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Quality Management and Blockchain Adoption in a Supply Chain

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Abstract: In the past, it was difficult to check, identify, and trace product quality. Quality violation regularly takes place when consumers know product quality is overstated. In this paper, we examine the motivation for and implication of a supply chain that adopts blockchain technology to improve product quality in supply chains. We build up a stylish model in which a two-echelon supply chain consisting of one manufacturer and one retailer. The manufacturer decides whether or not to adopt blockchain and the retailer sells products to consumers. Our results imply that the manufacturer always provides a low-quality product without blockchain but when the quality-cost ratio is sufficiently high with the affordable blockchain adoption cost, blockchain technology could encourage the manufacturer to produce high-quality products.

Keywords: blockchain, supply chain, quality control, supply chain dynamics, uncertainty.

1. INTRODUCTION

1.1 Research Motivation and Introduction

Product quality is an important criterion for consumers to make purchase decisions (Shen et al. 2020). Many consumers are not sufficiently knowledgeable to identify real product quality. A part of consumers may evaluate the product that has high quality while the remaining part of consumers may judge that the product has low quality. Such product quality information asymmetry results in the loss for consumers who may be cheated by overstated marketing (Shen et al. 2019). As a result, consumers may stop purchasing if product quality is uncertain. The industrialists are looking for an efficient way to avoid product quality uncertainty.

Blockchain is a form of distributed ledger technology to enhance traceability, certifiability, trackability and verifiability (Babich and Hilary 2019). Blockchain technology has been used to improve supply chain transparency that affects the channel's dynamics and resilience (Dolgui et al. 2019). If the firm establishes the product's provenance knowledge through blockchain, consumers could know the information of origin, authenticity, custody, and integrity, and then identify real product quality (Montecchi et al. 2019). A natural question may raise: can blockchain adoption encourage supply chain member to enhance product quality?

In this paper, we aim to identify the motivation for and implication of adopting blockchain to improve product quality in the supply chain. We build up a stylish model in which a two-echelon supply chain consisting of one manufacturer and one retailer. The manufacturer decides whether or not to adopt blockchain. Our preliminary results show that the supply chain always provides low-quality products when product quality uncertainty is taking place. When product quality uncertainty is addressed by blockchain with the affordable cost, the supply chain produces high-quality products when the quality-cost ratio is sufficiently high. Our results provide important insights to clarify the motivation for the manufacturer to produce high-quality products with blockchain but low-quality products without blockchain.

1.2 Organization of This Paper

The organization of this paper is as follows. Section 2 reviews the relevant literature. Section 3 introduces the model and Section 4 evaluates the value of adopting blockchain. Section 5 concludes the paper with managerial insights. Section 6 shows the future research directions for extending this conference paper to a full paper for journal publication. All proofs are placed in Appendix.

2. LITERATURE REVIEW

Recently, many scholars have recognized the value of adopting blockchain in supply chain management (Zhu and Kouhizadeh 2019). Queiroz et al. (2019) analyse 27 papers on blockchain and supply chain management integration. They argue that blockchain applications may disrupt traditional industries such as health care, transportation and retail. Wang et al. (2019) provide a literature review on blockchain technology in supply chain management. Their opinions are that the value of blockchain technology includes extended visibility and traceability, supply chain digitalization and disintermediation, improved data security and smart contracts. Morkunas et al. (2019) identify the six steps of asset exchange using blockchain: 1) propose transaction, 2) add a cryptographic signature, 3) broadcast to a network of computers, 4) authenticate transaction, append to the blockchain, and 6) complete transaction. They argue that blockchain technology could affect customer segments, value proposition, channels, customer relationships, revenue streams, key resources, key partnerships, and cost structure.

Adopting blockchain may address consumers' product quality uncertainty. Adopting blockchain forces supply chain members to provide transparent supply chain information. Saberi et al. (2019) identify the relationship of blockchain technology and sustainable supply chain management. They argue that blockchain technology adoption could trace sustainable practices in supply chains and manage product movement for transparency. Blockchain technology improves supply chain performance by the realization of transparency, visibility, and smart execution with strategic formal coordination. Blockchain has been used to improve data quality. Choi and Luo (2019) evaluate how blockchain adoption improves data quality for demand forecasting in the fashion supply chain. They find that using blockchain could enhance social welfare. Blockchain is utilized to identify product authenticity. Choi (2019) develops an analytical model to examine how blockchain-based platform ensures product authenticity and the use of blockchain influence consumers and the firms in the diamond industry. Montecchi et al. (2019) identify that using blockchain could provide provenance knowledge, namely, information about the product's origin, production, modifications, and custody. They develop a provenance knowledge framework and show the processes of assurance enhancement and perceived risk reduction. In this study, different from the existing literature on blockchain adoption in supply chains, our paper is the first one to examine how blockchain address product quality uncertainty and how product quality is affected by blockchain adoption.

3. THE MODEL

We consider a supply chain consisting of one manufacturer (*M*) and one retailer (*R*). The manufacturer as a Stackelberg leader designs and produces products. The retailer as a follower orders product from the manufacturer and then sells to consumers. The manufacturer decides product quality q and the unit wholesale price w. The unit production cost is c. The retailer decides the unit retail price p and ordering quantity based on the market demand. There are four stages in our game.

1. First, the manufacturer decides whether or not to use blockchain in a supply chain. We use Y and N to represent blockchain and non-blockchain cases, respectively.
2. Second, the manufacturer offers a contract which includes a wholesale price and the decision of blockchain adoption. Product quality is the private information for the manufacturer.
3. Third, based on the contract, the retailer decides the retail price.
4. Fourth, consumers purchase products based on their utility in terms of retail price and perceived product quality.

Consumers are heterogenous in terms of the willingness to pay (WTP) for products. The consumer preferences are captured by v, which follows a uniform distribution over $[0,1]$. Consumers are price and quality sensitive. In other words, higher product quality or a lower price drives up consumer utility of WTP for products. Without blockchain adoption, product quality is uncertain for consumers. The consumer utility U^N is

$$U^N = v - p + \overline{q},$$

where $\overline{q} = aq_H + (1-a)q_L$ and $q_H > q_L$.

Thanks to new technology blockchain, consumers can know product quality exactly through the system of blockchain (Babich and Hilary 2019; Choi 2019). For products with blockchain adoption, product quality is certain. The consumer utility U_i^Y is

$$U_i^Y = v - p + q_i,$$

where $i = H, L$.

Consumers will purchase products when consumer utility is positive. Thus, for the case without blockchain adoption, the market demand is

$$D^N = 1 - p + \overline{q}.$$

For the case with blockchain adoption, the market demand is

$$D_i^Y = 1 - p + q_i.$$

We consider that implementing blockchain is costly. K is the manufacturer's cost of implementing blockchain, where $K \geq 0$. $K = 0$ implies that adopting blockchain is free. The profit functions for the retailer and manufacturer without blockchain adoption are

$$\pi_R^N(p) = (p - w)D^N \text{ and}$$

$$\pi_M^N(w) = (w - c_i)D^N.$$

The profit functions for the retailer and manufacturer with blockchain adoption are

$$\pi_R^Y(p) = (p - w)D_i^Y \text{ and}$$

$$\pi_M^Y(w) = (w - c_i)D_i^Y - K,$$

where $c_H > c_L$.

4. PRELIMINARY RESULTS

4.1 No Blockchain Adoption

By using the backward induction, we can yield the optimal retailer price and wholesale price are

$p^{N*} = \left(3\bar{q} + 3 + c_i\right)/4$ and

$w^{N*} = \left(\bar{q} + 1 + c_i\right)/2$.

We substitute the optimal retail and wholesale prices into the profit functions of the retailer and manufacturer. We can find the optimal profits for the retailer and manufacturer are

$\pi_{R_i}^{N*} = \left(\bar{q} + 1 - c_i\right)^2 /16$ and

$\pi_{M_i}^{N*} = \left(\bar{q} + 1 - c_i\right)^2 /8$.

Before using products, consumers are not able to identify product quality. In our paper, we consider that the manufacturer decides to provide the high-quality or low-quality product. We compare the case that the manufacturer offers the high-quality product with the case that the manufacturer offers the low-quality one. We can find Proposition 1.

Proposition 1. *Without blockchain adoption,* $\pi_{R_H}^{N*} < \pi_{R_L}^{N*}$ *and* $\pi_{M_H}^{N*} < \pi_{M_L}^{N*}$.

Without blockchain adoption, consumers are uncertain about product quality. Consumers are not able to identify product quality before using it, and not allowed to return them after identifying the real product quality level. In such a one-period model, the manufacturer has no incentive to provide the high-quality product. As we consider a non-repeated game, it is intuitive that both the manufacturer and retailer perform better to sell a low-quality product. Thus, in the latter section, we will compare the case that the supply chain sells a low-quality product without blockchain adoption with the case with it.

4.2 Blockchain Adoption

With blockchain adoption, consumers can trace the production process and identify product quality exactly. By using the backward induction, we can yield the optimal retail and wholesale prices

$p_i^{Y*} = \left(3q_i + 3 + c_i\right)/4$ and

$w_i^{Y*} = \left(q_i + 1 + c_i\right)/2$.

After substituting them into the profit functions, we can obtain the optimal retailer's and manufacturer's profits under different level of product quality:

$\pi_{R_i}^{Y*} = \left(q_i + 1 - c_i\right)^2 /16$ and

$\pi_{M_i}^{Y*} = \left(q_i + 1 - c_i\right)^2 /8 - K$.

With blockchain adoption, we compare the manufacturer's profits under high-quality and low-quality cases. Define $\square = \left(q_H - q_L\right)/\left(c_H - c_L\right)$ be the quality-cost ratio, where $\square > 0$. When $\square$ is larger than 1, it implies that a high-quality product is more economically effective than a low-quality one, and when $\square$ is smaller than 1, it implies that a low-quality product is more economically effective than a high-quality one

Proposition 2. *With blockchain adoption,*

(i) *when* $\square \geq 1$, $\pi_{R_H}^{Y*} \geq \pi_{R_L}^{Y*}$ *and* $\pi_{M_H}^{Y*} \geq \pi_{M_L}^{Y*}$;

(ii) *when* $\square < 1$, $\pi_{R_H}^{Y*} < \pi_{R_L}^{Y*}$ *and* $\pi_{M_H}^{Y*} < \pi_{M_L}^{Y*}$.

With blockchain adoption, consumers know product quality exactly. Different from the case without blockchain adoption, we can see that blockchain adoption could stop the manufacturer from providing a low-quality product. When a high-quality product is more economically effective than a low-quality one ($\square \geq 1$), the manufacturer and retailer are willing to sell a high-quality product; whereas when a low-quality product is more economically effective than a high-quality one ($\square < 1$), both the manufacturer and retailer are willing to continue to sell a low-quality product like non-blockchain adoption.

4.3 Analytical Comparison

We compare the results in Sections 4.1 and 4.2. We aim to identify under which condition, the supply chain could adopt blockchain.

Proposition 3. *When* $K = 0$,

(i) *if* $\square \geq 1/\left(1-a\right)$, $\pi_{R_H}^{Y*} \geq \pi_{R_L}^{N*} > \pi_{R_L}^{Y*}$ *and* $\pi_{M_H}^{Y*} \geq \pi_{M_L}^{N*} > \pi_{M_L}^{Y*}$;

(ii) *if* $1 \leq \square < 1/\left(1-a\right)$, $\pi_{R_L}^{N*} > \pi_{R_H}^{Y*} \geq \pi_{R_L}^{Y*}$ *and* $\pi_{M_L}^{N*} > \pi_{M_H}^{Y*} \geq \pi_{M_L}^{Y*}$;

(iii) *if* $\square < 1$, $\pi_{R_L}^{N*} \geq \pi_{R_L}^{Y*} > \pi_{R_H}^{Y*}$ *and* $\pi_{M_L}^{N*} \geq \pi_{M_L}^{Y*} > \pi_{M_H}^{Y*}$.

Proposition 3 implies that when adopting blockchain is free for the manufacturer, the quality-cost ratio is critical for the manufacturer to decide when he sells a high- or low-quality product, and when he adopts or does not adopt blockchain. To be specific, when the quality-cost ratio is sufficiently large, selling a high-quality product with blockchain is beneficial to both the manufacturer and retailer; when the quality-cost ratio is sufficiently small, using blockchain is not profitable and selling a high-quality product is not profit as a low-quality product without blockchain.

Proposition 4 indicates that when adopting blockchain is not free, the retailer's and manufacturer's profits in terms of various quality-cost ratio and the cost of adopting blockchain.

Proposition 4. *When $K \neq 0$, the results are shown in Table 1.*

Table 1. Profit comparison when $K \neq 0$

Conditions		Retailer's profit	Manufacturer's profit
$\square \geq 1/(1-a)$	$K \leq \bar{K}$	$\pi_{R_H}^{Y*} \geq \pi_{R_L}^{N*} > \pi_{R_L}^{Y*}$	$\pi_{M_H}^{Y*} \geq \pi_{M_L}^{N*} > \pi_{M_L}^{Y*}$
	$K > \bar{K}$		$\pi_{M_L}^{N*} > \pi_{M_H}^{Y*} > \pi_{M_L}^{Y*}$
$1 \leq \square < 1/(1-a)$	$K \leq \bar{K}$	$\pi_{R_L}^{N*} > \pi_{R_H}^{Y*} \geq \pi_{R_L}^{Y*}$	$\pi_{M_H}^{Y*} \geq \pi_{M_L}^{N*} > \pi_{M_L}^{Y*}$
	$K > \bar{K}$		$\pi_{M_L}^{N*} > \pi_{M_H}^{Y*} \geq \pi_{M_L}^{Y*}$
$\square < 1$	NA	$\pi_{R_L}^{N*} \geq \pi_{R_L}^{Y*} > \pi_{R_H}^{Y*}$	$\pi_{M_L}^{N*} \geq \pi_{M_L}^{Y*} > \pi_{M_H}^{Y*}$

Note. $\bar{K} = \{C[(1-a)\square - 1](A + B + aC\square + 2)\}/8$, *where* $A = q_H - c_H$, $B = q_L - c_L$, *and* $C = c_H - c_L$.

From Proposition 4, we can find that the manufacturer's decision regarding adopting blockchain and producing a high-quality product may be different from the retailer's preference due to the cost of adopting blockchain is not free. Only when the cost of adopting blockchain is sufficiently small and the quality-cost ratio is sufficiently high, the manufacturer will produce a high-quality product with blockchain adoption and the retailer's preference is the same as the manufacturer's decision. When the quality-cost ratio is sufficiently small with the affordable blockchain adoption cost, both the manufacturer and the retailer are not willing to adopt blockchain. We interestingly find that both the manufacturer and retailer are not willing to provide a low-quality product with blockchain. Our results provide important insights to clarify the motivation for the manufacturer to produce a high-quality product with blockchain, not a low-quality product without blockchain.

5. CONCLUSIONS AND MANAGERIAL INSIGHTS

In this paper, we examine the motivation for the supply chain to implement blockchain. We build up a stylish model in which a two-echelon supply chain consisting of one manufacturer and one retailer. The manufacturer decides whether or not to adopt blockchain. Our results imply that adopting blockchain could encourage the supply chain to provide high-quality product. Based on our analytical results, we can have the following managerial insights.

✧ The manufacturer's action without blockchain adoption

Without blockchain adoption, consumers are uncertain about product quality. If consumers are not able to identify product quality before using it, and not allowed to return them after identifying the quality level, the manufacturer has no incentive to provide a high-quality product in such a one-period model. As we consider a non-repeated game, it is intuitive that both the manufacturer and retailer perform better to sell a low-quality product.

✧ The manufacturer's action with blockchain adoption

The manufacturer is willing to adopt blockchain if the quality-cost ratio is sufficiently high so that a high-quality product is produced and sold. With blockchain adoption, consumers know product quality exactly. Different from no blockchain adoption, we can see that blockchain adoption could stop the manufacturer from providing a low-quality product. When the high-quality product is more economically effective than the low-quality one, the manufacturer and retailer are willing to sell the high-quality product, whereas when the low-quality product is more economically effective than high-quality one, both the manufacturer and retailer are willing to continue to sell the low-quality product like non-blockchain adoption.

✧ The cost of blockchain influences product quality

Only when the cost of adopting blockchain is sufficiently small and the quality-cost ratio is sufficiently high, the manufacturer will produce high-quality products with blockchain adoption and the retailer's preference is the same as the manufacturer's decision. Both the manufacturer and retailer are not willing to provide low-quality products with blockchain. Our results provide important insights to clarify the motivation for the manufacturer to produce high-quality products with blockchain but low-quality products without blockchain. Adopting blockchain could improve product quality in a supply chain.

6. FUTURE RESEARCH DIRECTIONS FOR EXTENDING TO FULL PAPER

This conference paper shows the preliminary results of this study. To extend this paper for submitting to a journal after the conference, our future research directions are as follows. First, in this paper, we consider product return is not possible. If there is no blockchain, a part of consumers who value the product is high quality will receive low-quality products. This may lead consumers to regret. If the retailer allows consumers to return the products. How does product return affect blockchain adoption for the retailer and manufacturer? Second, consumers can receive the extra benefits thanks to blockchain adoption. Our aim is to evaluate how the extra benefits for blockchain adoption affect supply chain's decisions.

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Appendix A. PROOFS

Proof of Proposition1.

As $c_H > c_L$, we have $\pi_{R_H}^{N*} < \pi_{R_L}^{N*}$ *and* $\pi_{M_H}^{N*} < \pi_{M_L}^{N*}$. ■

Proof of Proposition2.

When $\square \geq 1$, we have $q_H - c_H \geq q_L - c_L$ and obtain $\pi_{R_H}^{Y*} \geq \pi_{R_L}^{Y*}$ and $\pi_{M_H}^{Y*} \geq \pi_{M_L}^{Y*}$.

When $\square < 1$, we have $q_H - c_H < q_L - c_L$ and obtain $\pi_{R_H}^{Y*} < \pi_{R_L}^{Y*}$ and $\pi_{M_H}^{Y*} < \pi_{M_L}^{Y*}$. ■

Proof of Proposition3.

When $q_H - c_H \geq \bar{q} - c_L$ (simplify to be $\square \geq 1/(1-a)$), we could have $\pi_{R_H}^{Y*} \geq \pi_{R_L}^{N*}$, and $\pi_{M_H}^{Y*} \geq \pi_{M_L}^{N*}$.

Since $1/(1-a) > 1$ we obtain $\pi_{R_H}^{Y*} \geq \pi_{R_L}^{N*} > \pi_{R_L}^{Y*}$, and $\pi_{M_H}^{Y*} \geq \pi_{M_L}^{N*} > \pi_{M_L}^{Y*}$; if $\square < 1/(1-a)$, it is easily to have $\pi_{R_L}^{N*} > \pi_{R_H}^{Y*}$ and $\pi_{M_L}^{N*} > \pi_{M_H}^{Y*}$.

Combining the results in Proposition 2,

- if $1 \leq \square < 1/(1-a)$, we can have $\pi_{R_L}^{N*} > \pi_{R_H}^{Y*} \geq \pi_{R_L}^{Y*}$ and $\pi_{M_L}^{N*} > \pi_{M_H}^{Y*} \geq \pi_{M_L}^{Y*}$;
- if $\square < 1$, we have $\pi_{R_H}^{Y*} < \pi_{R_L}^{Y*}$ and $\pi_{M_H}^{Y*} < \pi_{M_L}^{Y*}$. Since $\bar{q} > q_L$, we could obtain $\pi_{R_L}^{N*} \geq \pi_{R_L}^{Y*} > \pi_{R_H}^{Y*}$ and $\pi_{M_L}^{N*} \geq \pi_{M_L}^{Y*} > \pi_{M_H}^{Y*}$. ■

Proof of Proposition4.

- When $\Delta \geq 1/(1-a)$, if $K \leq \{c[(1-a)\square - 1](A + B + ac\square + 2)\}/8$, we have $\pi_{M_H}^{Y*} \geq \pi_{M_L}^{N*} > \pi_{M_L}^{Y*}$, whereas if $K > \{c[(1-a)\square - 1](A + B + ac\square + 2)\}/8$, then we obtain $\pi_{M_L}^{N*} > \pi_{M_H}^{Y*} > \pi_{M_L}^{Y*}$.
- When $1 \leq \square < 1/(1-a)$, if $K \leq \{c[(1-a)\square - 1](A + B + ac\square + 2)\}/8$, we have $\pi_{M_H}^{Y*} \geq \pi_{M_L}^{N*} > \pi_{M_L}^{Y*}$, whereas if $K > \{c[(1-a)\square - 1](A + B + ac\square + 2)\}/8$, then we obtain $\pi_{M_L}^{N*} > \pi_{M_H}^{Y*} \geq \pi_{M_L}^{Y*}$,
- When $\square < 1$, we then have $\pi_{M_L}^{N*} \geq \pi_{M_L}^{Y*} > \pi_{M_H}^{Y*}$, if $K > 0$. ■