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Analyzing the Effects of Government Subsidies on Dual-Channel Fresh Food Supply Chains with the Implementation of Blockchain Traceability Technology

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Abstract. With the rapid development of the social economy, consumer preferences have evolved significantly. Nowadays, consumers place a higher emphasis on product quality and origin. The challenge is to ensure effective supervision of the entire food production process, from farm to consumers' tables, and to address traceability and accountability issues when food safety problems arise. The emergence of blockchain technology offers a promising solution. Blockchain's decentralization and traceability capabilities can effectively monitor food status information. However, given the cost of implementing blockchain technology and the varying degrees of sensitivity consumers have to product quality and price, the question arises: should supply chains have strong incentives to adopt blockchain technology? This paper focuses on the fresh agricultural product supply chain, encompassing both online and offline retailers, and employs the Stackberg game model to examine the impact of blockchain technology adoption under a government subsidy scenario. The research findings of this article indicate that the decision to introduce blockchain technology by online suppliers is influenced by the cost associated with each unit of fresh products. Furthermore, government subsidies prove advantageous primarily for online retailers.

Keywords: Fresh food supply chain; blockchain; traceability.

1. Introduction

In recent years, food safety problems have frequently led to severe consequences. In 2006, more than 200 people in 26 states were infected and fell ill, with 14 experiencing renal failure and 3 fatalities. Even children were affected by these issues, experiencing stunted physical development, reduced height, lower intelligence compared to their peers, and accompanying kidney disease and other syndromes. Furthermore, there have been several food safety incidents, such as the "ditch oil" production and sale incident in 2010 and the "lean meat essence" incident in 2011. These incidents often occur within the context of food industrialization, as merchants prioritize profit over safety, leading to problems like difficulties in postponing recalls and insufficient accountability. Therefore, the rapid and accurate traceability of products in the food supply chain cannot be overlooked.

Product traceability involves identifying or recording all the links from production to sales. In the 1970s, barcode technology, one of the earliest methods for product traceability, was applied in the field of food traceability. Subsequently, traceability technologies based on image codes and wireless radio frequency recognition were widely adopted in the food, pharmaceutical, and animal husbandry industries, as well as other fields.

Fresh products are among the most consumed items by consumers. Any issues in the fresh supply chain can affect a large number of consumers. The rapid development and innovation of blockchain technology have helped us address numerous practical problems. This article thoroughly explores the traceability features of blockchain and uses this technology to oversee the entire product lifecycle. It prevents food safety issues and streamlines traceability and accountability procedures in the event of safety incidents. While introducing new technology may entail additional costs for merchants, potentially impacting their operations, these costs are eventually passed on to

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consumers. Consumers vary in their sensitivity to price and quality, which, in turn, influences their purchase decisions.

Regarding public safety and well-being, the government formulates measures and takes corresponding actions to ensure social stability. For instance, during the COVID-19 outbreak, consumers became concerned about the source and quality of fresh agricultural products. Blockchain technology offers traceability and information disclosure, allowing consumers to quickly trace the origin of products. However, some participants in the fresh supply chain may opt not to use blockchain technology due to its implementation costs. Therefore, the government has a strong incentive to support the adoption of blockchain technology in the fresh supply chain. This support may come in the form of funding or policies to encourage relevant enterprises to implement blockchain technology. Based on this analysis, this article examines the impact of government subsidies on the fresh supply chain and the motivating effect of such subsidies on its participants.

2. Literature References

The fresh supply chain is an organizational structure consisting of agricultural producers, processors, suppliers of agricultural production materials, logistics service providers, and consumers [7]. There is an abundance of literature covering various aspects of the fresh supply chain. For instance, concerning channel selection, researchers like Chen et al. have integrated consumer channel selection models to determine the best dual channel strategy for manufacturers [8]. Bernstein and others have examined the channel selection of retailers, revealing that online channels do not necessarily result in higher profits [9]. Wang and colleagues have investigated retailer channel selection strategies, finding that retailers tend to opt for dual channel strategies only when the cost gap is substantial enough [10].

Regarding information sharing and information asymmetry, Ma and their team have considered asymmetric information in the decentralized decision-making model. They found that fragmented decision-making can lead to distortions in orders and sales prices, ultimately resulting in a loss of supply chain profits [11]. Liu and colleagues have explored the information sharing strategy in the fresh agricultural retail supply chain, discovering that information sharing can benefit electronic retailers, who often choose to share information voluntarily [12]. Chen and their team have researched demand information sharing between retailers and two competitors [13].

Concerning the impact of blockchain on the supply chain, Gurtu and Johny conducted a comprehensive review of 299 research papers on blockchain and supply chains. They found that blockchain can effectively reduce the role of intermediaries, thus enhancing supply chain efficiency. This technology is poised to have a disruptive impact on supply chains in multiple industries [14]. Longo and colleagues have introduced a supply chain model based on blockchain technology that realizes the concept of a circular economy and addresses many of the current supply chain's shortcomings [15]. Schmidt and Wagner argue that transaction cost theory provides a better framework for understanding how blockchain affects supply chain relationships, particularly in terms of transaction costs and governance decisions [16].

Additionally, there are numerous studies exploring the application of blockchain in supply chains from various perspectives. Kamble and their colleagues have identified and established a link between the promotion of blockchain technology in the agricultural supply chain, emphasizing transparency as a crucial driver for its application [17]. Wu and Yu have examined the impact of blockchain technology on platform supply chains from the perspective of information transparency and transaction costs [18]. Tao and their team have investigated the impact of blockchain technology on optimal pricing and quality decisions under different supply chain structures, finding that, in some cases, suppliers may be motivated to use blockchain technology to enhance product quality [19]. Wu and their colleagues have researched the strategy of implementing blockchain technology in the supply chain of fresh agricultural products, involving suppliers, third-party

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logistics service providers (3PL), and electronic retailers, concluding that adopting blockchain technology may not always be the best decision for the fresh agricultural supply chain [20].

The impact of subsidy strategies on supply chains has also been studied. Zhong and their team have considered both centralized and decentralized decision-making models to explore the influence of subsidies, showing that government subsidies for cooperatives are more effective than those for consumers, regardless of the supply chain structure [21]. He and others have examined the impact of the epidemic on the interaction between epidemic pricing, production capacity, and retailer sales models, finding that while government subsidies have increased retailer profits in some cases, they can also harm consumers in specific situations [22].

In summary, many scholars have conducted research on issues related to fresh supply chain channel selection, performance improvement, and blockchain applications, indicating the significant potential of blockchain technology for supply chains. However, in-depth research on the application of blockchain technology within the fresh supply chain remains limited. Therefore, this article aims to explore the application of blockchain technology in the fresh supply chain and discuss the impact of government subsidies, blockchain, and other technologies on supply chain participants.

3. Main Text

3.1 Dual channel competition model

We considered a fresh agricultural product supply chain, consisting of a supplier that provides products to both an online retailer and an offline retailer, who in turn serve consumers. As illustrated in the figure, the online retailer directly sells fresh agricultural products to consumers, and so does the offline retailer. This setup results in lower retailer competition. When consumers purchase fresh agricultural products online, their perceived quality level of the product is denoted as $\overline{q_0}(0 < \overline{q_0} < 1)$, whereas the actual quality level of the product is represented as $q_0(0 < q_0 < 1)$.

(1) When the fresh food supply chain does not incorporate blockchain technology, consumers perceive the quality level of fresh agricultural products sold by online retailers as $\overline{q_0}$, while the perceived quality level of a product purchased from an offline retailer closely aligns with the actual quality level q_0 of the product.

(2) When blockchain technology is integrated into the fresh food supply chain, the use of blockchain technology enables consumers to perceive the quality of fresh agricultural products sold by online retailers in a manner consistent with their experience when purchasing from offline retailers. In this scenario, the perceived quality level almost always matches the actual quality level q_0 of the product.

This article assumes the following key points:

1、The article assumes a normalized market size, which accurately reflects the real-world conditions and does not impact the article's conclusions.

2、In the research scenario of this article, we assume that both online retailers and offline retailers have concurrent market demands, and no monopoly situation arises. Furthermore, the market comprises consumers with varying degrees of sensitivity to quality and price. Here, α and β represent consumer sensitivity to quality and price, respectively $(\alpha, \beta \in (0,1))$.

3、The distribution of consumer evaluations of products is represented as $\theta \epsilon [0, Q]$ and follows a uniform distribution $\theta \sim U[0,1]$.

3.1.1Modelling Dual-Channel Competition in the Fresh Food Supply Chain Without Blockchain Technology

The utility function for consumers purchasing fresh agricultural products from online retailers is expressed as $U_0 = \alpha \overline{q_0} \theta - \beta p_0$, where p_0 represents the sales price on the online e-commerce platform.

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The utility function for consumers purchasing fresh agricultural products from offline retailers is given by $U_r = \alpha q_r \theta - \beta p_r$, where p_r represents the sales price of offline retailers and q_r is the product quality level of offline retailers. When $q_r = 1$, consumers opt for the highest quality products since they can physically inspect and select products in offline stores, thus ensuring the purchase of the best-quality fresh agricultural products. It is assumed here that we exclude any errors made by consumers while shopping offline.

When $U_0 > \max\{U_r, 0\}$, consumers choose to make their purchases online. Conversely, when $U_r > \max\{U_0, 0\}$, consumers opt for offline purchases.

The following are the demand and revenue functions for online and offline retailers:

$$D_0 = \int_{\frac{\beta p_0}{\alpha \overline{q_0}}}^{\frac{\beta(p_r - p_0)}{\alpha(1-\overline{q_0})}} d\theta = \frac{\beta}{\alpha}\left(\frac{p_r - p_0}{1-\overline{q_0}} - \frac{p_0}{\overline{q_0}}\right) \qquad D_r = \int_{\frac{\beta(p_r - p_0)}{\alpha(1-\overline{q_0})}}^{1} d\theta = \left(1 - \frac{\beta(p_r - p_0)}{\alpha(1-\overline{q_0})}\right)$$

$$\pi_0 = p_0 \frac{\beta}{\alpha}\left(\frac{p_r - p_0}{1-\overline{q_0}} - \frac{p_0}{\overline{q_0}}\right) \qquad \pi_r = p_r\left(1 - \frac{\beta(p_r - p_0)}{\alpha(1-\overline{q_0})}\right)$$

Theorem 1: In a scenario where the fresh food supply chain does not employ blockchain technology, and online and offline retailers engage in competition, the optimal average strategy for the supply chain is as follows: $p_0^N = \frac{\alpha \overline{q_0}(1-\overline{q_0})}{\beta(4-\overline{q_0})}$; $p_r^N = \frac{2\alpha(1-\overline{q_0})}{\beta(4-\overline{q_0})}$; $\pi_0^N = \frac{\alpha \overline{q_0}(1-\overline{q_0})}{\beta(4-\overline{q_0})^2}$; $\pi_r^N = \frac{4\alpha(1-\overline{q_0})}{\beta(4-\overline{q_0})^2}$.

Proof: $\frac{d\pi_0}{dp_0} = \frac{\beta}{\alpha}\frac{p_r \overline{q_0} - 2p_0}{(1-\overline{q_0})\overline{q_0}}$, $\frac{d^2\pi_0}{dp_0{}^2} = \frac{\beta}{\alpha}\frac{-2}{(1-\overline{q_0})\overline{q_0}} < 0$, $\frac{d\pi_r}{dp_r} = 1 - \frac{\beta(2p_r - p_0)}{\alpha(1-\overline{q_0})}$, $\frac{d^2\pi_r}{dp_r{}^2} = \frac{\beta}{\alpha}\frac{-2}{1-\overline{q_0}} < 0$ $\frac{d\pi_0}{dp_0} = 0, \frac{d\pi_r}{dp_r} = 0 \Rightarrow p_0^N = \frac{\alpha \overline{q_0}(1-\overline{q_0})}{\beta(4-\overline{q_0})}, p_r^N = \frac{2\alpha(1-\overline{q_0})}{\beta(4-\overline{q_0})}$. By incorporating p_0^N and p_r^N into the retailer's revenue function, we can derive the following results: $\pi_0^N = \frac{\alpha \overline{q_0}(1-\overline{q_0})}{\beta(4-\overline{q_0})^2}$, $\pi_r^N = \frac{4\alpha(1-\overline{q_0})}{\beta(4-\overline{q_0})^2}$.

In general, when the perceived quality level of fresh produce sold by an online retailer is higher, the retailer tends to increase the sales price of the product. However, by examining the optimal strategy solution, we find that consumers' perceived quality level, denoted as $\overline{q_0}$, for fresh agricultural products sold by online retailers does not exhibit a straightforward, monotonic relationship with the sales price p_0^N of online retailers. Specifically, when $\overline{q_0} \in (0, 4 - 2\sqrt{3})$, the sales price p_0^N for online retailers increases monotonically within this interval. However, when $\overline{q_0} \in (4 - 2\sqrt{3}, 1)$, the sales price p_0^N decreases. This means that when consumers' perceived quality level of agricultural products purchased online exceeds a certain threshold, the sales price of online retailers decreases instead.

When consumers perceive a lower quality level of fresh agricultural products online, and there's a significant gap between their perception and the quality level they perceive when shopping offline, online retailers take measures to enhance consumers' perception of higher product quality. In such cases, this can boost consumers' purchase intention, leading to increased sales for the online retailer, and subsequently, the retailer raises the sales price to increase income.

Conversely, when consumers perceive the quality level of fresh agricultural products online to be greater and similar to what they perceive through offline shopping, online retailers implement strategies to lower the sales price of products, attracting more consumers and boosting sales.

When $\alpha > \beta$, which indicates a quality-sensitive consumer, the retailer can raise the sales price to generate higher revenue. Quality-sensitive consumers are willing to pay more for superior products. Conversely, this doesn't hold true for price-sensitive consumers. Hence, the optimal strategy for retailers is to distinguish between consumer types and offer tailored products or services, thereby maximizing their revenue.

3.1.2Modelling Dual-Channel Competition in the Fresh Food Supply Chain With Blockchain Technology

Many enterprises lack the resources to build their own blockchain platforms and must rely on purchasing related technical services to leverage blockchain technology. In the model presented in this article, online retailers acquire blockchain technology services from blockchain service providers. Through blockchain technology, they can transparently disclose the true quality level of

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their products and establish comprehensive monitoring of fresh agricultural products throughout their journey, from production to sale on the platform. This end-to-end traceability and platform management enhances the safety oversight of fresh agricultural products. The cost incurred by online retailers to implement blockchain technology depends on the fees charged by these service providers. In most instances, the introduction cost is closely tied to product demand. Additional expenses associated with traceability technology primarily involve cloud computing and label costs. It's important to note that this model excludes research and development costs and fixed construction expenses related to blockchain technology. Instead, it assumes a linear cost c for the application of blockchain technology.

The utility function for consumers purchasing fresh agricultural products online is expressed as $U_0 = \alpha q_0 \theta - \beta p_0$. Here, q_0 represents the true quality of the product disclosed by the platform using blockchain technology, and p_0 is the sales price on the online e-commerce platform.For consumers purchasing fresh agricultural products from offline retailers, their utility function is represented as $U_r = \alpha q_r \theta - \beta p_r$, where p_r represents the sales price of offline retailers, and q_r denotes the product's quality level.

In this scenario, the revenue function for the online and offline retailer is as follows:

$$\pi_0 = (p_0 - c)\frac{\beta}{\alpha}\left(\frac{p_r - p_0}{1-q_0} - \frac{p_0}{q_0}\right) \qquad \pi_r = p_r\left(1 - \frac{\beta(p_r - p_0)}{\alpha(1-q_0)}\right)$$

Theorem 2: When the fresh food supply chain adopts blockchain technology, and online and offline retailers compete, the optimal average strategy for the supply chain is as follows: $p_0^B = \frac{\alpha q_0(1-q_0)+2\beta c}{\beta(4-q_0)}$, $p_r^B = \frac{2\alpha(1-q_0)+\beta c}{\beta(4-q_0)}$; $\pi_0^B = \frac{[\beta c(q_0-2)+\alpha q_0(1-q_0)]^2}{\beta q_0(1-q_0)(4-q_0)^2}$; $\pi_r^B = \frac{[\beta c+2\alpha(1-q_0)]^2}{\beta(1-q_0)(4-q_0)^2}$.

Proof: The proof step is the same as theorem 1.

The adoption of blockchain technology has significantly influenced the fresh agricultural product supply chain. In the case of online retailers, they often seek to recover the costs associated with implementing blockchain technology, which leads to an increase in the price p_0^B. However, this increase in p_0^B typically results in a reduction in sales volume. Additionally, changes in the profits of online retailers are also tied to the actual quality level of their products. As online retailers raise p_0^B, offline retailers tend to respond by increasing p_r^B in order to boost their own revenue.

3.2 The Influence of Government Regulations on Dual Channels in the Fresh Food Supply Chain

The fresh food supply chain initially refrains from implementing blockchain technology due to cost constraints. However, to address food safety concerns, the government decides to offer subsidies, denoted as s ($0 < s < c$), to incentivize supply chain members to adopt blockchain technology. In this scenario, the revenue functions for both online retailers and offline retailers are as follows:

$$\pi_0 = (p_0 - c + s)\frac{\beta}{\alpha}\left(\frac{p_r - p_0}{1-q_0} - \frac{p_0}{q_0}\right) \qquad \pi_r = p_r\left(1 - \frac{\beta(p_r - p_0)}{\alpha(1-q_0)}\right)$$

Theorem 3: When the government increases subsidies for blockchain technology, the optimal equilibrium strategy for the fresh food supply chain is as follows: $p_0^* = \frac{\alpha q_0(1-q_0)+2\beta(c-s)}{\beta(4-q_0)}$, $p_r^* = \frac{2\alpha(1-q_0)+\beta(c-s)}{\beta(4-q_0)}$; $\pi_0^* = \frac{[\beta c(q_0-2)+\alpha q_0(1-q_0)]^2}{\beta q_0(1-q_0)(4-q_0)^2}$, $\pi_r^* = \frac{[\beta(c-s)+2\alpha(1-q_0)]^2}{\beta(1-q_0)(4-q_0)^2}$.

Proof: The proof step is the same as theorem 1.

When the government provides subsidies to online retailers adopting blockchain technology, the gap between offline and online sales prices, originally given by $\frac{\alpha(2-q_0)(1-q_0)-\beta c}{\beta(4-q_0)}$, is reduced to $\frac{\alpha(2-q_0)(1-q_0)-\beta(c-s)}{\beta(4-q_0)}$. This reduction in the price gap between online and offline sales is a direct result of government subsidies. These subsidies enable online retailers to decrease the unit cost of fresh products. As a result, the cost of introducing blockchain technology is not entirely passed on to consumers but is partially covered by the government. Consumers generally view government

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subsidies to businesses that ultimately benefit them as a positive initiative. The consequence of this shift is that offline retailers are compelled to lower their sales prices to maintain a competitive edge, given the decreasing sales prices of online retailers.

4. Summary

This paper investigates a fresh produce supply chain encompassing both online and offline retailers. Given the varying perceived and actual product quality levels of fresh agricultural products depending on the consumer's choice of purchasing channel, as well as the associated costs of implementing blockchain technology within the fresh food supply chain, we aim to assess the repercussions of blockchain technology introduction on this supply chain and explore the influence of government subsidies on retailers. The key findings of this article can be summarized as follows:

(1) Blockchain technology exerts a significant impact on the fresh food supply chain. It aids consumers in obtaining a better understanding of product quality levels, thereby enhancing the sales of online retailers. However, the introduction of blockchain may not necessarily translate into higher profits for online retailers, as they must manage the additional costs incurred by implementing this technology. Interestingly, the adoption of blockchain technology by offline retailers can lead to increased profits for them. This is because online retailers may need to raise their prices to offset the expenses associated with blockchain technology. Consequently, offline retailers also raise their prices to bolster their revenue.

(2) The decision of whether online retailers should implement blockchain technology primarily hinges on the additional cost incurred per unit of fresh products during its application. When the cost of applying blockchain technology to each unit of fresh agricultural products satisfies specific conditions, online retailers should consider introducing blockchain technology to disclose the genuine quality information of fresh agricultural products.

(3) Government subsidies prove advantageous for online retailers, serving as an incentive for them to adopt blockchain technology. However, these subsidies may have adverse effects on offline retailers.

(4) Before embracing blockchain technology, retailers should assess the distribution of consumer types in the market and offer products or services tailored to each group to optimize their revenue.

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