Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 5567263, 20 pages
https://doi.org/10.1155/2023/5567263

Research Article

Dual-Channel Decisions under Blockchain and Returns

Guangdong Liu, [1,2] **Ziyang Li**, [1] **and Jinggui Chen** [1]

[1] *School of Business, Fuyang Normal University, Fuyang, China*
[2] *School of Information, Chuzhou University, Chuzhou, China*

Correspondence should be addressed to Guangdong Liu; 1359162826@qq.com

Received 27 February 2023; Revised 11 July 2023; Accepted 12 July 2023; Published 5 September 2023

Academic Editor: Francisco R. Villatoro

Copyright © 2023 Guangdong Liu et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Blockchain is currently used in a wide range of industries to improve the efficiency of the circulation of goods and effectively reduce counterfeiting in supply chains. In order to improve consumer trust in their purchases and reduce returns, the paper develops four models of consumers return based on blockchain technology from a consumer utility perspective. We conducted a Stackelberg game to analyze the impact of return modes and blockchain technology on optimal decisions and consumers, where consumers can return goods through the original channel, all through the online channel, and all through the offline channel. The major results of our study show that when blockchain technology is not used, the costs of return hassles in one channel can have an impact on other channels, and the adoption of online returns is advantageous to both consumers and the retailer. When blockchain technology is used, the manufacturer offers the retailer a lower wholesale price as a subsidy for the unit validation fee, which is always advantageous to the retailer. In most situations, implementing blockchain technology can boost consumer surplus. Only if the fixed cost of blockchain technology is low would the manufacturer adopt it.

1. Introduction

Online retail sales of physical goods reached 13.1 trillion yuan in 2021, up to 14.1% year over year, and accounted for 24.5% of all retail sales of social consumer goods, according to the 49th China Internet Development Statistics Report [1]. Online shopping has become a habit due to the rise in its consumption, but unlike traditional offline physical store purchases, consumers cannot physically experience or cognitively comprehend the goods they are purchasing online; instead, they must rely on the merchant's promotional videos and pictures to understand how the products work and look. Statista estimates that by 2020, the costs of returns will have increased to $550 billion in the U.S. alone, with at least 20% of all online purchases being returned. This rate is nearly twice as high as that of traditional brick-and-mortar retailers. Due to information asymmetry, which results in consumers' differing perceptions of products in online channels and a high return rate, as well as the costs associated with returns (such as packing and mailing), consumers' shopping preferences are influenced. It is therefore practically crucial to assist consumers in learning more about products in order to enhance the shopping experience and, in turn, decrease product returns in order to support the steady growth of the supply chain.

Online shopping is also a common occurrence when it comes to customer returns, in addition to offline brick-and-mortar establishments. This is due to the difficulty in identifying product information, such as fraudulent statements on food labels or ingredients, or imitations of the food itself, which causes consumers to lose faith in their purchases and negatively affects corporate reputation and customer satisfaction [2]. For instance, the practice of passing off conventional foods as having a green food label undermines customer confidence in the designation and harms the organic market [3]. Manufacturers, sales platforms, etc., will conduct product traceability to identify the issue as a result. Consumers' trust in products and purchase intent can be increased, purchase barriers can be reduced, and the rate of customer returns can all be decreased with the support of the traceability system [4]. The typical supply chain traceability system, on the other hand, has issues with easy data manipulation, a lack of openness and reliability, and ineffective transmission [5]. Blockchain technology offers an information platform based on openness, transparency, neutrality, reliability, and security for all participants in the supply chain, including authorities and regulators [6]. It is a distributed ledger with the two key characteristics of decentralization and difficulty of tampering [7].

Blockchain technology can be used to trace the information of products quickly and accurately, create a credible environment for consumers, and reduce return behavior [8]; realize real-time information sharing for enterprises, improve the operation and management of enterprises, and maintain the interests and development of the supply chain [9]. For instance, Limousin, the company in charge of the French beef brand Blason Prestige, participated in the "2nd China International Import Expo" and highlighted the usage of a blockchain solution built on the Foodgates platform. In order to achieve full traceability of goods and reduce the risk of COVID-19 and other bacteria, fungi, and parasites in the meat supply chain, consumers can learn the geographic location of the source of goods, logistics process time, inspection, and testing reports, and other detailed information through QR codes [10].

The use of blockchain technology in the supply chain is a topic that is well worth researching because it has many benefits. Many academics think that using blockchain technology will help the supply chain evolve [11]. But will the adoption of blockchain technology be taken into account in certain situations, and whether it will inevitably be advantageous for the supply chain? There has not been much study on how using blockchain technology affects supply chain returns in the literature up to this point. As a result, we look into the following topics in our study: (1) How does the dual-channel supply chain price under different return modes and what factors will affect the pricing decisions of enterprises? (2) In what situations and to what extent could supply chain participants benefit from the deployment of blockchain technology? (3) How does the use of blockchain technology affect market demands and pricing decisions and is it good for consumers?

We build a two-stage supply chain with a manufacturer and a retailer in order to better comprehend the problems driving these inquiries. Without the use of blockchain technology, we were able to reach the equilibrium results for several return models. Then, we compare the equilibrium results under various models and study the trend of the equilibrium findings under various models. The firm may then implement blockchain technology and carry out the previous process once more. Numerical analysis is used to confirm the model's validity before discussing how the inclusion of blockchain technology may affect supply chain performance.

The contributions of our study are as follows: first, we investigate consumers' decisions to return products from various channels and analyze the influence of this on supply chain decisions, which is rarely covered in existing research. Second, to enhance the use of blockchain technology in the supply chain, our study combines blockchain technology with the return issue. Last but not least, a theoretical and numerical analysis of the influence of blockchain technology on supply chain performance enables businesses to make informed decisions.

The remainder of the paper is organized as follows. Section 2 presents a review of the relevant literature. Section 3 describes the problem and model assumptions. Section 4 gives the equilibrium results under different return models without blockchain and analyzes and compares them. In Section 5, we have the manufacturer introduce blockchain technology and repeat this work in Section 4. Section 6 verifies the conclusions we obtained with numerical analysis. Section 7 summarizes the conclusions and gives the limitations of the study and future research directions.

2. Literature Review

This paper is related to supply chain management with the blockchain technology application and returns in the supply chain.

2.1. Applications of Blockchain Technology in Supply Chains. Blockchain technology has attracted global attention and has the potential to revolutionize supply chain management and sustainable development achievements [12]. Many scholars have specifically studied the stages, methods, benefits, and scenarios of blockchain applications in supply chains. Cao et al. [13] found that the application of blockchain platforms can increase production and total surplus and stimulate green investments, but care needs to be taken to control operational costs. Wu et al. [14] found that the leader of the fresh product supply chain should implement blockchain under the coordination of a two-part tariff contract to maximize profits. Ye et al. [15] found that early adoption of blockchain in the agri-food supply chain will yield more benefits than subsequent adoption, and blockchain does not always benefit the consumer surplus and the social welfare. However, Liu et al. [16] found that the adoption of blockchain can reduce consumers' concerns about food safety and increase their surplus. Behnke and Janssen [17] identified key boundary conditions for the successful use of blockchain to ensure information sharing and traceability through a template analysis of interviews. Liu et al. [18] found that the application of blockchain prompted retailers to offer more lenient return policies and enhanced consumer surplus. Liu et al. [19] constructed a game theory model based on the use of blockchain to solve the fraudulent returns problem, and the study showed that the adoption of blockchain depends on the efficiency of investment in product innovation and the return losses. Differently, we construct four game-theoretic models considering three different return methods to study the impact of return methods and blockchain on optimal decision-making and consumers.

However, some studies have pointed out that blockchain technology cannot be widely applied to all scenarios in supply chains. That is to say, the use of blockchain technology is subject to certain restrictions. Ji et al. [20] proposed that manufacturers should only adopt blockchain technology if consumers are sensitive to it beyond a certain level, and the unit verification fee paid by the retailer to the manufacturer is subsidized by the manufacturer to the retailer in the form of a lower wholesale price. Choi [21] found that blockchain-enabled supply chains generate lower operational risk than traditional supply chains if the cost of the bank's services is high enough, and it can result in higher expected profits and lower risk for the supply chain and its members. Choi and Luo [22] pointed out that the implementation of blockchain technology can help improve social welfare but can be detrimental to supply chain profitability. Xu et al. [23] used the Stackelberg game approach to study remanufacturing with blockchain, and they found that without the cap-and-trade regulation, using blockchain would instead shrink market share. Although the implementation of blockchain has many benefits, it inevitably encounters many challenges and difficulties during the implementation process. Liu et al. [24] proposed that applying blockchain technology in maritime supply chains will face technical, applied, regulatory, and secure challenges in specific implementation and application. Mirabelli and Solina [25] found that factors such as lack of standards, stakeholder resistance, and insufficient scalability will hinder the spread of blockchain technology. Li et al. [26] proposed that blockchain is beneficial to food safety, operations, and sustainability in the food supply chain but will encounter challenges in technology, cost, government regulation, and awareness.

We review the methods, stages, scenarios, benefits, obstacles, and challenges of blockchain applications in supply chains. There is relatively little literature studying the impact of different return methods and blockchain on supply chain operations decisions and consumers from an operations management perspective. Also, we propose a cost threshold for the manufacturer to introduce blockchain through numerical simulation analysis, aiming to make better decisions for companies to introduce blockchain.

2.2. Returns in Supply Chains. It has been found that consumers' consumption decisions are often influenced by merchants' return policies, with 82% of consumers indicating that an overly cumbersome return process would discourage them from making a purchase, and the average return rate for online shopping has reached 22% [27, 28]. As an important after-sales service, the study of returns in the supply chain has received more and more attention. Liu et al. [29] considered the hassle costs of consumer returns and analyzed the impact of return losses on retailers' optimal pricing and profits across different channels from three different return methods. Ma et al. [30] considered two return policies, allowing and disallowing returns, and applied the Stackelberg game approach to analyze the impact of return policies on retail prices, commission rates, and profits in a two-stage supply chain consisting of a retailer and a P2P platform. Wang and He [31] used the Stackelberg game to study the return policies of a mass customization dual-channel supply chain under a retailer selling two products (standard and customized products) directly or through an agent. Jena and Meena [32] analyzed test-in-store-and-buy-online retailing strategies in the absence and presence of product return policies and their impact on supply chain profitability and price competition among manufacturers. Huang and Jin [33] found that in a monopolistic environment, buy-online-and-return-in-store (BORS) can hurt retailers; however, a competitive environment can make both types of retailers willing to offer BORS under almost all conditions, benefiting both the supply chain and its members. Cao and Choi [34] examined the impact of companies offering both full-trade-in-return and partial-trade-in-return policies on company decisions and consumer surplus. The study finds that which return policy a company chooses depends on the residual value of the product and the satisfaction rate of the new product.

Current research related to returns in supply chains has focused on the impact of return policies and supply chain performance, with little consideration of return costs and different return methods from the consumer's perspective. Therefore, we introduce blockchain technology by considering the costs of consumer returns and different return methods to study whether blockchain technology should be introduced and how it affects pricing decisions and supply chain performance.

In summary, in the literature related to the application of blockchain technology in the supply chain, there is less literature discussing how blockchain technology affects consumer channel choice. While most of the relevant literature on return factors focuses on dual-channel or omnichannel sales, and some of the literature considers return policies or pricing strategies, there is little coverage on how blockchain technology affects dual-channel return methods and supply chain performance. We construct a dual-channel supply chain consisting of a manufacturer and a traditional retailer. Based on the assumption that consumers have different perceptions of products in different channels, considering such parameters as consumers' hassle costs, product validation time, probability of quality products, and blockchain technology costs, the impact of different channel return methods without blockchain technology and the adoption of blockchain technology on pricing decisions are investigated. In Table 1, we summarize the main differences between our study and the relevant literature.

3. Problem Description and Model Assumptions

3.1. Problem Description and Assumptions. We develop a supply chain with a manufacturer and a retailer as the leader and follower, respectively. The manufacturer controls the online channel, and the retailer owns and operates the offline brick-and-mortar store. According to whether blockchain technology is adopted or not and the various return methods chosen by customers, it is divided into original return models without blockchain technology (model NO), online return models without blockchain technology (model NM), offline return models without blockchain technology (model NR), and dual-channel models with blockchain technology (model B), as shown in Figure 1.

Table 1: Comparison between our study and other related studies.

Authors	Blockchain benefits	Return channels	Application scenarios
Liang and Xiao [35]	Reliability and trustworthy	None	Online direct selling and online distribution
Xu and Choi [36]	Transparency and certification	Online and offline channels	Platform operations under cap-and-trade
Cao et al. [13]	Visibility, smart contract, and authenticity	None	Agricultural supply chain
Liu et al. [18]	Transparency and information disclosure	Retail channel	Traditional two-echelon supply chain
Liu et al. [19]	Trustworthy	Retail channel	Platform supply chain
Ji et al. [20]	Traceability	None	Competitive supply chain
Choi [21]	Transparency	None	Supply chain finance
Choi and Luo [22]	Security and reliability	None	Fashion supply chain
Xu et al. [23]	Trustworthy and traceability	None	Remanufacturing and cap-and-trade
Liu et al. [29]	None	Online and offline channels	Omnichannel retail
Ma et al. [30]	None	Retail channel	P2P platform operations
Wang and He [31]	None	Online channel	E-commerce supply chain
Jena and Meena [32]	None	Online channel	Omnichannel retail
Huang and Jin [33]	None	Online and offline channels	Omnichannel retail
Cao and Choi [34]	None	Trade-in-return	Selling own branded products
Our study	Authenticity and efficiency trustworthy	Online and offline channels	Online direct sales and offline retailing

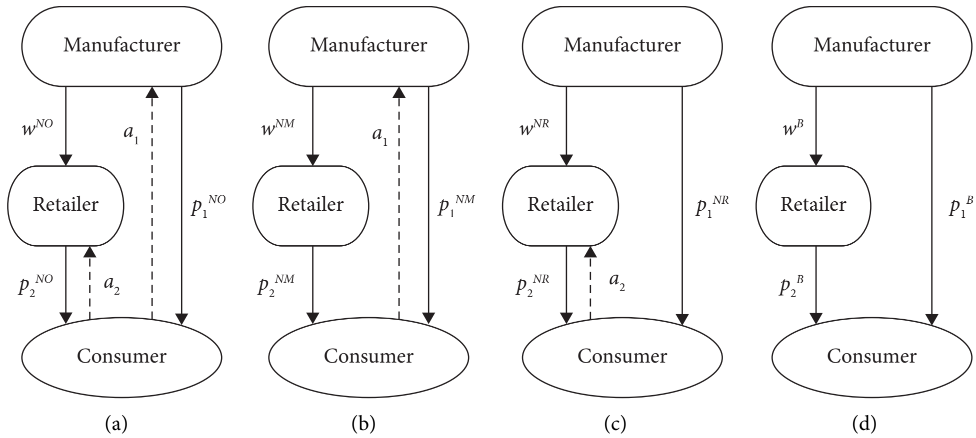


Figure 1: Dual-channel supply chain structure. (a) Model NO. (b) Model NM. (c) Model NR. (d) Model B.

Consumers' willingness to pay for products through various channels is taken into account, and it is assumed that their willingness to pay for products through online and offline channels differs because consumers through offline channels can actually experience the features of the products, whereas consumers through online channels can only understand the products through information such as pictures and videos released by online stores, which is uncertain.

According to Chiang et al. [37], it is assumed that the customer's willingness to pay for the product v is uniformly distributed between $[0, 1]$. Due to the uncertainty of online customers' purchases, their product value perception discount percentage is $\theta \in (0, 1)$, where $1 - \theta$ is the expected value loss of products from online customers, online customers' willingness to pay for products is θv, and their willingness to give up purchase or return is 0. Similar to Gong et al. [38], in order to simplify the analysis, it is assumed that the manufacturer's unit production cost is 0, the wholesale price is w, and the sales price is p_1 in the online channel. The retailer sells the products to consumers at retail price p_2.

Referring to Choi [39], it is assumed that the time spent by consumers to verify the products without the blockchain technology is $t_i\,(i = 1, 2)$, and the time spent to verify the products with blockchain technology is $T_i\,(i = 1, 2)$, $T_i < t_i$. The consumer's sensitivity coefficient for time loss is η, then the consumer's loss in verifying products is ηt. Assuming that the return hassle cost of products purchased online by consumers is a_1, such as consumers need to package products for mailing; the return hassle cost of products purchased offline by consumers is a_2, such as consumers need to specifically go to the store to return products [29]. When blockchain technology is not used, consumers cannot trace the source of products and may purchase counterfeit products, then consumers will return products, and the manufacturer and the retailer will get zero profits. Referring to Liang and Xiao [35] and Xu and Choi [36], the adoption of blockchain technology can ensure that consumers buy quality products, i.e., $\beta = 1$, they will not return products. At the same time, we assume that the potential market demand is 1, and each consumer can purchase at most one product. The return hassle cost and verification time brought to consumers by online and offline channels may be different [40], that is, the return hassle cost and verification time of products purchased through online channels are less than those purchased through offline channels.

Without blockchain technology, consumers are unable to verify the authenticity of products and may end up buying counterfeit goods, i.e., $\beta \in [0, 1)$; as a result, consumers will return goods, leaving the manufacturer and the retailer with no profit. With the introduction of blockchain technology, consumers will be more likely to purchase high-quality goods and not return them. Assume that there is a one-unit maximum purchase per consumer and that the potential market demand is one. We consider the potential differences in return hassle costs and verification time between the online and offline channels. So we assume that $a_1 \leq a_2$, $t_1 \leq t_2$, and $T_1 \leq T_2$, that is, that products bought online have a lower return hassle cost and shorter verification times than those bought offline [40].

If consumers do not have a preference between products sold through online and offline channels, the choice of the channel depends on how much value they will ultimately receive. Based on the above assumptions, the consumer's total utility function is equal to the consumer's willingness to pay minus the cost of time lost in verifying the product and the cost of hassle in returning the product. The utility U_1 and U_2 obtained by consumers through online and offline channels are as follows:

$$\begin{cases} U_1 = \theta v - p_1 - \eta t_1 - a_1(1 - \beta), \\ U_2 = v - p_2 - \eta t_2 - a_2(1 - \beta). \end{cases} \tag{1}$$

Equation (1) indicates that consumers use the original channel return mode. In this paper, consumers will employ additional return modes in addition to the initial channel return method. This paper first examines the original channel return mode chosen by consumers in the absence of blockchain technology, then examines the cross-return mode where consumers choose exclusively online returns or exclusively offline returns, and finally examines the effects of the manufacturer adoption of blockchain technology on supply chain pricing and members' profits.

3.2. Notations. For clarity, we give the notations in Table 2.

4. Dual-Channel Return Model without Blockchain Technology

4.1. NO Model: Consumers Return Products through Original Channels. According to the previous assumptions, consumers choose which channel to purchase products based on the overall utility of the two channels. According to equation (1), consumers will choose to buy online products when $U_1 \geq U_2$ and $U_1 \geq 0$, i.e., $v \in [(p_1 + \eta t_1 + a_1(1-\beta)/\theta), (p_2 - p_1 + \eta(t_2 - t_1) + (1-\beta)(a_2 - a_1)/1-\theta)]$; consumers will choose to buy offline products when $U_2 \geq U_1$ and $U_2 \geq 0$, i.e., $v \geq \max\{(p_2 - p_1 + \eta(t_2 - t_1) + (1-\beta)(a_2 - a_1)/1-\theta), p_2 + \eta t_2 + a_2(1-\beta)\}$; when $U_1 = U_2 \geq 0$, i.e., $v = (p_2 - p_1 + \eta(t_2 - t_1) + (1-\beta)(a_2 - a_1)/1-\theta) \geq 0$, there is no difference in the utility obtained by consumers when purchasing products from online or offline channels. From this, we can get the demand functions of two channels as follows:

$$D_1^{NO} = \frac{p_2 - p_1 + \eta(t_2 - t_1) + (1-\beta)(a_2 - a_1)}{1-\theta} - \frac{p_1 + \eta t_1 + a_2(1-\beta)}{\theta},$$
$$D_2^{NO} = 1 - \frac{p_2 - p_1 + \eta(t_2 - t_1) + (1-\beta)(a_2 - a_1)}{1-\theta}, \tag{2}$$

where $(p_1 + \eta t_1 + a_1(1-\beta)/p_2 + \eta t_2 + a_2(1-\beta)) \leq \theta \leq 1 - p_2 + p_1 + \eta(t_1 - t_2) + (1-\beta)(a_1 - a_2)$, otherwise, consumers will only buy from a single channel, there is no dual channel, and we only study the dual-channel scenario. Therefore, in the NO model, the optimization models of the manufacturer and the retailer are as follows:

$$\max_{w^{NO}, p_1^{NO}} \pi_m^{\text{NO}} = w^{\text{NO}} \beta D_2^{\text{NO}} + p_1^{\text{NO}} \beta D_1^{\text{NO}},$$
$$\max_{p_2^{NO}} \pi_r^{\text{NO}} = \left(p_2^{\text{NO}} - w^{\text{NO}}\right) \beta D_2^{\text{NO}}. \tag{3}$$

In the NO model, the manufacturer and the retailer play a Stackelberg game: the manufacturer is the leader, first deciding on the wholesale price and online direct sales price; the retailer is the follower, then deciding on the offline retail price. Solving by the reverse induction, we have the optimal results for the NO model, which are described in the following Theorem 1.

Theorem 1. *In the NO model, the optimal retail prices and wholesale price are as follows:*

$$w^{NO*} = \frac{1 - \eta t_2 - a_2(1-\beta)}{2},$$
$$p_1^{NO*} = \frac{\theta - \eta t_1 - a_1(1-\beta)}{2},$$
$$p_2^{NO*} = \frac{3 - \theta - (1-\beta)(3a_2 - a_1) - \eta(3t_2 - t_1)}{4}. \tag{4}$$

Furthermore, the demands for online and offline products can be obtained as follows:

$$D_1^{NO*} = \frac{(1-\beta)(a_2 - a_1) + \eta(t_2 - t_1)}{4(1-\theta)} - \frac{\theta + \eta t_1 + a_1(1-\beta)}{2\theta} + \frac{3}{4},$$
$$D_2^{NO*} = \frac{(1-\beta)(a_1 - a_2) + \eta(t_1 - t_2)}{4(1-\theta)} + \frac{1}{4}. \tag{5}$$

The optimal profits for the manufacturer and the retailer are as follows:

Table 2: Symbols and notations.

Notations	Definitions
i	Channel i, where $i \in \{1, 2\}$ and 1 and 2 refer to the online channel and offline channel, respectively
j	Supply chain members j, where $j \in \{m, r\}$, and m and r refer to the manufacturer and the retailer, respectively
U	The total utility obtained by the consumer
v	Consumers' willingness to pay
θ	The online product value perception discount percentage
η	Consumer time loss sensitivity coefficient
t_i	Product validation time for channel i without blockchain technology
T_i	Product validation time for channel i with blockchain technology
a_i	The return hassle cost for channel i
β	The probability of the product being verified as quality
f	The unit validation fee paid by the retailer to the manufacturer
F	A fixed fee for the manufacturer to introduce blockchain technology
w	The manufacturer's wholesale price
p_i	The retail unit price of channel i
D_i	Demand of channel i
π_j	Profit of member j

$$\begin{aligned}
\pi_m^{NO*} &= \frac{\left[\beta\left(1-a_2+a_2\beta-\eta t_2\right)\left(1+a_1-a_1\beta+a_2\beta-a_2-\theta+\eta t_1-\eta t_2\right)\right]}{8(1-\theta)} \\
&\quad - \frac{\left[\beta\left(\theta-a_1+a_1\beta-\eta t_1\right)\left(\theta-2a_1+2a_1\beta+a_1\theta+a_2\theta-2\eta t_1-\theta^2-a_1\beta\theta-a_2\beta\theta+\theta\eta t_1+\theta\eta t_2\right)\right]}{8\theta(1-\theta)}, \qquad (6) \\
\pi_r^{NO*} &= \frac{\beta\left(1+a_1-a_2-\theta-a_1\beta+a_2\beta+\eta t_1-\eta t_2\right)^2}{16(1-\theta)}.
\end{aligned}$$

The proof is displayed in Appendix A.

Theorem 1 shows that the optimal sales volume in the online (offline) channel is decreasing in the online (offline) return hassle cost and increasing in the offline (online) return hassle cost. While this finding is intuitive, it reveals an important insight: the cost of return hassles to consumers brought about by the manufacturer or retailer developing a return policy can have an impact on other channels. Specifically, many previous studies only found that differences in channel pricing or costs affect demands in the respective channels [30, 31, 41]. In contrast, our study considers the return hassle costs for both channels and interestingly finds the impact of return policies on the other channels. According to our observation, this is widespread in practice. For example, among online platforms, clothing merchants on Taobao.com often provide return insurance for consumers, which undoubtedly alleviates the cost of return hassles for consumers, making sales of the same clothing often greater than on JD.com, which does not provide return insurance.

Proposition 2. *In the NO model, the change trends of the retail prices, wholesale price, and demands of the two channels with parameters θ, η, and β are as follows.*

(1) $\partial w^{NO*}/\partial\theta = 0$, $(\partial p_1^{NO*}/\partial\theta) > 0$, $(\partial p_2^{NO*}/\partial\theta) < 0$, $(\partial D_1^{NO*}/\partial\theta) > 0$, *and* $(\partial D_2^{NO*}/\partial\theta) < 0$

(2) $(\partial w^{NO*}/\partial\eta) < 0$, $(\partial p_1^{NO*}/\partial\eta) < 0$, $(\partial p_2^{NO*}/\partial\eta) < 0$*; if* $t_1 < (\theta t_2/2 - \theta)$, *and then* $(\partial D_1^{NO*}/\partial\eta) > 0$*;* $(\partial D_2^{NO*}/\partial\eta) < 0$

(3) $(\partial w^{NO*}/\partial\beta) > 0$, $(\partial p_1^{NO*}/\partial\beta) > 0$, $(\partial p_2^{NO*}/\partial\beta) > 0$, *if* $a_1 < (\theta a_2/2 - \theta)$, *and then* $(\partial D_1^{NO*}/\partial\beta) < 0$*;* $(\partial D_2^{NO*}/\partial\beta) > 0$

The proof is displayed in Appendix B.

According to Proposition 2 (1), the wholesale price is unrelated to how consumers perceive the value of an online product, and as consumer perception of the value of an online product rises, so do online retail price and demand, whereas offline retail price and demand decline. It suggests that when consumers' perceptions of online products improve, some of them may switch from using physical channels to making purchases online. As a result, the manufacturer would raise the price at which online products are sold in order to make more money. It suggests that some consumers may switch from making offline purchases to making purchases online when the perceived value of online products rises. As a result, the manufacturer will raise the selling price of online products to enhance profits.

According to Proposition 2 (2), as the consumer time loss sensitivity coefficient rises, the wholesale price, retail price, and demand of offline channel fall. The total utility gained by consumers from buying products declines as the time loss sensitivity coefficient rises, which causes a corresponding decline in demand for offline products. As a result, the manufacturer and the retailer will actively lower retail prices to stimulate consumer demands in order to prevent losses. However, when the verification time for online products is much less than that for offline products, a higher time loss sensitivity coefficient will increase the demand for online channels. In this case, consumers who are sensitive to time loss will shift from offline channels to online channels, leading to an increase in demand for online channels.

According to Proposition 2 (3), the wholesale price, retail price, and demand of offline channel all rise as the likelihood that consumers would buy high-quality products rises. Consumer demands for offline products increase as the likelihood of buying a quality product rises, consumers are less likely to return the product, and the overall utility gained from their purchase rises. As a result, prices rise to allow both the manufacturer and the retailer to make more money. However, when the cost of return hassle is much lower in the online channel than in the offline channel, a higher rate of quality products will instead reduce the demand for the online channel. When the rate of quality products is high, consumers' return rates are low, and the low return hassle cost is not enough to attract them to buy online products. In this case, the lower return hassle cost is not enough to make up for the discount in willingness to buy, so consumers are still more willing to purchase offline products.

Consumer demands for offline products increase as the likelihood of buying a quality product rises, consumers are less likely to return the product, and the overall utility gained from their purchase rises. As a result, prices rise to allow both the manufacturer and the retailer to make more money.

4.2. NM Model: Consumers All Return Products through Online Channel. Assuming that every client opts for the online return option, this has the effect of raising the cost of return hassle for customers who shop both online and offline while remaining constant for those who shop online. When consumers all returns goods through online channels, the following are the utility functions of customers:

$$\begin{cases} U_1 = \theta v - p_1 - \eta t_1 - a_1(1-\beta), \\ U_2 = v - p_2 - \eta t_2 - a_1(1-\beta). \end{cases} \tag{7}$$

Which channel to buy the product for consumers still depends on the size of the total utility obtained. Similar to the analysis method in 4.1, the demand functions of the two channels can be obtained as follows:

$$\begin{aligned} D_1^{NM} &= \frac{p_2 - p_1 + \eta(t_2 - t_1)}{1-\theta} - \frac{p_1 + \eta t_1 + a_1(1-\beta)}{\theta}, \\ D_2^{NM} &= 1 - \frac{p_2 - p_1 + \eta(t_2 - t_1)}{1-\theta}, \end{aligned} \tag{8}$$

where $(p_1 + \eta t_1 + a_1(1-\beta)/p_2 + \eta t_2 + a_1(1-\beta)) \le \theta \le 1 - p_2 + p_1 + \eta(t_1 - t_2)$, otherwise, consumers will only buy from a single channel, there is no dual channel, and we only study the dual-channel scenario. Therefore, in the model NM, the optimization models of the manufacturer and the retailer are as follows:

$$\begin{aligned} &\max_{w^{NM}, p_1^{NM}} \pi_m^{NM} = w^{NM}\beta D_2^{NM} + p_1^{NM}\beta D_1^{NM}, \\ &\max_{p_2^{NM}} \pi_r^{NM} = \left(p_2^{NM} - w^{NM}\right)\beta D_2^{NM}. \end{aligned} \tag{9}$$

Solving by the reverse induction, we have the optimal results for the model NM, which are described in the following Theorem 3.

Theorem 3. *In the model NM, the optimal retail prices and wholesale price are as follows:*

$$\begin{aligned} w^{NM*} &= \frac{1 - \eta t_2 - a_1(1-\beta)}{2}, \\ p_1^{NM*} &= \frac{\theta - \eta t_1 - a_1(1-\beta)}{2}, \\ p_2^{NM*} &= \frac{3 - \theta - 2a_1(1-\beta) - \eta(3t_2 - t_1)}{4}. \end{aligned} \tag{10}$$

Furthermore, the demands for online and offline products can be obtained as follows:

$$\begin{aligned} D_1^{NM*} &= \frac{\eta(t_2 - t_1)}{4(1-\theta)} - \frac{\theta + \eta t_1 + a_1(1-\beta)}{2\theta} + \frac{3}{4}, \\ D_2^{NM*} &= \frac{\eta(t_1 - t_2)}{4(1-\theta)} + \frac{1}{4}. \end{aligned} \tag{11}$$

The optimal profits for the manufacturer and the retailer are as follows:

$$\begin{aligned} \pi_m^{NM*} &= \frac{\beta(a_1 - a_1\beta + \eta t_2 - 1)^2}{8} + \frac{\beta(a_1 - a_1\beta + \eta t_1 - \theta)^2}{8\theta}, \\ \pi_r^{NM*} &= \frac{\beta(1 - a_1 + a_1\beta - \eta t_2)(1 - \theta - \eta t_2 + \eta t_1)}{16}. \end{aligned} \tag{12}$$

Theorem 3 shows that the optimal sales volume of the online channel increases only with the increase in the online return hassle cost, and the optimal sales volume of the offline channel is not affected by the return hassle cost. This finding differs from Theorem 1 due to the fact that all consumers choose to return goods from the online channel in the model NM. This phenomenon is also common in practice, for example, Chinese law provides consumers with a right to return goods without reason within 7 days of online shopping, which cannot be used for offline stores. Obviously, whether a merchant has a seven-day no-excuse return policy will not affect the sales of its offline stores. This finding contains an interesting management insight: the choice of sales channel may differ for demand-driven companies, which do not need to consider the impact on offline stores to develop online return policies when consumers can only return goods online.

Proposition 4. *In the model NM, the change trends of the retail prices, wholesale price, and demands of the two channels with parameters θ, η, and β are as follows.*

(1) $(\partial w^{NM*}/\partial\theta) = 0$, $(\partial p_1{}^{NM*}/\partial\theta) > 0$, $(\partial p_2{}^{NM*}/\partial\theta) < 0$, $(\partial D_1{}^{NM*}/\partial\theta) > 0$, *and* $(\partial D_2{}^{NM*}/\partial\theta) < 0$

(2) $(\partial w^{NM*}/\partial\eta) < 0$, $(\partial p_1{}^{NM*}/\partial\eta) < 0$, $(\partial p_2{}^{NM*}/\partial\eta) < 0$; *if* $t_1 < (\theta t_2/2 - \theta)$, *and then* $(\partial D_1{}^{NM*}/\partial\eta) > 0$; $(\partial D_2{}^{NM*}/\partial\eta) < 0$

(3) $(\partial w^{NM*}/\partial\beta) > 0$, $(\partial p_1{}^{NM*}/\partial\beta) > 0$, $(\partial p_2{}^{NM*}/\partial\beta) > 0$, $(\partial D_1{}^{NM*}/\partial\beta) > 0$, *and* $(\partial D_2{}^{NM*}/\partial\beta) = 0$

The proof is displayed in Appendix C.

Some of the conclusions in Proposition 4 are similar to Proposition 2 and will not be repeated here. The difference is that under the model NM, consumers' demand for offline products is independent of the probability that the product is quality, and the demand for offline products is the same when consumers use online and offline return modes ($D_2{}^{NM*} = D_2{}^{NR*}$), so the retailer will raise the price of offline products to make more profit.

4.3. Model NR: Consumers All Return Products through Offline Channel. Assuming that consumers all choose the offline return mode, it means that the return hassle cost for consumers in both channels becomes a_2, thus affecting the return hassle cost for consumers who purchase products in the online channel, but not changing the utility for consumers who purchase products in the offline channel. Therefore, when all consumers return products through offline channels, the utility functions of consumers are as follows:

$$\begin{cases} U_1 = \theta v - p_1 - \eta t_1 - a_2(1-\beta), \\ U_2 = v - p_2 - \eta t_2 - a_2(1-\beta). \end{cases} \tag{13}$$

Which channel to buy the product for consumers still depends on the size of the total utility obtained, and the demand functions for both channels can be obtained as follows:

$$\begin{aligned} D_1{}^{NR} &= \frac{p_2 - p_1 + \eta(t_2 - t_1)}{1-\theta} - \frac{p_1 + \eta t_1 + a_2(1-\beta)}{\theta}, \\ D_2{}^{NR} &= 1 - \frac{p_2 - p_1 + \eta(t_2 - t_1)}{1-\theta}, \end{aligned} \tag{14}$$

where $(p_1 + \eta t_1 + a_2(1-\beta)/p_2 + \eta t_2 + a_2 \ (1-\beta)) \le \theta \le 1 - p_2 + \ p_1 + \eta(t_1 - t_2)$; otherwise, consumers will only buy from a single channel, there is no dual channel, and we only study the dual-channel scenario. Therefore, in the model NR, the optimization models of the manufacturer and the retailer are as follows:

$$\begin{aligned} \max_{w^{NR}, p_1{}^{NR}} \pi_m{}^{NR} &= w^{NR}\beta D_2{}^{NR} + p_1{}^{NR}\beta D_1{}^{NR}, \\ \max_{p_2{}^{NR}} \pi_r{}^{NR} &= \left(p_2{}^{NR} - w^{NR}\right)\beta D_2{}^{NR}. \end{aligned} \tag{15}$$

Solving by the reverse induction, we have the optimal results for the model NR, which are described in the following Theorem 5.

Theorem 5. *In the model NR, the optimal retail prices and wholesale price are as follows:*

$$\begin{aligned} w^{NR*} &= \frac{1 - \eta t_2 - a_2(1-\beta)}{2}, \\ p_1{}^{NR*} &= \frac{\theta - \eta t_1 - a_2(1-\beta)}{2}, \\ p_2{}^{NR*} &= \frac{3 - \theta - 2a_2(1-\beta) - \eta(3t_2 - t_1)}{4}. \end{aligned} \tag{16}$$

Furthermore, the demands for online and offline products can be obtained as follows:

$$\begin{aligned} D_1{}^{NR*} &= \frac{\eta(t_2 - t_1)}{4(1-\theta)} - \frac{\theta + \eta t_1 + a_2(1-\beta)}{2\theta} + \frac{3}{4}, \\ D_2{}^{NR*} &= \frac{\eta(t_1 - t_2)}{4(1-\theta)} + \frac{1}{4}. \end{aligned} \tag{17}$$

The optimal profits for the manufacturer and the retailer are as follows:

$$\begin{aligned} \pi_m{}^{NR*} &= \frac{\beta(a_2 - a_2\beta - \theta + \eta t_1)}{2} * \left[\frac{\theta + a_2 - a_2\beta + \eta t_1}{2\theta} - \frac{3 - 3\theta - \eta t_1 + \eta t_2}{4(1-\theta)}\right] + \frac{\beta(1 - a_2 + a_2\beta - \eta t_2)(1 - \theta - \eta t_2 + \eta t_1)}{8(1-\theta)}, \\ \pi_r{}^{NR*} &= \frac{\beta(1 - \theta - \eta t_2 + \eta t_1)^2}{16(1-\theta)}. \end{aligned} \tag{18}$$

Theorem 5 shows that the optimal sales in the online channel increase only with the decrease of the offline return hassle cost, and the optimal sales in the offline channel are not affected by the return hassle cost. This finding differs from Theorem 3 due to the fact that consumers all choose to return products from the offline channel in the model NR. Although this finding is not very intuitive, we can find corresponding examples in practice. Many retailers have implemented omnichannel strategies, and one of the key strategies is to offer buy-online-and-return-in-store (BORS) services to consumers, such as Uniqlo, Hewlett-Packard, Walmart, and other well-known retail brands. During the COVID-19 epidemic, BORS reduced the cost of return hassles for consumers, which could effectively reduce the high return rate online and increase in-store purchases [33, 42]. From this finding, we can learn that the return of goods is an important after-sales service. When consumers choose to return goods offline, companies still need to consider the impact of their return hassle costs on online channel purchases. If the offline return hassle costs are too high, it will reduce sales in the online channel.

Proposition 6. *In the model NM, the change trends of the retail prices, wholesale price, and demands of the two channels with parameters θ, η, and β are as follows.*

(1) $(\partial w^{NR*}/\partial\theta) = 0$, $(\partial p_1^{NR*}/\partial\theta) > 0$, $(\partial p_2^{NR*}/\partial\theta) < 0$, $(\partial D_1^{NR*}/\partial\theta) > 0$, *and* $(\partial D_2^{NR*}/\partial\theta) > 0$

(2) $(\partial w^{NR*}/\partial\eta) < 0$, $(\partial p_1^{NR*}/\partial\eta) < 0$, $(\partial p_2^{NR*}/\partial\eta) < 0$; *if* $t_1 < (\theta t_2/2 - \theta)$, *and then* $(\partial D_1^{NR*}/\partial\eta) > 0$; $(\partial D_2^{NR*}/\partial\eta) < 0$

(3) $(\partial w^{NR*}/\partial\beta) > 0$, $(\partial p_1^{NR*}/\partial\beta) > 0$, $(\partial p_2^{NR*}/\partial\beta) > 0$, $(\partial D_1^{NR*}/\partial\beta) > 0$, *and* $(\partial D_2^{NR*}/\partial\beta) = 0$

The proof is displayed in Appendix D.

It is clear from Proposition 6 that consumer demand for offline products under the model NR is also independent of the probability that the product is quality. The other conclusions are similar to Proposition 2 and will not be repeated here.

4.4. Comparative Analysis of Model NO, Model NM, and Model NR

Proposition 7. *The following relationships can be obtained for the three return models without blockchain:*

(1) $w^{NM*} > w^{NO*} = w^{NR*}$

(2) $p_1^{NO*} = p_1^{NM*} > p_1^{NR*}$ *and* $p_2^{NM*} > p_2^{NR*} > p_2^{NO*}$

(3) $D_1^{NO*} > D_1^{NM*} > D_1^{NR*}$ *and* $D_2^{NM*} = D_2^{NR*} > D_2^{NO*}$

The proof is displayed in Appendix E.

Proposition 7 presents the findings of a comparison of three return models' optimal pricing and requests in the absence of blockchain technology. The NM model has the greatest wholesale price, offline demand, and retail price of the two channels; the model NR has the lowest wholesale price, online retail price, and demand; the NO model has the highest online retail price and demand, and the lowest offline retail price and demand. Due to the lower hassle costs associated with online returns compared to offline returns, consumers will benefit more overall from returning products online, which will increase demands for both online and offline channels and provide the manufacturer and the retailer with an incentive to raise prices to increase profits. Instead, if all returns are made through offline channels, consumers would receive less overall value from the products, and the manufacturer and the retailer will have to lower their prices in order to retain a profit. Different consumers' perceptions of online products mean that the method of returning goods entirely through online channels cannot entirely make up for the decline in demand for online channels brought on by these perceptions. As a result, when customers return goods through the original channels, demand for the online channel is at its maximum, and the manufacturer will boost the online retail price to increase his profit.

When compared to physical channels, the inconvenience associated with product returns for customers via online channels is comparatively low. Online returns can lower the amount of inventory in offline locations and minimize costs for offline merchants, while consumers who buy things offline and prefer to return them online may receive additional benefits. In contrast, choosing to return goods through an offline route causes the retailer to suffer bigger losses when the additional revenue brought in by customer returns is minimal. The demands and retail prices of the NM model are always higher than the NR model for both channels, as shown by Propositions 7 (2) and (3). Through advertising and live commerce, the manufacturer can raise online product awareness, which can further raise the product's price and enhance the manufacturer's ideal profit. To encourage customers to choose to return goods more frequently via online channels, the manufacturer can also work with logistics firms to introduce value-added services such as freight insurance.

5. Dual-Channel Return Model with Blockchain Technology

The retailer joining the blockchain platform can achieve information exchange and let customers rapidly trace the source of products, decreasing the returns. The manufacturer introducing blockchain technology can enable enterprises to have both product traceability and sales functions. For instance, the JD.com blockchain anticounterfeit monitoring technology syncs GIA diamond grade data with the Everledger blockchain network, which offers clients independently certified diamond certificates and provenance information through the JD.com app, cell phone, and desktop website [39]. By using blockchain technology, consumers can authenticate products without having to go through additional channels (e.g., third-party authentication agencies), which lowers the cost of doing so. Therefore, in the case of the manufacturer introducing blockchain technology, we have $T_i \leq t_i\,(i = 1, 2)$, $\beta = 1$, and consumer returns that do not occur. In this paper, the manufacturer establishes the blockchain information platform, assuming that the fee paid by the manufacturer is a fixed value F. The retailer, as a member of the blockchain system, can share information with consumers in order to enhance the utility of purchased products by using blockchain technology, assuming that the retailer needs to pay a unit verification fee (f) to use the blockchain platform established by the manufacturer. The utility functions for the consumer in the case of adopting blockchain technology are as follows:

$$\begin{cases} U_1 = \theta v - p_1 - \eta T_1, \\ U_2 = v - p_2 - \eta T_2. \end{cases} \tag{19}$$

Which channel to buy the product for consumers still depends on the size of the utility obtained from both channels. Similarly, the demand functions for both channels can be obtained as follows:

$$\begin{aligned} D_1^{\ B} &= \frac{p_2 - p_1 + \eta(T_2 - T_1)}{1-\theta} - \frac{p_1 + \eta T_1}{\theta}, \\ D_2^{\ B} &= 1 - \frac{p_2 - p_1 + \eta(T_2 - T_1)}{1-\theta}, \end{aligned} \tag{20}$$

where $(p_1 + \eta T_1 / p_2 + \eta T_2) \le \theta \le 1 - p_2 + p_1 + \eta(T_1 - T_2)$; otherwise, consumers will only buy from a single channel, there is no dual channel, and we only study the dual-channel scenario. Therefore, the optimization models for the manufacturer and the retailer under the introduction of blockchain technology by the manufacturer are as follows:

$$\begin{aligned} \max_{w^B, p_1^{\ B}} \pi_m^{\ B} &= w^B \beta D_2^{\ B} + p_1^{\ B} \beta D_1^{\ B}, \\ \max_{p_2^{\ B}} \pi_r^{\ B} &= \left(p_2^{\ B} - w^B\right) \beta D_2^{\ B}. \end{aligned} \tag{21}$$

Solving by the reverse induction, we have the optimal results for the model B, which are described in the following Theorem 8.

Theorem 8. *In the model B, the optimal retail prices and wholesale price are as follows:*

$$\begin{aligned} w^{B*} &= \frac{1 - \eta T_2}{2} - f, \\ p_1^{\ B*} &= \frac{\theta - \eta T_1}{2}, \\ p_2^{\ B*} &= \frac{3 - \theta - \eta(3T_2 - T_1)}{4}. \end{aligned} \tag{22}$$

Furthermore, the demands for online and offline products can be obtained as follows:

$$\begin{aligned} D_1^{\ B*} &= \frac{\eta(T_2 - T_1)}{4(1-\theta)} - \frac{\theta + \eta T_1}{2\theta} + \frac{3}{4}, \\ D_2^{\ B*} &= \frac{\eta(T_1 - T_2)}{4(1-\theta)} + \frac{1}{4}. \end{aligned} \tag{23}$$

The optimal profits for the manufacturer and the retailer are as follows:

$$\begin{aligned} \pi_m^{\ B*} &= \frac{\theta - \eta T_1}{2} * \left(\frac{3 - 3\theta - \eta T_1 + \eta T_2}{4(1-\theta)} - \frac{\theta + \eta T_1}{2\theta}\right) + \frac{(1 - \eta T_2)(1 - \theta - \eta T_2 + \eta T_1)}{8(1-\theta)} - F, \\ \pi_r^{\ B*} &= \frac{(1 - \theta - \eta T_2 + \eta T_1)^2}{16(1-\theta)}. \end{aligned} \tag{24}$$

From Theorem 8, it is clear that the unit verification fee f only affects the wholesale price w^{B*}. The unit verification fee f is equivalent to a decrease of f in the wholesale price of the manufacturer. Therefore, in the model B, we can consider $w^{B*} + f$ as the wholesale price of the manufacturer, that is, $w^{B*} + f = (1 - \eta T_2/2)$. This means that the manufacturer subsidizes the retailer in the form of a lower wholesale price, that is, the size of f has no effect on the manufacturer or the retailer.

Proposition 9. *In model B, the change trends of the retail prices, wholesale price, and demands of the two channels with parameters θ, η, f, and F are as follows.*

(1) $(\partial w^{B*}/\partial\theta) = 0$, $(\partial p_1^{\ B*}/\partial\theta) > 0$, $(\partial p_2^{\ B*}/\partial\theta) < 0$, $(\partial D_1^{\ B*}/\partial\theta) > 0$, *and* $(\partial D_2^{\ B*}/\partial\theta) < 0$

(2) $(\partial w^{B*}/\partial\eta) < 0$, $(\partial p_1^{\ B*}/\partial\eta) < 0$, $(\partial p_2^{\ B*}/\partial\eta) < 0$; *if* $T_1 < (\theta T_2/2 - \theta)$, *and then* $(\partial D_1^{\ B*}/\partial\eta) > 0$; $(\partial D_2^{\ B*}/\partial\eta) < 0$

(3) $(\partial w^{B*}/\partial f) < 0$, $(\partial p_1^{\ B*}/\partial f) = (\partial p_2^{\ B*}/\partial f) = (\partial D_1^{\ B*}/\partial f) = (\partial D_2^{\ B*}/\partial f) = (\partial \pi_m^{\ B*}/\partial f) = (\partial \pi_r^{\ B*}/\partial f) = 0$

(4) $(\partial w^{B*}/\partial F) = (\partial p_1^{\ B*}/\partial F) = (\partial p_2^{\ B*}/\partial F) = (\partial D_1^{\ B*}/\partial F) = (\partial D_2^{\ B*}/\partial F) = (\partial \pi_r^{\ B*}/\partial F) = 0$ *and* $(\partial \pi_m^{\ B*}/\partial F) < 0$

The proof is displayed in Appendix F.

The use of blockchain technology, as demonstrated by Proposition 9, demonstrates that the unit validation fee only impacts the wholesale price. This is due to the fact that the unit verification fee is paid by the retailer to the manufacturer in exchange for a lower wholesale price, which has no impact on either party's profits as it boosts and decreases their earnings. The larger the unit validation fee, the larger the manufacturer's subsidy to the retailer. Thus, the retailer always benefits from the use of blockchain technology. The manufacturer's profit will be impacted by the blockchain set charge, but not the wholesale pricing, retail prices, requests, or retailer's profit. The manufacturer's profit declines when the fixed blockchain platform charge goes up. This is because the manufacturer creates the blockchain platform, and the retailer can only implement information sharing by paying the unit verification fee.

Proposition 10. *The following relationships can be obtained by comparing the impact of adopting blockchain technology or not on pricing strategy and demands:*

(1) *If* $\eta > \eta_2$, *then* $w^{B*} > w^{NM*} > w^{NO*} = w^{NR*}$. *If* $\eta_1 < \eta < \eta_2$, *then* $w^{NM*} > w^{B*} > w^{NR*} = w^{NO*}$. *If* $\eta < \eta_1$, *then* $w^{NM*} > w^{NR*} = w^{NO*} > w^{B*}$;

(2) ${p_1}^{B*} > {p_1}^{NO*} = {p_1}^{NM*} > {p_1}^{NR*}$. *If* $t_1 - T_1 < 3(t_2 - T_2)$, *then* ${p_2}^{B*} > {p_2}^{NM*} > {p_2}^{NR*} > {p_2}^{NO*}$. *If* $t_1 - T_1 > 3(t_2 - T_2)$ *and* $\eta < \eta_3$, *then* ${p_2}^{B*} > {p_2}^{NM*} > {p_2}^{NR*} > {p_2}^{NO*}$. *If* $t_1 - T_1 > 3(t_2 - T_2)$ *and* $\eta_3 < \eta < \eta_4$, *then* ${p_2}^{NM*} > {p_2}^{B*} > {p_2}^{NR*} > {p_2}^{NO*}$. *If* $t_1 - T_1 > 3(t_2 - T_2)$ *and* $\eta_4 < \eta < \eta_5$, *then* ${p_2}^{NM*} > {p_2}^{NR*} > {p_2}^{B*} > {p_2}^{NO*}$. *If* $t_1 - T_1 > 3(t_2 - T_2)$ *and* $\eta > \eta_5$, *then* ${p_2}^{NM*} > {p_2}^{NR*} > {p_2}^{NO*} > {p_2}^{B*}$.

(3) *If* $t_1 - T_1 > (\theta(t_2 - T_2)/2 - \theta)$ *and* $\eta > \eta_6$, *then* ${D_1}^{B*} > {D_1}^{NO*} > {D_1}^{NM*} > {D_1}^{NR*}$. *If* $t_1 - T_1 > (\theta(t_2 - T_2)/2 - \theta)$ *and* $\eta < \eta_6$, *then* ${D_1}^{NO*} > {D_1}^{B*} > {D_1}^{NM*} > {D_1}^{NR*}$. *If* $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$ *and* $\eta < \eta_6$, *then* ${D_1}^{B*} > {D_1}^{NO*} > {D_1}^{NM*} > {D_1}^{NR*}$. *If* $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$ *and* $\eta_6 < \eta < \eta_7$, *then* ${D_1}^{NO*} > {D_1}^{B*} > {D_1}^{NM*} > {D_1}^{NR*}$. *If* $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$ *and* $\eta_7 < \eta < \eta_8$, *then* ${D_1}^{NO*} > {D_1}^{NM*} > {D_1}^{B*} > {D_1}^{NR*}$. *If* $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$ *and* $\eta > \eta_8$, *then* ${D_1}^{NO*} > {D_1}^{NM*} > {D_1}^{NR*} > {D_1}^{B*}$. *If* $t_2 - T_2 > t_1 - T_1$, *then* ${D_2}^{B*} > {D_2}^{NM*} = {D_2}^{NR*} > {D_2}^{NO*}$. *If* $t_2 - T_2 < t_1 - T_1$ *and* $\eta < \eta_9$, *then* ${D_2}^{NM*} = {D_2}^{NR*} > {D_2}^{B*} > {D_2}^{NO*}$. *If* $t_2 - T_2 < t_1 - T_1$ *and* $\eta > \eta_9$, *then* ${D_2}^{NM*} = {D_2}^{NR*} > {D_2}^{NO*} > {D_2}^{B*}$.

The proof is displayed in Appendix G.

Proposition 10 (1) shows that the wholesale price with blockchain is highest when the time loss sensitivity coefficient is high; when the time loss sensitivity is low, the wholesale price with blockchain is lowest. A large time loss sensitivity coefficient means that consumers care about the time it takes to verify products, and for this reason, consumers are willing to pay a higher price in exchange for faster service. As a result, the manufacturer has an incentive to raise wholesale prices to make greater profits.

We define $t_1 - T_1$ $(t_2 - T_2)$ as the level of blockchain technology in the online (offline) channel. Intuitively, $t_1 - T_1$ $(t_2 - T_2)$ is the reduced verification time of online (offline) products after adopting blockchain, and the larger the reduced verification time is, the higher the level of blockchain technology. Propositions 10 (2) and (3) indicate that the online retail price is the highest with blockchain. The manufacturer has to pay costs associated with adopting blockchain technology, so it has to increase the price of online products to compensate for blockchain costs. When the level of blockchain technology in the online channel is greater, consumers will increase their purchases even if the price of online products is the highest. For example, according to a survey by CEIBS and JD.com, sales of nutritional supplements increased by 29.4% after the traceability service was provided [16]. However, when the level of blockchain technology in the online channel is low, then the online channel sales depend on the time loss sensitivity. If the time loss sensitivity coefficient is high, then consumers will shift from the online channel to the offline channel to buy.

When the level of blockchain technology in the offline channel is high, the consumers will increase their offline product purchases and the retailer will raise the price of offline products to make more profits. And when the level of blockchain technology in the offline channel is low and the time loss sensitivity coefficient is high, then consumers will shift from offline channels to buy online, and the retailer will have to reduce the price of offline products to increase the sales. In this case, the manufacturer squeezes the retailer's profit margin by raising the wholesale price. Overall, the higher the level of blockchain technology in the online (offline) channel, the more popular the online (offline) products will be with the consumers. Otherwise, it depends on the time loss sensitivity coefficient.

6. Numerical Analysis

In this section, we did numerical analyzes to support the strategic decision to implement blockchain technology based on the size of the fixed blockchain charge as well as the change in pricing and profits of supply chain participants under various return models. According to the study of Jin and Guo [43], we use the following settings: $a_1 = 0.2$, $a_2 = 0.3$, $t_1 = 0.3$, $t_2 = 0.4$, $T_1 = 0.15$, $T_2 = 0.25$, $\beta = 0.7$, and $f = 0.09$. We have taken F, η, and θ as independent variable parameters. To ensure the validity of the model and the ease of analysis, let $F \in [0, 0.15]$, $\eta \in [0, 1]$, and $\theta \in [0.2, 0.8]$.

6.1. Comparison of Supply Chain Pricing Decisions. Regardless of the return mode, Figure 2 demonstrates that the wholesale and retail prices of both channels decline when the consumer time loss sensitivity coefficient rises. Online direct sales prices rise as consumer perceptions of the value of the products rise, whereas offline retail prices are the exact opposite. Figure 2(a) shows that the wholesale price with blockchain decreases at a slower rate as the time loss sensitivity coefficient increases than when blockchain is not used. If consumers are more sensitive to time loss, they are prepared to pay more for better and faster service. The manufacturer will raise the wholesale price for greater profitability. Figure 2(b) shows that the online retail price with blockchain is consistently greater than the online retail price without the blockchain. Figure 2(c) shows that when the level of

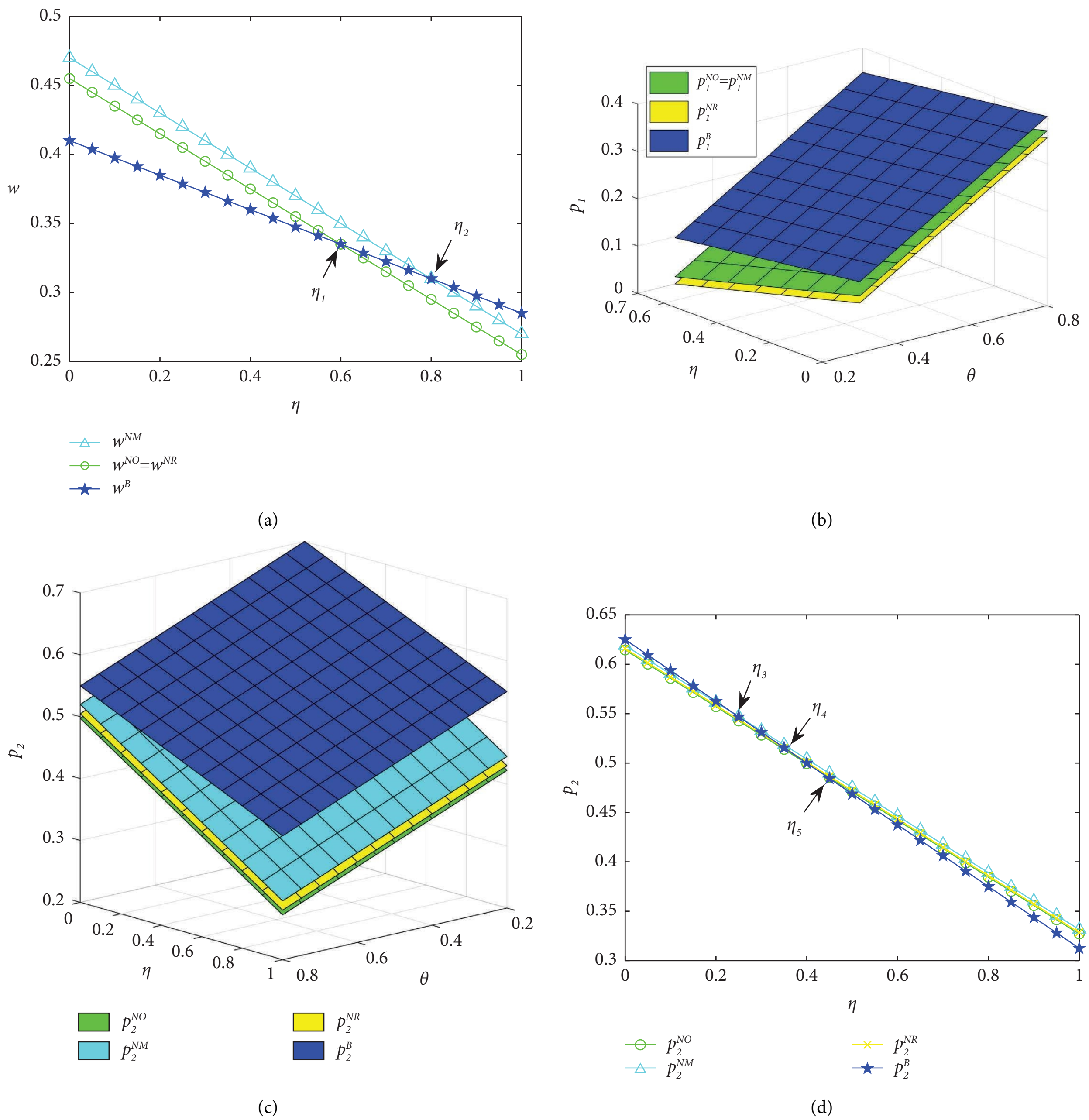


FIGURE 2: The impact of η and θ on the pricing of different return models. (a) The wholesale price. (b) The online direct retail price. (c) The offline retail price $(t_1 - T_1 < 3(t_2 - T_2))$. (d) The offline retail price $(t_1 - T_1 > 3(t_2 - T_2))$.

blockchain technology in the offline channel is greater, the online direct prices have the following relationships: ${p_2}^{B*} > {p_2}^{NM*} > {p_2}^{NR*} > {p_2}^{NO*}$. Figure 2(d) shows that when the level of blockchain technology in the offline channel is very small, the offline price with blockchain decreases at a faster rate as the time loss sensitivity coefficient increases than when blockchain is not used. In this case, blockchain technology cannot attract consumers to purchase, and the retailer has to lower the offline retail price to increase demand.

6.2. The Impact of Blockchain Fixed Fee on Manufacturer's Profit. We established the parameters $\eta = 0.5$ and $\theta = 0.7$ to examine how blockchain fixed fees affect the profit of the manufacturer. Figure 3 illustrates how the manufacturer's profit falls when the blockchain fixed charge rises after the manufacturer adopts blockchain technology. This is because the manufacturer's profit with blockchain technology is strictly decreasing with F when other parameters are determined, while the manufacturer's profit without blockchain technology is independent of F. When $F < 0.0876$, the manufacturer's profit after adopting blockchain technology is greater than the case without blockchain technology, and when $F > 0.0945$, the manufacturer's profit after adopting blockchain technology is less than the case without blockchain technology. This demonstrates that a crucial consideration in

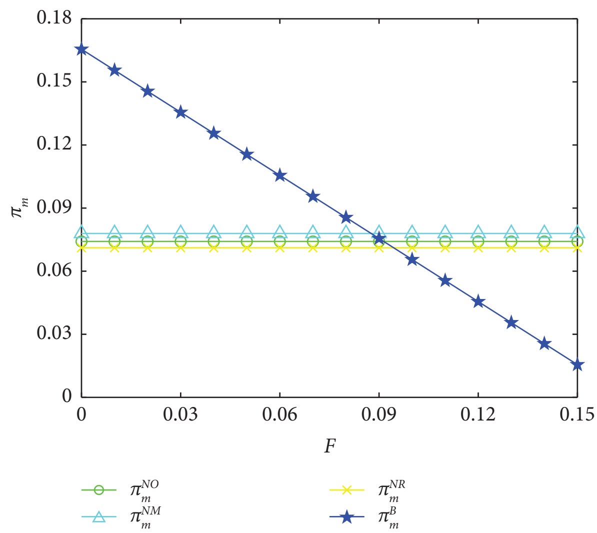
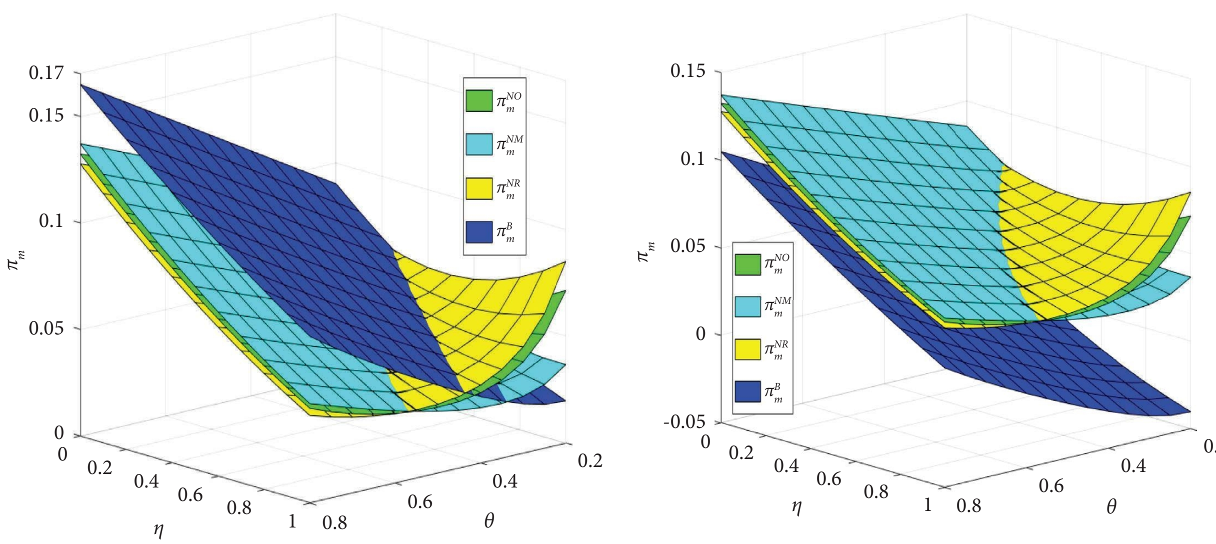


Figure 3: The impact of F on the profit of the manufacturer with different return models.



(a) (b)

Figure 4: The impact of η and θ on manufacturer's profit under different return models. (a) Manufacturer's profit ($F = 0.06$). (b) Manufacturer's profit ($F = 0.12$).

a manufacturer's decision to adopt blockchain technology is the fixed blockchain fee.

6.3. Comparison of Supply Chain Members' Profits. The manufacturer's profit declines as η grows, as shown in Figure 4. When blockchain technology is implemented, the manufacturer's profit increases, but not when it is not implemented. As seen in Figure 4(a), the manufacturer's profit is better without blockchain technology only when η is larger and θ is smaller with a modest blockchain fixed charge. In most cases, adopting blockchain technology may boost a manufacturer's profit. To strengthen consumer perception of online goods and increase sales, the manufacturer can improve product advertising online. The manufacturer using blockchain technology is least profitable when the blockchain fixed fee is higher, as indicated in Figure 4(b). The manufacturer must consider the blockchain fixed fee while deciding whether to implement blockchain technology and should reasonably control the fixed cost of blockchain.

Contrary to what is seen in Figure 5, the retailer's profit decreases with the increase of θ, as opposed to the manufacturer's. This is so because the online channel is within the manufacturer's control. With the growth, some customers will switch from offline to online shopping, lowering the retailer's profit. The store always makes more money after using blockchain technology than those who do not, proving that the retailer always benefits when a manufacturer introduces blockchain technology. This is so that the manufacturer, who pays the blockchain fixed charge, can subsidize the retailer's unit validation fee at a reduced wholesale cost while the retailer is responsible for paying the unit validation fee.

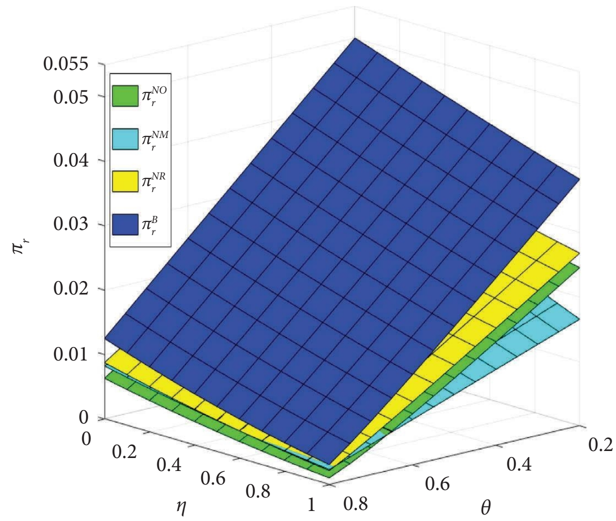


FIGURE 5: The impact of η and θ on retailer's profit under different return models.

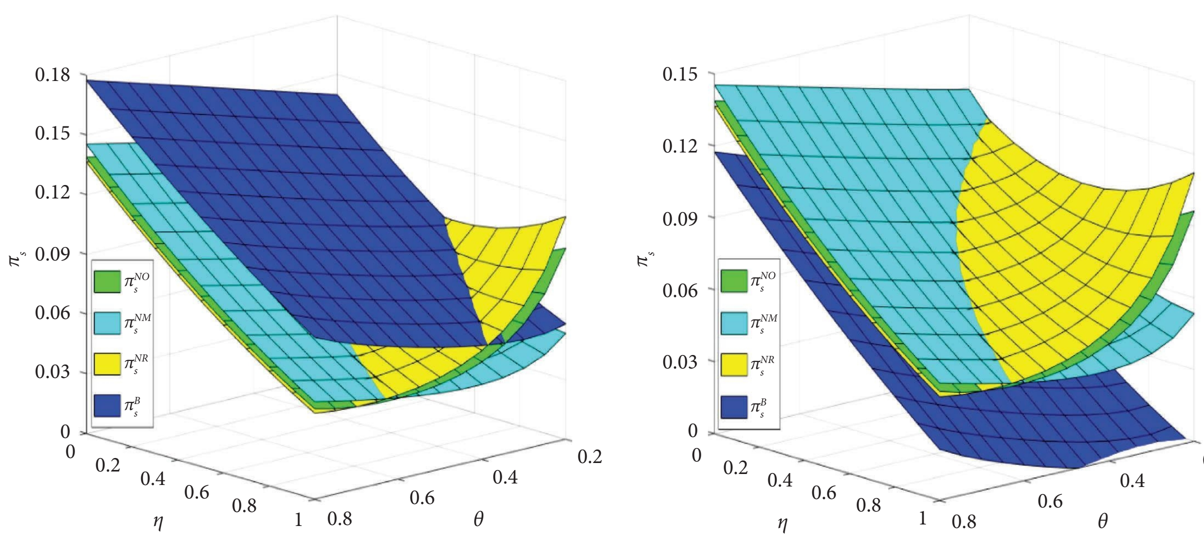


FIGURE 6: The impact of η and θ on total profit of supply chain under different return models. (a) Total profit of supply chain ($F = 0.06$). (b) Total profit of supply chain ($F = 0.12$).

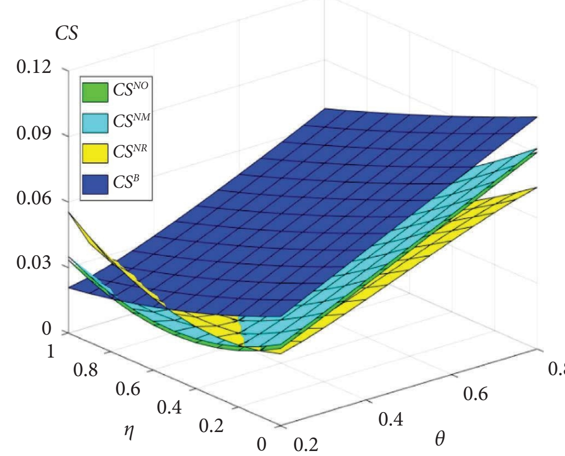
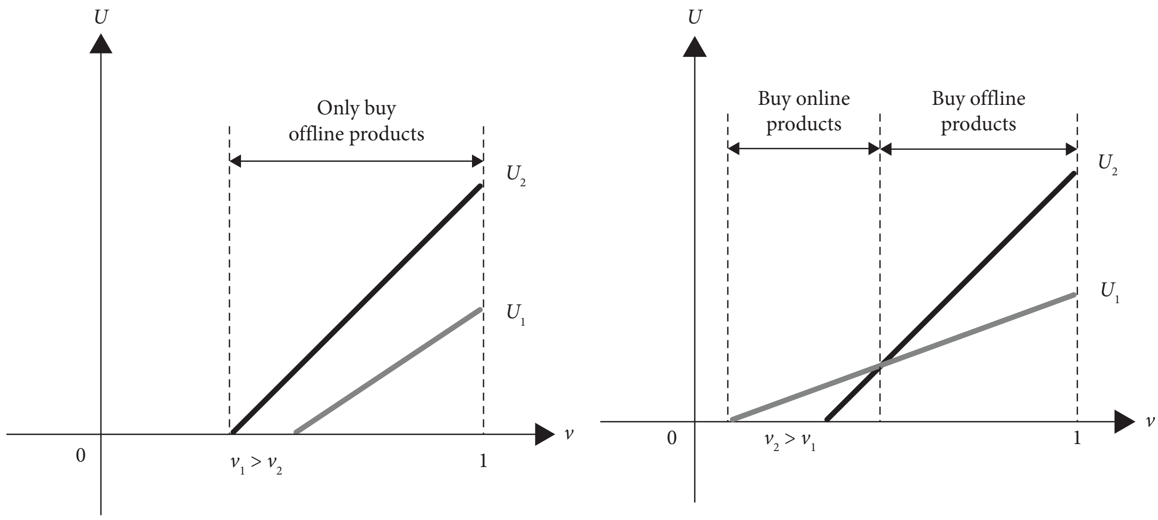


FIGURE 7: The impact of η and θ on consumer surplus of supply chain under different return models.



(a) (b)

Figure 8: Consumers' channel selection.

Figure 6 shows that the total supply chain profit decreases as η increases. As shown in Figure 6(a), with a small blockchain fixed fee, the total supply chain profit is higher without blockchain technology only when η is larger and θ is small. Under most conditions, the adoption of blockchain technology can increase total supply chain profit. As shown in Figure 6(b), the supply chain with blockchain technology is the least profitable in the case of a larger blockchain fixed fee. Therefore the manufacturer has to control the blockchain cost reasonably so that the total profit of the supply chain is maximized.

6.4. Comparison of Consumer Surplus. According to Liu et al. [44], The consumer surplus for NO model is $CS^{NO} = \int_A^B (\theta v - p_1 - \eta t_1 - a_1(1-\beta))\mathrm{d}v + \int_B^1 (v - p_2 - \eta t_2 - a_2(1-\beta))\mathrm{d}v$, where $A = (p_1 + \eta t_1 + a_2(1-\beta)/\theta)$ and $B = (p_2 - p_1 + \eta(t_2 - t_1) + (1-\beta)(a_2 - a_1)/1-\theta)$.

Similarly, the consumer surplus can be calculated for the other three models. As shown in Figure 7, it shows the impact of η and θ values on consumer surplus. It is clear that with the increase of θ, the consumer surplus also increases. The consumer surplus without blockchain technology is greater than with blockchain technology only for a specific value, that is to say, only when the value of η is larger and the value of θ is smaller. Under most conditions, consumer surplus is higher with blockchain technology than without blockchain technology, indicating that the adoption of blockchain technology can increase the total consumer utility and consumers are willing to pay higher prices in exchange for better services and therefore will reduce the return rate to promote the stability of the supply chain.

7. Conclusions

Based on the hypothesis that consumers perceive products differently when they are purchased through different channels, we created a dual-channel supply chain. We then investigated the effects of return modes through various channels, both with and without the use of blockchain technology, on the profits and channel pricing of supply chain members, taking into account factors such as the cost of consumer return hassle, the amount of time it takes to verify the products, and the likelihood that a product will be defective. The conclusions of the paper indicate as follows: (1) The wholesale price, retail prices, and demand of offline channel, whether or not blockchain technology is used, are inversely related to the customer time loss sensitivity coefficient; when the online product validation time is small, the online channel demand increases with the time loss sensitivity coefficient; the online retail price is directly proportional to the online product value perception, while the offline retail price is the exact reverse. Only the wholesale price will be impacted by the retailer's unit verification cost. (2) While the retailer pays a unit validation fee, the manufacturer actually subsidizes this fee to the retailer at a lower wholesale price; therefore, the retailer always benefits from the deployment of blockchain technology. The fixed blockchain cost, the consumer time loss sensitivity coefficient, and the perceived worth of the goods online will all influence whether the manufacturer adopts blockchain technology. (3) Both customers and the retailer profit when consumers return goods online even when blockchain technology is not involved. The wholesale price, retail price, and demand with blockchain are influenced by the level of blockchain technology and the time loss sensitivity coefficient. A high level of blockchain technology and a high time loss sensitivity coefficient will make consumers willing to spend more money to shorten the verification time. When the level of blockchain technology in the offline channel is very low and the consumer sensitivity coefficient is large, the manufacturer will raise the wholesale price while the retailer lowers the offline retail price, resulting in the manufacturer squeezing the retailer's profit margins. The implementation of blockchain technology can typically result in a larger consumer surplus.

We provide some management considerations based on these findings. (1) Consumers' choice of purchase channel is influenced by the costs of return hassle, thus businesses should design fair return policies to lower consumers' return costs for increased profitability. More than 146,000 businesses in Jiangsu Province, China, have joined the return alliance since the province began testing a no-reason return policy for brick-and-mortar establishments in 2020. Consumers gain from this decision, and it also makes brick-and-mortar establishments more competitive with regard to Internet retailers. (2) The manufacturer adopts blockchain technology only when the blockchain fixed fee is high, indicating the potential for free-rider behavior in the supply chain, but the retailer adopts blockchain technology at all times. In order to use the blockchain technology that the manufacturer has offered, supply chain participants should set up the proper contracts. This is the greatest option for supply chain participants, supply chain systems, and consumers. (3) The arrival of the blockchain 3.0 era has made blockchain widely used in various industries [45]. The manufacturer should improve the level of blockchain technology and balance the technological differences between the two channels to avoid competitive conflicts between the two channels. The application of blockchain makes consumers willing to spend more money for better service and better quality products, which also allows the manufacturer and retailer to gain more profits from raising prices, but they need to pay attention to the control of blockchain costs.

Future research may expand on our work in a number of ways. In a dual-channel supply chain, the impact of blockchain technology and various return models on return selection and pricing decisions is taken into account. After using products offline, some customers may really compare the two channels' worth, which can affect the demand for the other channel. This influence might be positive or negative, therefore it is a topic worth further research. Our study can be further expanded in the future. For example, examining how blockchain technology affects social welfare when government subsidies are used.

Appendix

A. Proof of Theorem 1

First, we discuss the range of values for θ. From $U_1 = 0$ and $U_2 = 0$, we obtain $v_1 = (p_1 + \eta t_1 + a_1(1-\beta)/\theta)$ and $v_2 = p_2 + \eta t_2 + a_2(1-\beta)$. If $v_1 > v_2$, then U_2 is always great than U_1, and Figure 8(a) depicts this scenario in detail. In this case, consumers only buy offline products, and the demand of the online channel is zero. There is no dual channel in the supply chain, and we only study the dual channel scenario, so we do not consider this scenario. If $v_2 > v_1$, i.e., $(p_1 + \eta t_1 + a_2(1-\beta)/p_2 + \eta t_2 + a_2(1-\beta)) \leq \theta$, consumers will buy products from two channels, and Figure 8(b) depicts this scenario in detail. From $U_1 = U_2$, we obtain $v^* = (p_2 - p_1 + \eta(t_2 - t_1) + (1-\beta)(a_2 - a_1)/1-\theta)$. Since $v \in [0,1]$, we get $\theta \leq 1 - p_2 + p_1 + \eta(t_1 - t_2) + (1-\beta)(a_1 - a_2)$. Based on the above results, we obtain $(p_1 + \eta t_1 + a_1(1-\beta)/p_2 + \eta t_2 + a_2(1-\beta)) \leq \theta \leq 1 - p_2 + p_1 + \eta (t_1 - t_2) + (1-\beta)(a_1 - a_2)$.

Then, we solve the model by backward induction. We know that the second order derivative of π_r^{NO} with respect to p_2^{NO} is $-2\beta/(1-\beta) < 0$ and π_r^{NO} is concave on p_2^{NO}. It can be obtained from $(\partial \pi_r^{NO}/p_2^{NO}) = 0$ that $p_2^{NO} = ((1-\beta)(a_1 - a_2) + \eta(t_1 - t_2) + p_1 + w + 1/2)$. Substituting p_2^{NO} into π_m^{NO}, we know that the Hessian matrix of π_m^{NO} in terms of w^{NO} and p_1^{NO} is $H = \begin{bmatrix} -\beta/1-\theta & \beta/1-\theta \\ \beta/1-\theta & -\beta/1-\theta-1/\theta \end{bmatrix}$, easy to get $|H| = (2\beta^2/\theta(1-\theta)) > 0$. Hence, π_m^{NO} is strictly concave with respect to w^{NO} and p_1^{NO}. From $(\partial \pi_m^{NO}(w^{NO}, p_1^{NO})/\partial w^{NO}) = 0$ and $\partial \pi_m^{NO}(w^{NO}, p_1^{NO})/\partial p_1^{NO} = 0$, then we get $w^{NO*} = (1 - \eta t_2 - a_2(1-\beta)/2)$ and $p_1^{NO*} = (\theta - \eta t_1 - a_1(1-\beta)/2)$. Substituting w^{NO*} and p_1^{NO*} into p_2^{NO}, we get $p_2^{NO*} = (3 - \theta - (1-\beta)(3a_2 - a_1) - \eta(3t_2 - t_1)/4)$.

The proof of Theorem 2–4 is similar to Theorem 1, so we omit it.

B. Proof of Proposition 1

Finding the first-order partial derivatives of optimal decision variables and D_i^{NO*} in model NO, with respect to θ, η, and β, respectively, we can get the following:

(1) $(\partial w^{NO*}/\partial\theta) = 0$, $(\partial p_1^{NO*}/\partial\theta) = (1/2) > 0$, $(\partial p_2^{NO*}/\partial\theta) = -(1/4) < 0$, $(\partial D_1^{NO*}/\partial\theta) = (2a_1(1-\beta)(1-2\theta) + \theta^2(a_1 + a_2)(1-\beta) + \theta^2\eta(t_1 + t_2) + 2\eta t_1(1-2\theta)/4\theta^2(1-\theta)^2) \geq (2a_1(1-\beta)(1-2\theta) + 2a_1\theta^2(1-\beta) + 2\theta^2\eta t_1 + 2\eta t_1(1-2\theta)/4\theta^2(1-\theta)^2) = (2a_1(1-\beta)(1-\theta)^2 + 2\eta t_1(1-\theta)^2/4\theta^2(1-\theta)^2) > 0$, and $= -(\partial D_2^{NO*}/\partial\theta)((1-\beta)(a_2 - a_1) + \eta(t_2 - t_1)/4(1-\theta)^2) < 0$;

(2) $(\partial w^{NO*}/\partial\eta) = -(t_2/2) < 0$, $(\partial p_1^{NO*}/\partial\eta) = -(t_1/2) < 0$, $(\partial p_2^{NO*}/\partial\eta) = -(3t_2 - t_1/4) < 0$; $(\partial D_1^{NO*}/\partial\eta) = (\theta t_1 + \theta t_2 - 2t_1/4\theta(1-\theta))$. If $t_1 < (\theta t_2/2-\theta)$, then $(\partial D_1^{NO*}/\partial\eta) > 0$; $(\partial D_2^{NO*}/\partial\eta) = -(t_2 - t_1/4(1-\theta)) < 0$;

(3) $(\partial w^{NO*}/\partial\beta) = (a_2/2) > 0$, $(\partial p_1^{NO*}/\partial\beta) = (a_1/2) > 0$, $(\partial p_2^{NO*}/\partial\beta) = (3a_2 - a_1/4) > 0$; $(\partial D_1^{NO*}/\partial\beta) = (2a_1 - \theta a_1 - \theta a_2/4\theta(1-\theta))$. If $a_1 < (\theta a_2/2-\theta)$, then $(\partial D_1^{NO*}/\partial\beta) < 0$; $(\partial D_2^{NO*}/\partial\beta) = (a_2 - a_1/4(1-\theta)) > 0$.

C. Proof of Proposition 2

Finding the first-order partial derivatives of optimal decision variables and D_i^{NM*} in model NM, with respect to θ, η, and β, respectively, we can get the following equations.

(1) $(\partial w^{NM*}/\partial\theta) = 0$, $(\partial p_1^{NM*}/\partial\theta) = (1/2) > 0$, $(\partial p_2^{NM*}/\partial\theta) = -(1/4) < 0$, $(\partial D_1^{NM*}/\partial\theta) = (\eta(t_2 - t_1)/4(1-\theta)^2) + (\theta + \eta t_1 + a_1(1-\beta)/2\theta^2) > 0$, and $(\partial D_2^{NM*}/\partial\theta) = -(\eta(t_2 - t_1)/4(1-\theta)^2) < 0$;

(2) $(\partial w^{NM*}/\partial\eta) = -(t_2/2) < 0$, $(\partial p_1^{NM*}/\partial\eta) = -(t_1/2) < 0$, $(\partial p_2^{NM*}/\partial\eta) = -(3t_2 - t_1/4) < 0$; $(\partial D_1^{NM*}/\partial\eta) = (\theta t_1 + \theta t_2 - 2t_1/4\theta(1-\theta))$. If $t_1 < (\theta t_2/2-\theta)$,

then $(\partial D_1^{NM*}/\partial\eta) > 0$; $(\partial D_2^{NM*}/\partial\eta) = -(t_2 - t_1/4(1-\theta)) < 0$;

(3) $(\partial w^{NM*}/\partial\beta) = (a_1/2) > 0$, $(\partial p_1^{NM*}/\partial\beta) = (a_1/2) > 0$, $(\partial p_2^{NM*}/\partial\beta) = (a_1/2) > 0$, $(\partial D_1^{NM*}/\partial\beta) = (a_1/2\theta) > 0$, and $(\partial D_2^{NM*}/\partial\beta) = 0$.

D. Proof of Proposition 3

Finding the first-order partial derivatives of optimal decision variables and D_i^{NR*} in model NR, with respect to θ, η, and β, respectively, we can get the following:

(1) $(\partial w^{NR*}/\partial\theta) = 0$, $(\partial p_1^{NR*}/\partial\theta) = (1/2) > 0$, $(\partial p_2^{NR*}/\partial\theta) = -(1/4) < 0$, $(\partial D_1^{NR*}/\partial\theta) = (\eta(t_2 - t_1)/4(1-\theta)^2) + (\theta + \eta t_1 + a_2(1-\beta)/2\theta^2) > 0$, and $(\partial D_2^{NR*}/\partial\theta) = -(\eta(t_2 - t_1)/4(1-\theta)^2) < 0$;

(2) $(\partial w^{NR*}/\partial\eta) = -(t_2/2) < 0$, $(\partial p_1^{NR*}/\partial\eta) = -(t_1/2) < 0$, $(\partial p_2^{NR*}/\partial\eta) = -(3t_2 - t_1/4) < 0$; $(\partial D_1^{NR*}/\partial\eta) = (\theta t_1 + \theta t_2 - 2t_1/4\theta(1-\theta))$. If $t_1 < (\theta t_2/2 - \theta)$, then $(\partial D_1^{NR*}/\partial\eta) > 0$; $(\partial D_2^{NR*}/\partial\eta) = -(t_2 - t_1/4(1-\theta)) < 0$;

(3) $(\partial w^{NR*}/\partial\beta) = (a_2/2) > 0$, $(\partial p_1^{NR*}/\partial\beta) = (a_2/2) > 0$, $(\partial p_2^{NR*}/\partial\beta) = (a_2/2) > 0$, $(\partial D_1^{NR*}/\partial\beta) = (a_2/2\theta) > 0$, and $(\partial D_2^{NR*}/\partial\beta) = 0$.

E. Proof of Proposition 4

Comparing the optimal decision variables and demands in the three models NO, NM, and NR, we have the following:

(1) $w^{NO*} - w^{NM*} = -((1-\beta)(a_2 - a_1)/2) < 0$ and $w^{NO*} - w^{NR*} = 0$;

(2) $p_1^{NO*} - p_1^{NM*} = 0$, $p_1^{NO*} - p_1^{NR*} = ((1-\beta)(a_2 - a_1)/2) > 0$, $p_2^{NO*} - p_2^{NM*} = -(3(1-\beta)(a_2 - a_1)/4) < 0$, $p_2^{NO*} - p_2^{NR*} = -((1-\beta)(a_2 - a_1)/4) < 0$, and $p_2^{NM*} - p_2^{NR*} = ((1-\beta)(a_2 - a_1)/2) > 0$;

(3) $D_1^{NO*} - D_1^{NM*} = ((1-\beta)(a_2 - a_1)/4(1-\theta)) > 0$, $D_1^{NO*} - D_1^{NR*} = ((1-\beta)(a_2 - a_1)(2-\theta)/4\theta(1-\theta)) > 0$, $D_1^{NM*} - D_2^{NR*} = ((1-\beta)(a_2 - a_1)/2\theta) > 0$, $D_2^{NM*} - D_2^{NR*} = 0$, and $D_2^{NM*} - D_2^{NO*} = ((1-\beta)(a_2 - a_1)/4(1-\theta)) > 0$.

From the above, we have $w^{NM*} > w^{NO*} = w^{NR*}$, $p_1^{NO*} = p_1^{NM*} > p_1^{NR*}$, $p_2^{NM*} > p_2^{NR*} > p_2^{NO*}$, $D_1^{NO*} > D_1^{NM*} > D_1^{NR*}$, and $D_2^{NM*} = D_2^{NR*} > D_2^{NO*}$.

F. Proof of Proposition 5

Finding the first-order partial derivatives of optimal decision variables and D_i^{B*} in model B, with respect to θ, η, f, and F, respectively, we can get the following:

(1) $(\partial w^{B*}/\partial\theta) = 0$, $(\partial p_1^{B*}/\partial\theta) = (1/2) > 0$, $(\partial p_2^{B*}/\partial\theta) = -(1/4) < 0$, $(\partial D_2^{B*}/\partial\theta) = -(\eta(T_2 - T_1)/4(1-\theta)^2) < 0$, and $(\partial D_1^{B*}/\partial\theta) = (2\eta T_1(1-2\theta) + \eta\theta^2(T_1 + T_2)/4\theta^2(1-\theta)^2) \geq (2\eta T_1(1-2\theta) + 2\eta\theta^2 T_1/4\theta^2(1-\theta)^2) = (2\eta T_1(1-\theta)^2/4\theta^2(1-\theta)^2) > 0$;

(2) $(\partial w^{B*}/\partial\eta) = -(T_2/2) < 0$, $(\partial p_1^{B*}/\partial\eta) = -(T_1/2) < 0$, $(\partial p_2^{B*}/\partial\eta) = -(3T_2 - T_1/4) < 0$, $(\partial D_2^{B*}/\partial\eta) = -(T_2 - T_1/4(1-\theta)) < 0$; $(\partial D_1^{B*}/\partial\eta) = (\theta T_1 + \theta T_2 - 2T_1/4\theta(1-\theta))$. If $T_1 < (\theta T_2/2 - \theta)$, then $(\partial D_1^{B*}/\partial\eta) > 0$;

(3) $(\partial w^{B*}/\partial f) = -1$, $(\partial p_1^{B*}/\partial f) = 0$, $(\partial p_2^{B*}/\partial f) = 0$, $(\partial D_1^{B*}/\partial f) = 0$, $(\partial D_2^{B*}/\partial f) = 0$, and $(\partial \pi_m^{B*}/\partial f) = 0$, $(\partial \pi_r^{B*}/\partial f) = 0$;

(4) $(\partial w^{B*}/\partial F) = 0$, $(\partial p_1^{B*}/\partial F) = 0$, $(\partial p_2^{B*}/\partial F) = 0$, $(\partial D_1^{B*}/\partial F) = 0$, $(\partial D_2^{B*}/\partial F) = 0$, $(\partial \pi_m^{B*}/\partial F) = -1 < 0$, and $(\partial \pi_r^{B*}/\partial F) = 0$.

G. Proof of Proposition 6

Comparing the optimal decision variables and demands when not adopting and when adopting blockchain, we have the following:

(1) Denoting $\eta_2 = (2f - a_1(1-\beta)/t_2 - T_2)$ and $\eta_1 = (2f - a_2(1-\beta)/t_2 - T_2)$, from the assumptions $a_2 > a_1$ and $t_2 > T_2$, it is easy to get $\eta_2 > \eta_1$. $w^{B*} - w^{NM*} = (a_1(1-\beta) + \eta(t_2 - T_2)/2) - f$; if $\eta > \eta_2$, then $w^{B*} > w^{NM*}$; $w^{B*} - w^{NR*} = (a_2(1-\beta) + \eta(t_2 - T_2)/2) - f$, if $\eta > \eta_1$, then $w^{B*} > w^{NR*}$; $w^{B*} - w^{NO*} = (a_2(1-\beta) + \eta(t_2 - T_2)/2) - f$, if $\eta > \eta_1$, then $w^{B*} > w^{NO*}$. Since $\eta_2 > \eta_1$, when $\eta > \eta_2$, we obtain $w^{B*} > w^{NM*} > w^{NR*} = w^{NO*}$; when $\eta_1 < \eta < \eta_2$, we obtain $w^{NM*} > w^{B*} > w^{NR*} = w^{NO*}$; when $\eta < \eta_1$, we obtain $w^{NM*} > w^{NR*} = w^{NO*} > w^{B*}$.

(2) Denoting $\eta_3 = (2a_1(1-\beta)/3T_2 + t_1 - T_1 - 3t_2)$, $\eta_4 = (2a_2(1-\beta)/3T_2 + t_1 - T_1 - 3t_2)$, and from the assumptions $a_2 > a_1$, $t_i > T_i$, and $t(T)_2 > t(T)_1$, if $t_1 - T_1 > 3(t_2 - T_2)$, then we obtain $\eta_5 > \eta_4 > \eta_3$. $p_1^{B*} - p_1^{NO*} = (a_1(1-\beta) + \eta(t_1 - T_1)/2) > 0$. $p_2^{B*} - p_2^{NM*} = (2a_1(1-\beta) + \eta(T_1 - t_1 + 3t_2 - 3T_2)/4)$, $p_2^{B*} - p_2^{NR*} = (2a_2(1-\beta) + \eta(T_1 - t_1 + 3t_2 - 3T_2)/4)$, $p_2^{B*} - p_2^{NO*} = ((3a_2 - a_1)(1-\beta) + \eta(T_1 - t_1 + 3t_2 - 3T_2)/4)$. If $t_1 - T_1 < 3(t_2 - T_2)$, then $p_2^{B*} > p_2^{NM*} > p_2^{NR*} > p_2^{NO*}$. Since $\eta_5 > \eta_4 > \eta_3$, if $t_1 - T_1 > 3(t_2 - T_2)$ and $\eta < \eta_3$, then $p_2^{B*} > p_2^{NM*} > p_2^{NR*} > p_2^{NO*}$; if $t_1 - T_1 > 3(t_2 - T_2)$ and $\eta_3 < \eta < \eta_4$, then $p_2^{NM*} > p_2^{B*} > p_2^{NR*} > p_2^{NO*}$; if $t_1 - T_1 > 3(t_2 - T_2)$ and $\eta_4 < \eta < \eta_5$, then $p_2^{NM*} > p_2^{NR*} > p_2^{B*} > p_2^{NO*}$; if $t_1 - T_1 > 3(t_2 - T_2)$ and $\eta > \eta_5$, then $p_2^{NM*} > p_2^{NR*} > p_2^{NO*} > p_2^{B*}$.

(3) Denoting $\eta_6 = (2a_1(1-\beta) - \theta(a_1 + a_2)(1-\beta)/\theta(t_2 - T_2) - (2-\theta)(t_1 - T_1))$, $\eta_7 = (2a_1(1-\beta)(1-\theta)/\theta(t_2 - T_2) - (2-\theta)(t_1 - T_1))$, and $\eta_8 = (2a_2(1-\beta)(1-\theta)/\theta(t_2 - T_2) - (2-\theta)(t_1 - T_1))$, if $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$, then $\eta_8 - \eta_7 = (2(a_2 - a_1)(1-\beta)(1-\theta)/\theta(t_2 - T_2) - (2-\theta)(t_1 - T_1)) > 0$, $\eta_8 - \eta_6 = -(2(a_2 - a_1)(1-\beta)(2-\theta)/\theta(t_2 - T_2) - (2-\theta)(t_1 - T_1)) > 0$ and $\eta_7 - \eta_6 = -(2\theta(a_2 - a_1)(1-\beta)/\theta(t_2 - T_2) - (2-\theta)(t_1 - T_1)) > 0$, we obtain $\eta_8 > \eta_7 > \eta_6$. $D_1^{B*} - D_1^{NO*} = (2a_1(1-\beta) - \theta(1-\beta)(a_1 + a_2) + \eta(2t_1 - \theta t_1 - \theta t_2 + \theta T_1 + \theta T_2 - 2T_1)/4\theta(1-\theta))$,

$D_1^{B*} - D_1^{NM*} = (2a_1(1-\beta)(1-\theta) + \eta(2t_1 - \theta t_1 - \theta t_2 + \theta T_1 + \theta T_2 - 2T_1)/4\theta(1-\theta))$, $D_1^{B*} - D_1^{NR*} = (2a_2(1-\beta)(1-\theta) + \eta(2t_1 - \theta t_1 - \theta t_2 + \theta T_1 + \theta T_2 - 2T_1)/4\theta(1-\theta))$. If $t_1 - T_1 > (\theta(t_2 - T_2)/2 - \theta)$ and $\eta > \eta_6$, then $D_1^{B*} > D_1^{NO*} > D_1^{NM*} > D_1^{NR*}$; if $t_1 - T_1 > (\theta(t_2 - T_2)/2 - \theta)$ and $\eta < \eta_6$, then $D_1^{NO*} > D_1^{B*} > D_1^{NM*} > D_1^{NR*}$. Since $\eta_8 > \eta_7 > \eta_6$, if $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$ and $\eta < \eta_6$, then $D_1^{B*} > D_1^{NO*} > D_1^{NM*} > D_1^{NR*}$, if $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$ and $\eta_6 < \eta < \eta_7$, then $D_1^{NO*} > D_1^{B*} > D_1^{NM*} > D_1^{NR*}$, if $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$ and $\eta_7 < \eta < \eta_8$, then $D_1^{NO*} > D_1^{NM*} > D_1^{B*} > D_1^{NR*}$, and if $t_1 - T_1 < (\theta(t_2 - T_2)/2 - \theta)$ and $\eta > \eta_8$, then $D_1^{NO*} > D_1^{NM*} > D_1^{NR*} > D_1^{B*}$. Denoting $\eta_9 = ((1-\beta)(a_2 - a_1)/t_1 - T_1 - t_2 + T_2)$. $D_2^{B*} - D_2^{NO*} = ((1-\beta)(a_2 - a_1) + \eta(T_1 - T_2 + t_2 - t_1)/4(1-\theta))$, $D_2^{B*} - D_2^{NM*} = D_2^{B*} - D_2^{NR*} = (\eta(T_1 - T_2 + t_2 - t_1)/4(1-\theta))$. If $t_2 - T_2 > t_1 - T_1$, then $D_2^{B*} > D_2^{NM*} = D_2^{NR*} > D_2^{NO*}$. If $t_2 - T_2 < t_1 - T_1$ and $\eta < \eta_9$, then $D_2^{NM*} = D_2^{NR*} > D_2^{B*} > D_2^{NO*}$; if $t_2 - T_2 < t_1 - T_1$ and $\eta > \eta_9$, then $D_2^{NM*} = D_2^{NR*} > D_2^{NO*} > D_2^{B*}$.

Data Availability

The data used to support the findings of this study are included within the paper and available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was supported by Anhui Planning Office of Philosophy and Social Science (Grant no. AHSKQ2020D49).

References

[1] CNNIC, "The 49th statistical report on China's Internet development," 2022, https://www.cnnic.net.cn/NMediaFile/old_attach/P020220721404263787858.pdf.

[2] L. Manning and J. Monaghan, "Integrity in the fresh produce supply chain: solutions and approaches to an emerging issue," *The Journal of Horticultural Science and Biotechnology*, vol. 94, no. 4, pp. 413–421, 2019.

[3] K. Giannakas, "Information asymmetries and consumption decisions in organic food product markets," *Canadian Journal of Agricultural Economics/Revue canadienne d' agroeconomie*, vol. 50, no. 1, pp. 35–50, 2002.

[4] S. Appelhanz, V. S. Osburg, W. Toporowski, and M. Schumann, "Traceability system for capturing, processing and providing consumer-relevant information about wood products: system solution and its economic feasibility," *Journal of Cleaner Production*, vol. 110, no. 1, pp. 132–148, 2016.

[5] P. K. Patro, R. Jayaraman, K. Salah, and I. Yaqoob, "Blockchain-based traceability for the fishery supply chain," *IEEE Access*, vol. 10, pp. 81134–81154, 2022.

[6] F. Tian, "An agri-food supply chain traceability system for China based on RFID & blockchain technology," in *Proceedings of the 2016 13th international conference on service systems and service management (ICSSSM)*, pp. 1–6, IEEE, Kunming, China, June 2016.

[7] A. G. Gad, D. T. Mosa, L. Abualigah, and A. A. Abohany, "Emerging trends in blockchain technology and applications: a review and outlook," *Journal of King Saud University-Computer and Information Sciences*, vol. 34, no. 9, pp. 6719–6742, 2022.

[8] M. Hader, D. Tchoffa, A. E. Mhamedi, P. Ghodous, A. Dolgui, and A. Abouabdellah, "Applying integrated Blockchain and Big Data technologies to improve supply chain traceability and information sharing in the textile sector," *Journal of Industrial Information Integration*, vol. 28, Article ID 100345, 2022.

[9] A. Stroumpoulis and E. Kopanaki, "Theoretical perspectives on sustainable supply chain management and digital transformation: a literature review and a conceptual framework," *Sustainability*, vol. 14, no. 8, Article ID 4862, 2022.

[10] A. Iftekhar and X. Cui, "Blockchain-based traceability system that ensures food safety measures to protect consumer safety and COVID-19 free supply chains," *Foods*, vol. 10, no. 6, p. 1289, 2021.

[11] M. K. Lim, Y. Li, C. Wang, and M. L. Tseng, "A literature review of blockchain technology applications in supply chains: a comprehensive analysis of themes, methodologies and industries," *Computers & Industrial Engineering*, vol. 154, Article ID 107133, 2021.

[12] M. Kouhizadeh, S. Saberi, and J. Sarkis, "Blockchain technology and the sustainable supply chain: theoretically exploring adoption barriers," *International Journal of Production Economics*, vol. 231, Article ID 107831, 2021.

[13] Y. Cao, C. Yi, G. Wan, H. Hu, Q. Li, and S. Wang, "An analysis on the role of blockchain-based platforms in agricultural supply chains," *Transportation Research Part E: Logistics and Transportation Review*, vol. 163, Article ID 102731, 2022.

[14] X. Y. Wu, Z. P. Fan, and B. B. Cao, "An analysis of strategies for adopting blockchain technology in the fresh product supply chain," *International Journal of Production Research*, vol. 61, no. 11, pp. 3717–3734, 2023.

[15] T. Ye, J. Yuan, S. H. A. Raza et al., "Evolutionary analysis of buffalo sterol regulatory element-binding factor (SREBF) family genes and their affection on milk traits," *Animal Biotechnology*, vol. 2, pp. 1–12, 2022.

[16] S. Liu, G. Hua, Y. Kang, T. Edwin Cheng, and Y. Xu, "What value does blockchain bring to the imported fresh food supply chain," *Transportation Research Part E: Logistics and Transportation Review*, vol. 165, Article ID 102859, 2022.

[17] K. Behnke and M. Janssen, "Boundary conditions for traceability in food supply chains using blockchain technology," *International Journal of Information Management*, vol. 52, Article ID 101969, 2020.

[18] X. Liu, Z. Zhou, F. Zhong, and J. Shi, "Improving supply chain transparency with blockchain technology when considering product returns," *International Transactions in Operational Research*, vol. 8, 2023.

[19] Z. Liu, X. Cai, W. Niu, and L. Zhang, "Combating fraudulent returns using blockchain technology," *International Transactions in Operational Research*, vol. 10, 2023.

[20] G. Ji, S. Zhou, K. H. Lai, K. H. Tan, and A. Kumar, "Timing of blockchain adoption in a supply chain with competing manufacturers," *International Journal of Production Economics*, vol. 247, Article ID 108430, 2022.

[21] T. M. Choi, "Supply chain financing using blockchain: impacts on supply chains selling fashionable products," *Annals of Operations Research*, vol. 7, 2020.
[22] T. M. Choi and S. Luo, "Data quality challenges for sustainable fashion supply chain operations in emerging markets: roles of blockchain, government sponsors and environment taxes," *Transportation Research Part E: Logistics and Transportation Review*, vol. 131, pp. 139–152, 2019.
[23] X. Xu, L. Yan, T. M. Choi, and T. C. E. Cheng, "When is it wise to use blockchain for platform operations with remanufacturing?" *European Journal of Operational Research*, vol. 309, no. 3, pp. 1073–1090, 2023.
[24] J. Liu, H. Zhang, and L. Zhen, "Blockchain technology in maritime supply chains: applications, architecture and challenges," *International Journal of Production Research*, vol. 61, no. 11, pp. 3547–3563, 2023.
[25] G. Mirabelli and V. Solina, "Blockchain-based solutions for agri-food supply chains: a survey," *International Journal of Simulation and Process Modelling*, vol. 17, no. 1, pp. 1–15, 2021.
[26] K. Li, J. Y. Lee, and A. Gharehgozli, "Blockchain in food supply chains: a literature review and synthesis analysis of platforms, benefits and challenges," *International Journal of Production Research*, vol. 61, no. 11, pp. 3527–3546, 2023.
[27] S. Rao, E. Rabinovich, and D. Raju, "The role of physical distribution services as determinants of product returns in Internet retailing," *Journal of Operations Management*, vol. 32, no. 6, pp. 295–312, 2014.
[28] F. Yang, P. Hu, F. Zhao, and C. Hu, "Customer returns model in a dual-channel supply chain," *Journal of Modelling in Management*, vol. 10, no. 3, pp. 360–379, 2015.
[29] J. Liu, X. Zhang, J. Chen, and S. Liu, "Research on return modes and pricing for omni channel retailers," *Chinese Journal of Management Science*, vol. 30, pp. 252–263, 2022.
[30] W. Ma, C. Zhao, H. Ke, and Z. Chen, "Retailer's return policy in the presence of P2P secondary market," *Electronic Commerce Research and Applications*, vol. 39, Article ID 100899, 2020.
[31] J. Wang and S. He, "Optimal decisions of modularity, prices and return policy in a dual-channel supply chain under mass customization," *Transportation Research Part E: Logistics and Transportation Review*, vol. 160, Article ID 102675, 2022.
[32] S. K. Jena and P. Meena, "Shopping in the omnichannel supply chain under price competition and product return," *Journal of Retailing and Consumer Services*, vol. 65, Article ID 102848, 2022.
[33] M. Huang and D. Jin, "Impact of buy-online-and-return-in-store service on omnichannel retailing: a supply chain competitive perspective," *Electronic Commerce Research and Applications*, vol. 41, Article ID 100977, 2020.
[34] K. Cao and T. M. Choi, "Optimal trade-in return policies: is it wise to be generous?" *Production and Operations Management*, vol. 31, no. 3, pp. 1309–1331, 2022.
[35] X. Liang and J. Xiao, "Blockchain-based dual-channel supply chain pricing decision and online channel selection strategy," *Chinese Journal of Management Science*, vol. 31, pp. 29–38, 2023.
[36] X. Xu and T. M. Choi, "Supply chain operations with online platforms under the cap-and-trade regulation: impacts of using blockchain technology," *Transportation Research Part E: Logistics and Transportation Review*, vol. 155, Article ID 102491, 2021.
[37] W. Y. K. Chiang, D. Chhajed, and J. D. Hess, "Direct marketing, indirect profits: a strategic analysis of dual-channel supply-chain design," *Management Science*, vol. 49, no. 1, pp. 1–20, 2003.
[38] H. Gong, M. Zhao, J. Ren, and Z. Hao, "Live streaming strategy under multi-channel sales of the online retailer," *Electronic Commerce Research and Applications*, vol. 55, Article ID 101184, 2022.
[39] T. M. Choi, "Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains," *Transportation Research Part E: Logistics and Transportation Review*, vol. 128, pp. 17–29, 2019.
[40] C. Tan, R. Liu, and C. Zhao, "Pricing strategy of vaccine supply chain based on blockchain technology," *Journal of Industrial Engineering and Engineering Management*, vol. 36, no. 6, pp. 205–220, 2022.
[41] T. Zhang, Z. Tang, and Z. Han, "Optimal online channel structure for multinational firms considering live streaming shopping," *Electronic Commerce Research and Applications*, vol. 56, Article ID 101198, 2022.
[42] Y. Feng, J. Zhang, L. Feng, and G. Zhu, "Benefit from a high store visiting cost in an omnichannel with BOPS," *Transportation Research Part E: Logistics and Transportation Review*, vol. 166, Article ID 102904, 2022.
[43] L. Jin and M. Guo, "The impact of differentiated brands competing manufacture's encroachment under different supply chain power structures," *Chinese Journal of Management*, vol. 15, pp. 135–143, 2018.
[44] C. Y. Liu, H. Wang, J. Tang, C. T. Chang, and Z. Liu, "Optimal recovery model in a used batteries closed-loop supply chain considering uncertain residual capacity," *Transportation Research Part E: Logistics and Transportation Review*, vol. 156, Article ID 102516, 2021.
[45] D. Di Francesco Maesa and P. Mori, "Blockchain 3.0 applications survey," *Journal of Parallel and Distributed Computing*, vol. 138, pp. 99–114, 2020.