The Impact of Demand Information Transparency on Endogenous Supply Process Reliability in Blockchain Era

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Abstract. With supply disruption occurring frequently nowadays, suppliers increasingly undertake costly effort to improve its own supply reliability. Meanwhile, some retailers are issued with blockchain technology, which reduces information asymmetry for suppliers, thereby mitigating supply disruptions. This study investigates how the demand information transparency via the retailer's adoption of blockchain affect the supplier's process reliability level. Although conventional wisdom suggests that the supplier will enjoy an information superiority if keeping the demand information private, we reveal that the retailer may opt to adopt the blockchain technology to achieve demand information transparency with the supplier, and such information transparency of blockchain-adoption system can incentivize the supplier to set an efficient supply reliability improvement level.

Keywords: Blockchain technology · demand information transparency · supply disruption · supply reliability improvement

1 Introduction

To mitigate delivery risk, a growing number of suppliers chooses to improve its process reliability, and such supply reliability improvement incurs huge costs. In practice, to relieve suppliers' economic pressures caused by supply reliability improvement, many downstream retailers (e.g., Altera, BMW, and Huawei) volunteer to offers incentives to improve suppliers' reliability improvement. Meanwhile, the development of emergent information technologies such as blockchain and artificial intelligence enable the enterprises to handle supply chain disruption more feasibly. Meanwhile, extant literature on blockchain technology mainly focuses on tourism [1], chemistry [2], and finance [3]. However, many firms (i.e., Walmart, IBM, and Hyundai Motors) implement blockchain system to achieve for a transparent information-sharing mechanism, that enables their suppliers to make an improved reliability level on supply disruption management according to the accurate demand information [4–6]. Despite the benefit of demand information transparency via adopting blockchain technology, conventional wisdom suggests that retailers are reluctant to adopt blockchain technology to keep their information advantage. The contradictory between theoretical wisdom and practical evidence motivates us

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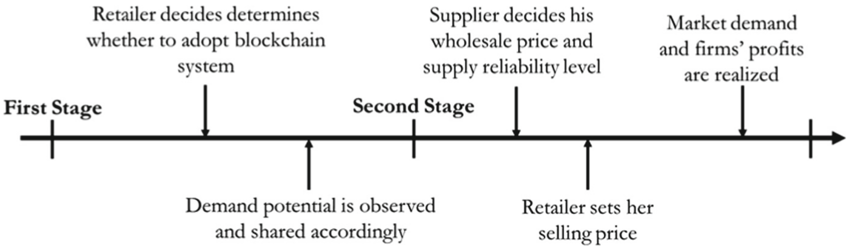

Fig. 1 Game sequence

to ask a question: can demand information transparency of blockchain-adoption promote the supplier's reliability level?

2 Model Setting

Consider a vertical supply chain with a supplier (he) selling products at a wholesale price w to a retailer (she), who sells the product to consumers in an uncertain market. We use $q = \theta_i - p$ to represent the inverse demand function for the retail market, where θ_i is uncertain demand potential and follows $\theta_i = \begin{cases} \theta_h \text{ with probability } 1/2 \\ \theta_l \text{ with probability } 1/2 \end{cases}$ [7, 8].

Moreover, we assumed that the supplier's output is completely destroyed when a disruption occurs (i.e., all-or-nothing supply). Specifically, for a production quantity x, the output is ρx, where $\rho = \begin{cases} 1 \text{ with probability } z \\ 0 \text{ with probability } 1-z \end{cases}$. $0 < z \leq 1$ is viewed as the perfect-yield probability, that is, *supply reliability*. Moreover, the supplier can invest in the supply reliability improvement level z with a fixed cost $\beta z^2/2$, where β captures the cost coefficient of reliability improvement [9–11]. In line with theoretical and practical evidence, due to proximity to end consumers, the retailer could obtain more accurate demand information. Assumed that the retailer can ex ante get the demand potential type θ_i, while the supplier only knows the prior distribution for θ_i. However, if the retailer adopts the blockchain technology, the supplier also observes the demand potential type θ_i because of the information transparency. Moreover, the sequence of events proceeds as shown in Fig. 1.

3 Blockchain Model

We first introduce the scenario in which the retailer will not adopt blockchain technology. We then present the scenario, wherein the retailer shares demand information via adopting blockchain technology.

3.1 Benchmark: Non-Blockchain Model (Scenario N)

When the retailer does not opt to blockchain-adoption technology, the retailer obtains the accurate demand potential, thus the retailer sets q_i in line with θ_i, which maximizes her payoff:

$$\pi_M(p_i) = z(\theta_i - p_i)(p_i - w). \tag{1}$$

Because the supplier is not known the accurate demand potential type, he determines z and w in line with the prior distribution of θ_i:

$$\Pi_S(w, z) = z\left(\frac{1}{2}(\theta_h - p_h) + \frac{1}{2}(\theta_l - p_l)\right)w - \frac{\beta z^2}{2}. \tag{2}$$

Lemma 1 characterizes the firms' equilibrium pricing decisions and the optimal reliability improvement level.

Lemma 1. *If the retailer does not adopt blockchain technology, the equilibrium decisions are*

(a) *when* $1 < \frac{\theta_h}{\theta_l} \leq 1 + \sqrt{2}$,
$w^N = \frac{\theta_h+\theta_l}{4}, z^N = min\left\{\frac{(\theta_h+\theta_l)^2}{32\beta},\ 1\right\}, p_h^N = \frac{5\theta_h+\theta_l}{8},\ p_l^N = \frac{5\theta_l+\theta_h}{8}$;
(b) *when* $\frac{\theta_h}{\theta_l} > 1 + \sqrt{2}$,

$$w^N = \frac{\theta_h}{2}, z^N = min\left\{\frac{\theta_h^2}{16\beta},\ 1\right\}, p_h^N = \frac{3\theta_h}{4},\ p_l^N = \forall p > \theta_l$$

Lemma 1 shows that the equilibrium outcomes depend on demand variability, where we interpret $\frac{\theta_h}{\theta_l}$ as "demand variability." Specifically, at a low demand variability (i.e., $1 < \frac{\theta_h}{\theta_l} \leq 1 + \sqrt{2}$), Lemma 1 (a) shows that the supplier sets the equilibrium expected wholesale price (i.e., $w^N = \frac{\theta_h+\theta_l}{4}$) and supply reliability improvement level (i.e., $z^N = min\left\{\frac{(\theta_h+\theta_l)^2}{32\beta},\ 1\right\}$) conditional on the prior distribution for the demand potential when the retailer does not adopt blockchain technology. Lemma 1 (b) shows that at a high demand variability (i.e., $\frac{\theta_h}{\theta_l} > 1 + \sqrt{2}$), the supplier has enough incentive to give up the small profit when the low-type demand market is realized, while he sets $w^N = \frac{\theta_h}{2}$ to maximizes the profit when the high-type demand market is realized because θ_h is much higher than θ_l. It makes sense that the supplier distorts the wholesale price upward ($w^N = \frac{\theta_h}{2}$) which forces the retailer's product order to be zero (i.e., $q_l^N = 0$) when the low-type demand potential occurs.

Moreover, based on Lemma 1, under scenario N, the retailer's expected profit is given by (i) when$1 < \frac{\theta_h}{\theta_l} \leq 1 + \sqrt{2}$, $\Pi_M^N = \begin{cases} \frac{(\theta_h+\theta_l)^2(5\theta_h^2-6\theta_h\theta_l+5\theta_l^2)}{2048\beta}, & if\ \frac{(\theta_h+\theta_l)^2}{32} < \beta, \\ \frac{(5\theta_h^2-6\theta_h\theta_l+5\theta_l^2)}{64}, & if\ 0 < \beta \leq \frac{(\theta_h+\theta_l)^2}{32}, \end{cases}$

(ii) when$\frac{\theta_h}{\theta_l} > 1 + \sqrt{2}$, $\Pi_M^N = \begin{cases} \frac{\theta_h^4}{512\beta}, & if\ \frac{\theta_h^2}{16} < \beta, \\ \frac{\theta_h^2}{32}, & if\ 0 < \beta \leq \frac{\theta_h^2}{16}. \end{cases}$

3.2 Blockchain-Adoption Model (Scenario S)

Then, we consider the blockchain-adoption model. Here, when the retailer implements the blockchain system, the retailer and the supplier is known the demand potential type θ_i, where $\theta_i \in \{\theta_h, \theta_l\}$. The retailer's and supplier's payoff functions are as follows:

$$\pi_{M-i}(p_i) = z_i(\theta_i - p_i)(p_i - w_i). \tag{3}$$

$$\pi_{S-i}(z_i, w_i) = z_i(\theta_i - p_i)w_i - \frac{\beta z_i^2}{2} \tag{4}$$

Similarly, Lemma 2 characterizes the firms' equilibrium decisions under scenario S.

Lemma 2. *If the retailer adopts blockchain technology, the equilibrium decisions are* $w_i^S = \frac{\theta_i}{2}$, $z_i^S = min\left\{\frac{\theta_i^2}{8\beta}, 1\right\}$, $p_i^S = \frac{3\theta_i}{4}$, Where $\theta_i \in \{\theta_h, \theta_l\}$.

Lemma 2 finds that the optimal decisions is line with the demand potential type. In addition, as the cost coefficient of reliability improvement β increases, the reliability improvement level z_i^S decreases. Meanwhile, under scenario S, the retailer's expected profit is given by $\Pi_M^S = \begin{cases} \frac{\theta_h^4+\theta_l^4}{256\beta}, & if\, \frac{\theta_h^2}{8} < \beta, \\ \frac{1}{256}\left(8\theta_h^2 + \frac{\theta_l^4}{\beta}\right), & if\, \frac{\theta_l^2}{8} < \beta \leq \frac{\theta_h^2}{8}, \\ \frac{\theta_h^2+\theta_l^2}{32}, & if\, 0 < \beta \leq \frac{\theta_l^2}{8}. \end{cases}$

3.3 Equilibrium Blockchain Adoption Outcome

By comparing Π_M^N and Π_M^S, we explore the retailer's optimal decision on adopting blockchain technology.

Proposition 1. (i) *When* $1 < \frac{\theta_h}{\theta_l} \leq 1 + \sqrt{2}$, *the retailer adopts the blockchain technology if* $\beta > \frac{5\theta_h^4+4\theta_h^3\theta_l-2\theta_h^2\theta_l^2+4\theta_h\theta_l^3-3\theta_l^4}{64\theta_h^2}$; *otherwise, she does not adopt the blockchain technology;*

(ii) *when* $\frac{\theta_h}{\theta_l} > 1 + \sqrt{2}$, *the retailer adopts the blockchain technology.*

Surprisingly, under endogenous reliability improvement process, Proposition 1 reveals that the retailer is more willing to achieve demand information transparency via adopting blockchain technology under certain conditions. Specifically, Proposition 1 (i) shows that the retailer's optimal blockchain-adoption decision exhibits a cutoff option: at a low demand heterogeneity, the retailer does not opt to adopt the blockchain technology when the cost coefficient of reliability improvement is relatively low. This is because at a low cost coefficient of reliability improvement, the supplier volunteers to invest in supply reliability improvement. In this circumstance, although demand information transparency via adopting blockchain technology can induce the supplier to set a more efficient reliability improvement level, its incentive effect on reliability improvement is limited, whereas the adoption of blockchain technology leads to a more aggressive wholesale price, which undermines the retailer. However, with an increase in the cost coefficient of reliability improvement, the supplier has weak motivation to improve supply reliability, and the incentive effect of information transparency via adopting blockchain technology is magnified. Therefore, the retailer's benefit from implementation of blockchain technology outweighs its hurt, the retailer prefers to adopt the blockchain technology when the cost coefficient of reliability improvement meets $\beta > \frac{5\theta_h^4+4\theta_h^3\theta_l-2\theta_h^2\theta_l^2+4\theta_h\theta_l^3-3\theta_l^4}{64\theta_h^2}$.

Moreover, Proposition 1 (*ii*) reveals that the retailer opts to share information via adopting blockchain technology at a high demand heterogeneity (i.e., $\frac{\theta_h}{\theta_l} > 1 + \sqrt{2}$). When the retailer prefers not to implement blockchain technology, the supplier cannot obtain the accurate demand potential, and thus he will set a sufficiently high wholesale price only in line with the high-type demand potential and abandon the low-type demand potential. This wholesale pricing setting hurts the retailer, thus the retailer opts to adopt blockchain technology to induce more efficient wholesale price through demand information transparency.

4 Conclusion

Our work reveals that information transparency via adopting blockchain technology boosts supply reliability improving motivation which, in turn, attenuates the disruption risk. Essentially, demand information transparency via blockchain technology leads the supplier to make a more aggressive wholesale price, while it also incentivizes a more efficient reliability improvement. Specifically, only when the demand heterogeneity is low and the cost coefficient of reliability improvement is high, the supplier is more willing to invest in the supply reliability improvement, thus the retailer does not implement blockchain technology; otherwise, the retailer adopts blockchain technology to achieve information transparency. Moreover, the aforementioned discussions provide guidelines for automotive firms, such as Volkswagen, BMW, and Hyundai, and nonautomotive firms, such as Huawei, Apple, and Xiaomi, in demand information transparency via adopting blockchain technology. The finding draws the managerial implications: when facing the threat of supply disruption, information transparency via adopting blockchain technology benefits all the supply members, and thus managers should implement the blockchain technology with more flexibility.

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