mathematics

MDPI

Article

Self-Built or Third-Party Blockchain Traceability Strategy in a Dual-Channel Supply Chain Considering Consumers' Traceability Awareness

Yuling Sun *, Xiaomei Song, Xiang Fang and Jian Guo

College of Economics and Management, Nanjing Tech University, Nanjing 211816, China; 202161113019@njtech.edu.cn (X.S.); 201961213038@njtech.edu.cn (X.F.); 202161113008@njtech.edu.cn (J.G.)
* Correspondence: syl_nj@njtech.edu.cn

Abstract: Blockchain is widely used in the manufacturing industry. This paper establishes a dual-channel supply chain composed of a manufacturer and an e-retailer. A monopoly manufacturer conducts indirect online selling through retailers as well as direct offline selling. The manufacturer chooses to adopt a self-built blockchain traceability system (SBT) or a third-party blockchain traceability system (TBT). Game analysis is developed to depict the pricing decision for the manufacturer and e-retailer. The optimal pricing decisions of the supply chain between manufacturer and e-retailer for different blockchain traceability strategies are obtained. We explore the influence of consumers' traceability awareness on the decisions of dual-channel supply chain members when adopting different blockchain traceability strategies. The main results show that when the fee paid to the blockchain service provider is low, the manufacturer will prefer to adopt TBT. Moreover, we prove that consumers' traceability awareness, the cost of adopting TBT, the blockchain traceability technology level, and the research and development cost factor of blockchain technology could affect the decisions of supply chain members. Finally, some management suggestions are provided.

Keywords: dual-channel supply chain; blockchain technology; consumers' traceability awareness

MSC: 90B06

Citation: Sun, Y.; Song, X.; Fang, X.; Guo, J. Self-Built or Third-Party Blockchain Traceability Strategy in a Dual-Channel Supply Chain Considering Consumers' Traceability Awareness. *Mathematics* **2023**, *11*, 4312. https://doi.org/10.3390/math11204312

Academic Editor: Yong He

Received: 24 July 2023
Revised: 12 October 2023
Accepted: 12 October 2023
Published: 16 October 2023

1. Introduction

With the rapid development of Internet technology, it is popular for consumers to purchase products via online channels. In particular, the continued outbreak of COVID-19 since 2020 has pushed more and more consumers to shop online. According to the Statistical Report on the Development Status of the Internet in China, by the end of December 2022, the number of China's netizens had reached 1.067 billion, and the Internet penetration rate reached 75.6% [1]. In 2022, China's e-commerce transactions reached CNY 4382.99 billion, an increase of 3.5% compared to 2021. According to the first-quarter financial statements released by Walmart in 2023, net e-commerce sales in the United States (Walmart) grew by 54%. More and more brand manufacturers are selling products via e-commerce platforms. At the same time, brand manufactures sell products offline via direct-sale stores. For example, the manufacturers LVMH, Nike, and Mengniu sell products in direct-sale stores and on Amazon, JD chaoshi, or Tmall chaoshi at the same time.

However, products sold on e-commerce platforms can be inauthentic because consumers cannot distinguish inauthentic from authentic products before purchasing them online. Even when products sold on e-commerce platforms are officially certified by the brand manufacturers, consumers still have doubts about their authenticity [2]. The authenticity of products sold on e-commerce platforms by brand manufacturers such as Apple, Gucci, and Kering can be difficult to determine. According to reports, nearly 90 percent of Apple product chargers sold on Amazon's U.S. website are fake. Brand manufacturers such as Kering and Gucci have sued a major Chinese online platform over fakes [3]. Online deceptive counterfeits have destroyed consumers' trust in brand manufacturers and e-commerce platforms.

Blockchain technology has been seen as one of the most promising technologies in providing information transparency and traceability [4]. Blockchain technology can effectively guarantee the reliability, authenticity, security, and timely feedback of transaction data, and can be used for the anti-counterfeit traceability of products [5]. It also helps all authorized businesses access information on the blockchain [6], allowing consumers to grasp information relating to product production and distribution. In reality, some manufacturers prefer third-party blockchain traceability systems to carry out product traceability. Alibaba provides blockchain traceability of products' originality for fashion brands [7]. JD provides a blockchain traceability service for brand companies such as Wuliangye, SK-II, and Yili based on an anti-counterfeiting blockchain traceability system. Amazon provides blockchain traceability for Nestlé's new coffee brand, Chain of Origin, to display information on where the coffee beans are grown, roasted, made, etc. Analogously, the products sold on anmo-malls such as Frog Prince and Runben are traced through third-party blockchain traceability. By scanning the QR code of product traceability, consumers can obtain information on the origin, batch, logistics, and distributors of products based on blockchain authentication.

Other manufacturers prefer to develop blockchain traceability systems to carry out product traceability. For example, Nike developed NFC + blockchain to carry out product traceability. By scanning NFC chips on the commodities, consumers can see the style, shipping warehouse, and shipping time of the commodities through blockchain authentication, which greatly improves the consumers' experience and protects their rights and interests. NFC+blockchain has been applied to nearly 130,000 pairs of Nike's 17 popular shoe models. De Beers established Tracr™ to track the journey of diamonds throughout the value chain, ensuring consumer trust in the origin of De Beers diamonds. Dalian Xinyulong also developed a blockchain traceability system for sea cucumbers. Consumers can trace detailed information on sea cucumbers regarding their breeding, release, fishing, processing, finished products, and other links.

Enterprises using the blockchain traceability services of third-party blockchain traceability systems may display limited traceability information because the traceability level is fixed and constrained by the third-party blockchain traceability platform. A self-built blockchain system could choose a more suitable traceability level and provide more comprehensive traceability information. This is helpful for attracting more customers. However, it requires significant research and development costs. It is an interesting question whether dual-channel manufacturers and e-retailers should adopt self-built or third-party blockchain traceability systems. The cost of self-built blockchain traceability systems is higher than that of third-party blockchain traceability systems, but the blockchain traceability level may be lower than that of the third party.

Some studies have shown that consumers have traceability awareness. Wu et al. [8] and Fan et al. [9] proved that consumer traceability awareness could affect the adoption of blockchain technology in the supply chain. However, the overall impact of consumers' traceability awareness for blockchain traceability strategies on the dual-channel supply chain is unclear.

Considering consumers' traceability awareness in a dual-channel supply chain, we will focus on the following research questions:

(1) What are the equilibrium decisions when adopting a third-party blockchain traceability system (TBT) and a self-built blockchain traceability system (SBT)?
(2) How do different blockchain scenarios in a dual-channel supply chain affect supply chain members' optimal decisions?
(3) Which kind of blockchain scenarios are beneficial for the e-retailer and the manufacturer?
(4) What is the impact of consumers' traceability awareness on supply chain members' decisions when adopting different blockchain traceability strategies?

To answer these questions, we develop a game model to describe a dual-channel supply chain. We consider a setting in which a brand manufacturer sells the same product through two channels: a direct offline channel and an online retail channel. In this setting, the brand manufacturer can adopt a self-built blockchain system or third-party blockchain system. We first simulate the equilibrium strategies of the two participants in two scenarios: (1) with an SBT and (2) with a TBT. Meanwhile, the effects of several parameters on optimal strategies are identified through sensitivity analysis. Finally, we obtain conditions under which the brand manufacturer should adopt an SBT by analyzing the impacts of consumers' traceability awareness on the optimal strategy and profit of both parties.

Our research shows that SBT does not always benefit the manufacturer and e-retailer using a dual-channel supply chain considering consumers' traceability awareness. When making the decision between SBT and TBT, a manufacturer should focus on the impact of consumers' traceability awareness on their traceability strategy. We find that a selection of blockchain technologies in an online indirect sales channel and an offline direct sales channel is associated with blockchain research and development cost, consumers' traceability awareness, consumers' channel preference, and the blockchain traceability level. These findings will provide useful managerial implications for dual-channel supply chains adopting the blockchain traceability strategy.

This paper is divided into the following five parts: the first part is the introduction, which introduces the research background and problems; the second part is the literature review, which summarizes the status of related research and presents the innovative points of this paper; the third part is the model construction, which puts forward the hypothesis of this paper and constructs a dual-channel supply chain model adopting a TBT and an SBT; the fourth part is the simulation analysis, which explores the influence of consumers' traceability awareness on dual-channel supply chain decisions; and the fifth part is the conclusion, which summarizes the main findings of this paper and puts forward corresponding management options.

2. Literature Review

We explore the impact of different blockchain traceability strategies on dual-channel supply chain decisions considering consumers' traceability awareness. The research is related to two steams of studies: the application of blockchain technology in the supply chain and dual-channel supply chain management.

For the application of blockchain technology in the supply chain, some of the literature has analyzed the application conditions and setting of blockchain on the supply chain via qualitative analysis or empirical analysis. Based on bibliometrics and network analysis methods, Moosavi et al. [10] pointed out that blockchain can improve the transparency, traceability, efficiency, and information security of supply chain management. Wang and Yang [11] proved that trust-building and supply chain flexibility in the supply chain can be affected by the information transparency and security of blockchain technology. Maher and Ashish [12] found that the most prominent drivers affecting blockchain adoption in the supply chain are the comparative advantages and external pressures of blockchain technology. Some scholars focus on the impacts of blockchain technology adoption and capture it with mathematical models. Niu et al. [13] analyzed the conditions for multinational companies to adopt blockchain technology. Pun et al. [14] studied the role of blockchain technology on optimal decisions and analyzed the conditions necessary to adopt blockchain technology in combating counterfeit products. Choi (2019) [15] analyzed the role of blockchain technology platforms in diamond certification. Dong et al. [16] studied the impacts of blockchain technology on the decisions of food supply chain members. Wu et al. [17] pointed out that the allocation ratio of blockchain traceability costs could affect blockchain technology adoption strategies in the fresh product supply chain. Wang et al. [18] analyzed the impact of blockchain technology in the port supply chain, considering blockchain technology costs. Orji et al. [19] found that technical factors, government policies, and the availability of specific blockchain tools affect blockchain application based on ANP modeling in the freight logistics industry. Choi and Ouyang [20] found that using a blockchain-based product-sourcing certification platform is beneficial for both firms and consumers, and that fixed service costs and fixed setup costs could affect a blockchain-based product-sourcing certification platform. Fan et al. [9] proved that the consumer awareness of traceability and blockchain costs affects the introduction of blockchain technology by supply chain members. There are also several studies focusing on the application of blockchain technology in government regulation and food traceability [21,22]. Our study expands this literature stream by analyzing the impacts of consumers' traceability awareness in SBT and TBT. We find that manufacturers will adopt SBT when consumers' traceability awareness is high enough.

Research on dual-channel supply chain management is popular. Some of the literature has focused on solutions to channel conflicts [23–25] or operational decisions in dual-channel supply chains [26,27]. Some studies have explored the impact of a dual-channel strategy [28–30]. Some scholars have explored the impact of channel price sensitivity, consumer loss aversion behavior, and government subsidies on supply chain decision making based on dual channels. For example, Pal and Sarkar [31] proved that channel price sensitivity could affect the profit of dual-channel supply chain members. Based on the reverse supply chain perspective, Xu et al. [32] analyzed the impact of consumer loss aversion behavior on the recycling pricing and profit of each node in the supply chain. Abhijit et al. [33] showed that government subsidies are beneficial for the suppliers and manufacturers of a three-layer green supply chain model with a dual-channel structure, and they can reduce the cost of green products. Song et al. [34] studied the impact of manufacturer fairness concerns on dual-channel supply chain members' decisions under government subsidies and showed that when manufacturers focus on equity, product greenness increases with government subsidies. Other scholars have also explored the issue of channel selection. Xiao et al. [35] proved that unit production cost, the marginal cost of product variety, and customer adaptation cost affect a manufacturer's choice of whether to adopt dual channels. Wang et al. [36] explored the opportunity for manufacturers to choose between a physical plus a direct electronic channel and a physical plus a consignment electronic channel. Differently from the above works, this paper investigates the impact of consumers' traceability awareness on the supply chain members' choice of dual channels between self-built blockchain traceability and third-party blockchain traceability. We find that consumers' traceability awareness has an impact on the decisions of members of a dual-channel supply chain.

In recent years, some scholars have analyzed dual-channel supply chains based on blockchain technology. Some scholars have explored the impact of factors such as production cost, premium effect, labeling cost, operating costs of blockchain, direct sales costs, and demand fluctuations on the adoption of blockchain technology [6,37]. Some scholars have explored the impact of blockchain technology on decisions in dual-channel supply chains. Xu et al. [38] discussed that blockchain technology can help products become greener and more profitable for manufacturers and platforms. Zhang et al. [39] found that applying blockchain technology is beneficial for manufacture and retailers of dual-channel supply chains. The longer a product is traceable, the lower the price of the online traceable product will be. Zhu et al. [40] studied a dual-channel supply chain dominated by brand manufacturers and showed that the adoption of blockchain technology is always beneficial for retailers; however, the adoption of blockchain technology is not always beneficial for brand owners. Only when the total market's potential improvement effect is sufficiently large is the brand owner willing to adopt blockchain technology. Other scholars have explored the interaction between blockchain technology adoption and channel selection. Li and Li [41] found that the online direct sales plus consignment sales approach is more suitable for manufacturers who introduce blockchain technology. Li et al. [42] found that genuine companies take the initiative to degenerate the established dual-channel sales model into a single-channel sales model due to the adoption of blockchain technology. Wang et al. [43] found that when the cost of blockchain and the service level of traditional channels are low, adopting a blockchain platform can incentivize manufacturers to open their online channel. Differently from the previous studies, we focus on the selection of a blockchain technology and the impact of this selection on the decisions of dual-channel supply chain members. We find that the selection of a blockchain technology in an online indirect sales channel and an offline direct sales channel is associated with blockchain research and development cost, consumers' traceability awareness, consumers' channel preference, and blockchain traceability level.

Our paper is closely related to the following works that consider blockchain adoption. Fan et al. [9] focused on the impact of consumers' traceability awareness on the introduction strategy of blockchain technology in a single-channel supply chain. They found that supply chains adopted blockchain technology when consumers' traceability awareness and the cost-sharing ratio of blockchain technology met certain conditions. Zhang et al. [39] explored the impact of blockchain introduction on pricing decisions in online direct channels and offline indirect channels. They found that with the increase of traceability sensitivity coefficient, the sales price of traceability products decreases, and the retail price of offline standard products increases. Similar to this article, Zhang et al. [6] studied the impact of blockchain technology introduction on the decisions of dual-channel supply chain members in offline direct sales and online indirect sales. Additionally, they found that unit blockchain operating costs, direct sales costs, and demand fluctuations could affect supply chain members' adoption of blockchain strategies. Different from the above works, this study explores the impact of consumers' traceability awareness on blockchain traceability strategy choice in online indirect sales and offline direct sales. This study constructs a dual-channel supply chain model based on SBT and TBT, respectively, and identifies the conditions for adopting SBT and TBT for dual-channel supply chains. Then, we analyze the impact of consumers' traceability awareness on the decision of dual-channel supply chain members to adopt one of two blockchain traceability strategies. We find that when the fee paid to the blockchain service provider meets a certain condition, the manufacturer adopts TBT; however, when consumers' traceability awareness is less than a certain value and the blockchain traceability technology level of TBT is less than a certain value, the online price of the e-retailer adopting SBT is higher than that of the e-retailer adopting TBT and the offline price and the wholesale price of the manufacturer adopting SBT are higher than those of the manufacturer adopting TBT. Consumers' traceability awareness could affect the equilibrium decision of supply chain members; that is, the online price of the e-retailer and the offline price of the manufacturer and the wholesale price of the manufacturer increase with consumers' traceability awareness when adopting TBT and SBT.

3. Model Construction

3.1. Problem Description

We consider a dual-channel supply chain consisting of a manufacturer M and an e-retailer R. In the supply chain of the branded product, the brand manufacturer usually plays the role of the leader, while the e-retailer plays the role of the followers of the same status [40]. The manufacturer is the leader of the dual-channel supply chain. The manufacturer sells a homogeneous product through a direct offline channel and an indirect online channel. The manufacturer and e-retailer use blockchain technology to trace the information of the product, and the cost of adopting the blockchain technology can be shared among the supply chain members. The manufacturer determines the wholesale price of the e-retailer w and the direct sales price of the offline channel p_M. Then, the e-retailer decides the sale price of the online channel. As the supply chain adopts the blockchain technique, consumers can scan the two-dimensional code on the product's package to check the traceability information and further judge the quality of the product. The structure of the benchmark model is shown in Figure 1.

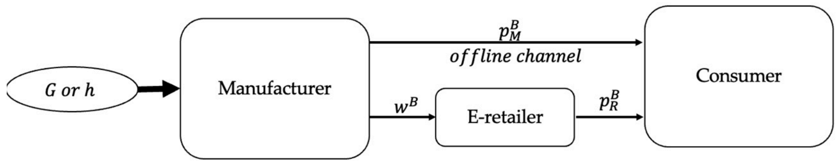

Figure 1. Decision-making process of dual-channel supply chain.

Table 1 shows all the notations in this paper.

Table 1. Parameter description.

Notation	Description
α	Potential market size, $\alpha > 0$.
c	Unit cost of producing the product, $0< c < \frac{\theta\alpha}{1-b}$.
θ	Consumer preference for purchasing products through online channels (Consumers' channel preference), $0 < \theta < 1$.
b	Price elasticity coefficient between channels, $0 < b < 1$.
β	Consumers' traceability awareness, $0 < \beta < 1$.
G	Fee paid by the manufacturer to a third-party blockchain service provider, $G > 0$.
g_1	Blockchain traceability technology level provided by a third-party blockchain technology enterprise, $g_1 > 0$.
f_1	The unit verification fee paid by the e-retailer to the manufacturer in the TBT scenario.
f_2	The unit verification fee paid by the e-retailer to the manufacturer in the SBT scenario.
k	Research and development cost factor of blockchain technology, $k > 0$.
p_{R1}^B	The online price of the e-retailer when adopting TBT.
p_{R2}^B	The online price of the e-retailer when adopting SBT.
p_{M1}^B	The offline price of the manufacturer when adopting TBT.
p_{M2}^B	The offline price of the manufacturer when adopting SBT.
${w_1}^B$	The wholesale price of the manufacturer when adopting TBT.
${w_2}^B$	The wholesale price of the manufacturer when adopting SBT.
g_2	Blockchain traceability technology level of self-built blockchain system, $g_2 > 0$.
D_{R1}^B	The demand of the e-retailer when adopting TBT.
D_{R2}^B	The demand of the e-retailer when adopting SBT.
D_{M1}^B	The demand of the manufacturer when adopting TBT.
D_{M2}^B	The demand of the manufacturer when adopting SBT.
π_{R1}^B	The profits of the e-retailer when adopting TBT.
π_{R2}^B	The profits of the e-retailer when adopting SBT.
π_{M1}^B	The profits of the manufacturer when adopting TBT.
π_{M2}^B	The profits of the manufacturer when adopting SBT.
π_{S1}^B	The total profits of the supply chain when adopting TBT.
π_{S2}^B	The total profits of the supply chain when adopting SBT.

3.2. Adopting TBT

In the TBT scenario, the manufacturer and e-retailer adopt a third-party blockchain traceability service provided by a third-party professional blockchain technology research and development institution. The manufacturer and the e-retailer have a Stackelberg game relationship because the manufacturer dominates. When the manufacturer chooses to adopt TBT, the e-retailer follows and adopts TBT. Firstly, the manufacturer pays a fixed fee for the TBT service and determines its wholesale price and offline direct sales price to maximize its own profit. Referring to Fan et al. [9], the manufacturer and e-retailer pay a certain fixed fee, G, in exchange for the blockchain traceability service. Subsequently, the e-retailer shares the fixed fee for TBT with the manufacturer and determines its optimal retail price based on the manufacturer's decision. Referring to Li et al. [41], the e-retailer pays the unit verification fee, f_1, to the manufacturer in the TBT scenario. Referring to the assumptions of Cao et al. [44], the demand for the product in the dual-channel supply chain is assumed to be a function of the relevant selling price and the traceability level.

The demand functions of the indirect online channel D_{M1}^{B} and the direct offline channel D_{R1}^{B} can be obtained as follows:

$$D_{R1}^{B} = \theta\alpha - p_{R1}^{B} + bp_{M1}^{B} + \beta g_1 \tag{1}$$

$$D_{M1}^{B} = (1-\theta)\alpha - p_{M1}^{B} + bp_{R1}^{B} + \beta g_1 \tag{2}$$

The profits of the manufacturer and the online e-retailer using a third-party blockchain traceability service are as follows:

$$\pi_{R1}^{B} = \left(p_{R1}^{B} - w_1{}^{B} - f_1\right)D_{R1}^{B} \tag{3}$$

$$\pi_{M1}^{B} = \left(w_1{}^{B} - c + f_1\right)D_{R1}^{B} + \left(p_{M1}^{B} - c\right)D_{M1}^{B} - G \tag{4}$$

The total profits of the supply chain can be obtained as follows:

$$\pi_{S1}^{B} = \left(p_{R1}^{B} - c\right)D_{R1}^{B} + \left(p_{M1}^{B} - c\right)D_{M1}^{B} - G \tag{5}$$

Lemma 1. *In the case of TBT, the optimal decisions for a manufacturer and e-retailer in a dual-channel supply chain are, respectively:*

$$p_{R1}^{B*} = \frac{(b+1)\left(b^2-1\right)c + (\theta\alpha+\beta g_1)\left(b^2-3\right) - ((1-\theta)2\alpha + 2\beta g_1)b}{4\left(b^2-1\right)} \tag{6}$$

$$p_{M1}^{B*} = \frac{\left(b^2-1\right)c - (\theta\alpha+\beta g_1)b - (1-\theta)\alpha - \beta g_1}{2\left(b^2-1\right)} \tag{7}$$

$$w_1^{B*} = \frac{\left(b^2-1\right)(c-2f_1) - ((1-\theta)\alpha+\beta g_1)b - \beta g_1 - \theta\alpha}{2\left(b^2-1\right)} \tag{8}$$

Proof. See Appendix A. □

Substituting (6)–(8) into the profit functions of the e-retailer and the manufacturer, the optimal profits for the manufacturer and e-retailer and the total profits of the supply chain at this time can be found, respectively:

$$\pi_{R1}^{B*} = \frac{((b-1)c + \theta\alpha + \beta g_1)^2}{16}$$

$$\begin{aligned}\pi_{M1}^{B*} = \tfrac{1}{8\left(b^2-1\right)} \quad & \left(-b^4c^2 - 2c(\theta\alpha+\beta g_1+c)b^3\right.\\ & +\left(-\alpha^2\theta^2 + (2c(\theta-2) - 2\theta\beta g_1)\alpha + 4c^2 - 6cg_1\beta - \beta^2 g_1{}^2\right)b^2\\ & +\left(4\theta(\theta-1)\alpha^2 + (-4\beta g_1 + 2\theta c)\alpha - 4g_1{}^2\beta^2 + 2c\beta g_1 + 2c^2\right)b\\ & \left.+\left(4\theta - 3\theta^2 - 2\right)\alpha^2 - 2(\theta-2)(-\beta g_1 + c)\alpha - 3(-\beta g_1 + c)^2\right) - G\end{aligned}$$

$$\begin{aligned}\pi_{S1}^{B*} = \pi_{R1}^{B*} + \pi_{M1}^{B*} \quad & = \tfrac{((b-1)c+\theta\alpha+\beta g_1)^2}{16}\\ & +\tfrac{1}{8\left(b^2-1\right)}\left(-b^4c^2 - 2c(\theta\alpha+\beta g_1+c)b^3\right.\\ & +\left(-\alpha^2\theta^2 + (2c(\theta-2) - 2\theta\beta g_1)\alpha + 4c^2 - 6cg_1\beta - \beta^2 g_1{}^2\right)b^2\\ & +\left(4\theta(\theta-1)\alpha^2 + (-4\beta g_1 + 2\theta c)\alpha - 4g_1{}^2\beta^2 + 2c\beta g_1 + 2c^2\right)b\\ & \left.+\left(4\theta - 3\theta^2 - 2\right)\alpha^2 - 2(\theta-2)(-\beta g_1 + c)\,\alpha - 3(-\beta g_1 + c)^2\right) - G\end{aligned}$$

Lemma 2. *The impact of consumers' traceability awareness and channel preference on the online price of the e-retailer, the offline price of the manufacturer, and the wholesale price for the model in the TBT scenario is as follows*: $\frac{\partial p_{R1}^{B*}}{\partial \beta} > 0$, $\frac{\partial p_{M1}^{B*}}{\partial \beta} > 0$, $\frac{\partial w_1{}^{B*}}{\partial \beta} > 0$, $\frac{\partial p_{R1}^{B*}}{\partial \theta} > 0$, $\frac{\partial p_{M1}^{B*}}{\partial \theta} < 0$, $\frac{\partial w_1{}^{B*}}{\partial \theta} > 0$.

Proof. See Appendix B. □

Lemma 2 suggests that when a dual-channel manufacturer and e-retailer use third-party blockchain traceability services, consumers' traceability awareness has a positive impact on the offline price, online price, and wholesale price. As consumers' traceability awareness increases, the offline price, online price, and wholesale price increase. Consumers' channel preference has a positive effect on the online price and wholesale price. As consumers' channel preference increases, both the online price and wholesale price increase. However, consumers' channel preference has a negative effect on the offline price. As consumers' channel preference increases, the offline price decreases. This is because, as consumers' traceability awareness increases, both the e-retailer and manufacturer increase their profits by raising their retail prices, while the manufacturer also extracts profits from the e-retailer by raising their wholesale prices. Similarly, as consumers' channel preference increases, the e-retailer earns more profit by raising retail prices, while the manufacturer lowers their prices to attract more consumers and squeeze the e-retailer by raising their wholesale prices.

3.3. Adopting SBT

In the SBT scenario, the manufacturer builds their own blockchain system. In contrast to the TBT scenario, the manufacturer must decide the optimal level of blockchain traceability technology because the research and development input cost is related to the traceability level of the blockchain technology. Let the blockchain technology research and development input cost be h. According to the assumption of the previous literature [45], h is assumed to be a quadratic function of the blockchain technology traceability level $h = 1/2kg_2^2$; g_2 expresses the blockchain technology level; and k denotes the blockchain technology research and development cost coefficient. In the SBT scenario, the game sequence is as follows: first, the manufacturer decides the blockchain technology level, g_2, and then determines the product's online wholesale price and offline direct sale price to maximize its own profit. Subsequently, the e-retailer determines its optimal retail price based on the manufacturer's decision.

The demand functions for the manufacturer and the e-retailer are as follows:

$$D_{R2}^{B} = \theta\alpha - p_{R2}^{B} + bp_{M2}^{B} + \beta g_2 \tag{9}$$

$$D_{M2}^{B} = (1-\theta)\alpha - p_{M2}^{B} + bp_{R2}^{B} + \beta g_2 \tag{10}$$

The profits of the manufacturer and e-retailer are as follows:

$$\pi_{R2}^{B} = \left(p_{R2}^{B} - w_2{}^{B} - f_2\right)D_{R2}^{B} \tag{11}$$

$$\pi_{M2}^{B} = \left(w_2{}^{B} - c + f_2\right)D_{R2}^{B} + \left(p_{M2}^{B} - c\right)D_{M2}^{B} - \frac{1}{2}kg_2^2 \tag{12}$$

Thus, the total profits of the supply chain are as follows:

$$\pi_{S2}^{B} = \left(p_{R2}^{B} - c\right)D_{R2}^{B} + \left(p_{M2}^{B} - c\right)D_{M2}^{B} - \frac{1}{2}kg_2^2 \tag{13}$$

Lemma 3. *In the case of SBT, when* $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, *the optimal decisions for the manufacturer and the e-retailer are, respectively,*

$$p_{R2}^{B*} = \frac{2b^3ck + \left(2k(\theta\alpha + c) + 2\beta^2 c\right)b^2 + \left(((\theta-1)4\alpha - 2c)k + 2\beta^2((2\theta-1)\alpha + 4c)\right)b - (6\theta\alpha + 2c)k + 6\beta^2\left(\left(\theta - \frac{1}{2}\right)\alpha + c\right)}{(b+1)\left(8k(b-1) + 2\beta^2(b+3)\right)} \tag{14}$$

$$p_{M2}^{B*} = \frac{\beta^2\left(2c\left(b^2+3\right) + 8bc + (1-2\theta)\alpha\right) - 4k\left(\left(1-b^2\right)c + b\theta\alpha + (1-\theta)\alpha\right)}{(b+1)\left(8k(b-1) + 2\beta^2(b+3)\right)} \tag{15}$$

$$w_2^{B*} = \frac{\left(2\beta^2(c-f_2)+4k(c-2f_2)\right)b^2+\left(((2\theta-1)\alpha+8(c-f_2))\beta^2+4\alpha k(\theta-1)\right)b+((4\theta-2)\alpha+6(c-f_2))\beta^2-4k(\theta\alpha+c-2f_2)}{(b+1)\left(8k(b-1)+2\beta^2(b+3)\right)} \tag{16}$$

$$g_2^* = \frac{\beta\left(-b^2c - (\theta\alpha + 2c)b - (2-\theta)\alpha + 3c\right)}{4k(b-1) + \beta^2(b+3)} \tag{17}$$

Proof . See Appendix C. □

Substituting (14)–(17) into the profit functions of the e-retailer and the manufacturer, the optimal profits for manufacturer and e-retailer and the total profit of the supply chain in the TBT scenario can be found, respectively:

$$\pi_{R2}^{B*} = \frac{\left(k(b-1)(\theta\alpha + bc - c) + \alpha\beta^2\left(\theta - \frac{1}{2}\right)\right)^2}{8\left(4k(b-1) + \beta^2(b+3)\right)^2}$$

$$\begin{aligned} \pi_{M2}^{B*} \quad &= \frac{1}{\left(16(b-1)k+4\beta^2(b+3)\right)(b+1)}\Big(\Big(\big(-2b^2\theta^2 + \left(8\theta^2 - 8\theta\right)b - 6\theta^2 + 8\theta \\ &-4)\alpha^2 - 4c(b-1)(b+1)(b\theta - \theta + 2)\alpha \\ &-2c^2(b+3)(b+1)(b-1)^2\Big)k + 2(4\theta-2)^2\beta^2\alpha^2\Big) \end{aligned}$$

$$\begin{aligned} \pi_{S2}^{B*} = \pi_{R2}^{B*} + \pi_{M2}^{B*} \quad &= \frac{\left(k(b-1)(\theta\alpha+bc-c)+\alpha\beta^2\left(\theta-\frac{1}{2}\right)\right)^2}{8\left(4k(b-1)+\beta^2(b+3)\right)^2} \\ &+\frac{1}{\left(16(b-1)k+4\beta^2(b+3)\right)(b+1)}\Big(\Big(\big(-2b^2\theta^2 + \left(8\theta^2 - 8\theta\right)b - 6\theta^2 + 8\theta \\ &-4)\alpha^2 - 4c(b-1)(b+1)(b\theta-\theta+2)\alpha - 2c^2(b+3)(b+1)(b-1)^2\Big)k \\ &+2(4\theta-2)^2\beta^2\alpha^2\Big) \end{aligned}$$

In order to explore the relationship between prices and profits when adopting TBT and SBT, we conduct a comparative analysis of the online price, offline price, wholesale price, manufacturer's profits, and retailer's profits when adopting TBT and SBT. Proposition 1 presents the comparison results between the optimal prices when adopting TBT and SBT. The relationships of the profits of the supply chain members when adopting TBT and SBT are presented in Propositions 2 and 3.

Proposition 1. *The comparative results for the prices of the e-retailer and the manufacturer are given as follows:*

(i) when $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$ *and* $g_1 < g_2^*$, $p_{R1}^{B*} < p_{R2}^{B*}$, $p_{M1}^{B*} < p_{M2}^{B*}$;

(ii) when $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$ *and* $g_1 < g_2^* - \frac{2(f_1-f_2)(b-1)}{\beta}$ $w_1^{B*} < w_2^{B*}$.

Proof. See Appendix D. □

Proposition 1 indicates that when blockchain traceability technology level provided by a third-party blockchain technology enterprise is less than that of a self-built blockchain system (i.e., $g_1 < g_2^*$), the online price of the e-retailer in the SBT scenario is higher than that of the e-retailer in the TBT and the offline price of the manufacturer in the SBT scenario is higher than that of the manufacturer in the TBT scenario. When the blockchain traceability technology level provided by a third-party blockchain technology enterprise is less than a certain value (i.e., $g_1 < g_2^* - \frac{2(f_1-f_2)(b-1)}{\beta}$), the wholesale price of the manufacturer in the SBT scenario is higher than that of the manufacturer in the TBT scenario.

Proposition 2. *When $G \le H$, the manufacturer should adopt TBT. Otherwise, the manufacturer should adopt SBT.*

Proof. See Appendix E. □

Proposition 2 indicates that the manufacturer should adopt blockchain traceability services provided by a TBT system when the fixed fee paid by the manufacturer to a third-party blockchain technology enterprise is low because the manufacturer can obtain more profits in the TBT scenario. When the fixed fee paid by the manufacturer to a third-party blockchain technology enterprise is high, the manufacturer will prefer to adopt SBT.

Proposition 3. *Compared with π_{R1}^{B*} and π_{R2}^{B*}, we have:*

(i) when $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \le \frac{8(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$ or $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \ge g_2^*$, e-retailer adopts TBT.

(ii) when $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $\frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^* < g_1 < g_2^*$ or $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_2^* < g_1 < \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$, e-retailer always prefers to adopt SBT.

(iii) when $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \le g_2^*$ or $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \ge \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$, e-retailer prefers to adopt TBT.

Proof. See Appendix F. □

Proposition 3 indicates that when the research and development cost factor of blockchain technology is high and the blockchain traceability technology level provided by a third-party blockchain technology enterprise is low (i.e., $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \le \frac{8(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$), the e-retailer should adopt TBT because the profits of an e-retailer adopting TBT are higher than those of an e-retailer adopting SBT. And when the research and development cost factor of blockchain technology is high and the blockchain traceability technology level provided by a third-party blockchain technology enterprise is relatively high (i.e., $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \ge g_2^*$), the e-retailer should adopt TBT. Otherwise, the e-retailer should adopt SBT (i.e., $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $\frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^* < g_1 < g_2^*$). When the research and development cost factor of blockchain technology is low and the blockchain traceability technology level provided by a third-party blockchain technology enterprise is less than the blockchain traceability technology level of a self-built blockchain system (i.e., $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \le g_2^*$), the e-retailer should adopt TBT because the profits of the e-retailer adopting TBT are higher than those of the e-retailer adopting SBT. And when the research and development cost factor of blockchain technology is low and the blockchain traceability technology level provided by a third-party blockchain technology enterprise is relatively high (i.e., $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \ge \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$), the e-retailer should adopt TBT. Otherwise, the e-retailer should adopt SBT (i.e., $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_2^* < g_1 < \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$).

4. Numerical Analysis

In order to observe the supply chain decision in different situations more intuitively, each parameter was assigned a value without violating the basic assumptions, and the correctness of the above proposition was further argued using numerical arithmetic examples. Based on the previous literature and without loss of generality [7,27], we set $\alpha = 200, b = 0.3, c = 1, g_1 = 5, G = 10, k = 6,\ f_1 = 1, f_2 = 1.2$, and $\theta = 0.5$.

4.1. Blockchain Technology Adoption

By comparing the profits of the manufacturer when adopting TBT and SBT, we determine the optimal strategies of blockchain technology adoption in Proposition 2. To investigate the impact of consumers' traceability awareness, β, and the research and development cost factor of blockchain technology, k, on blockchain technology adoption, we draw the impact of consumers' traceability awareness considering different research and development cost factors of blockchain technology, as shown in Figure 2.

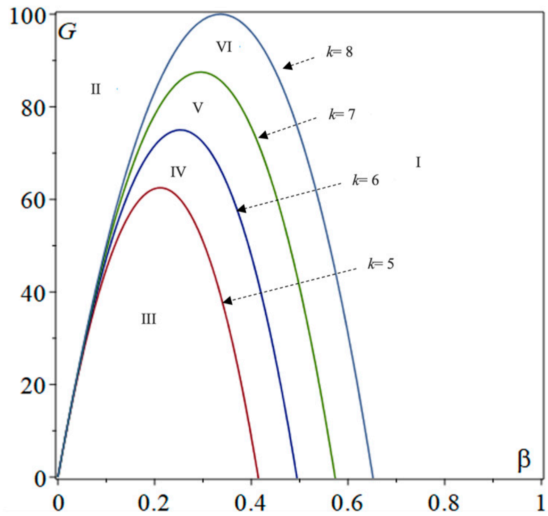

Figure 2. Blockchain technology adoption decisions of the manufacturer.

Figure 2 shows the interactive effect of the three parameters on the blockchain technology adoption decision of the manufacturer. Regions I and II indicate that the manufacturer should definitely adopt SBT. The remaining regions (regions III, IV, V, and VI) indicate that the manufacturer should adopt TBT. With the increase of the research and development cost factor of blockchain technology, the selection range of TBT increases. When the consumers' traceability awareness is greater, the manufacturer is more willing to choose SBT. Only when the consumers' traceability awareness is high enough, as the research and development cost factor of blockchain technology increases, is adopting SBT better for the manufacturer.

4.2. Consumers' Traceability Awareness Impact on e-Retailers

To investigate the impact of consumers' traceability awareness, β, on the e-retailer's profits and price, we draw the changes in the retailers' profits and price as consumers' traceability awareness increases, as shown in Figures 3 and 4.

As seen in Figure 3, the e-retailer's profits in both the TBT and SBT scenarios increase with consumers' traceability awareness. When the consumers' traceability awareness is higher than a certain value, scenario SBT outperforms scenario TBT because the e-retailer's profits in the SBT scenario are higher than those in the TBT scenario. In this case, adopting SBT could improve e-retailer's profits.

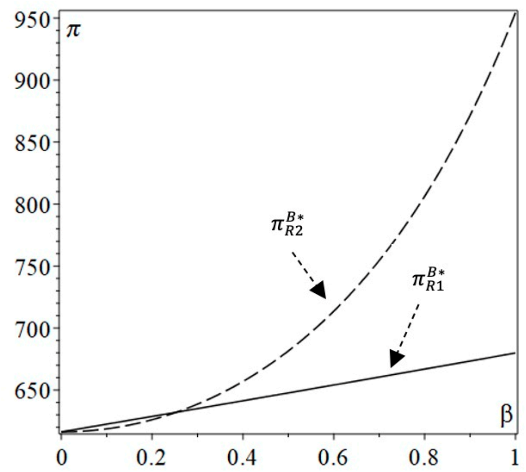

Figure 3. Impact of consumers' traceability awareness on e-retailer's profits.

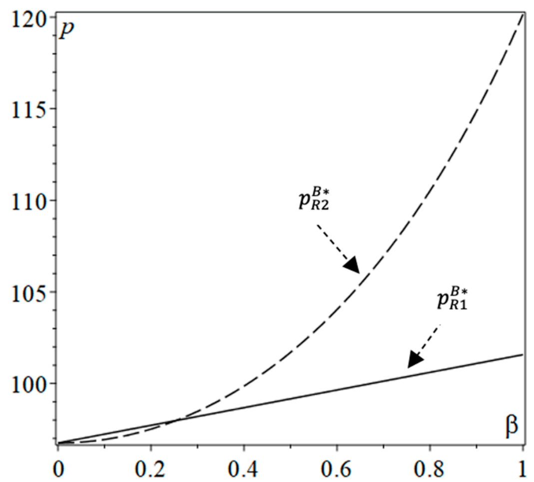

Figure 4. Impact of consumers' traceability awareness on e-retailer's online price.

In Figure 4, the online price of the e-retailer in both the TBT and SBT scenarios increases with consumers' traceability awareness. When the consumers' traceability awareness is higher than a certain value, the online price of the e-retailer in the SBT scenario is higher than that in the TBT scenario. A higher consumers' traceability awareness means that consumers will pay more attention to the traceability level of blockchain technology and the demand for the high traceability level of blockchain technology will increase. Therefore, products with a high traceability level will be more attractive to consumers. A higher consumers' traceability awareness prompts the e-retailer to invest more costs to improve the traceability level of blockchain technology. The e-retailer will charge a higher online price to obtain more profits. Comparing Figures 3 and 4, the online price of the e-retailer will increase with consumers' traceability awareness, thereby ensuring the increase of the e-retailer's profits.

4.3. Consumers' Traceability Awareness Impact on the Manufacturer

In order to study the impact of consumers' traceability awareness, β, on the manufacturer's decisions, we draw the changes in the manufacturer's decisions as consumers' traceability awareness increases, as seen in Figures 5 and 6.

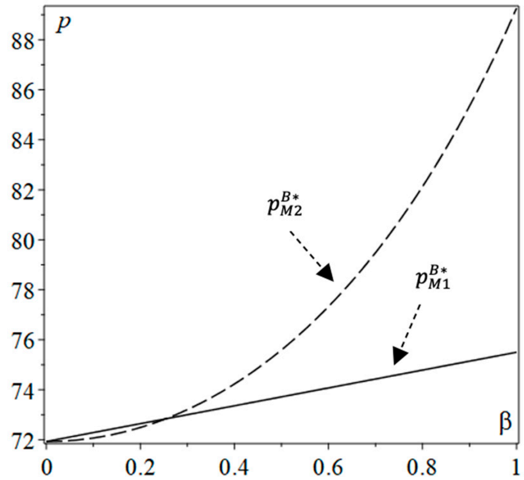

Figure 5. Impact of consumers' traceability awareness on manufacturer's offline price.

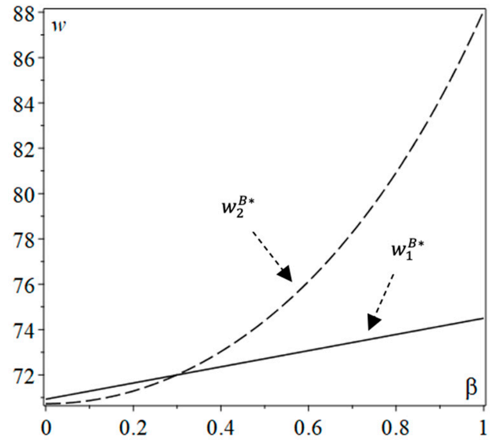

Figure 6. Impact of consumers' traceability awareness on manufacturer's online wholesale price.

Figure 5 shows the impact of consumers' traceability awareness on the manufacturer's offline price. The offline price of the manufacturer in both the TBT and SBT scenarios increases with the consumers' traceability awareness. When the consumers' traceability awareness is higher than a certain value, the offline price of the manufacturer in the SBT scenario is higher than that of the manufacturer in the TBT scenario. A higher consumers' traceability awareness prompts the manufacturer to invest more costs to improve the traceability level of blockchain technology. The manufacturer will charge a higher offline price to obtain more profits.

Figure 6 shows the impact of consumers' traceability awareness on the manufacturer's online wholesale price. The wholesale price of the manufacturer in both the TBT and SBT scenarios increases with the consumers' traceability awareness. When the consumers' traceability awareness is higher than a certain value, the wholesale price of the manufacturer in the SBT scenario is higher than that of the manufacturer in the TBT scenario. Comparing Figures 5 and 6, the offline price and the online wholesale price of the manufacturer will increase with consumers' traceability awareness, thereby ensuring that the manufacturer obtains more profits.

5. Conclusions

In this paper, we explore two blockchain adoption scenarios in a dual-channel supply chain consisting of a manufacturer and an e-retailer. The manufacturer not only sells their products through the e-retailer, but they also sell their products through a direct offline channel. The blockchain adoption scenarios include (a) the TBT scenario, in which the manufacturer and retailer adopt a blockchain technology service from a third-party platform, and (b) the SBT scenario, in which the manufacturer and retailer adopt the blockchain system provided by the manufacturer. By constructing game models, we derive the equilibrium wholesale price, offline price, online price, and the maximum profit of the manufacturer and the e-retailer in two scenarios. We compare the equilibrium solution of the supply chain members adopting SBT and TBT. Furthermore, we analyze the influence of consumers' traceability awareness on supply chain members' decisions. The main conclusions of our study can be summarized as follows:

First, the manufacturer should adopt blockchain traceability services provided by a third-party platform when the fee paid by the manufacturer to a third-party blockchain service provider is low. The manufacturer obtains more profit in the TBT scenario when the fixed fee paid by the manufacturer to a third-party blockchain technology enterprise is smaller than a certain value. Moreover, we find that with the increase of the research and development cost factor of blockchain technology, the selection range of TBT increases. When the consumers' traceability awareness is higher, the manufacturer is more willing to choose SBT.

Second, when consumers' traceability awareness is less than a certain value and the blockchain traceability technology level of TBT is less than a certain value, the online price of the e-retailer, the offline price of the manufacturer, and the wholesale price of the manufacturer in the SBT scenario are higher. When the research and development cost factor of blockchain technology and the blockchain traceability technology level of TBT meet certain conditions, the profits of the e-retailer in the TBT scenario are higher than those of the e-retailer in the SBT scenario.

Third, consumers' traceability awareness could affect the equilibrium decision of supply chain members in the dual-channel supply chain. The online price of the e-retailer, the offline price of the manufacturer, and the wholesale price of the manufacturer increase with consumers' traceability awareness in both the TBT and SBT scenarios. Fan et al. [9] found that the higher the consumer's traceability awareness, the higher the prices in the supply chain. However, when the manufacturer's and e-retailer's prices reach a certain threshold, consumers' traceability awareness has no effect on them. Different from Fan's conclusion, we find that consumers' traceability awareness always has an effect on the prices of supply chain members. A higher consumer traceability awareness will prompt members of the supply chain to charge higher prices in both the TBT and SBT scenarios.

Our findings provide insight into the supply chain members in a dual-channel supply chain with a choice in blockchain technology. We elucidate the following managerial insights: first, the manufacturer should pay attention to the cost of adopting a third-party blockchain traceability service and to consumers' traceability awareness when determining the optimal blockchain traceability system for dual-channel supply chains. When the fixed fee paid by the manufacturer to a third-party blockchain technology provider is relatively small, or when consumers' traceability awareness is comparatively small, the manufacturer can obtain more profit in the TBT scenario. Second, e-retailers should pay attention to the blockchain traceability technology level and the research and development cost factor of blockchain technology. When the dual-channel supply chain determines the blockchain traceability system, it is necessary to compare the blockchain traceability level of different traceability systems: for example, the completeness of information provided, including the origin information, production information, processing information, as well as logistics information. In addition, it is also important to focus on the research and development cost factor of blockchain technology. Third, supply chain members should pay more attention to consumers' traceability awareness. It is helpful for determining the key concern of consumers regarding product traceability. For example, for the traceability of meat, the key information that concerns consumers is feed information production information, processing information, logistics information, and so on. For luxury goods, consumers pay more attention to the origin information, production information, identification information, as well as logistics information.

Finally, we have highlighted some potential directions for future research. First, we focus on the dual-channel supply chain of a manufacturer-dominated system, in which the retailer is the follower. In reality, there are some retailers that dominate their dual-channel system. It would be interesting to study the blockchain choice strategies of a dual-channel supply chain that is retailer-dominated. Second, we only study a single manufacturer and a single supplier, and it is also a good idea to study the introduction of blockchain technology in a system with multiple manufacturers and multiple retailers. Third, it is popular for consumers to return products bought online. It may also be interesting to consider blockchain choice strategies for dual-channel supply chains considering returns behavior.

Author Contributions: Conceptualization, Y.S.; methodology, Y.S. and X.F.; formal analysis and visualization, X.S.; writing—original draft, Y.S. and X.S.; writing—review and editing, X.F. and J.G. All authors have read and agreed to the published version of the manuscript.

Funding: National Natural Science Foundation of China (71301073, 71701093, 71801125); National Social Science Foundation of China (22&ZD122); and Humanities and Social Science Foundation Project of Ministry of Education (20YJC630142).

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Proof of Lemma 1

The second-order partial derivative of the e-retailer profit Function (3) with respect to p_{R1}^B is obtained as $\frac{\partial^2 \pi_{R1}^B}{\partial p_{R1}^{B2}} = -2$. Therefore, the e-retailer profit function is a concave function with respect to p_{R1}^B, and there exists an optimal solution. Calculating the first-order partial derivative of p_{R1}^B for π_{R1}^B and making it equal to 0, we obtain

$$p_{R1}^B = \frac{\theta\alpha + bp_{M1}^B + {w_1}^B + \beta g_1 + f_1}{2}$$

Substituting p_{R1}^B into the manufacturer's profit Function (4) and calculating the second-order partial derivatives of p_{M1}^B and ${w_1}^B$ for π_{M1}^B, we can obtain the Hessian matrix for π_{M1}^B:

$$H\left(\pi_{M1}^B\right) = \begin{bmatrix} b^2 - 2 & b \\ b & -1 \end{bmatrix}$$

The Hessian matrix is negative definite, so the manufacturer's profit function is a concave function with respect to p_{M1}^B, ${w_1}^B$. The first-order partial derivatives of p_{M1}^B, ${w_1}^B$ for π_{M1}^B are made equal to 0, and we can obtain:

$$p_{M1}^{B*} = \frac{(b^2-1)c - (\theta\alpha + \beta g_1)b - (1-\theta)\alpha - \beta g_1}{2(b^2-1)}$$

$$w_1^{B*} = \frac{(b^2-1)(c-2f_1) - ((1-\theta)\alpha + \beta g_1)b - \beta g_1 - \theta\alpha}{2(b^2-1)}$$

Taking the above result back to p_{R1}^B again, we obtain:

$$p_{R1}^{B*} = \frac{(b+1)(b^2-1)c + (\theta\alpha + \beta g_1)(b^2-3) - ((1-\theta)2\alpha + 2\beta g_1)b}{4(b^2-1)}$$

Appendix B. Proof of Lemma 2

Calculating the first-order partial derivatives with respect to β and θ for p_{R1}^{B*}, p_{M1}^{B*}, ${w_1}^{B*}$, q_{R1}^{B*}, and q_{M1}^{B*}, respectively, we obtain $\frac{\partial p_{R1}^{B*}}{\partial \beta} = \frac{(b-3)g_1}{4(b-1)} > 0$, $\frac{\partial p_{R1}^{B*}}{\partial \theta} = \frac{\alpha(b+3)}{4b+4} > 0$, $\frac{\partial p_{M1}^{B*}}{\partial \beta} = \frac{-g_1}{2(b-1)} > 0$, $\frac{\partial p_{M1}^{B*}}{\partial \theta} = \frac{-\alpha}{2(b+1)} < 0$, $\frac{\partial {w_1}^{B*}}{\partial \beta} = \frac{-g_1}{2(b-1)} > 0$, $\frac{\partial {w_1}^{B*}}{\partial \theta} = \frac{\alpha}{2(b+1)} > 0$.

Appendix C. Proof of Lemma 3

The second-order partial derivative of the e-retailer profit Function (11) with respect to p_{R2}^B yields $\frac{\partial^2 \pi_{R2}^B}{\partial p_{R2}^{B2}} = -2$, so the e-retailer profit function is a concave function with respect to p_{R2}^B and there exists an optimal solution. Finding the first-order partial derivative of p_{R2}^B for π_{R2}^B and making it equal to 0 yields:

$$p_{R2}^B = \frac{\theta\alpha + b p_{M1}^B + {w_2}^B + \beta g + f_2}{2}$$

Substituting p_{R2}^B into the manufacturer's profit Function (12) and calculating the second-order partial derivatives of p_{M2}^B, ${w_2}^B$, g for π_{M2}^B, the resulting Hesse matrix is

$$H(\pi_{M2}^B) = \begin{bmatrix} b^2 - 2 & b & \frac{1}{2}b\beta + \beta \\ b & -1 & \frac{1}{2}\beta \\ \frac{1}{2}b\beta + \beta & \frac{1}{2}\beta & -k \end{bmatrix}$$

Because $H(1) = b^2 - 2 < 0$ and $H(2) = 2\left(1 - b^2\right) > 0$, the Hessian matrix is negative definite when $H(3) = \frac{1}{2}(b+1)\left(4k(b-1) + \beta^2(b+3)\right) < 0$, so $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$.

Let $\frac{\partial \pi_{M2}^B}{\partial p_{R2}^B}$, $\frac{\partial \pi_{M2}^B}{\partial p_{M1}^B}$, $\frac{\partial \pi_{M2}^B}{\partial g}$ be equal to 0; the joint cubic equation can be obtained as follows:

$$p_{M2}^{B*} = \frac{\beta^2\left(2c\left(b^2+3\right) + 8bc + (1-2\theta)\alpha\right) - 4k\left(\left(1-b^2\right)c + b\theta\alpha + (1-\theta)\alpha\right)}{(b+1)\left(8k(b-1) + 2\beta^2(b+3)\right)}$$

$$w_2^{B*} = \frac{\left(2\beta^2(\mathrm{c}-f_2)+4k(c-2f_2)\right)b^2+\left(((2\theta-1)\alpha+8(c-f_2))\beta^2+4\alpha k(\theta-1)\right)b+((4\theta-2)\alpha+6(c-f_2))\beta^2-4k(\theta\alpha+c-2f_2)}{(b+1)\left(8k(b-1)+2\beta^2(b+3)\right)}$$

$$g_2^* = \frac{\beta\left(-b^2c - (\theta\alpha+2c)b - (2-\theta)\alpha + 3c\right)}{4k(b-1) + \beta^2(b+3)} \quad \left(0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}\right)$$

Then, substituting p_{M2}^{B*}, w_2^{B*} into p_{R2}^B, we obtain:

$$p_{R2}^{B*} = \frac{2b^3ck+\left(2k(\theta\alpha+c)+2\beta^2c\right)b^2+\left(((\theta-1)4\alpha-2c)k+2\beta^2((2\theta-1)\alpha+4c)\right)b-(6\theta\alpha+2c)k+6\beta^2\left(\left(\theta-\frac{1}{2}\right)\alpha+c\right.}{(b+1)\left(8k(b-1)+2\beta^2(b+3)\right)}$$

Appendix D. Proof of Proposition 1

The optimal price decisions for a manufacturer and e-retailer in a TBT scenario are, respectively:

$$p_{R1}^{B*} = \frac{(b+1)\left(b^2-1\right)c + (\theta\alpha + \beta g_1)\left(b^2-3\right) - ((1-\theta)2\alpha + 2\beta g_1)b}{4\left(b^2-1\right)}$$

$$p_{M1}^{B*} = \frac{\left(b^2-1\right)c - (\theta\alpha + \beta g_1)b - (1-\theta)\alpha - \beta g_1}{2\left(b^2-1\right)}$$

$$w_1^{B*} = \frac{(b^2-1)(c-2f_1) - ((1-\theta)\alpha + \beta g_1)b - \beta g_1 - \theta\alpha}{2(b^2-1)}$$

The optimal price decisions for a manufacturer and e-retailer in an SBT scenario are, respectively:

$$p_{R2}^{B*} = \frac{2b^3ck + \left(2k(\theta\alpha+c)+2\beta^2c\right)b^2 + \left(((\theta-1)4\alpha-2c)k + 2\beta^2((2\theta-1)\alpha+4c)\right)b - (6\theta\alpha+2c)k + 6\beta^2\left(\left(\theta-\frac{1}{2}\right)\alpha+c\right)}{(b+1)\left(8k(b-1)+2\beta^2(b+3)\right)}$$

$$p_{M2}^{B*} = \frac{\beta^2\left(2c\left(b^2+3\right)+8bc+(1-2\theta)\alpha\right) - 4k\left(\left(1-b^2\right)c + b\theta\alpha + (1-\theta)\alpha\right)}{(b+1)\left(8k(b-1)+2\beta^2(b+3)\right)}$$

$$w_2^{B*} = \frac{\left(2\beta^2(c-f_2)+4k(c-2f_2)\right)b^2 + \left(((2\theta-1)\alpha+8(c-f_2))\beta^2 + 4\alpha k(\theta-1)\right)b + ((4\theta-2)\alpha+6(c-f_2))\beta^2 - 4k(\theta\alpha+c-2f_2)}{(b+1)\left(8k(b-1)+2\beta^2(b+3)\right)}$$

$$p_{R1}^{B*} - p_{R2}^{B*} = \frac{\beta(b-3)\left(g_1\left((b+3)\beta^2+4k(b-1)\right) + \left(b^2c + (\theta\alpha+2c)b + (2-\theta)\alpha - 3c\right)\beta\right)}{(b-1)\left(16k(b-1)+4\beta^2(b+3)\right)}$$

$$p_{M1}^{B*} - p_{M2}^{B*} = \frac{-\beta\left(g_1\left((b+3)\beta^2+4k(b-1)\right) + \left(b^2c + (\theta\alpha+2c)b + (2-\theta)\alpha - 3c\right)\beta\right)}{(b-1)\left(8k(b-1)+2\beta^2(b+3)\right)}$$

$$w_1^{B*} - w_2^{B*} = \frac{-g_1\beta\left((b+3)\beta^2+4k(b-1)\right) - \left(b^2c + (\theta\alpha+2c)b + (2-\theta)\alpha - 3c\right)\beta^2}{(b-1)\left(8k(b-1)+2\beta^2(b+3)\right)} - (f_1 - f_2)$$

When $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $(b+3)\beta^2 + 4k(b-1) < 0$, $8k(b-1) + 2\beta^2(b+3) < 0$, $16k(b-1) + 4\beta^2(b+3) < 0$.

Because $0 < b < 1$, $b-1 < 0$, $b-3 < 0$.

When $g_1 < \frac{\left(-b^2c-(\theta\alpha+2c)b+(\theta-2)\alpha+3c\right)\beta}{(b+3)\beta^2+4k(b-1)} = g_2^*$, $p_{R1}^{B*} < p_{R2}^{B*}$, $p_{M1}^{B*} < p_{M2}^{B*}$.

When $g_1 < \frac{\left(-b^2c-(\theta\alpha+2c)b+(\theta-2)\alpha+3c\right)\beta}{((b+3)\beta^2+4k(b-1))} - \frac{2(f_1-f_2)(b-1)}{\beta} = g_2^* - \frac{2(f_1-f_2)(b-1)}{\beta}$, $w_1^{B*} < w_2^{B*}$.

Thus, when $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$ and $g_1 < g_2^*$, $p_{R1}^{B*} < p_{R2}^{B*}$, $p_{M1}^{B*} < p_{M2}^{B*}$.

When $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$ and $g_1 < g_2^* - \frac{2(f_1-f_2)(b-1)}{\beta}$ $w_1^{B*} < w_2^{B*}$.

Appendix E. Proof of Proposition 2

The profits for a manufacturer in a TBT scenario are:

$$\begin{aligned}\pi_{M1}^{B*} = \frac{1}{8(b^2-1)} \quad & \left(-b^4c^2 - 2c(\theta\alpha+\beta g_1+c)b^3\right.\\ & +\left(-\alpha^2\theta^2 + (2c(\theta-2) - 2\theta\beta g_1)\alpha + 4c^2 - 6cg_1\beta - \beta^2 {g_1}^2\right)b^2\\ & +\left(4\theta(\theta-1)\alpha^2 + (-4\beta g_1 + 2\theta c)\alpha - 4{g_1}^2\beta^2 + 2c\beta g_1 + 2c^2\right)b\\ & \left.+\left(4\theta - 3\theta^2 - 2\right)\alpha^2 - 2(\theta-2)(-\beta g_1 + c)\alpha - 3(-\beta g_1 + c)^2\right) - G\end{aligned}$$

The profits for a manufacturer in an SBT scenario are:

$$\pi_{M2}^{B*}=\frac{1}{\left(16(b-1)k+4\beta^2(b+3)\right)(b+1)}(((-2b^2\theta^2+(8\theta^2-8\theta)b-6\theta^2+8\theta$$
$$-4)\alpha^2-4c(b-1)(b+1)(b\theta-\theta+2)\alpha$$
$$-2c^2(b+3)(b+1)(b-1)^2)k+2(4\theta-2)^2\beta^2\alpha^2)$$

$$\begin{aligned}\pi_{M2}^{B*}-\pi_{M1}^{B*}= &\ \tfrac{1}{\left(16(b-1)k+4\beta^2(b+3)\right)(b+1)}(((-2b^2\theta^2+\left(8\theta^2-8\theta\right)b-6\theta^2\\ &+8\theta-4)\alpha^2-4c(b-1)(b+1)(b\theta-\theta+2)\alpha\\ &-2c^2(b+3)(b+1)(b-1)^2\Big)k+2(4\theta-2)^2\beta^2\alpha^2)\\ &-\tfrac{1}{8(b^2-1)}(-b^4c^2-2c(\theta\alpha+\beta g_1+c)b^3\\ &+\left(-\alpha^2\theta^2+(2c(\theta-2)-2\theta\beta g_1)\alpha+4c^2-6cg_1\beta-\beta^2{g_1}^2\right)b^2\\ &+\left(4\theta(\theta-1)\alpha^2+(-4\beta g_1+2\theta c)\alpha-4{g_1}^2\beta^2+2c\beta g_1+2c^2\right)b\\ &+\left(4\theta-3\theta^2-2\right)\alpha^2-2(\theta-2)(-\beta g_1+c)\alpha-3(-\beta g_1+c)^2)+G\end{aligned}$$

When $\pi_{M2}^{B*}\le\pi_{M1}^{B*}$, that is, $G\le\frac{1}{8(b^2-1)}\left(-b^4c^2-2c(\theta\alpha+\beta g_1+c)b^3+\left(-\alpha^2\theta^2+(2c(\theta-2)-2\theta\beta g_1)\alpha+4c^2-6cg_1\beta-\beta^2{g_1}^2\right)b^2+\left(4\theta(\theta-1)\alpha^2+(-4\beta g_1+2\theta c)\alpha-4{g_1}^2\beta^2+2c\beta g_1+2c^2\right)b+\left(4\theta-3\theta^2-2\right)\alpha^2-2(\theta-2)(-\beta g_1+c)\alpha-3(-\beta g_1+c)^2\right)-\frac{1}{\left(16(b-1)k+4\beta^2(b+3)\right)(b+1)}(((-2b^2\theta^2+\left(8\theta^2-8\theta\right)b-6\theta^2+8\theta-4)\alpha^2-4c(b-1)(b+1)(b\theta-\theta+2)\alpha-2c^2(b+3)(b+1)(b-1)^2)k+2(4\theta-2)^2\beta^2\alpha^2)$, let $H=\frac{1}{8(b^2-1)}\left(-b^4c^2-2c(\theta\alpha+\beta g_1+c)b^3+\left(-\alpha^2\theta^2+(2c(\theta-2)-2\theta\beta g_1)\alpha+4c^2-6cg_1\beta-\beta^2{g_1}^2\right)b^2+\left(4\theta(\theta-1)\alpha^2+(-4\beta g_1+2\theta c)\alpha-4{g_1}^2\beta^2+2c\beta g_1+2c^2\right)b+\left(4\theta-3\theta^2-2\right)\alpha^2-2(\theta-2)(-\beta g_1+c)\alpha-3(-\beta g_1+c)^2\right)-\frac{1}{\left(16(b-1)k+4\beta^2(b+3)\right)(b+1)}\left(((-2b^2\theta^2+\left(8\theta^2-8\theta\right)b-6\theta^2+8\theta-4)\alpha^2-4c(b-1)(b+1)(b\theta-\theta+2)\alpha-2c^2(b+3)(b+1)(b-1)^2\right)k+2(4\theta-2)^2\beta^2\alpha^2\Big)$.

Thus, when $G\le H$, a manufacturer should choose to use blockchain traceability services provided by a TBT system.

Appendix F. Proof of Proposition 3

The optimal profit for an e-retailer in a TBT scenario is:

$$\pi_{R1}^{B*}=\frac{((b-1)c+\theta\alpha+\beta g_1)^2}{16}$$

The optimal profit for an e-retailer in an SBT scenario is:

$$\pi_{R2}^{B*}=\frac{\left(k(b-1)(\theta\alpha+bc-c)+\alpha\beta^2\left(\theta-\frac{1}{2}\right)\right)^2}{8(4k(b-1)+\beta^2(b+3))^2}$$

$$\begin{aligned}\pi_{R1}^{B*}-\pi_{R2}^{B*}= &\ \tfrac{1}{2\left((b+3)\beta^2+4k(b-1)\right)^2}\Big(\beta\big(g_1\left((b+3)\beta^2+4k(b-1)\right)\\ &+\left(b^2\mathrm{c}+(\theta\alpha+2\mathrm{c})b+(2-\theta)\alpha\right.\\ &\left.-3c\right)\beta\big)\Big(\tfrac{\beta}{8}\big(g_1\left((b+3)\beta^2+4k(b-1)\right)\\ &+\left(b^2\mathrm{c}+(\theta\alpha+2\mathrm{c})b+(2-\theta)\alpha+(8\theta-4)\alpha-3c\right)\beta\big)\\ &+(b-1)(\theta\alpha+bc-c)k)\Big)\end{aligned}$$

Let $Z=g_1\left((b+3)\beta^2+4k(b-1)\right)+\left(b^2\mathrm{c}+(\theta\alpha+2\mathrm{c})b+(2-\theta)\alpha-3c\right)\beta$,

Thus, $\pi_{R1}^{B*}-\pi_{R2}^{B*}=\frac{\beta Z\left(\frac{\beta}{8}(Z+(8\theta-4)\alpha\beta)+(b-1)(\theta\alpha+bc-c)k\right)}{2\left((b+3)\beta^2+4k(b-1)\right)^2}$.

When $0<\beta<2\sqrt{\frac{k(1-b)}{b+3}}$, $4k(b-1)+\beta^2(b+3)<0$.

When $Z\ge0$ and $Z\ge\frac{8(1-b)(\theta\alpha+bc-c)k}{\beta}+(4-8\theta)\alpha\beta$, $\pi_{R1}^{B*}\ge\pi_{R2}^{B*}$.

Because $0<c<\frac{\theta\alpha}{1-b}$, $\theta\alpha+bc-c>0$.

If $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$, when $g_1 \le \frac{\frac{8(1-b)(\theta\alpha+bc-c)k}{\beta}+(4-8\theta)\alpha\beta-\left(b^2c+(\theta\alpha+2c)b+(2-\theta)\alpha-3c\right)\beta}{(b+3)\beta^2+4k(b-1)} = \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$, $\pi_{R1}^{B*} \ge \pi_{R2}^{B*}$.

If $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$, when $g_1 \le \frac{\left(-b^2c-(\theta\alpha+2c)b-(2-\theta)\alpha+3c\right)\beta}{(b+3)\beta^2+4k(b-1)} = g_2^*$, $\pi_{R1}^{B*} \ge \pi_{R2}^{B*}$.

When $Z \le 0$ and $Z \le \frac{8(1-b)(\theta\alpha+bc-c)k}{\beta} + (4-8\theta)\alpha\beta$, $\pi_{R1}^{B*} \ge \pi_{R2}^{B*}$.

Because $0 < c < \frac{\theta\alpha}{1-b}$, $\theta\alpha + bc - c > 0$.

If $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$, when $g_1 \ge \frac{\left(-b^2c-(\theta\alpha+2c)b-(2-\theta)\alpha+3c\right)\beta}{(b+3)\beta^2+4k(b-1)} = g_2^*$, $\pi_{R1}^{B*} \ge \pi_{R2}^{B*}$.

If $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$, when $g_1 \ge \frac{\frac{8(1-b)(\theta\alpha+bc-c)k}{\beta}+(4-8\theta)\alpha\beta-\left(b^2c+(\theta\alpha+2c)b+(2-\theta)\alpha-3c\right)\beta}{(b+3)\beta^2+4k(b-1)} = \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$, $\pi_{R1}^{B*} \ge \pi_{R2}^{B*}$.

If $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$, when $\frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^* < g_1 < g_2^*$, $\pi_{R1}^{B*} < \pi_{R2}^{B*}$.

If $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$, when $g_2^* < g_1 < \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$, $\pi_{R1}^{B*} < \pi_{R2}^{B*}$.

Thus, when $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \le \frac{8(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}$ $+g_2^*$ or $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \ge g_2^*$, $\pi_{R1}^{B*} \ge \pi_{R2}^{B*}$.

When $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k > \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $\frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^* < g_1 < g_2^*$ or $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_2^* < g_1 < \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}$ $+g_2^*$, $\pi_{R1}^{B*} < \pi_{R2}^{B*}$.

When $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \le g_2^*$ or $0 < \beta < 2\sqrt{\frac{k(1-b)}{b+3}}$, $k \le \frac{(8\theta-4)\alpha\beta^2}{8(1-b)(\theta\alpha+bc-c)}$ and $g_1 \ge \frac{8k(1-b)(\theta\alpha+bc-c)+(4-8\theta)\alpha\beta^2}{\beta((b+3)\beta^2+4k(b-1))}+g_2^*$, $\pi_{R1}^{B*} \ge \pi_{R2}^{B*}$.

References

1. China Internet Network Information Center. The 51st Statistical Report on the Development Status of China's Internet. Available online: https://www.cnnic.com.cn/IDR/ReportDownloads/202307/P020230707514088128694.pdf (accessed on 2 March 2023). (In Chinese).
2. Montecchi, M.; Plangger, K.; Etter, M. It's real, trust me! Establishing supply chain provenance using blockchain. *Business Horizons* **2019**, *62*, 283–293. [CrossRef]
3. Sun, J.; Zhang, X.; Zhu, Q. Counterfeiters in online marketplaces: Stealing your sales or sharing your costs. *J. Retail.* **2020**, *96*, 189–202. [CrossRef]
4. MacCarthy, B.L.; Ivanov, D. The digital supply chain—Emergence, concepts, definitions, and technologies. In *The Digital Supply Chain*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 3–24. [CrossRef]
5. Saurabh, S.; Subhasis, T.; Shahid, H.; John, G.B.; Syed, M.J. Identification and Authentication in Healthcare Internet-of-Things Using Integrated Fog Computing Based Blockchain Model. *Internet Things* **2021**, *15*, 100422.
6. Zhang, T.Y.; Dong, P.W.; Chen, X.F.; Gong, Y. The impacts of blockchain adoption on a dual-channel supply chain with risk-averse members. *Omega* **2023**, *114*, 102747. [CrossRef]
7. Shen, B.; Dong, C.; Minner, S. Combating copycats in the supply chain with permissioned blockchain technology. *Prod. Oper. Manag.* **2022**, *31*, 138–154. [CrossRef]
8. Wu, X.Y.; Fan, Z.P.; Li, G.M. Strategic analysis for adopting blockchain technology under supply chain competition. *Int. J. Logist. Res. Appl.* **2022**, *26*, 1–24. [CrossRef]
9. Fan, Z.P.; Wu, X.Y.; Cao, B.B. Considering the traceability awareness of consumers: Should the supply chain adopt the blockchain technology? *Ann. Oper. Res.* **2022**, *309*, 837–860. [CrossRef]
10. Moosavi, J.; Naeni, L.M.; Fathollahi-Fard, A.M.; Fiore, U. Blockchain in supply chain management: A review, bibliometric, and network analysis. *Environ. Sci. Pollut. Res.* **2021**. [CrossRef]
11. Wang, M.M.; Yang, Y. An empirical analysis of the supply chain flexibility using blockchain technology. *Front. Psychol.* **2022**, *13*, 1004007. [CrossRef]
12. Maher, A.N.; Agi, A.K.J. Blockchain technology in the supply chain: An integrated theoretical perspective of organizational adoption. *Int. J. Prod. Econ.* **2022**, *247*, 108458.
13. Niu, B.; Mu, Z.; Cao, B.; Gao, J. Should multinational firms implement blockchain to provide quality verification? *Transp. Res. E Logist. Transp. Rev.* **2021**, *145*, 102121. [CrossRef]

14. Pun, H.; Swaminathan, J.M.; Hou, P. Blockchain adoption for combating deceptive counterfeits. *Prod. Oper. Manag.* **2021**, *30*, 864–882. [CrossRef]
15. Choi, T.M. Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains. *Transport. Res. E Logist. Transport.* **2019**, *128*, 17–29. [CrossRef]
16. Dong, L.X.; Jiang, P.P.; Xu, F.S. Impact of traceability technology adoption in food supply chain networks. *Manag. Sci.* **2022**, *69*, 1324–1934. [CrossRef]
17. Wu, X.Y.; Fan, Z.P.; Cao, B.B. An analysis of strategies for adopting blockchain technology in the fresh product supply chain. *Int. J. Prod. Res.* **2021**, *61*, 3717–3734. [CrossRef]
18. Wang, J.; Liu, J.; Wang, F.; Yue, X. Blockchain technology for port logistics capability: Exclusive or sharing. *Transp. Res. Part B Methodol.* **2021**, *149*, 347–392. [CrossRef]
19. Orji, I.J.; Kusi-Sarpong, S.; Huang, S.F.; Vazquez-Brust, D. Evaluating the factors that influence blockchain adoption in the freight logistics industry. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *141*, 102025. [CrossRef]
20. Choi, T.M.; Ouyang, X. Initial coin offerings for blockchain based product provenance authentication platforms. *Int. J. Prod. Econ.* **2021**, *233*, 107995. [CrossRef]
21. Ding, Q.Y.; Gao, S.; Zhu, J.; Yuan, C. Permissioned blockchain-based double-layer framework for product traceability system. *IEEE Access* **2019**, *8*, 6209–6225. [CrossRef]
22. Mao, B.; He, J.; Cao, J.; Gao, W.; Pan, D. Food traceability system based on 3d city models and deep learning. *Ann. Data Sci.* **2016**, *3*, 89–100. [CrossRef]
23. Cattani, K.; Gilland, W.; Heese, H.S.; Swaminathan, J. Boiling frogs: Pricing strategies for a manufacturer adding a direct channel that competes with the traditional channel. *Prod. Oper. Manag.* **2006**, *15*, 40–56. [CrossRef]
24. Chen, J.; Zhang, H.; Sun, Y. Implementing coordination contracts in a manufacturer Stackelberg dual-channel supply chain. *Omega* **2012**, *40*, 571–583. [CrossRef]
25. Wu, H.; Cai, G.; Chen, J.; Sheu, C. Online manufacturer referral to heterogeneous retailers. *Prod. Oper. Manag.* **2015**, *24*, 1768–1782. [CrossRef]
26. Li, G.; Xue, J.; Li, N.; Ivanov, D. Blockchain-supported business model design, supply chain resilience, and firm performance. *Transport. Res. E Logist. Transport.* **2022**, *163*, 102773. [CrossRef]
27. Guan, X.; Liu, B.; Chen, Y.J.; Wang, H. Inducing supply chain transparency through supplier encroachment. *Prod. Oper. Manag.* **2020**, *29*, 725–749. [CrossRef]
28. Tsay, A.A.; Agrawal, N. Channel conflict and coordination in the e-commerce age. *Prod. Oper. Manag.* **2004**, *13*, 93–110. [CrossRef]
29. Guan, H.; Gurnani, H.; Geng, X.; Luo, Y. Strategic inventory and supplier encroachment. *Manuf. Serv. Oper. Manag.* **2019**, *21*, 536–555. [CrossRef]
30. Gao, L.; Guo, L.; Orsdemir, A. Dual-channel distribution: The case for cost information asymmetry. *Prod. Oper. Manag.* **2021**, *30*, 494–521. [CrossRef]
31. Pal, B.; Sarkar, A. Effects of green improvement and pricing policies in a double dual-channel competitive supply chain under decision-making power strategies. *RAIRO Oper. Res.* **2022**, *56*, 931–953. [CrossRef]
32. Xu, J.Y.; Meng, Q.F.; Chen, Y.Q.; Zhao, J. Dual-Channel Pricing Decisions for Product Recycling in Green Supply Chain Operations: Considering the Impact of Consumer Loss Aversion. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1792. [CrossRef]
33. Barman, A.; De, P.K.; Chakraborty, A.K.; Lim, C.P.; Das, R. Optimal pricing policy in a three-layer dual-channel supply chain under government subsidy in green manufacturing. *Math. Comput. Simul.* **2023**, *204*, 401–429. [CrossRef]
34. Song, L.; Xin, Q.; Chen, H.; Liao, L.; Chen, Z. Optimal Decision-Making of Retailer-Led Dual-Channel Green Supply Chain with Fairness Concerns under Government Subsidies. *Mathematics* **2023**, *11*, 284. [CrossRef]
35. Xiao, T.; Choi, T.M.; Cheng, T.C.E. Product variety and channel structure strategy for a retailer-Stackelberg supply chain. *Eur. J. Oper. Res.* **2014**, *233*, 114–124. [CrossRef]
36. Wang, C.; Leng, M.; Liang, L. Choosing an online retail channel for a manufacturer: Direct sales or consignment? *Int. J. Prod. Econ.* **2018**, *195*, 338–358. [CrossRef]
37. Zhao, S.; Li, W.L. Blockchain-based traceability system adoption decision in the dual-channel perishable goods market under different pricing policies. *Int. J. Prod. Res.* **2023**, *61*, 4548–4574. [CrossRef]
38. Xu, X.P.; Zhang, M.Y.; Dou, G.-W.; Yu, Y.G. Coordination of a supply chain with an online platform considering green technology in the blockchain era. *Int. J. Prod. Res.* **2023**, *61*, 3793–3810. [CrossRef]
39. Zhang, R.; Xia, Z.W.; Liu, B. Optimal Pricing Decisions for Dual-Channel Supply Chain: Blockchain Adoption and Consumer Sensitivity. *Complexity* **2022**, *2022*, 4605455. [CrossRef]
40. Zhu, S.C.; Li, J.; Wang, S.Y.; Xia, Y.S.; Wang, Y.J. The role of blockchain technology in the dual-channel supply chain dominated by a brand owner. *Int. J. Prod. Econ.* **2023**, *258*, 108791. [CrossRef]
41. Li, Q.; Li, H.L. Pricing Decisions and Online Channel Selection Strategies in Dual-Channel Supply Chains considering Block Chain. *Discret. Dyn. Nat. Soc.* **2022**, *2022*, 3027249. [CrossRef]
42. Li, Z.W.; Xu, X.H.; Bai, Q.G.; Guan, X.; Zeng, K. The interplay between blockchain adoption and channel selection in combating counterfeits. *Transport. Res. E-Log.* **2021**, *155*, 102451. [CrossRef]
43. Wang, J.; Zhang, Q.; Hou, P.W.; Li, Q.H. Effects of platform's blockchain strategy on brand manufacturer's distribution strategy in the presence of counterfeits. *Comput. Ind. Eng.* **2023**, *177*, 109028. [CrossRef]

44. Cao, B.B.; Zhu, M.F.; Tian, Q. Optimal Operation Policies in a Cross-Regional Fresh Product Supply Chain with Regional Government Subsidy Heterogeneity to Blockchain-Driven Traceability. *Mathematics* **2022**, *10*, 4592. [CrossRef]
45. Dai, B.; Nu, Y.; Xie, X.; Li, J.B. Interactions of traceability and reliability optimization in a competitive supply chain with product recall. *Eur. J. Oper. Res.* **2021**, *290*, 116–131. [CrossRef]