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Research Article

Research on Supply Chain Coordination Based on Block Chain Technology and Customer Random Demand

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Based on disruptive innovation and Stackelberg noncooperative game theory, the paper focuses on supply chain coordination under the combined effects of block chain technology and random demand. Firstly, both a decentralized and a centralized supply chain decision models are built in a single-cycle newsvendor random demand situation. Then, through revenue sharing contract the study designs a brand-new supply chain coordination model which is Del trust, decentralized, and traded anonymously. Furthermore, the numerical comparative analysis on the optimal decision and supply chain coordination are conducted. It is found that the whole supply chain revenue can achieve and even beyond the performance level of the centralized supply chain with effectively expanding sales market and reducing supply chain risk. When the retail price is stable and supply chain is coordinated with revenue sharing mechanism, decentralized supply chain can achieve minimum optimal revenue. Coordination results have effect on short-term revenues of block chain members only. Implications and suggestions for future research in supply chain coordination are provided.

1. Introduction

Because of the uncertainty of competition and changing of the market, customer demand is becoming more and more random, which must be highly paid attention to and valued as one significant factor by supply chain members [1–4]. Random demand can lead to the difficulty of supply chain coordination and risk management among supply chain members; therefore, how to effectively manage the random demand has become a core challenge for supply chain decision-makers and researchers to consider [2–6]. Among random demand problems, this paper focuses on the supply chain coordination between a single manufacturer and single retailer under single cycle newsvendor random demand model. The two parties have developed a certain degree of trust mechanism while the core, centralized enterprise has a leading position [3–7]. However, the existence of these trust mechanism and centralized enterprises may generate a variety of difficulties including higher cost, lower efficiency, poor chronology, unsafe data storage, and lower robustness of supply chain. These create new challenges to current supply chain techniques and coordination theory [8–11].

Block chain technology possesses the technical features including decentralization, distrust, agent elimination, chronology, anonymity, group maintenance, opening-sourcing, being programmable, dispersed, unchangeable encrypted data, safety, and reliability. Moreover, it is hopeful that block chain technology can remodel and change the current forms of human social activities thoroughly, and the technology has been implemented and achieved positive practice and application in many fields including banking, finance, security, insurance, express, notarization, medicine, music, crowd funding, dispersed data, intelligent manufacturing, and the Internet of Things [8–11]. Decentralized trust based point-to-point transaction, cooperation, and coordination can be achieved by block chain technology with the methods of encrypting data, time stamping, distributed consensus, and economic incentives. Thus, information chain can be altered to value chain in order to offer a feasible and coordinative way to address the current and universal supply chain issues including high cost by centralized organizations, low efficiency, unsafely data storage, and poor robustness [8–11].

Furthermore, in the real practice, supply chains are mostly decentralized supply chains which may lead to double marginalization, bullwhip effect, and other negative effects; thus a rational supply chain coordination mechanism needs to be built to bond all involved members [7, 12–15]. Revenue sharing contract can bond the above parties together and help decentralized supply chains achieve the performance of centralized supply chains [3, 7, 13]. Especially, with the support of block chain technique, commodity pricing power belongs to none of the parties, so revenue sharing contract needs to be implemented to coordinate the order and wholesale price, expand market share, and enhance the advantages of block chain. Therefore, in order to improve whole profit of supply chain and reduce risks of high cost, low efficiency, poor chorology, and unsafely data storage which resulted by trust mechanism and centralized enterprises, application of Revenue sharing contract, and coordination issues of interests relationship among supply chain members under single cycle newsvendor random demand model, based on consideration of synergy brought by block chain technique and random demand, should be more valuable for scholars to focus on and study in future.

The remainder of the paper is organized as follows. Following the literature review in Section 2, the research model is introduced in Section 3. Section 4 discusses the supply chain coordination strategy with calculation for manufacturer and retailer based on block chain concept. After the analysis and comparison of relevant statistics from the models in Section 5, our interpretations of the results and research conclusion are presented in Section 6.

2. Literature Review

Pasternack applied Return Contract to study supply chain coordination problem of single cycle newsvendor random demand model facing by suppliers and dealers for the first time [7]. Following that, researches on this issue were conducted by many scholars. Cachon and Lariviere addressed the conditions of contract coordination through comparison and analysis of revenue sharing contract and price discount, quantity discount, and Return Contract [1]. They also stated that in single cycle newsvendor random demand model formed by single supplier and single buyer and other situation, Revenue Contract can achieve not only the Pareto optimum, but also the random revenue distribution of supply chain. He [9] investigated a supply chain channel coordination problem under stochastic demand and both sales effort and retail price sensitive with standard newsvendor setting. Chen and Bell adopted a two buyback prices' agreement which were unsold inventory and customer returns between a manufacturer and a retailer in a decentralized supply chain where the retailer simultaneously determines the retail price and order quantity while experiencing customer returns and price dependent stochastic demand. They found the two buyback prices' agreement could achieve perfect supply chain coordination and win–win for both manufacturers and retailers [10].

Li and Su studied the coordination problem of competitive disadvantage supply chain under the situation of random demand and revocable strategy [2]. Govindana and Popiuc researched a two- and three-echelon reverse supply chain coordination by revenue sharing contract to explore the implications of recycling from an efficiency perspective for all participants in the process [11]. In their mode, the customer was willing to return obsolete units as a function of the discount offered by the retailer in exchange for recycling devices with a remanufacturing value. The results showed that performance measures and total supply chain profits improved through coordination.

Zhao and Zhu studied a revenue-sharing mechanism to examine how to coordinate a remanufacturing supply chain between a remanufacturer and a retailer considering stochastic remanufacturability rate and random demand [12]. The research results showed that a revenue-sharing contract can increase profit for the remanufacturer, the retailer, and the whole supply chain. Their case study demonstrated that the government subsidy could benefit from the proposed revenue-sharing mechanism and the profit increase for the whole supply chain.

Giri and Chakraborty coordinated a supply chain considering instantaneous/noninstantaneous supplies from single-vendor to single-buyer whose replenishment time interval was not dependent upon the input with stochastic demand and uncertain yield [13]. They further extended to consider a revenue sharing contract to align incentives of decentralized partners within the supply chain. The coordinated policy was beneficial in comparison to the individual policies made by the supply chain partners.

Furthermore, Stackelberg noncooperative gaming is applied to study the supply chain coordination and risks sharing issues formed by single supplier and singe dealer [2, 14–16].

However, these researches are related to the supply chain coordination problem of single cycle newsboy random demand model in which certain degree's trust mechanism is possessed in the supply chain and one of the parties is core enterprise in the supply chain performing the leading role. And the existence of trust mechanism and centralized enterprises may usually lead to multiple issues for the supply chain including high cost, low efficiency, poor chorology, unsafely data storage, and poor robustness and other problems.

In the area of block chain, Christidis and Devetsikiotis stated that a block chain could enable trustless networks and worked as a distributed data structure which was replicated and shared among the members of a network [17]. Block chains could solve the double-spending problem which was similar to the bilateral effect in a supply chain. Khandelwal et al. claimed that a block chain was a distributed ledger of transactions which were maintained by a network of trustless nodes [18]. Block chains could previously run only through a trusted intermediary, operating in a decentralized fashion, without the need for a central authority while achieving the same functionality with the same amount of certainty [19–21].

Based on the literatures above, block chain technology and interruptive innovation theory, in the situation of random demand and rebuy strategy, can be combined together. Our study applies Stackelberg noncooperative gaming theory and revenue sharing contract into analyzing the brand-new coordination mechanism of supply chain under single cycle newsboy random demand model with the features of Del trust, decentralization, and traded anonymous.

In the current research, we mainly contribute to the extant literature in the following two ways. First, the coordination problem in the situation of customer random demand is necessary but the research in this topic is still scant. Most extant papers are related to the trust mechanism to certain degree possessed by all parties in the supply chain with real-name registered trade with one party as the core enterprise and holding the dominant position. Our study focuses on supply chain coordination problems related to Del trust, decentralization, and traded anonymous. This innovative perspective can enrich and supplement the previous study. Second, most previous studies with the results for coordination have more influences on short-term revenue of other members in the supply chain and lead to poor robustness. Our study combines block chain technology and random demand situation while the coordination result has few influences on the short-term revenue of other members of block chain (other members); thus our research can improve the robustness of supply chain significantly.

3. Model Description

Assuming there are multiple manufacturers M $(M_1 M_2 \ldots M_n)$ and multiple retailers R $(R_1 R_2 \ldots R_m)$ in the supply chain, in which supply chain members are dispersed in areas and regions, no core enterprises within the network, the position, power, and responsibility of enterprises at every level are equal; any damage or loss of the enterprises of any level has no effect on the overall system operations, namely, decentralized and distributed management phenomenon with robustness. And no trust requirement for data exchanging among levels in the supply chain and all the operation regulations and data are transparent and visible to all the members. Therefore, enterprises at different levels cannot and are not capable of cheating others within the regulated rules and time. Because there is no trust is required among enterprises at different levels, all the trades do not need to disclose identity; namely, all the enterprises involved are anonymous. Every retailer R in the supply chain will face the random demand sales market of single cycle newsboy and will start to place orders before the selling season of each single cycle.

The stochastic demand model is mainly embodied by the one-cycle newsvendor model used by predecessors. In the newsvendor model, the purchasing quantity is determined by the demand, and the demand quantity is a random variable X [6, 22].

The distribution function of the stochastic demand variable X is a function F (x) = P (X < x), and the distribution of the stochastic demand variable function means that if X is a stochastic variable, then Y = g (X) is also a stochastic variable, and the distribution law of Y is the distribution of the function of the stochastic demand variable X.

The impact from the current decisions of retailer R on short future can be ignored and one-cycle schedule is only needed for one time. Additionally, since all the products will be delivered before demand, all inventory that is either ordered or manufactured can be used to satisfy demand directly with no waiting. Assuming X as the market and customer demand variation of the retailer R within the sales season, and its Probability Distribution Function and Cumulative Distribution Function are f(x) and $F(x) = P(X \leq x)$, $F(\cdot)$ is continuous differentiable and strictly increasing, $F(0) = 0$, $\overline{F}(x) = 1 - F(x)$, the demand average value of customer demand variation X is $u = E(x) = \int_0^\infty x f(x) dx$, and set ω is the unified wholesaling price of manufacturer in the supply chain, p is the unified sales price of retailer in the supply chain, and both will remain unchangeable in the short-term.

Lack of trust between supply chain members leads to low competitiveness of supply chain. To satisfy the survival and development need of the members themselves and the whole supply chain and to improve the overall competitiveness of the supply chain, the contract for trading should be signed by supply chain members which contains honest trade contact with high cost of breaking contract and confidentiality breach, agreement of applying block chain technology, and related ideas. Namely, all the trades can only be transacted after the implementation of one-off random orders which will be opened to all the supply chain members involved through the recordable and traceable internal sharing platform in the form of certain key and code, reaching the consensus of all the members.

The key means to ensure the safety of trades and code can be helpful to the result that other members in the supply chain can see the trade but cannot know which are the two parties involved, and even if the vendor and purchaser only know the information about itself but no information about the other side. Tracing will be activated by certain one-off decrypted method which will be applied after the internal sharing platform received the application from the breached party with the code, identifying code, and other methods. After it is activated, all the members can view the detail trade information and the event of default of the two parties and deal with the event according to contract rules. To ensure the safety and privacy of the trade among members, only the information about breach of contract applied will be decrypted, instead of other information.

Once the trade is settled, it cannot be denied and regretted; otherwise, high penalty of which the loss will overweight the gain must be paid. Namely, the penalty will be multiple times compared to the trade amount which is too high to break the contract for both sides, so there is few contact breaking issues. And all trades must be kept secret by all supply chain members; otherwise, high penalty is required to be paid. Namely, any member cannot give away the secret, so there are few secret divulging issues.

Assuming, in the supply chain, a retailer R1 needs to purchase some products from manufacturer M1 now, Q1 is the order amount of retailer R1, and the expected production of manufacturer M1 which refers to M1 expects to manufacture products according to the order amount from R1. The ordered products should be open to other members $M_2 \dots M_n, R_2 \dots R_m$ in the supply chain, and consensus needs to be reached by these members. Once the trade is settled, it cannot be denied; otherwise, the high penalty must be paid. Assume g_r and g_m refer to the penalty cost that will be paid by the defaulting retailer R_1 and the penalty cost of outstock for the goodwill (penalty of outstock) of manufacturer M_1, respectively, and $g = g_r + g_m$; because of the none-deniability of the trade between retailer R_1 and manufacturer M_1, namely, g_r and g_m are too big, so both sides will not breach the contract normally. Moreover, c_m and c_r refer to the production unit cost for the manufacturer and the marginal cost for the retailer. And c_r refers to the cost to acquire product unit, instead of the cost during products selling and based on block chain idea $c_r \longrightarrow 0$; for the products that have not been sold within the sales season can be returned to manufacture from retailer, with the unit refund price as $\alpha\omega$ and α as the refund discount coefficient. In the short term after the trade, the overall supply chain performance will only be influenced by the trade; at the same time, revenue of other members in the supply chain will remain the same in the short-term, assuming as $\pi(M_2 \dots M_n, R_2 \dots R_m)$.

According to "bilateral marginal revenue", if retail R_1 places the optimal orders based on its own interest, the the overall optimal revenue cannot be achieved by the order amount. And revenue sharing contract can be one of the feasible methods to address the "bilateral marginal revenue" issues. With the implementation of revenue sharing contract, manufacturer M_1 will sell the products to retailer R_1 with the wholesaling price ω_ϕ which is lower than its marginal cost c_m, and retailer R_1 will retain the revenue of expected sales part ϕ; namely, $\phi\pi_{r_1}(Q_1, \omega_\phi)$, $\phi \in [0,1]$, and the remaining part $(1-\phi)\pi_{r_1}(Q_1, \omega_\phi)$ will be returned to manufacturer M_1, Q_1, ω_ϕ are the decision variables. In this case, the optimal revenue for R and the whole supply chain can be reached at the same time, and the revenue gained by M and R will not be lower than that before the implementation of revenue sharing contract; therefore, the coordinative status of the whole supply chain can be achieved.

4. Supply Chain Coordination Based on Block Chain Idea

According to the model description, the formulas of expected revenue $\pi_{r_1}(Q_1)$ of retailer R_1, the expected revenue $\pi_{m_1}(Q_1)$ of manufacturer M_1, and the expected revenue of the whole supply chain π are as follows:

$$\pi_{r_1}(Q_1) = (p - \omega - c_r) Q_1 - g_r \int_{Q_1}^{\infty} (x - Q_1) f(x)\,dx - (1-\alpha)\omega \int_0^{Q_1} (Q_1 - x) f(x)\,dx \quad (1)$$

$$\pi_{m_1}(Q_1) = (\omega - c_m) Q_1 - g_m \int_{Q_1}^{\infty} (x - Q_1) f(x)\,dx - \alpha\omega \int_0^{Q_1} (Q_1 - x) f(x)\,dx \quad (2)$$

$$\pi = \pi(M_{2,} \dots M_n, R_{2,} \dots R_m) + (p - c) Q_1 - g \int_{Q_1}^{\infty} (x - Q_1) f(x)\,dx - \omega \int_0^{Q_1} (Q_1 - x) f(x)\,dx \quad (3)$$

Within that, $\int_0^{\infty}\{Q_1 - X, 0\}^+ f(x)dx = \int_0^{Q_1}(Q_1 - x) f(x)dx$ refers to retailer R_1's expected 的 leftover amount, and $\int_0^{\infty}\{X - Q_1, 0\}^+ f(x)dx = \int_{Q_1}^{\infty}(x - Q_1) f(x)dx$ refers to retailer R_1's anticipated outstock amount.

4.1. Decentralized Supply Chain Situation. According to block chain ideas, the status of retailer R_1 and manufacturer M_1 is completely equal. However, because retailer R_1 needs to purchase products from manufacturer M_1, retailer R_1 is subordinated to manufacturer M_1 in the real practice; namely, manufacture M_1 holds the dominant status while retailer R_1 stays as the passive and subordinate status, which can be seen as Stackelberg gaming problem.

According to Backward Induction, $\partial^2\pi_{r_1}(Q_1)/\partial Q_1{}^2 = -f(Q_1)[g_r + (1-\alpha)\omega] < 0$, so $\pi_{r_1}(Q_1)$ is Q_1's convex function, and retailer R_1 has the only optimal order amount. The optimal order amount $Q_1{}'$ of retailer R_1 and expected revenue $E\prod_{r_1}(Q_1{}')$ are

$$Q_1{}' = F^{-1}\left[\frac{(p - \omega - c_r)}{g_r + (1-\alpha)\omega}\right] \quad (4)$$

$$E\prod_{r_1}(Q_1{}') = (p - \omega - c_r) Q_1{}' - g_r \int_{Q_1{}'}^{\infty} (x\text{-}Q_1{}') f(x)\,dx - (1-\alpha)\omega \int_0^{Q_1{}'} (Q_1{}' - x)(x)\,dx \quad (5)$$

and manufacturer M_1 and expected revenue $E\prod_{m_1}(Q_1{}')$ are

$$E\prod_{m_1}(Q_1{}') = (\omega - c_m) Q_1{}' - g_m \int_{Q'}^{\infty} (x - Q_1{}') f(x)\,dx - \alpha\omega \int_0^{Q_1{}'} (Q_1{}' - x) f(x)\,dx \quad (6)$$

The overall expected revenue of the whole supply chain $E\prod(Q_1{}')$ is

$$E\prod\left(Q_1{}'\right) = \pi\left(M_{2,}\ldots M_n, R_{2,}\ldots R_m\right) + (p-c)\,Q_1{}' - g\int_{Q_1{}'}^{\infty}\left(x - Q_1{}'\right)f(x)\,dx - \omega\int_0^{Q_1{}'}\left(Q_1{}' - x\right)f(x)\,dx \tag{7}$$

4.2. Supply Chain Coordination. According to revenue sharing contract, the revenue functions of retailer R_1, manufacturer M_1, and the whole supply chain are as follows:

$$\pi_{r_1}(Q_1) = \phi\left[\left(p - \omega_\phi - c_r\right)Q_1 - g_r\int_{Q_1}^{\infty}(x - Q_1)\,f(x)\,dx - (1-\alpha)\,\omega_\phi\int_0^{Q_1}(Q_1 - x)\,f(x)\,dx\right] \tag{8}$$

$$\pi_{m_1}(Q_1) = (1-\phi)\left[\left(p - \omega_\phi - c_r\right)Q_1 - g_r\int_{Q_1}^{\infty}(x - Q_1)\,f(x)\,dx - (1-\alpha)\,\omega_\phi\int_0^{Q_1}(Q_1 - x)\,f(x)\,dx\right] + \left(\omega_\phi - c_m\right)\cdot Q_1 - g_m\int_{Q_1}^{\infty}(x - Q_1)\,f(x)\,dx - \alpha\omega_\phi\int_0^{Q_1}(Q_1 - x)\,f(x)\,dx \tag{9}$$

$$\pi = \pi\left(M_{2,}\ldots M_n, R_{2,}\ldots R_m\right) + \left(p - \omega_\phi - c_r\right)Q_1 - (1-\alpha)\,\omega_\phi\int_0^{Q_1}(Q_1 - x)\,f(x)\,dx + \left(\omega_\phi - c_m\right)Q_1 - g_m\int_{Q_1}^{\infty}(x - Q_1)\,f(x)\,dx - \alpha\omega_\phi\int_0^{Q_1}(Q_1 - x)\,f(x)\,dx - g_r\int_{Q_1}^{\infty}(x - Q_1)\,f(x)\,dx \tag{10}$$

Proposition 1. *Constrained by revenue sharing contract, the coordinative wholesaling price $\omega_\phi''^{*}$ exists between retailer R_1 and manufacturer M_1.*

Proof. $\partial^2\pi_{r_1}(Q_1)/\partial Q_1{}^2 = -\phi f(Q_1)[g_r + (1-\alpha)\omega_\phi] \le 0$, so $\pi_{r_1}(Q_1)$ is a concave function about Q_1 and retailer R_1 has the only and optimal order amount $Q_1{}''$

$$Q_1{}'' = F^{-1}\left[\frac{p - \omega_\phi - c_r}{g_r + (1-\alpha)\,\omega_\phi}\right] \tag{11}$$

Therefore, $\partial^2\pi_{m_1}(Q_1)/\partial Q_1{}^2 = -2f(Q_1)(g_r + (1-\alpha)\omega_\phi) + \phi f(Q_1)(g_m + \alpha\omega_\phi) \le 0$; we can know that $\pi_{m_1}(Q_1)$ is a concave function about Q_1, and Q''_{m_1}, the optimal sales quantity of M_1.

So $\partial^2\pi_{m_1}(Q_1)/\partial Q_1{}^2 = -2f(Q_1)(g_r + (1-\alpha)\omega_\phi) + \phi f(Q_1)(g_m + \alpha\omega_\phi) \le 0$:

$$Q''_{m_1} = F^{-1}\left[\frac{p - c_m - c_r - \phi\left(p - \omega_\phi - c_r\right)}{(1-\phi)\,g_r + (1 - \phi - \alpha\phi)\,\omega_\phi + g_m}\right] \tag{12}$$

Let $Q_1{}'' = Q''_{m_1}$; then

$$-(1 - 2\alpha\phi)\,\omega_\phi^2 - \left(1 - \phi + g_m + g_r\phi - c_m - \alpha p + \alpha c_m + \alpha c_r + 2\alpha\phi p - 2c_r\alpha\phi\right)\omega_\phi + g_m\left(p - c_r\right) + g_r c_m = 0 \tag{13}$$

Let $a = 2\alpha\phi - 1$, $b = -(1 - \phi + g_m + g_r\phi - c_m - \alpha p + \alpha c_m + \alpha c_r + 2\alpha\phi p - 2c_r\alpha\phi)$, $c = g_m(p - c_r) + g_r c_m$; then, constrained by revenue sharing contract, retainer R_1 and manufacturer M_1 must coordinate the wholesale price $\omega_\phi''^{*}$ to satisfy

$$\omega_\phi''^{*} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{14}$$

Thus, proposition can be proved. □

Then the economic order quality is

$$Q_1{}''^{*} = F^{-1}\left[\frac{p - \omega_\phi''^{*} - c_r}{g_r + (1-\alpha)\,\omega_\phi''^{*}}\right] \tag{15}$$

Constrained by revenue sharing contract, revenue expectation of retailer R_1, manufacturer M_1, and the whole supply chain are

$$E\prod_{r_1}\left(Q_1{}''^{*}\right) = \phi\left\{\left(p - \omega_\phi''^{*} - c_r\right)Q_1{}''^{*} - g_r\int_{Q_1{}''^{*}}^{\infty}\left(x - Q_1{}''^{*}\right)f(x)\,dx - (1-\alpha)\,\omega_\phi''^{*}\int_0^{Q_1{}''^{*}}\left(Q_1{}''^{*} - x\right)f(x)\,dx\right\} \tag{16}$$

$$E\prod_{m_1}\left(Q_1{}''^*\right) = (1-\phi)\left[\left(p-\omega_\phi''^* - c_r\right)Q_1{}''^* - g_r\int_{Q_1{}''^*}^{\infty}\left(x-Q_1{}''^*\right)f(x)\,dx - (1-\alpha)\,\omega_\phi''^*\int_0^{Q_1{}''^*}\left(Q_1{}''^*-x\right)f(x)\,dx\right] + \left(\omega_\phi''^* - c_m\right)Q_1{}''^* - g_m\int_{Q_1{}''^*}^{\infty}\left(x-Q_1{}''^*\right)f(x)\,dx - \alpha\omega_\phi''^*\int_0^{Q_1{}''^*}\left(Q_1{}''^*-x\right)f(x)\,dx \quad (17)$$

$$E\prod\left(Q_1{}''^*\right) = \pi\left(M_{2,}\dots M_n, R_{2,}\dots R_m\right) + (p-c)\cdot Q_1{}''^* - g\int_{Q_1{}''^*}^{\infty}\left(x-Q_1{}''^*\right)f(x)\,dx - \omega_\phi''^*\int_0^{Q_1{}''^*}\left(Q_1{}''^*-x\right)f(x)\,dx \quad (18)$$

4.3. Centralized Supply Chain. The revenue function of centralized supply chain is

$$\pi(Q_1) = \pi\left(M_{2,}\dots M_n, R_{2,}\dots R_m\right) + (p-c)\,Q_1 - g\int_{Q_1}^{\infty}(x-Q_1)\,f(x)\,dx - \omega\int_0^{Q_1}(Q_1-x)\,f(x)\,dx \quad (19)$$

As $\partial^2\pi(Q_1)/\partial Q_1{}^2 = -f(Q_1)(g+\omega) < 0$, therefore, $\pi(Q_1)$ is a concave function about Q_1. There is an optimal order quantity of system; namely, when $Q_1{}'''$, the optimal order quantity, is

$$Q_1{}''' = F^{-1}\left[\frac{p-c}{g+\omega}\right] = F^{-1}\left[\frac{p-c_m-c_r}{g_m+g_r+\omega}\right] \quad (20)$$

then, the optimal profit of the system is

$$E\prod\left(Q_1{}'''\right) = \pi\left(M_{2,}\dots M_n, R_{2,}\dots R_m\right) + (p-c)\,Q_1{}''' - g\int_{Q_1{}'''}^{\infty}\left(x-Q_1{}'''\right)f(x)\,dx - \omega\int_0^{Q_1{}'''}\left(Q_1{}'''-x\right)f(x)\,dx \quad (21)$$

4.4. Discussion of Revenue Sharing Factor ϕ Value of Retailer R_1 and Manufacturer M_1. Under the situation of distributed supply chain, the optimal decision of retailer R_1 is partial optimal decision instead of the overall optimal decision for the whole supply chain. Under the bond of revenue sharing contract, the main purpose of the coordinative decisions from retailer R_1 and manufacturer M_1, $Q_1{}''''$, and $\omega_\phi''^*$ is to improve the performance of distributed supply chain to the overall performance of the centralized supply chain; namely, $E\prod(Q_1{}''^*) = E\prod(Q_1{}''')$, so,

$$Q_1{}''^* = Q_1{}''' = F^{-1}\left[\frac{p-c_m-c_r}{g_m+g_r+\omega}\right] \quad (22)$$

Besides, under the circumstance of no bond from the contract, the decision made by retailer R_1 is similar to the overall supply chain decisions. Differently, marginal cost of centralized supply chain is c, while the marginal cost faced by retailer R_1 is $\omega_\phi''^*$; therefore, the optimal order decision $Q_1{}''''$ of retailer R_1 under the circumstance of decentralized supply chain can be acquired by altering c to $\omega_\phi''^*$ in formula (20):

$$Q_1{}'''' = F^{-1}\left[\frac{p-\omega_\phi''^*}{g+\omega}\right] \quad (23)$$

Due to $\omega_\phi''^* > c$, then $(p-\omega_\phi''^*)/(g+\omega)-(p-c)/(g+\omega) \geq 0$, so $Q_1{}'''' \geq Q_1{}'''$.

Now, the expected revenue of retailer R_1 is

$$E\prod_{r_1}\left(Q_1{}''''\right) = \left(p-\omega-c_r\right)Q_1{}'''' - g_r\int_{Q_1{}''''}^{\infty}\left(x-Q_1{}''''\right)f(x)\,dx - (1-\alpha)\,\omega\int_0^{Q_1{}''''}\left(Q_1{}''''-x\right)f(x)\,dx \quad (24)$$

The expected revenue of manufacturer M_1 is

$$E\prod_{m_1}\left(Q_1{}''''\right) = \left(\omega-c_m\right)Q_1{}'''' - g_m\int_{Q_1{}''''}^{\infty}\left(x-Q_1{}'\right)f(x)\,dx - \alpha\omega\int_0^{Q_1{}''''}\left(Q_1{}'-x\right)f(x)\,dx \quad (25)$$

The precondition to make sure that both retailer R_1 and manufacturer M_1 can accept the contact above is to ensure the profit for both sides under the contact cannot be lower than the profit that will be gained under decentralized. Namely, the profit of retailer R_1 and manufacturer M_1 is the improvement of Pareto must be achieved by the contact, and inequality (26) should be satisfied at the same time:

$$E\prod_{r_1}\left(Q_1{}''^*\right) \geq E\prod_{r_1}\left(Q_1{}''''\right), \qquad E\prod_{m_1}\left(Q_1{}''^*\right) \geq E\prod_{m_1}\left(Q_1{}''''\right) \quad (26)$$

During the design process of revenue sharing contract, manufacturer needs to ensure the range of numerical value

Table 1: The EOQ under the three situations of block chain technology and random demand.

	Decentralized supply chain	Revenue sharing supply chain	Centralized supply chain
EOQ	$Q_1{}' = 1073$	$Q_1{}''^{*} = 1081$, ($\phi = 0.25$) $Q_1{}''^{*} = 1086$, ($\phi = 0.50$) $Q_1{}''^{*} = 1077$, ($\phi = 0.75$)	$Q_1{}''' = 1078$

of revenue sharing factor ϕ be satisfied with inequality (26). Only by this way retailer R_1 will accept the contact while the interest of manufacturer M_1 can be maintained as well. The specific range of numerical value of ϕ should be decided according to the bargaining ability between retailer R_1 and manufacturer M_1 and the status of retailer R_1 and manufacturer M_1 in the supply chain, respectively.

5. Statistics Analysis

Assuming that the supply chain consists of multiple manufacturers M $(M_1 M_2 \ldots M_n)$ and multiple retailers R $(R_1 R_2 \ldots R_m)$, retailer R_1 will begin to place orders to manufacturer M_1 every single cycle before the selling season. Market demand follows the normal distribution $N(1000, 100^2)$, and retail price $P = 35$. Based on block chain ideas, the penalty of breaking the contact for retailer R_1 and the cost of goodwill resulting by outstock for manufacturer M_1 are comparatively high; assuming $g_m = g_r = 50$, then the total penalty cost $g = g_m + g_r = 100$. The production cost of manufacturer M_1 $c_m = 8$, based on block chain model; the marginal cost of retailer R_1 is very low; assuming that $c_r = 0.1$, the wholesaling price of manufacturer M_1 $\omega = 20$, the revenue sharing factor of retailer R_1 $\phi \in \{0.25, 0.5, 0.75\}$, and return discount factor $\alpha = 0.75$. $\pi(M_2 \ldots M_n, R_2 \ldots R_m) = 500000000$.

Therefore, the optimal order quality under the three situations of block chain technology and random demand are as shown in Table 1.

According to Table 1, based on random demand and block chain ideas, when the retail price is settled, EOQ of decentralized supply chain is the lowest. And under the circumstance of revenue sharing, the EOQ firstly increased and then decreased according to the change of sharing factor ϕ. When $\phi = 0.5$, ϕ reached the highest point and the EOQ of centralized supply chain is higher than that of decentralized supply chain, but the revenue of centralized supply chain is lower than that of decentralized supply chain. Therefore, based on random demand and block chain ideas and with the application of the combination of repurchase strategy and revenue sharing contract, the order purchasing amount can be improved effectively; the market sharing can be enlarged, and, at the same time, the stock out amount and excessive products amount can be reduced to decrease the products return amount.

Then the optimal revenue under the three situations of block chain technology and random demand are as shown in Table 2.

According to Tables 1 and 2, based on block chain technology and random demand situation, the optimal revenue decentralized supply chain is the lowest as 50024075. With the coordination of revenue sharing contact, when the sharing factor $\phi = 0.75$, the optimal overall revenue of the whole supply chain is the highest as 50026014 and that of centralized supply chain is in the middle of them as 50024210. Under the situation of decentralized supply chain, the revenue of retailers is 13792.96, which is higher than the retailers' optimal revenue (2370,02, 3355.23, and 8531.60, respectively) under the coordination of revenue sharing. And the optimal revenue of manufacturers is 10282.22, which is lower than the manufacturers' optimal revenue (21812.26, 18137.45, and 17482.08, respectively) under the coordination of revenue sharing. Although the optimal revenue of both sides is more equal, the overall revenue of the whole supply chain is lower, which is negative for the supply chain development in the long term.

When the retail price is settled, with the coordination of revenue sharing mechanism, the optimal revenue of retailers will increase and decrease according to the increase and decrease of the sharing factor, while the optimal revenue of manufacturers will change oppositely. This mechanism will be beneficial for manufacturers and the whole supply chain system, but harmful for retailers. Therefore, under this mechanism, retailers can give up certain interest to enlarge the market sales volume, reduce risks, maximize the overall revenue of the whole supply chain, and improve the overall revenue of the whole supply chain to the degree equal to or more than that of centralized supply chain.

6. Conclusion

Block chain technology has become a popular approach to apply into different disciplines to explore problems including customer random demand. Our research suggests that key decision-makers in supply chains should consider and value the synergy impact of block chain technology and customer random demand; then we may reduce supply chain risks, maintain supply chain robustness, and improve the core competitiveness of supply chains. Based on interruptive innovation and Stackelberg noncooperative gaming theory, this paper has built the decision models of decentralized supply chain and centralized supply chain and implements revenue sharing contact. Our research has constructed a new supply chain coordination model with features of Del trust, decentralization, and traded anonymous and explored the supply chain coordination under the combined effect of block chain technology and random demand.

The research has got some results. When assuming sales price remains, the overall optimal revenue of decentralized

Table 2: The optimal revenue under the three situations of block chain technology and random demand.

Supply chain types	Value of sharing factor ϕ	Coordinative wholesaling price $\omega_{\phi}''^{*}$	The optimal revenue for retailers	The optimal revenue for manufacturers	The revenue for other members in the supply chain	The optimal revenue of the whole supply chain
Decentralized supply chain	-	-	13792.96	10282.22	50000000	50024075
	$\phi = 0.25$	$\omega_{\phi}''^{*} = 24.1$	2370.02	21812.26	50000000	50024182
revenue sharing supply chain	$\phi = 0.50$	$\omega_{\phi}''^{*} = 26.7$	3355.23	18137.45	50000000	50021493
	$\phi = 0.75$	$\omega_{\phi}''^{*} = 22.3$	8531.60	17482.08	50000000	50026014
centralized supply chain	-	-	-	-	-	50024210

supply chain under the optimal decisions is minimal and can be of benefit for retailers, but can be harmful for manufacturers and the whole supply chain, leading to negative influence on supply chain robustness in the long term. Also, the coordinative supply chain with revenue sharing mechanism can increase sales, reduce risks, and improve the overall performance of the supply chain to the degree of centralized supply chain. The coordination result may be harmful for retailers but be beneficial for other supply chain members and the whole supply chain. Through the combination of repurchase strategy, revenue sharing contact, and appropriate sharing coefficient, the revenue of supply chain members can be more equal. Further, the coordination result will only influence the short-term revenue of members in the block chain, without effecting on other members' short-term revenue, consequently improving the supply chain robustness dramatically. Therefore, our research results can provide significant implications for both supply chain coordination theory and practice.

However, several limitations should be addressed for future research. First, this paper explored supply chain coordination under the synergy effect of customer random demand and block chain technology, without considering the synergy effect of stable demand and block chain. Second, this paper assumed that there is no defect in the products and ignored the impact of products checking strategy on supply chain coordination. In the future, we will conduct the research about the supply chain coordination issue related to products quality defect and checking strategy to explore the synergy effect of customer random demand and block chain technology.

Data Availability

The block chain and random demand data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] G. P. Cachon, "The allocation of inventory risk in a supply chain: push, pull, and advance-purchase discount contracts," *Management Science*, vol. 50, no. 2, pp. 222–238, 2004.

[2] Y. F. Li, Q. Su, and J. Zheng, "Supply chain coordination based on sensitive customer quality demand," *Advances in Information Sciences and Service Sciences*, vol. 4, no. 19, pp. 264–269, 2012.

[3] Y. F. Li and W. F. Jia, "Supply chain coordination with considering defective quality products cheaply processing understochastic demand," *Journal of Residuals Science & Technology*, vol. 13, no. 6, pp. 731–737, 2016.

[4] Y. F. Li, "Coordination and risk sharing with considering supply chain external quality fault," *Computer Modelling and New Technologies*, vol. 18, no. 12C, pp. 445–450, 2014.

[5] G. P. Caching, "Procuring fast delivery: Sole sourcing with information asymmetry," *Management Science*, vol. 52, no. 6, pp. 881–896, 2006.

[6] J. Mostard, R. de Koster, and R. Teunter, "The distribution-free newsboy problem with resalable returns," *International Journal of Production Economics*, vol. 97, no. 3, pp. 329–342, 2005.

[7] B. A. Pasternack, "Optimal pricing and return policies for perishable commodities," *Marketing Science*, vol. 4, no. 2, pp. 166–176, 1985.

[8] G. P. Cachon and M. A. Lariviere, "Supply chain coordination with revenue-sharing contracts: strengths and limitations," *Management Science*, vol. 51, no. 1, pp. 30–44, 2005.

[9] Y. He, X. Zhao, L. Zhao, and J. He, "Coordinating a supply chain with effort and price dependent stochastic demand," *Applied Mathematical Modelling*, vol. 33, no. 6, pp. 2777–2790, 2009.

[10] J. Chen and P. C. Bell, "Coordinating a decentralized supply chain with customer returns and price-dependent stochastic demand using a buyback policy," *European Journal of Operational Research*, vol. 212, no. 2, pp. 293–300, 2011.

[11] K. Govindan and M. N. Popiuc, "Reverse supply chain coordination by revenue sharing contract: a case for the personal computers industry," *European Journal of Operational Research*, vol. 233, no. 2, pp. 326–336, 2014.

[12] S. Zhao and Q. Zhu, "Remanufacturing supply chain coordination under the stochastic remanufacturability rate and the random demand," *Annals of Operations Research*, vol. 257, no. 1-2, pp. 661–695, 2017.

[13] B. C. Giri and A. Chakraborty, "Coordinating a vendor–buyer supply chain with stochastic demand and uncertain yield," *International Journal of Management Science and Engineering Management*, vol. 12, no. 2, pp. 96–103, 2017.

[14] S. E. Chick, H. Mamani, and D. Simchi-Levi, "Supply chain coordination and influenza vaccination," *Operations Research*, vol. 56, no. 6, pp. 1493–1506, 2008.

[15] I. Hwang, S. Radhakrishnan, and L. Su, "Vendor certification and appraisal: implications for supplier quality," *Management Science*, vol. 52, no. 10, pp. 1472–1482, 2006.

[16] Y. F. Li, "Supply Chain Coordination Considering Stochastic Demand and Raw Material Quality Defects," *International JoUrnal of u- and e-Service, Science and Technology*, vol. 9, no. 5, pp. 373–382, 2016.

[17] K. Christidis and M. Devetsikiotis, "Blockchains and smart contracts for the internet of things," *IEEE Access*, vol. 4, no. 1, pp. 2292–2303, 2016.

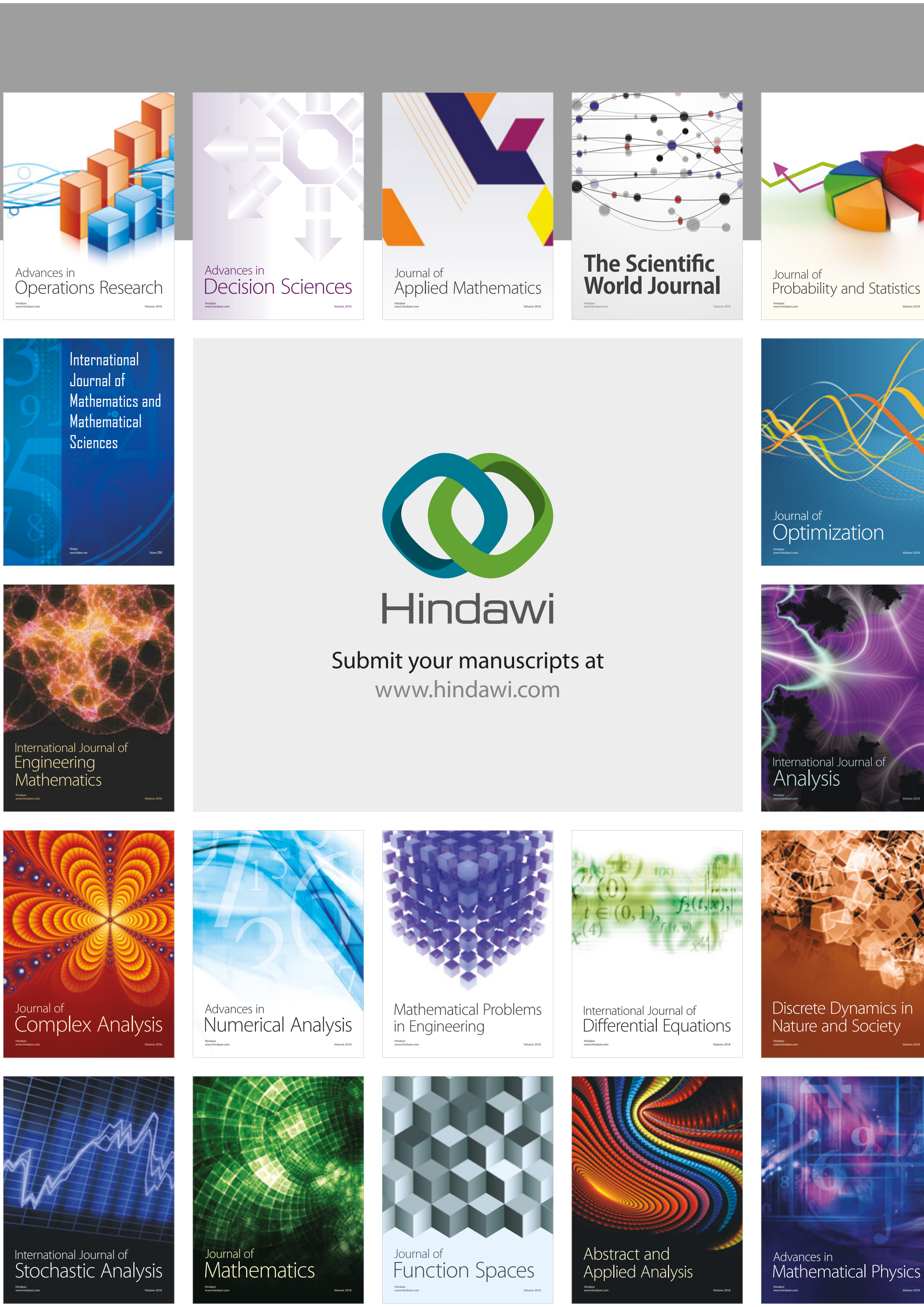
[18] S. Khandelwal, N. Gandhi, D. Choudhari, and P. Joshi, "HIBE Based Security for Content Distribution using Block Chains," *International Journal of Science Technology Management and Research*, vol. 3, no. 10, pp. 5–9, 2018.

[19] W. Ding, "Block chain based instrument data management system," *China Instrumentation*, vol. 10, no. 1, pp. 15–17, 2015.

[20] D. Kraft, "Difficulty control for blockchain-based consensus systems," *Peer-to-Peer Networking and Applications*, vol. 9, no. 2, pp. 397–413, 2016.

[21] D. Wilson and G. Ateniese, "From pretty good to great: enhancing pgp using bitcoin and the blockchain," in *Proceedings of the 9th International Conference on Network and System Security*, vol. 9408 of *Lecture Notes in Computer Science*, pp. 368–375, Springer International Publishing, 2015.

[22] J. P. Geunes, R. V. Ramasesh, and J. C. Hayya, "Adapting the newsvendor model for infinite-horizon inventory systems," *International Journal of Production Economics*, vol. 72, no. 3, pp. 237–250, 2001.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