the supply chain is achieved, that is, under the cost-sharing contract, the overall profit of the supply chain can be optimized.

It can be seen that the total profit of the supply chain under the cost-sharing contract is equal to the total profit under the centralized decision-making. There are two purposes of supply chain coordination. First, to optimize the overall profit of the supply chain; second, to make the profits of manufacturers and retailers more than when the supply chain contract is not adopted. However, it can be seen from the analysis that the producer's profit $\pi_{m-CS}^{B***}\leq 0$ under the coordination of the cost-sharing contract is less than that without the contract. This shows that the cost-sharing contract can only optimize the total profit of the supply chain, while the profit of the manufacturer is mainly transferred to the retailer, which will reduce the profit of the manufacturer, which is mainly beneficial to the retailer. Obviously, it is not a win-win situation for the supply chain. Therefore, the cost-sharing contract cannot realize the coordination of the supply chain.

3.6.2. Analysis of Benefit-Sharing Cost-Sharing Contract Coordination under Decentralized Decision-Making in the Context of Blockchain. Although the cost-sharing contract can maximize the profit of the supply chain, the profit of the manufacturer has been significantly reduced, while the profit of the retailer has increased, which has not achieved a win-win situation for all the main bodies of the supply chain. However, due to the unbalanced distribution of profits between manufacturers and retailers, cost-sharing contracts will not be adopted in real economic activities. Therefore, we then consider the use of an improved cost-sharing contract for coordination, that is, on the basis of the original cost-sharing contract coordination, we propose to let the retailer's sales draw ε proportion to the manufacturer. The introduction of subscript-CSRS indicates the state under the combined contract of cost-sharing and benefit-sharing.

At this point, the profits of organic food producers and retailers under the hybrid contract of cost-sharing and revenue-sharing can be obtained as follows:

$$\pi_{m-CSRS}^{B} = \left(w^{B}-c+\varepsilon p^{B}\right)\left(a-bp^{B}+\lambda e\right)-(1-\sigma)\left(c_{B}+\frac{k}{2}e^{2}\right), \quad (12)$$

$$\pi_{r-CSRS}^{B} = \left[(1-\varepsilon)p^{B}-w^{B}\right]\left(a-bp^{B}+\lambda e\right)-\sigma\left(c_{B}+\frac{k}{2}e^{2}\right). \quad (13)$$

Lemma 5. *Since $\partial^2\pi_{r-CSRS}^{B}/\partial(p^B)^2 = -2b(1-\varepsilon)<0$, there is an equilibrium decision, (p^{B****}, π_{m-CSRS}^{B****}, π_{r-CSRS}^{B****}, π_{CSRS}^{B****}) as follows:*

$$
\begin{aligned}
p^{B****} &= \frac{a+\lambda e}{2b} + \frac{bw^B}{2b(1-\varepsilon)},\\
\pi_{m-CSRS}^{B****} &= \frac{\varepsilon(a+\lambda e-bc)^2}{4b} - (1-\sigma)\left(c_B + \frac{k}{2}e^2\right),\\
\pi_{r-CSRS}^{B****} &= \frac{(1-\varepsilon)(a+\lambda e-bc)^2}{4b} - \sigma\left(c_B + \frac{k}{2}e^2\right),\\
\pi_{CSRS}^{B****} &= \frac{(a+\lambda e-bc)^2}{4b} - c_B - \frac{k}{2}e^2.
\end{aligned}
\tag{14}
$$

From the analysis in the previous section, we know that supply chain coordination can only be achieved under the following conditions:

$$
p^{B****} = \frac{a+\lambda e}{2b} + \frac{bw^B}{2b(1-\varepsilon)} = p^{B**} = \frac{a+bc+\lambda e}{2b}. \tag{15}
$$

The specific certification process is in Appendix.

Through algebraic analysis, it can be obtained that when $w^B = c(1-\varepsilon)$, the formula is established, and the supply chain can maximize profits at this time.

In order to achieve a win-win situation and achieve a state of supply chain coordination, the following conditions must be met: $\pi_{m-CSRS}^{B****} \geq \pi_m^{B*}$ and $\pi_{r-CSRS}^{B****} \geq \pi_r^{B*}$. It can be seen from the coordination of supply chain, $(1-2\varepsilon)(a+\lambda e-bc)^2/\ 8b\sigma \leq c_B + k/2e^2$ and $c_B + k/2e^2 \leq (3-4\varepsilon)(a+\lambda e-bc)^2/\ 16b\sigma$.

The final results show that the revenue-sharing factor ε and the cost-sharing factor σ can be solved. When ε and σ meet the conditions, the organic food supply chain reaches a coordinated state.

3.7. Results and Discussion. We have established the relationship between blockchain input cost and market demand function by assuming the conditions and relevant parameter variables. Firstly, in the comparative analysis between the traditional situation model under decentralized decision-making and the model under blockchain scenario, we conclude that the benefit of applying blockchain is to eliminate counterfeit organic food and increase the sales profit of retailers. Next, the profit functions of suppliers and retailers under decentralized decision-making and the overall profit of the supply chain under centralized decision-making are then derived. Since the optimal pricing under decentralized decision is not equal to the optimal pricing under centralized decision model. According to the coordination theory of supply chain, the supply chain under decentralized decision model can easily fall into a dysfunctional state. We demonstrate that the supply chain is indeed in a disjointed state by comparing the profits under decentralized decision-making and centralized decision-making. Since the input costs of blockchain are mainly borne by suppliers, we first propose a cost-sharing contract to coordinate the supply chain. Through the analysis, it is clear that a single cost-sharing contract cannot bring the supply chain to a coordinated state, so we consider introducing a revenue-sharing contract and consider allowing the retailer to give a portion of the revenue to the supplier. We find that when the cost-sharing factor and revenue-sharing factor vary within a certain range, the supply chain achieves a coordinated state. This suggests that a combination of revenue-sharing and cost-sharing contracts can lead to a coordinated organic food supply chain in a blockchain scenario. This section focuses on the derivation and analysis of algebraic equations, and the specific numerical arithmetic analysis is in the following, where we validate the previous findings.

4. Case Study

The Shanghai Dynamic Information System Co. Ltd., Shanghai, China, is considering the implementation of this newly proposed portfolio optimization solution. The lack of an accurate grasp of the organic food market and the pricing of the application costs of blockchain technology to make the right decisions was one of the main problems of this company, which led to high link costs. The ensuing high risk and lack of reward in producing organic food in the traditional model forced the managers of the food suppliers to optimize for the future to better cater to the consumer market.

The Shanghai Business Information Center released the results of a special questionnaire survey on the Shanghai organic food consumer market at the "China International Organic Food Expo," which opened in May. The survey interviewed more than 600 consumers who had organic food consumption experience and basically painted a picture of the characteristics and consumption preferences of the Shanghai organic food market. According to the survey, female consumers with a bachelor's degree or above, married with children, and an annual family income of 120,000–250,000 RMB are the main consumer group in the organic food market, accounting for 59%. The consumption rate of vegetables, grains, and fruits topped the list, and the popularity of other organic foods, including meat products, dairy products, and aquatic products, reached a high level. It is worth mentioning that the characteristics of cross-category consumption of the middle-aged and elderly groups are very obvious. High frequency of purchase and high price tolerance highlight the degree of consumer recognition. In terms of purchase frequency, the proportion of respondents who buy organic food once every two or three days is 44%, and those who buy every week is 36%, totaling 80%. Single consumption of more than 100 yuan accounted for 37%, more than 200 yuan accounted for 28%, a total of 65%, indicating that people who have experienced consumption of organic food to achieve a high level of recognition and loyalty, the overall health and durability of the market is strong. Supermarket chains are still the mainstream sales channels for organic food, and the scale of online consumption is expanding rapidly. The survey shows that 79.5% and 78.2% of consumers have purchased organic food in hypermarkets and fresh food supermarkets, respectively, substantially higher than other formats. 37.0% of consumers have purchased from online stores. The standardization of organic food, the ease of ordering of cold chain logistics, and maturation are driving the rapid expansion of online channel sales. The pursuit of health and quality of life is the motivation for these consumers to buy. When asked about the motivation for buying organic food, 77.5% and 73.2% of the respondents chose “health” and “quality assurance,” which have become the golden sign and core competitiveness of organic food to expand market share. When selecting organic food, 70%, 67%, and 65% of the respondents will focus on “freshness,” “safety,” and “nutrition,” respectively. The lowest concern for “packaging,” only 27%, from a side to reflect the proportion of self-consumption reached a considerable level. Organic food is gradually integrated into people’s lives. More than half of the respondents could not distinguish or incorrectly distinguish between organic food, green food, and other professional concepts. In addition, when asked about the use of chemical fertilizers in the organic food growing process, respondents also showed “confusion,” indicating that the concept of organic food and standards to be standardized and popularized. According to the survey, the overall satisfaction of respondents with the organic food market is high, with 21% and 58% of respondents being “satisfied” and “relatively satisfied,” respectively. When asked to improve the expected aspects, “industry standard management,” “commodity richness,” and “commodity quality” three top, were selected by the rate of 58.7%, 54.8%, and 51.5%, respectively.

In the traditional organic food supply chain model, starting from the organic food raw material planting, through the organic food processing enterprises for production, and then through the wholesale market, supermarkets, and other large intermediaries or retailer to deliver the finished organic food to the hands of organic food consumers. With the development of the Internet of Things, Internet, big data, cloud computing, and other information technology, organic food processing enterprises and upstream farmers and downstream retail merchants to cooperate and dependent with each other. Information sharing has been higher than before, but still not enough, and the real supply chain member enterprises should be connected together to form a synergistic and competitive whole.

A comparative analysis of the organic food supply chain traceability system in the context of traditional IoT technology and blockchain technology summarizes the advantages of adopting blockchain technology. Blockchain technology meets the current urgent needs of the industry. Blockchain is an innovative application mode of computer technologies such as cryptographic algorithms, consensus mechanisms, and distributed storage, and the combination of blockchain technology and traceability systems can improve the shortcomings of traditional organic food quality and safety traceability systems. The security of data is high in the blockchain context. The blockchain context is conducive to the supervision and pursuit of responsibility and the fight against counterfeiting.

Next, the profit prediction brought by blockchain technology to each member of the organic food supply chain is run in MATLAB R2021, implemented using a PC (CPU Core i7 and 16G RAM). The results obtained in the optimization are presented in the next section. The organic food quality and safety traceability system in the context of blockchain technology has many advantages, but the development of promotion in blockchain also encounters some obstacles, which makes it difficult to promote the blockchain traceability system. On the one hand, without informationization in the whole process of organic food supply chain circulation, there is no way to put information collection on the chain. On the other hand, some large enterprises recognize the many benefits brought by blockchain and actively adopt it, while Shanghai Dynamic Information System Co., Ltd. adopts blockchain because of its complicated technology, large investment, relatively high cost, and serious old-fashioned thinking, and the adoption of blockchain brings a relatively big impact on the traditional centralized operation mode, which is also an important reason to prevent SMEs from adopting blockchain. With the development and promotion of blockchain technology, when SMEs gradually realize the benefits brought by blockchain, the full-scale promotion and application of blockchain will become a reality.

5. Numerical Analysis

With the previous theoretical foreshadowing and formula derivation basis, we will use an example to conduct an empirical analysis of the previous research results. In cooperation with Shanghai Energy Information System Co., Ltd. to conduct field research and analysis, the organic food under the blockchain traceability scenario eliminates counterfeit organic food, significantly improves the trust and sales of products, and the cost of blockchain is not high. Therefore, this chapter will verify the relevant results of the investigation by assigning them. From the previous model derivation, it can be seen that several parameters that can be assigned in the model include: a, k, b, c, c_B, e, μ, and λ. Considering the reality, assign these parameters as follows: $a = 110, k = 20, b = 4, c = 1, c_B = 1, e = 0.9, \mu = 0.5, \lambda = 50$, and $e, \varepsilon, \sigma \in [0, 1]$.

5.1. The Impact of Organic Food Authenticity Rate μon Supply Chain Profits. In the context of the traditional traceability model, $Q^N = 110 - 4p^N$, the genuine rate of organic food $\mu = 0.5$.

At this point, the producer’s profit is $\pi_m^N = (w^N - 1)(110 - 4p^N) - 8.1$. The retailer’s profit is $\pi_r^N = 0.5(110 - 4p^N)p^N - (110 - 4p^N)w^N$. The optimal wholesale price, optimal sales price, optimal profit of producers and retailers, and total supply chain profit of organic food can be solved as follows: $w^{N^*} = 7.38$, $p^{N*} = 34.88$, $\pi_m^{N^*} = 162.56$, $\pi_r^{N^*} = 81.28$, and $\pi^{N^*} = 243.84$.

When the value of μ changes, it will have an impact on the total profit of organic food manufacturers, retailers, and supply chains as shown in Table 3.

Figure 2 shows that (1) with the increase in the authentic rate μ of organic food, the overall profits of manufacturers, retailers, and supply chains will increase. (2) This shows that

Table 3: The impact of organic food authenticity rate μ on supply chain profits.

μ	π_m^N	π_r^N	π^N
0.1	15.31	7.66	22.97
0.3	87.60	43.80	131.4
0.5	162.56	81.28	243.84
0.7	237.90	118.95	356.85
0.9	313.37	156.68	470.05

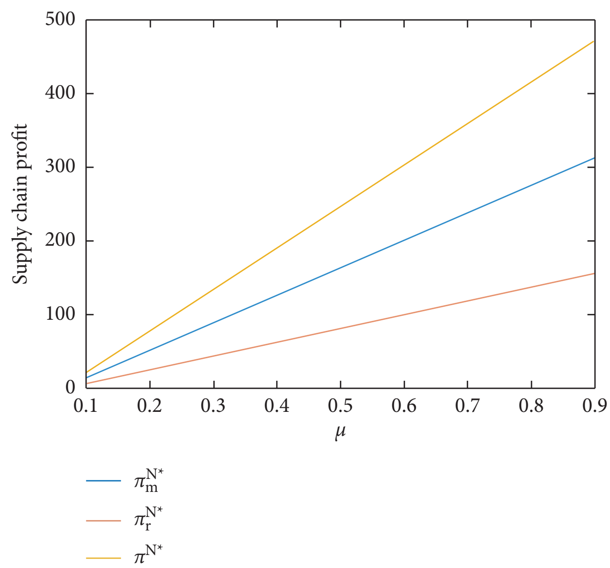

Figure 2: The impact of the genuine product rate μ on the profit of the supply chain.

even in the traditional supply chain model, increasing the genuine rate of organic food can make the supply chain more profitable. (3) Under the traditional model, it is not easy to improve the genuine rate of organic food and make consumers trust organic food.

5.2. The Impact of Organic Degree e on Supply Chain Profits. In the context of blockchain, the genuine rate of organic food is $\mu = 1$, and there is basically no fake and shoddy organic food, $e = 0.9$.

At this point, the producer's profit is $\pi_m^B = (w^B - 1)(-4p^B + 155) - 9.1$. The retailer's profit is $\pi_r^B = (p^B - w^B)(-4p^B + 155)$. The optimal wholesale price, the optimal selling price, the optimal profit of the producer and the retailer, and the total profit of the supply chain can be obtained as $w^{B*} = 19.88$, $p^{B*} = 29.32$, $\pi_m^{B*} = 703.43$, $\pi_r^{B*} = 356.27$, and $\pi^{B*} = 1059.70$.

By comparison, we can see that $\pi_m^{B*} > \pi_m^{N^*}$, $\pi_r^{B*} > \pi_r^{N^*}$, and $\pi^{B*} > \pi^{N^*}$, the overall profits of manufacturers, retailers, and supply chains are more in the context of blockchain, which shows that the adoption of blockchain can bring about an increase in the profits of all links in the supply chain, and blockchain technology is worthwhile. Adopted and promoted.

Figure 3 shows that (1) the total profit of organic food producers, retailers, and supply chains under the blockchain

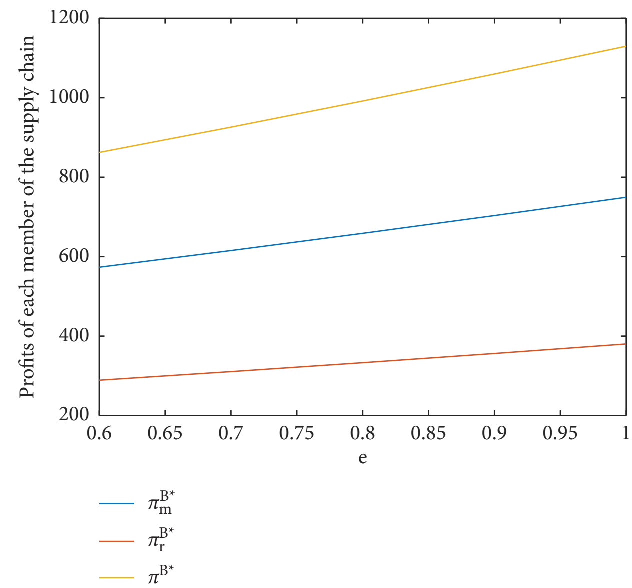

Figure 3: The impact of e on supply chain profits.

Table 4: The impact of organic degree e on supply chain profits.

e	μ	π_m^B	π_r^B	π^B
0.6	1	573.40	289.00	862.40
0.7	1	615.38	310.64	926.02
0.8	1	658.73	333.06	991.79
0.9	1	703.43	356.27	1059.7
1.0	1	749.50	380.25	1129.75

model is significantly higher than that of the traditional model. (2) We study and analyze the relationship between the organic degree e and the profit of the supply chain, and we will get the optimal profit of the manufacturer, the retailer, and the whole supply chain under different e conditions. As the organic level e increases, the profits of the main members of the supply chain also increase.

Comparing Tables 4 with 3, we can conclude that even with the same authenticity rate and the same organic level, the profit gained from adopting blockchain is always higher than that of not adopting blockchain, This also fully proves that the blockchain should be adopted.

In order to more intuitively express the relationship between the change of e and the change of supply chain profit, MATLAB software is used for simulation as shown in Figure 3.

5.3. The Impact of Cost-Sharing and Revenue-Sharing Factors on Supply Chain Profits. We consider using an improved cost-sharing contract for further coordination, and on the basis of the original cost-sharing contract, let the retailer give ε proportion of the revenue to the manufacturer. At this point, the profit function of the manufacturer and the retailer is $\pi_{m-\text{CSRS}}^B = (w - 1)(155 - 4p) - 9.1(1 - \sigma) + \varepsilon p(155 - 4p)$, $\pi_{r-CSRS}^B = [(1 - \varepsilon)p - w](155 - bp) - 9.1\sigma$. Figure 4 shows

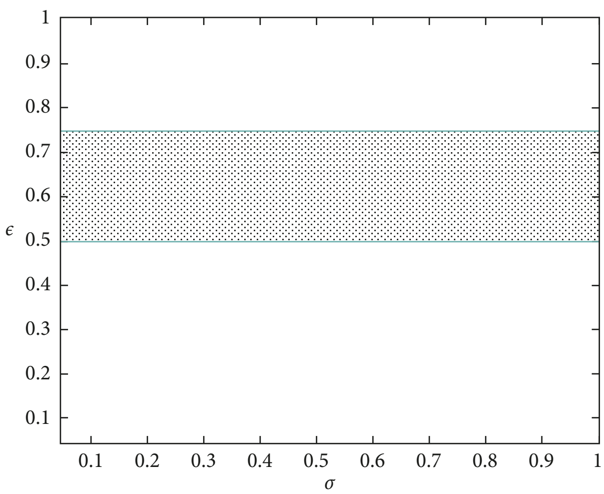

FIGURE 4: ε and σ value relationship.

that (1) supply chain coordination can be achieved when the benefit-sharing factor ε and the cost-sharing factor σ satisfy conditions. (2) In the interval of $\varepsilon \in [0.494, 0.750]$, $\sigma \in [0, 1]$; in other words, the value range is the shaded part in the figure. (3) The combined contract of revenue-sharing and cost-sharing can achieve Pareto improvement, the organic food supply chain based on blockchain can be coordinated, and all entities in the supply chain can achieve optimal profits.

According to the current research status of supply chain contracts, the way of benefit distribution and risk sharing between suppliers and retailers, and the way of order acquisition, supply chain contracts can be divided into the following main types: pricing contracts, repurchase contracts, quantity flexibility contracts, and revenue-sharing contracts. Pricing contract means that the retailer decides the order quantity according to the market demand and wholesale price, the supplier and the manufacturer organize the production according to the retailer's order quantity, the retailer is responsible for handling the inventory products, and the retailer forecasts the product sales. Therefore, the supplier's profit is determined in this contract, and the retailer fully assumes the risk of market uncertainty. This type of contract emerged earlier and is well developed and is widely used in a number of fields. Such a supply chain contract is very effective in markets with multiple (or infinite) consecutive sales cycles. This has now been built upon in the form of price protection contracts, where the supplier compensates the retailer for unsold goods when the wholesale price of the product falls over the product's life cycle. This type of covenant is often used in the field of personal computers and cell phones.

A buy-back contract is one in which the supplier buys back the remaining merchandise at the end of the sales season at a certain price, and the retailer can decide for itself whether to return all of the merchandise, with the supplier forecasting product sales. The supplier and the retailer share the risk of market uncertainty. In addition, this strategy also affects consumers, because before the emergence of this supply-land contract, retailers usually used discount promotions to dispose of surplus goods, and suppliers worry that this approach will affect the status of their brands in the minds of consumers, and damage their product brands, especially in certain limited high-priced goods. Some scholars fear that this behavior will harm the supplier's interests and ultimately lead to the nonviability of such contracts, but research shows that the supplier's interests instead rise much higher as a result, because the number of orders from retailers is often irrational under the incentive of such contracts. The repurchase contract is one of the most convenient contracts to coordinate the supply chain because of its ease of implementation between suppliers and retailers and is naturally a hot topic of research. This contract has also given rise to other types of contracts, such as the sales rebate contract, in which the retailer receives a rebate from the supplier for each additional item sold after a certain number of sales, in essence giving the retailer a direct incentive to increase sales. It also provides an incentive for the retailer to increase the order quantity and further improve the system performance. Buy-back covenants are often applied in seasonal commodity markets.

Quantity flexibility contracting is where the retailer books a portion of the product prior to the start of the selling season, the supplier organizes production accordingly, and the retailer, having obtained a firm market demand, can determine the final purchase volume within the quantity of product that the supplier can provide to obtain the expected revenue. Under the quantity elasticity contract approach, two fluctuation limits are imposed: one is the maximum fluctuation ratio per order period, and the supplier is then obliged to meet the maximum upper limit of purchase quantity to prevent losses caused by sellers increasing the order quantity and resulting in supply chain shortages; the other is the minimum lower limit of product quantity that retailers must purchase to prevent sellers overestimating demand and resulting in supply chain overcapacity. Under these two constraints, a higher retailer order quantity maximizes supply chain benefits and reduces the impact caused by the dual marginal effects of suppliers and retailers. The purpose of quantity flexibility contracts is to make buyers and sellers share the risk or benefits, and to induce retailers to carefully forecast demand and plan order quantities. Quantity elasticity contracts increase the average quantity of goods purchased by the retailer, incentivize the retailer to try to forecast market demand to increase their desired profitability, and ultimately have the potential to increase the overall effectiveness of the supply chain. Such covenants are widely used in the electronics and computer fields. It is widely used by large companies such as IBM.

One problem that is unavoidable in all of the above supply chain contracts is that when the initial wholesale price is too high, the producer will not be able to gain enough benefit from a lower number of orders from the retailer, and if the wholesale price is lowered in order to increase the number of orders, it is equally likely to harm the benefits on production. Revenue-sharing contracts are designed to resolve this conflict. In a revenue-sharing contract, the retailer delivers a percentage of the sales revenue to the manufacturer in order to obtain a lower wholesale price. This

Table 5: Advantages and disadvantages of the proposed method versus the traditional method.

	RS-CS	Pricing contract	Repurchase deed	Quantity flexibility contract
Advantages	Wide range of applications and easy supply chain coordination	Effective in markets with multiple consecutive sales cycles	Suppliers and retailers share the risk of market uncertainty	Buyer and seller share the risk or share the benefits
Disadvantages	A little complicated	The supplier's profit is fixed	Retailers are often irrational in their order numbers	Retailers have a minimum purchase volume

mechanism not only provides an incentive for the retailer to order more products at a lower price, but also ensures that the manufacturer's interests are not lost and that all parties in the supply chain are coordinated. In this contract, both parties share the market risk and the expectation of market sales. However, the revenue-sharing contract cannot be considered the best form of supply chain contract. It also has certain limitations, mainly in two aspects: on the one hand, it requires the seller to detect the buyer's revenue, thus increasing the overhead; on the other hand, because revenue-sharing reduces the buyer's marginal profit, it drives the buyer to promote the sale of competing goods from other suppliers that do not have a sharing contract. Such contracts emerged with great success in the impression industry at the end of the last century, and were then rapidly extended to other industries.

In view of the limitations of single revenue-sharing contracts, cost-sharing contracts were introduced on top of revenue-sharing contracts. Cost-sharing contracts are mostly used when there are common costs in the supply chain, while revenue-sharing is mostly used in conjunction with cost-sharing contracts to achieve supply chain coordination more easily. In this study, we have to consider the cost of blockchain, so by reading a lot of related literature, we can conclude that the use of revenue-sharing and cost-sharing contracts is applicable for this study. The supplier and the retailer share a percentage of the cost, while allowing the retailer to put up a percentage of the revenue to the supplier. In reality, a single revenue-sharing contract can hardly solve the practical problems faced in the supply chain, so a combination of revenue-sharing and cost-sharing contract is designed to coordinate and thus solve the problem of supply chain coordination. In addition, this proposed combination contract is slightly more complex in application compared to the traditional single contract.

The advantages and disadvantages of the combined revenue-sharing and cost-sharing contract proposed in this study are compared with other traditional single contracts in Table 5.

6. Managerial Insights and Practical Implications

To a certain extent, our research results can provide a theoretical reference for the coordinated management of organic food supply chains in the blockchain context. For organic food supply chains that adopt blockchain for traceability, a combination of benefit-sharing and cost-sharing contracts can be introduced to achieve supply chain coordination. It also has some reference value for enterprises that have not yet applied blockchain. At the same time, many agricultural products have already applied blockchain for traceability, and our research results and theories have some guidance for the coordinated supply chain management of other brands of agricultural products in the blockchain context.

Driven by both national policies and the demand of the organic food industry, many organic food companies will also start to gradually adopt blockchain for traceability to solve the distrust problem existing between supply chains, promote supply chain unity and collaboration, and improve supply chain performance in order to achieve supply chain coordination and drive the organic food industry to continue to move forward. Our findings have practical guidance for studying the coordination of organic food supply chains in a blockchain context.

Through our research results, it is recommended that organic food enterprises that have not yet applied blockchain traceability respond to the national call and meet the industry demand by actively adopting blockchain for the full traceability of organic food, protecting the information security of organic food, maintaining the brand image of organic food, establishing trust between the upstream and downstream supply chains, eliminating the inflow of fake and shoddy organic food into the supply chain, and improving the solidarity and collaboration between supply chains. Nowadays, more and more organic food companies are applying blockchain for traceability. For the coordinated management of organic food supply chain in the context of blockchain, we suggest introducing a combination of benefit-sharing and cost-sharing contracts, so that the supply chain can achieve optimal and win-win results.

7. Conclusions and Outlook

In recent years, the organic food supply chain has always had the pain point of counterfeiting and shoddy, resulting in distrust between the upstream and downstream of the supply chain, thus affecting the cooperation and coordination of the supply chain. Under the premise that blockchain technology is being promoted and applied, the introduction of blockchain can reshape the trust between the upstream and downstream of the organic food supply chain, improve the efficiency of collaboration between supply chains, and eliminate counterfeit and shoddy products. On this basis, we propose a research on contract coordination of organic food supply chain based on blockchain technology. In the context of blockchain, the coordination of organic food supply chain is studied, and appropriate contracts are introduced to coordinate the supply chain, so that the supply chain can reach the optimal state of coordination.

What we build is a secondary supply chain model composed of manufacturers and retailers. With the background of blockchain, we conduct research on the coordination of supply chains. We establish the supply chain model under the traditional model and the blockchain traceability scenario, introduce the organic degree of food, establish its relationship with market demand and blockchain input cost, and then use the Stackelberg game to carry out analysis. By comparing the traditional model under decentralized decision-making and the model under the blockchain context, it is found that the adoption of blockchain will increase the profit of retailers, which is also in line with the actual situation. There is basically no fake and shoddy organic food in the blockchain context, and it is very beneficial for retailers to use blockchain technology to trace the origin of organic food. Secondly, by studying the total profit of the supply chain under the centralized decision-making of the supply chain under the blockchain scenario, it is proved that the supply chain under the decentralized decision-making has not reached the optimal state, so further coordination is needed to make the supply chain optimal. Therefore, we first consider the introduction of cost-sharing contracts to coordinate the supply chain. The results show that under the cost-sharing contract, the organic food supply chain can maximize the profit of the supply chain, but the profit of the producer is less than that without contract coordination. A single cost-sharing contract cannot make the supply chain achieve coordination. Adding a revenue-sharing contract to the original cost-sharing contract, that is, considering allowing organic food retailers to share a part of the revenue with the manufacturer on the basis of the cost-sharing contract. The research results show that when the cost-sharing factor and the revenue-sharing factor are in specific when changing the range of organic food supply chain, it is possible to achieve a coordinated state of organic food supply chain, which is also an important conclusion of our research.

The results of this research and managerial insights are as follows:

(1) The increase in the genuine rate of organic food under the traditional model will bring higher profits to the supply chain (c.f. Table 3; Figure 2). This shows that even in the traditional supply chain model, increasing the genuine rate of organic food can make the supply chain more profitable.

(2) The adoption of blockchain can not only improve the genuine rate of products and combat counterfeit and shoddy organic food, but also the increase in trust in the context of blockchain will attract some consumers to buy organic food, bringing additional benefits to the supply chain.

(3) The total profit of organic food producers, retailers, and supply chains under the blockchain model is significantly higher than that of the traditional model. As the organic level increases, the profits of the main members of the supply chain also increase (c.f. Table 4; Figure 3).

(4) Comparing Tables 4 with 3, we can conclude that even with the same authenticity rate and the same organic level, the profit gained from adopting blockchain is always higher than that of not adopting blockchain, This also fully proves that the blockchain should be adopted.

(5) Supply chain coordination can be achieved when the benefit-sharing factor and the cost-sharing factor satisfy the conditions. The combined contract of revenue-sharing and cost-sharing can achieve Pareto improvement, the organic food supply chain based on blockchain can be coordinated, and all entities in the supply chain can achieve optimal profits (c.f. Figure 4).

The uncertainty of demand in the organic food supply chain and the costs of other aspects have not been taken into account, which will be improved in follow-up research. The source of the blockchain data is not considered fraudulent. Although the information already on the blockchain is real and cannot be tampered with, the source of the data cannot be fraudulently avoided. If the data itself is false, the blockchain cannot identify and prevent it. How to ensure the authenticity of source data is also one of the research directions of blockchain applications in the future. On the premise that blockchain technology is being vigorously promoted and applied, the introduction of blockchain can reshape the trust between upstream and downstream of the organic food supply chain, improve the cooperation efficiency between supply chains, and eliminate fake and shoddy products. Finally, we suggest that organic food enterprises actively adopt blockchain technology, which can lead to an increase in the profits of all links of the supply chain. Blockchain is worthy of adoption and promotion. In conclusion, it should be noted that the analysis in this study will help decision makers to choose the most appropriate option among the possible solutions based on their criteria. This proposed framework can also be extended in various cases where profits are out of balance in the organic food supply chain, such as safety and value gain.

Appendix

Proof of Lemma 1. Under the decentralized decision-making of the traditional supply chain, organic food producers and retailers each pursue the maximization of profits. Therefore, from the perspective of maximizing the profits of each member of the supply chain, we obtain $\partial \pi_r^N / \partial p^N = \mu (a - 2bp^N) + bw^N$ and $\partial^2 \pi_r^N / \partial (p^N)^2 = -2\mu b < 0$. Therefore, there is an optimal solution for π_r^N, and the reverse induction method is used to solve it, so that $\partial \pi_r^N / \partial p^N = 0$, the optimal sales price $p^{N*} = \mu a + bw^N / 2b\mu$ is obtained. Substituting p^{N*} into equation (1), which takes its second partial derivative with respect to w^N, we obtain

$\partial^2\pi_m^N/\partial(w^N)^2 = -b/\mu < 0$, where π_m^N is concave in w^N. Solving the first-order condition $\partial\pi_m^N/\partial w^N = 0$ for w^N, we obtain $w^{N^*} = \mu a + bc/2b$. Substituting both p^{N*} and w^{N^*} into equations (1) and (2), we obtain $\pi_m^{N^*} = (\mu a - bc)^2/8\mu b$, $\pi_r^{N^*} = (\mu a - bc)^2/16\mu b$, and $\pi^{N^*} = 3(\mu a - bc)^2/16\mu b$. □

Proof of Lemma 2. From the perspective of maximizing the profits of each member of the supply chain, we obtain $\partial^2\pi_r^B/\partial(p^B)^2 = -2b < 0$, where π_r^B is concave in p^B. Solving the first-order condition $\partial\pi_r^B/\partial p^B = 0$ for p^B, we obtain $p^{B*} = a + \lambda e + bw^B/2b$. Substituting p^{B*} into equation (4), which takes its second partial derivative with respect to w^B, we obtain $\partial^2\pi_m^B/\partial(w^B)^2 = -b < 0$, where π_m^B is concave in w^B. Solving the first-order condition $\partial\pi_m^B/\partial w^B = 0$ for w^B, we obtain $w^{B*} = a + \lambda e + bc/2b$. Substituting both p^{B*} and w^{B*} into equations (4) and (5), we obtain $\pi_m^{B*} = (a + \lambda e - bc)^2/8b - c_B - k/2e^2$, $\pi_r^{B*} = (a + \lambda e - bc)^2/16b$, $\pi^{B*} = 3(a + \lambda e - bc)^2/16b - c_B - k/2e^2$. □

Proof of Proposition 1. Based on Lemmas 1 and 2. By subtracting the retailer's profit under the blockchain model from the retailer's profit under the traditional model, we get $\pi_r^{B*} - \pi_r^{N^*} = \mu(a + \lambda e - bc)^2 - (\mu a - bc)^2/16\mu b$.

When $\mu = 1$, the minimum value is obtained, where the minimum value is greater than 0, that is, $\pi_r^{B*} - \pi_r^{N^*} > 0$ is always established, so $\pi_r^{B*} > \pi_r^{N^*}$ is always established. For retailers, the adoption of blockchain is beneficial. The profit of retailers under the blockchain model is always greater than that of retailers under the traditional model, which is proved. □

Proof of Proposition 2. Based on Lemmas 1 and 2. Subtracting the producer's profit under the blockchain with the producer's profit under the traditional model, we get $\pi_m^{B*} - \pi_m^{N^*} = \mu(a + \lambda e - bc)^2 - (\mu a - bc)^2/8\mu b - c_B - k/2e^2$. This equation is greater than 0, which depends on the demand gain brought by the organic preference of consumers and the application cost of blockchain and the additional green effort cost of producers. □

Proof of Proposition 3. Based on Lemmas 1 and 2. Subtracting the total supply chain profit π^{B*} under the blockchain model and the total supply chain profit π^{N^*} under the traditional model, we get $\pi^{B*} - \pi^{N^*} = 3[\mu(a+ \lambda e - bc)^2 - (\mu a - bc)^2]/ 16\mu b - c_B - k/2e^2$.

The total profit of the supply chain under the blockchain model is higher than the traditional situation, depending on the relationship between c_B, k, λ, and e. □

Proof of Corollary 1. Based on Proposition 3. To improve the total profit of the supply chain after applying the blockchain, in other words $\pi^{B*} \geq \pi^{N^*}$, we get $3(a + \lambda e- bc)^2/16b - c_B - ke^2/2 > 3(\mu a - bc)^2/16\mu b$, $c_B \leq 3[\mu(a + \lambda e- bc)^2 - (\mu a - bc)^2]/16\mu b - ke^2/2$. □

Proof of Corollary 2. Based on Proposition 3. Similar to Proofs of Corollary 1$\pi^{B*} \leq \pi^{N^*}$, after simplification, we get $c_B \geq 3[\mu(a + \lambda e - bc)^2 - (\mu a - bc)^2]/16\mu b - ke^2/2$. □

Proof of Lemma 3. Under the centralized model, organic food producers and retailers are regarded as one decision-making organization. Therefore, from the perspective of maximizing the profit of the supply chain system, we obtain $\partial^2\pi^B/\partial(p^B)^2 = -2b < 0$, where π^B is concave in p^B. Solving the first-order condition $\partial\pi^B/\partial p^B = 0$ for p^B, we obtain $p^{B**} = a + bc + \lambda e/2b$. Substituting p^{B**} into the overall supply chain profit π^B, we get that under centralized decision-making, the optimal total supply chain profit is $\pi^{B**} = (a - bc + \lambda e)^2/4b - c_B - ke^2/2$. □

Proof of Lemma 4. Solving equation (10) for the second partial derivative with respect to p^B, we obtain $\partial^2\pi_{r-\mathrm{CS}}^B/\partial(p^B)^2 = -2b < 0$, where π_{r-CS}^B is concave in p^B. Solving the first-order condition $\partial\pi_{r-\mathrm{CS}}^B/\partial p^B = 0$, for p^B, we obtain $p^{B***} = a + \lambda e + bw^B/2b$ and $w^{B***} = c$,

Substituting both p^{B***} and w^{B***} into equations (9) and (10), we obtain $\pi_{m-\mathrm{CS}}^{B***} = (\sigma - 1)(c_B + ke^2/2) \leq 0$, $\pi_{r-\mathrm{CS}}^{B***} = (a + \lambda e - bc)^2/4b - \sigma(c_B + ke^2/2)$, $\pi_{\mathrm{CS}}^{B***} = (a + \lambda e- bc)^2/4b - c_B - ke^2/2 = \pi^{B**}$. □

Proof of Lemma 5. Solving equation (13) for the second partial derivative with respect to p^B, we obtain $\partial^2\pi_{r-\mathrm{CSRS}}^B/\partial(p^B)^2 = -2b(1 - \varepsilon) < 0$, where π_{r-CSRS}^B is concave in p^B. Solving the first-order condition $\partial\pi_{r-CSRS}^B/\partial p^B = 0$ for p^B, we obtain $p^{B****} = a + \lambda e/2b + bw^B/2b(1 - \varepsilon)$ and $w^{B****} = c(1 - \varepsilon)$. Substituting both p^{B****} and w^{B****} into equations (12) and (13), we obtain $\pi_{m-\mathrm{CSRS}}^{B****} = \varepsilon(a + \lambda e- bc)^2/4b - (1 - \sigma)(c_B + k/2e^2)$, $\pi_{r-CSRS}^{B****} = (1 - \varepsilon)(a + \lambda e - bc)^2/4b - \sigma(c_B + k/2e^2)$, $\pi_{\mathrm{CSRS}}^{B****} = (a + \lambda e - bc)^2/4b- c_B - k/2e^2$. □

Data Availability

The data used to support the findings of this paper are included within the article (Numerical Analysis section).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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