Research Article

Optimal Pricing Decisions for Dual-Channel Supply Chain: Blockchain Adoption and Consumer Sensitivity

Rong Zhang,1 Zhiwei Xia,1 and Bin Liu2

1Research Center of Logistics, Shanghai Maritime University, Shanghai 201306, China
2Business School, University of Shanghai for Science and Technology, Shanghai 200093, China

Correspondence should be addressed to Bin Liu; liubhnu@163.com

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Counterfeiting is common in many industries. For the authenticity of online channel products and to combat counterfeiting, many companies have begun to use blockchain technology to trace product information. This paper investigates a dual-channel supply chain consisting of one manufacturer and one retailer, in which the manufacturer sells its standard products through the retailer and adopts blockchain technology to launch the online channel to sell the traceable products. A Stackelberg game is developed to depict the pricing decision and channel strategy choice for the manufacturer. It shows that both the manufacturer and the retailer can benefit from blockchain adoption. And the longer it takes for product traceability, the lower the price of online traceable products. It is beneficial for the manufacturer when consumers in the market are less concerned about information transparency. For consumer sensitivity, as consumers’ acceptance of direct sales channels increases, the selling prices of online traceable products have risen. Furthermore, as the traceability time-sensitivity coefficient increases, the sales price of the traceable products decreases, and the retail price of offline standard products rises. The conclusion of this paper has a certain guiding role for the dominant manufacturers in choosing whether to apply blockchain technology to improve the demand for traceable products.

1. Introduction

According to data from the National Bureau of Statistics, the national online retail sales in 2020 were 11.76 trillion RMB, while the online retail sales of physical goods were 9.76 trillion RMB Yuan, accounting for 24.9% of the total retail sales of consumer goods [1]. Although the online consumer market has continued to grow and develop in recent years, online consumers cannot access products and cannot effectively distinguish between the authenticity and reliability of product-related information. Products in the categories of fresh agriculture, mother and baby, alcohol, beauty and makeup, second-hand goods, luxury goods, cross-border goods, and medicine are often replaced by imposters on the Internet. For the manufacturer, to meet consumers’ personalized preferences and pursue consumers’ demand for product traceability, the manufacturer needs to deal with the problem of enhancing their profits while relieving channel conflicts, as well as the issue of consumers’ demand for product traceability by considering product information transparency. At present, there are shortcomings in the product sales chain, such as opaque product information, difficulty tracing the origin of products, and difficulty proving the authenticity of products, etc. By adopting blockchain technology, we can make use of its decentralized, nontemperable, traceable, collective maintenance, and open and transparent features [2]. Therefore, after setting a unique label for the product, the logistics information of each product can be tracked and recorded, and consumers who purchase products supported by blockchain technology can trace the source of the product. For example, Wyeth products, by adopting the anticounterfeiting traceability service of JD blockchain, enable consumers to purchase with confidence [3]. In 2016, Walmart tested the traceability of mangoes in a store, and it took 6 days, 18:26, to trace the mangoes back to their farm of origin. But after adopting blockchain technology, the traceability is completed, and all relevant information is obtained in only 2.2 seconds [4].
above are the results of the application of blockchain technology in enterprise practice, and the following is the theoretical research on the application of blockchain technology in practice by scholars.

In terms of research on the impact of blockchain technology on supply chain decision-making, scholars at home and abroad mainly focus on the impact of blockchain technology on traditional supply chain goals, customer viscosity, traceability, transaction costs, and social welfare. Kshetri [5] and Tian [6] propose that the application of blockchain to the supply chain will improve transparency and responsibility and increase customers’ trust in product features. Kamblea et al. [7] believe that traceability is the most important reason for the realization of blockchain technology in the agricultural supply chain. Zhang et al. [8] combine blockchain technology with the Internet of Things and big data to solve the difficult problem of collecting reliable data in life cycle assessment. Tönnissen and Frank [9] use a case analysis method to explain how to use blockchain technology in supply chain operations and management. Christoph and Stephan [10] propose that blockchain can limit the impact of opportunism, environmental and behavioral uncertainty in the supply chain, thereby reducing transaction costs. Yan and Zhang [11] discuss the influence of risk aversion coefficient and blockchain technology application degree on supply chain decision-making. Liang and Xiao [12] analyze the impact of the introduction of specific parameters such as blockchain technology on the channel selection of a dual-channel supply chain. Furthermore, many scholars have focused on investigating the dual-channel supply chain when the manufacturer provides homogeneous products. Chen et al. [13], Tang et al. [14], and Zhou and Ye [15] examine the influence of nonprice factors such as product quality on the sales of a single product in different channels. Wan et al. [16], Li et al. [17] reflect the negative impact of retailer services on the online channel and find that implementing product differentiation is beneficial to both online and offline channels. Dan et al. [18] investigate the impact of retail services in retail channels and customer loyalty on pricing decisions in dual-channel supply chains. In terms of supply chain pricing, Huang et al. [19] investigated the impact of supply chain members’ altruistic preference behavior on the pricing decisions of supply chain members when consumers’ green preferences were considered. Xu et al. [20] consider optimal pricing decisions and profit issues in centralized and decentralized systems of dual-channel supply chains under mandatory carbon emission regulation. Hosseini-Motlagh et al. [21] conduct a study on energy-saving efforts in remanufacturing and forward logistics in closed-loop supply chains and analyze how remanufacturing and energy-saving efforts affect competitive selling prices and recycling rates. Motlagha et al. [22] point out the impact of demand interruption on RSC in a reverse supply chain (RSC) system and obtain the optimal pricing under demand interruption and a harmonized scheme using a combined two-part tariff contract.

Our paper contributes to the literature on whether direct sales channels adopt blockchain technology and channel pricing strategies. In the existing dual-channel supply chain research, considering the few factors of blockchain technology, the research on the traceability time of online traceable product information transparency is also rarely involved. Christoph and Stephan [10] also focus on considering whether different dual-channel structures under homogeneous products need to introduce blockchain technology. This paper starts from the perspective of manufacturers opening online direct sales channels and introducing traceable products through channel invasion based on a single channel. Focus on consumer channel preferences, the level of transparency of blockchain product information, the differentiation of online and offline products and services in direct dual-channel pricing, and the decision on whether to bring traceable products online.

To sum up, this paper introduces blockchain technology into the dual-channel and provides some guidance for whether the online channel adopts blockchain technology. Furthermore, the impact on manufacturers and consumers is explained from the perspective of manufacturer information transparency. We will study how to help manufacturers adopt blockchain technology in direct sales channels to solve the problem of product inauthenticity and traceability. How manufacturers’ costs change and how consumer sensitivities affect manufacturers when adopting blockchain technology. Specifically, we will solve the following research issues:

1. Under what conditions will the manufacturer adopt blockchain technology to offer traceable products?
2. How should the manufacturer introduce traceable products to alleviate channel conflicts? What are the effects of adopting blockchain technology on the prices and profits of both the manufacturer and retailer?

2. Problem Description

The manufacturer sells standard products through offline traditional retail channels and sells traceable products through online direct sales channels, as shown in Figure 1. In this study, the manufacturer, as the leader of the Stackelberg game, decides the selling price in the direct channel and the wholesale price for the retailer. Then, the retailer, as the follower, determines the retail price of standard products. Third, both the manufacturer and the retailer are completely rational decision-makers, which means that both make optimal decisions based on the principle of maximizing their profits.

The retailer wholesales the standard product from the manufacturer at the wholesale price \( w \) and sells it to consumers at the retail price \( p_r \). The manufacturer sells the traceable products directly to consumers at the price \( p_d \). We denote consumers’ acceptance level of the online channel as \( \theta \), where \( 0 \leq \theta \leq 1 \), and the consumers’ valuation of the products as \( v \), which is uniformly distributed on. Then, the consumers’ valuation of the online products is \( \theta v \).

Consumer utility of the online direct sales channel is related to the level of transparency of traceable products’
information (product information includes transaction information, origin information, product information, and logistics information) and the time of traceable products’ traceability. Therefore, the consumer utility of the online retail channel can be expressed as \( U_d = \theta r - p_d + e - \beta t \). We denote the level of traceable products’ information transparency as \( e (0 \leq e \leq 1) \), which the larger the value, the more realistic the product. The consumers’ sensitivity to the traceable products’ traceability sensitivity to time is \( \beta \) and the time spent waiting for product traceability from the consumer is \( t \). Then, the consumer utility of the offline retail channel can be expressed as \( U_r = v - p_r \).

When the manufacturer and the retailer sell these two products at the same time, which product consumers choose depends on the size of the consumer’s surplus value. So, when \( U_d > U_r \) and \( U_d > 0 \), we have \( p_d - e + \beta t/\theta < v < p_r - p_d + e - \beta t/1 - \theta \), and consumers choose to buy online traceable products. When \( U_r > U_d \) and \( U_r > 0 \), we have \( v > \max (p_r - p_d + e - \beta t/1 - \theta, p_d - e + \beta t/\theta) \), and consumers choose to buy standard offline products. When \( U_d = U_r \), we have \( v = p_r - p_d + e - \beta t/1 - \theta \), under which there is no difference in the utility of consumers buying two products.

Through the residual value function, we get the online direct sales channel demand \( Q_d \) and the offline retail channel demand \( Q_r \), respectively as

\[
Q_d = \begin{cases} 
\frac{p_r - p_d + e - \beta t}{1 - \theta} - \frac{p_d - e + \beta t}{\theta}, & p_r > p_d - e + \beta t, \\
0, & \text{others},
\end{cases}
\]

\[
Q_r = \begin{cases} 
1 - \frac{p_r - p_d + e - \beta t}{1 - \theta}, & p_r > p_d - e + \beta t, \\
1 - \frac{p_r - e + \beta t}{\theta}, & \text{others}.
\end{cases}
\]

### 3. Dual-Channel Supply Chain Decision Model

#### 3.1. Dual-Channel Supply Chain Model for Online Traceable Products

The manufacturer and the retailer each make decisions for their profit maximization, and their profit functions are, respectively,

\[
\pi_m = wQ_r + \left( \frac{p_d}{l/t} \right) Q_d - \frac{e^2}{2},
\]

\[
\pi_r = \left( p_r - w \right) Q_r.
\]

We denote the cost of each traceability of the manufacturer as \( l/t \), and the cost of single traceability is related to time \( t \). Furthermore, the shorter the traceability time, the higher the cost. We refer to Aspremont [23] and other documents for the explanation and the form of innovation input cost. We denote one-time fixed cost to be paid by the manufacturer for introducing blockchain technology as \( e^2/2 \), which implies that the higher the level of transparency of traceable products information, the higher the cost, where \( p_d > l/t \).

When \( p_r \leq \left( p_d - e + \beta t \right)/\theta \), the online direct sales channel has zero sales, that is, consumers will only buy standard offline products, so this situation is outside the scope of the study. When \( p_r > \left( p_d - e + \beta t \right)/\theta \), both sales channels have their own demand. Therefore, using the inverse solution method, the retailer’s optimal response is obtained as

\[
p_r = \frac{(p_d + w - \theta - e + \beta t + 1)}{2}.
\]

From the first stage of the game, the manufacturer determines the sales price of online traceable products \( p_d \) and the wholesale price of offline standard products \( w \), and the optimal solution is

\[
p_d = \frac{\theta + e - \beta t + l/t}{2},
\]

\[
p_r = \frac{3 + \beta t - e - \theta + l/t}{2},
\]

\[
w^* = \frac{1}{2}.
\]

\[
p^*_d = \frac{2 / 2}{4}\theta(1 - \theta) + (2\theta^2 - 3\theta + 2)l/t + \theta^3 - \theta^2 + \theta/2
\]

\[
(4\theta^2 - 5\theta + 2).
\]

Substituting equations (7) and (8) into (4), the optimal selling price of offline retail channels can be derived as

\[
p^*_r = \frac{\theta(\beta + l/t)(\theta - 1) - \theta^2 + 4\theta^2 - 4\theta + 2/3}{4\theta^2 - 5\theta + 2}.
\]

Therefore, the maximum profits of the manufacturer and the retailer are, respectively,
\[ e^* = \frac{(\beta t + 1/t)(2 - \theta) + \theta^2 - \theta}{4\theta^2 - 5\theta + 2}, \]
\[ \pi_r^* = \frac{(1 - \theta)(\beta t + 1/t - \theta^2 + \theta - 1/2)}{(4\theta^2 - 5\theta + 2)^2}, \]
\[ \pi_m^* = \frac{(\theta - 2)(\beta^2 I^2 + 2\beta I + I^2/t^2) + 2(1 - \theta)(\beta t + 1/t) + \theta^2 - \theta + 1/2}{2(4\theta^2 - 5\theta + 2)}. \]

**Proposition 1.** As the level of information transparency of online traceable products increases, the selling price of online traceable products also increases, while the retail price of standard offline products decreases and the profitability of the retailer decrease.

**Proof.** Solving for the first-order condition of the optimal selling price \( p_d \) of the online traceable products, the optimal selling price \( p_r \) of the offline standard product, and the maximum profit \( \pi_r \) of the retailer for the level of information transparency of the traceable products \( e \), respectively, we can gain
\[
\frac{\partial p_r}{\partial e} = -\frac{1}{4} < 0, \quad \frac{\partial p_d}{\partial e} = \frac{1}{2} > 0.
\]

**Proposition 2.** shows that the manufacturer improves the level of information transparency of online direct marketing channels. Thus, consumers’ pursuit of information transparency makes them more inclined to purchase traceability products online. Thus, the manufacturer raises the sales price of online traceability products. The retailer is at a competitive disadvantage due to the impact of online direct marketing channels. Therefore, the only choice is to lower the sales price to maintain sales volume.

**Proposition 3.** As the time-sensitivity factor \( \beta \) for the traceability of the traceable products increases, the selling price of the traceable products decreases, while the retail price of standard offline products increases.

**Proof.** Solving for the first-order necessary condition of the optimal selling price \( p_d \) of the traceable products and the optimal selling price \( p_r \) of the offline standard product for the time-sensitivity coefficient \( \beta \) of the traceability of the traceable products, respectively, we can get
\[
\frac{\partial p_r}{\partial \beta} = \frac{t\theta(1 - \theta)}{4\theta^2 - 5\theta + 2} > 0, \quad \frac{\partial p_d}{\partial \beta} = \frac{2t\theta(1 - \theta)}{4\theta^2 - 5\theta + 2} < 0.
\]

**Proposition 4.** shows that as the time-sensitive factor of traceability of traceable products increases, the price of traceable products decreases. As a result, the manufacturer lowers the price of traceable products to offset the long wait time for consumers. In contrast, consumers’ increased trust in standard offline products have led retailers to raise prices.

**Proposition 5.** When \( \beta t + 1/t < 1/4 \), compared with the dual-channel supply chain of standard products, the retail price, the sales price of traceable products, and the profit of retailers in
the dual-channel supply chain using blockchain will all increase.

\[
p_r - p_r^S = \frac{\theta(\theta - 1)(4\beta t - 1) + l/t(4\theta^2 - 6\theta + 4)}{2(4\theta^2 - 5\theta + 2)} > 0, \\
p_d - p_d^S = \frac{\theta(\theta - 1)(4\beta t + 4l/t - 1)}{4(4\theta^2 - 5\theta + 2)} > 0, \\
\pi_r - \pi_r^S = \frac{\theta(1 - \theta)(4\beta t + 4l/t - 1)[4\theta(\beta t + l/t) - (8\theta^2 - 9\theta + 4)]}{16(4\theta^2 - 5\theta + 2)^2} > 0. 
\]

Proposition 6. shows that after adding an online traceability service based on a standard product dual channel, the cost of the online direct sales channel increases. As a result, the manufacturer takes advantage of consumers’ preference for online traceable products to increase prices in online direct sales channels. For the retailer, the emergence of traceable products has eased the channel competition brought about by selling homogeneous products online and offline. The retailer no longer needs to cut prices to retain consumers, and profits have also improved to a certain extent compared to standard product dual-channel supply chains.

4. Numerical Analysis

4.1. Effect of Consumer Online Channel Acceptance on Price. Numerical tests are conducted by taking \( \beta = 0.02, t = 2, l = 0.3 \) and \( \theta \) variations in the range \([0, 1]\), respectively, to obtain the effect of changes in consumer online channel acceptance level \( \theta \) on price. Figure 2 shows that as \( \theta \) gradually increases from 0 to 1, the sales price of online traceable products tends to increase, while the sales price of offline standard products tends to decrease. As consumer acceptance of online direct sales channels increases, consumers will be more likely to buy products online. Therefore, the manufacturer increases the selling price of online traceable products. For the retailer, due to the impact of direct sales channels, the retailer is at a disadvantage and can only choose to lower sales prices to maintain sales.

4.2. Comparison of the Manufacturer’ Profits in the Dual-Channel Supply Chain of the Traceable Products and Standard Products. Numerical experiments are conducted by taking \( \beta = 0.02, t = 2, l = 0.3, \) and \( \theta \) variations in the range \([0, 1]\) respectively. It can obtain a comparison of the profits of the two types of dual-channel supply chains used by the manufacturer. Figure 3 shows that when consumers’ acceptance of the direct sales channel is not big. Therefore, the blockchain input cost of the direct sales channel cannot be offset, which makes the manufacturer’s profit decline. In addition, when the acceptance of direct selling channels is higher than a certain value, the profit of the dual-channel supply chain adopting blockchain is always higher than that of the standard product dual-channel supply chain. When \( \theta \) is constant, and as \( \beta \) increases, the manufacturer’s profit in the dual-channel traceability product decreases. Only when \( \theta \) is too large and \( \beta \) is small enough, the profit of the manufacturer adopting the blockchain be greater than the profit of the manufacturer not adopting the blockchain.

4.3. Effect of Traceability Time on Price. Numerical experiments are conducted by taking \( \theta = 0.8, \beta = 0.02, l = 0.3 \), and \( t \) within the range of \([0, 10]\) respectively. It can be used to obtain the effect of traceability time on price. Figure 4 shows that when the traceability time of the traceable products continues to increase for direct sales channels, the sales price of traceable products continues to drop. For the retailer, the retail prices of offline standard products show a trend of rising first and then falling. When \( t \) increases to a critical value, it is always higher than the direct selling price.

5. Extension

This section extends our basic model by introducing consumers’ sensitivity parameters to the level of information transparency of traceable products to check the robustness of the conclusions. Specifically, after introducing parameters, a new dual-channel model is constructed. Then, we solve the corresponding optimal solution. Finally, we graphically explore the impact of the changes in the sum on manufacturers and retailers.

5.1. The Model by Introducing Consumers’ Sensitivity Parameters. The new model introduces consumers’ sensitivity to the transparency level of blockchain product information \( \gamma \), and other parameters are the same as the basic model. Therefore, the consumer utility of the online direct sales channel can be expressed as \( U_d = \theta v - p_d + ye - \beta t \). And the consumer utility of the offline retail channel can be expressed as \( U_r = v - p_r \).

Through the residual value function, we get the online direct sales channel demand \( Q_d \) and the offline retail channel demand \( Q_r \), respectively, as
Figure 2: Effect of $\theta$ on price.

Figure 3: Effect of $\theta$ on the manufacturer’s profit in the dual-channel supply chain adopting blockchain.

Figure 4: Effect of $t$ on price.
The manufacturer and the retailer each make decisions for their profit maximization, and their profit functions are, respectively,

\[ \pi_m = \mu Q_r + \left( p_d - \frac{I}{t} \right) Q_d - \frac{\eta \gamma^2}{2}, \quad (18) \]

\[ \pi_r = (p_r - \omega) Q_r. \]

According to the basic model solving method, the optimal solution is

\[ \pi^*_m = \frac{(1 - \theta) \left[ 2 \eta \beta (\beta t + l/t + 1 - \theta - \gamma^2) \right]^2}{4 \left[ y^2 (\theta - 2) + 4 \eta \theta (1 - \theta) \right]^2}, \]

\[ \pi^*_r = \frac{(2 - \theta) \left( \eta \beta^2 t^2 + 2 \eta \beta l + \eta^2 l^2 / t^2 \right) + 2 \eta \theta (\beta t + l/t) (\theta - 1) + \eta \theta (1 - \theta^2) - 1/2 \gamma^2}{2 \left[ y^2 (\theta - 2) + 4 \eta \theta (1 - \theta) \right]}. \]

5.2. Consumers’ Sensitivity to the Level of Information Transparency of Traceable Products. Numerical tests are conducted by taking \( \theta = 0.8, \ t = 2, \ l = 0.3, \eta = 1 \) and \( \gamma \) variations in the range \([0, 1]\), respectively. Therefore, we can get the impact of changes in consumers’ sensitivity to the transparency level of traceable product information on manufacturers and retailers.

Figure 5 shows that when consumers’ sensitivity to information transparency is lower than a certain value, the increase in consumers’ sensitivity to traceability time will increase the manufacturer’s profit. However, when it is higher than a certain value, consumers’ increased sensitivity to time will reduce the manufacturer’s profit. Therefore, the sensitivity of consumers to information transparency should not be too high, which will be more conducive to the increase of the manufacturers’ profits.

Figure 6 shows that the profit of retailers with dual channels of traceability products is always higher than that of retailers with dual channels of common products. In addition, when consumers’ sensitivity to information transparency is lower than a certain value, the increase in consumers’ sensitivity to traceability time will increase the retailer’s profit. However, when it is higher than a certain value, consumers’ increased sensitivity to time will reduce the retailer’s profit. Therefore, the sensitivity of consumers to information transparency should not be too high, which will be more conducive to the increase of retailer’s profits.
6. Conclusion

This paper investigates the dual-channel supply chain for online traceable products and uses the Stackelberg game to find the optimal decisions for the manufacturer and the retailer and compares the results with the product prices and profits of the dual-channel supply chain for standard products. In addition, we also extend the model by considering consumers’ sensitivity to the transparency of traceable product information. We can draw the following conclusions:

(1) The inclusion of traceable products in the dual-channel supply chain of standard products can increase the profits of both the manufacturer and the retailer and can mitigate channel competition.

(2) When consumers’ acceptance of online channels exceeds a certain threshold, the manufacturer’s profits will increase. But when consumers’ acceptance of online channels is below a certain threshold, the manufacturer’s profits will decrease. The manufacturer can obtain higher profits by controlling the transparency level of blockchain product information while also improving brand awareness.

(3) When the manufacturer adds online traceable products to their standard product dual-channel supply chains, they can mitigate the impact of online direct sales channels on offline retail channels, thus allowing the retailer to realize a degree of increased product sales prices and profits.

The conclusions of this article have a certain guiding effect on whether the dominant manufacturer chooses to apply the dual-channel supply chain model that considers the adoption of blockchain online.

This paper analyzes the impact of blockchain technology on dual-channel supply chain pricing from a manufacturer-dominated perspective. If we consider the complete information setting in this paper, However, in the presence of customer loyalty, the coordination problem of the supply chain with asymmetric information is an interesting and challenging issue. It can be further expanded in future research, such as further analyzing the role of blockchain in combination with social welfare and considering the impact of blockchain technology on sustainable development.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

All authors declare that there are no possible conflicts of interest.

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