The Impact of Blockchain on Fresh Product Supply Chain——A Model Based on Profit Maximization

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Abstract: To investigate whether blockchain can bring more benefits to fresh product supply chain, this paper builds a mathematical model based on profit maximization, discusses the relationship among the introducing cost of blockchain, marginal transaction cost caused by traditional platforms, and consumer willingness to pay (WTP). The following conclusions have been drawn. First, for suppliers and retailers, the party responsible for maintaining trading platform will bear more costs, and whether to introduce blockchain depends mainly on whether the profits from the blockchain can cover the cost of introducing it. Second, for consumers, the introduction of blockchain technology will always increase their utility.
Keywords: Fresh Food; Blockchain; Smart Contract

1. Related work

Currently, most supply chains use traditional online platforms to manage the flow of information and goods. The main related technologies are barcodes, QR codes, and radio-frequency identification devices. Most of them are based on a single enterprise, in which information is opaque, asymmetric and not easily shared. Additionally, existing traceability systems have a single point of failure, and once a node fails, the whole system will crash[1]. Finally, with traditional methods for recording transactions and tracking assets, participants in a network keep their own ledgers and other records. It's clearly inefficient due to delays in executing agreements and the duplication of effort required to maintain numerous ledgers[2]. To sum up, this pattern cannot limit the number of risks related to business transactions, ensure the visibility and transparency of all supply chain members, or record and make the transaction contents available to interested parties[3].

To overcome the difficulties above, blockchain technology has been put into use in the industry. Blockchain is a chain of blocks one after another. The chain is stored on all the servers, and as long as one server in the system works, the whole blockchain is safe. It is a shared, immutable ledger designed to facilitate transaction logging and asset tracking processes across business networks[2]. In this case, a blockchain-based supply chain does not have to hire information system experts to prevent, control, and stop cyberattacks and eventually restore the whole set of functionalities[4]. In addition, shared ledgers eliminate the increased workload and save on the related costs.

Smart contracts are an application of blockchain. A smart contract is an agreement or set of rules that govern a business transaction; it's stored on the blockchain and is executed automatically as part of a transaction. No more faxing or emailing documents back and forth for review, revision, and signatures[2]. Smart contracts could bring us trusted transactions that are traceable and irreversible without a third party. However, as a network composed of nodes and blocks, it requires a continuous redundancy of processing nodes which require time, energy, and consequently, costs[5].

The following questions arise: is it really profitable for fresh product supply chains to apply blockchain technology (specifically, smart contracts)? Will it really bring economic profits to the members of the supply chain including consumers? This paper establishes a simple model based on profit maximization, trying to describe how each party in the fresh product supply chain reacts to the traditional platform and smart contract.

2. Modelling

Our aim is to maximise corporate profits. Listed below are the main assumptions. (1) The fresh product supply chain industry only involves three parties: supplier, retailer and customer. The supplier sells fresh products at wholesale price w to the retailer, who sells them to the customer at retail price P. In the transaction between supplier and retailer, the retailer has no bargaining power. In the transaction between retailer and customer, the customer has no bargaining power. (2) Suppliers and retailers have two options for conducting their transactions. One is to use existing traditional trading platforms, and the other is to introduce blockchain technology. (3) In the transactions between suppliers and retailers, retailers are responsible for the construction and maintenance of the trading platform. Any costs incurred by the trading platform are borne by the retailer. (4) For consumers, the lower the price, the higher the demand. If we do this mathematically, we can let U represent the utility of customer, which is also the willingness to pay. We assume a linear relationship between demand and price as well as information transparency:

$$P = a - bQ$$

Based on the above assumptions, we can construct mathematical models for the two cases respectively. The two models below have two main differences: trading costs and demands. First, in the traditional trading platform, the transaction of each product generates a marginal cost β due to an increased workload caused by separate ledgers and information asymmetry. While in the blockchain-based smart contract, there is no such problems and cost, but an fixed introducing cost ε is needed. Second, consumers prefer fresh products with more detailed information, so that they are willing to pay more for products traded under the blockchain-based smart contract. In mathematics, we use the term τ to represent that premium. The demand function of products traded under the blockchain-based smart contract is $Q = a + \tau - bp$.

Table 1. Profit mechanisms of traditional trading platform and blockchain-based smart contract

	Traditional trading platform	Blockchain-based smart contract
Profit function of supplier	$\pi_T^S = (w_T - c) \cdot Q_T - \beta Q_T$	$\pi_B^S = (w_B - c) \cdot Q_B$
Profit function of retailer	$\pi_T^R = (P_T \cdot \gamma_T Q_T - w_T Q_T) - \beta Q_T$	$\pi_B^R = (P_B \cdot \gamma_B Q_B - w_B Q_B) - \varepsilon$
Function of consumer surplus	$CS_T = \int_{P_T^*}^{a} Q_T(P_T)\, dP_T$	$CS_B = \int_{P_B^*}^{a+\tau} Q_B(P_B)\, dP_B$
Demand function	$P_T = a - b\gamma_T Q_T$	$P_B = a + \tau - b\gamma_B Q_B$

3. Analysis

3.1 Solving the problem

3.1.1 Under the traditional platform

$$\pi_T^R = (P_T \cdot \gamma_T Q_T - w_T Q_T) - \beta Q_T$$

$$\frac{\partial \pi_T^R}{\partial Q_T} =- 2b\gamma_T^2 Q_T + (a\gamma_T - w_T - \beta)$$

Let $\frac{\partial \pi_T^R}{\partial Q_T^*} = 0$, we can get $Q_T^* = \frac{a\gamma_T - w_T - \beta}{2b\gamma_T^2}$. Q_T^* represents the retailer's best decision point for any given wholesale price. We can plug it into the supplier's profit function and find the supplier's optimal solution.

$$\pi_T^S = (w_T - c) \cdot Q_T - \beta Q_T$$

$$\frac{\partial \pi_T^S}{\partial w_T} = \frac{a\gamma_T - w_T - \beta}{2b\gamma_T^2} - \frac{w_T - c}{2b\gamma_T^2} + \frac{\beta}{2b\gamma_T^2}$$

Let $\frac{\partial \pi_T^S}{\partial w_T^*} = 0$, then $w_T^* = \frac{a\gamma_T + c}{2}$. We can calculate the maximum profit of the supplier and the retailer:

$$(\pi_T^S)^* = \frac{a^2\gamma_T^2 - 2a\gamma_T c + c^2 - 4a\gamma_T\beta + 4\beta c + 4\beta^2}{8b\gamma_T^2}$$

$$(\pi_T^R)^* = \frac{a^2\gamma_T^2 - 2a\gamma_T c + c^2 - 4a\gamma_T\beta + 4\beta c + 4\beta^2}{16b\gamma_T^2}$$

Let $w_T = w_T^*$, then $Q_T^* = \frac{a\gamma_T - c - 2\beta}{4b\gamma_T^2}$, $P_T^* = \frac{3a\gamma_T + c + 2\beta}{4\gamma_T}$. We can calculate consumer surplus:

$$CS_T = \int_{P_T^*}^{a} Q_T(P_T)\, dP_T$$

$$= \frac{(a\gamma_T - c - 2\beta)^2}{32b\gamma_T^2}$$

3.1.2 Under the blockchain-based smart contract

Through the same calculation method, we can get $w_B^* = \frac{(a+\tau)\gamma_B + c}{2}$, $Q_B^* = \frac{(a+\tau)\gamma_B - c}{4b\gamma_B^2}$, $P_T^* = \frac{3(a+\tau)\gamma_B + c}{4\gamma_B}$, $(\pi_B^S)^* = \frac{(a+\tau)^2\gamma_B^2 - 2(a+\tau)\gamma_B c + c^2}{8b\gamma_B^2}$, $(\pi_B^R)^* = \frac{(a+\tau)^2\gamma_B^2 - 2(a+\tau)\gamma_B c + c^2}{16b\gamma_B^2} - \varepsilon$, $CS_B = \frac{[(a+\tau)\gamma_B - c]^2}{32b\gamma_B^2}$.

3.2 Comparing the results

In order to make the comparison of the results more simple and intuitive, in the following comparison, we assume $\gamma_B = \gamma_T = \gamma$. It is assumed, for practical purposes, that the range of γ is [0.7,1]. Then, if, within the range of γ, the benefits of introducing blockchain technology are consistently greater than those of using traditional trading platforms, we consider it is worthwhile to introduce blockchain technology.

3.2.1 Comparison of supplier's and retailer's profits

Here it is assumed that both suppliers and retailers can gain more profits by introducing blockchain technology.

$$\begin{cases} (\pi_B^S)^* - (\pi_T^S)^* > 0 \\ (\pi_B^R)^* - (\pi_T^R)^* > 0 \\ \gamma_B = \gamma_T = \gamma, \gamma \in [0.7,1] \end{cases}$$

We can figure out that the requirements for introducing blockchain technology are:

$$\begin{cases} 2a\tau + \tau^2 - 16b\varepsilon \neq 0 \\ \frac{49}{50}a\tau + \frac{49}{100}\tau^2 - \frac{196}{25}b\varepsilon + \frac{14}{5}a\beta - \frac{7}{5}\tau c - 4\beta c - 4\beta^2 > 0 \\ 2a\tau + \tau^2 - 16b\varepsilon + 4a\beta - 2\tau c - 4\beta c - 4\beta^2 > 0 \end{cases}$$

or

$$\begin{cases} 2a\tau + \tau^2 - 16b\varepsilon = 0 \\ 4a\beta - 2\tau c > 0 \\ \frac{49}{50}a\tau + \frac{49}{100}\tau^2 - \frac{196}{25}b\varepsilon + \frac{14}{5}a\beta - \frac{7}{5}\tau c - 4\beta c - 4\beta^2 > 0 \end{cases}$$

3.2.2 Comparison of consumer surplus

$$CS_B - CS_T > 0$$

Still use that assumption $\gamma_B = \gamma_T = \gamma$, then the problem becomes

$$\tau\gamma + 2\beta > 0$$

So we can know that, according to this model, the introduction of blockchain will necessarily increase consumer surplus.

4. Conclusion

This paper constructs a mathematical model to highlight the key tradeoff between using traditional trading platform and introducing the smart contract-based trading platform, and analyses the circumstances in which each party will choose to introduce blockchain and smart contract technology. The following points have been drawn. First, for suppliers and retailers, the party responsible for maintaining the trading platform will bear more costs, and whether to introduce blockchain depends mainly on whether the profits from the blockchain can cover the cost of introducing it. Regardless of the reduced damage rate brought about by blockchain technology, the marginal cost of traditional trading platforms and consumers' preference for products with traceable information need to satisfy certain mathematical relationships. Second, for consumers, the introduction of blockchain technology will always increase their utility. Therefore, blockchain technology has potential to bring more benefits to society.

5. References

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