Electronic Supplementary Material

Blockchain adoption or contingent sourcing? Advancing food supply chain resilience in the post-pandemic era

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Appendix A. All proofs

Proof of Lemma 1

As $\dfrac{\partial^2 \pi_{O,O}^{R,N}}{\partial p^2} = -2(1-e_s\eta) < 0$, the profit function $\pi_{O,O}^{R,N}$ under Strategy (O,O) is concave with respect to price p. By solving the first order condition $\dfrac{\partial \pi_{O,O}^{R,N}}{\partial p} = (1-e_s\eta)(1-2p) = 0$, we have the optimal price $p_{O,O}^{R,N} = \dfrac{1}{2}$ by letting $\dfrac{\partial \pi_{O,O}^{R,N}}{\partial p} = 0$. Then, substituting $p_{O,O}^{R,N} = \dfrac{1}{2}$ into profit function, we have $\pi_{O,O}^{R,N} = \dfrac{1}{4}(1-e_s\eta) - e_s\eta K$. Similarly, the optimal prices and profits under the rest of sourcing strategies can be derived and they are summarized in Table 2 in the main text. From Table 2, it's obvious that $p_{A,A}^{B} > p_{A,A}^{N} > p_{O,O}^{N}$, $p_{O,A}^{N} > p_{O,O}^{N}$ and $p_{A,A}^{B} > p_{O,A}^{B} > p_{O,O}^{B} > p_{O,O}^{N}$. In addition, $\dfrac{e_s e_r}{1-e_s\eta(1-e_r)} < \dfrac{e_r}{1-e_s\eta(1-e_r)} < 1$ always holds, when $\eta < 1$. In that case, we have $p_{A,A}^{N} > p_{O,A}^{N}$ and $p_{O,A}^{B} > p_{O,A}^{N}$. (Q.E.D.)

Proof of Proposition 1

As $K > \bar{K}$ and $\pi_{O,O}^{R,N} < 0$, scenario (O,O) in the absence of blockchain cannot be the candidate of optimal strategies. Since $\pi_{O,A}^{R,N}$ decreases in K while $\pi_{A,A}^{R,N}$ is not affected by K, we obtain the threshold $K_0 = \frac{1}{4e_s\eta(1-e_r)}\left\{2(1-e_se_r)\Delta - \left[1-\frac{e_s{}^2e_r{}^2}{1-e_s\eta(1-e_r)}\right]\Delta^2\right\} - \frac{1}{4}$ by solving $\pi_{O,A}^{R,B} = \pi_{O,O}^{R,B}$. Then, $\pi_{A,A}^{R,N} > \pi_{O,A}^{R,N}$, if $K > K_0$. Especially, if $\Delta < \Delta_0 = 1 - \frac{1-e_s\eta(1-e_r)-e_se_r}{\sqrt{1-e_s\eta(1-e_r)}-e_se_r}$, then $K_0 < 0$, which means $\pi_{A,A}^{R,N} > \pi_{O,A}^{R,N}$ always holds. Note that if $K_0 - \bar{K} = \frac{-\left[1-\frac{e_s{}^2e_r{}^2}{1-e_s\eta(1-e_r)}\right]\Delta^2 + 2(1-e_se_r)\Delta - (1-e_r)}{4e_s\eta(1-e_r)} \le 0$, then, $K > K_0$ always holds.

Next, we conduct the sensitivity analysis on the thresholds. For K_0, which can be rewritten as $K_0 = \left\{[1-e_s\eta(1-e_r)]\left[1-\frac{e_se_r\Delta}{1-e_s\eta(1-e_r)}\right]^2 - (1-\Delta)^2\right\}\Big/[4e_s\eta(1-e_r)]$, when η is increasing, its denominator is increasing while its numerator is decreasing. Therefore, K_0 is decreasing in η. Differentiating Δ_0 and K_0 with respect to e_s and η respectively, we have:

$$\frac{\partial\Delta_0}{\partial e_s} = \frac{\eta(1-e_r)\left[1-e_s\eta(1-e_r)-e_se_r\sqrt{1-e_s\eta(1-e_r)}\right] + e_r\left[2-e_s\eta(1-e_r)\right]\left[1-\sqrt{1-e_s\eta(1-e_r)}\right]}{2\sqrt{1-e_s\eta(1-e_r)}\left[\sqrt{1-e_s\eta(1-e_r)}-e_se_r\right]^2} > 0,$$

$$\frac{\partial\Delta_0}{\partial\eta} = \frac{e_s(1-e_r)\left\{\left[\sqrt{1-e_s\eta(1-e_r)}-e_se_r\right]^2 + e_se_r(1-e_se_r)\right\}}{2\sqrt{1-e_s\eta(1-e_r)}\left[\sqrt{1-e_s\eta(1-e_r)}-e_se_r\right]^2} > 0,$$

$$\frac{\partial K_0}{\partial e_s} = -\left\{2-\left[1+\frac{e_se_r}{1-e_s\eta(1-e_r)}\right]^2\Delta\right\}\Delta\Big/\left[4e_s{}^2\eta(1-e_r)\right] < 0. \qquad \text{(Q.E.D.)}$$

Proof of Proposition 2

It's clear that $\pi_{A,A}^{R,N} > \pi_{A,A}^{R,B}$ and $\pi_{O,A}^{R,B} > \pi_{A,A}^{R,B}$ from Table 2, then scenario (A, A) with blockchain adoption is dominated by other strategies. As $\pi_{O,A}^{R,B}$ decreases in Δ while $\pi_{O,O}^{R,B}$ is not affected by Δ, we obtain the threshold $\Delta_1 = \frac{1}{e_s}(1-c_b)\left(1-\sqrt{1-e_s\eta}\right)$ that solves $\pi_{O,A}^{R,B} = \pi_{O,O}^{R,B}$. Then, $\pi_{O,A}^{R,B} > \pi_{O,O}^{R,B}$, if $\Delta < \Delta_1$; but $\pi_{O,A}^{R,B} < \pi_{O,O}^{R,B}$, otherwise. By differentiating Δ_1 with respect to e_s, η and c_b respectively, we have

$$\frac{\partial\Delta_1}{\partial e_s} = \frac{(1-c_b)\left(1-\sqrt{1-e_s\eta}\right)^2}{2e_s{}^2\sqrt{1-e_s\eta}} > 0, \quad \frac{\partial\Delta_1}{\partial\eta} = \frac{1-c_b}{2\sqrt{1-e_s\eta}} > 0 \text{ and } \frac{\partial\Delta_1}{\partial c_b} = -\frac{1}{e_s}\left(1-\sqrt{1-e_s\eta}\right) < 0. \qquad \text{(Q.E.D.)}$$

Lemma A1

Given retail price, the optimal sourcing strategies and the incentives for blockchain adoption are shown as follows.

1. When $\Delta < \min\{\Delta^N, c_b/(1-e_s)\}$, the optimal strategy is (A,A) without blockchain, and when $\Delta > \hat{\Delta}$, the optimal strategy is (O,O) with blockchain.

2. When $\min\{\Delta^N, c_b/(1-e_s)\} < \Delta < \hat{\Delta}$, the optimal decisions are shown in Table A1, where $\Delta^B = (p-c_b)\eta$,

$$\hat{\Delta} = \eta p + \frac{1-e_s\eta}{e_s e_r} c_b \quad , \quad \Delta^N = \eta p\left(1 - \frac{1-e_s}{1-e_s e_r}\right) \quad , \quad K' = \frac{(1-p)[e_s(1-e_r)\Delta + c_b - e_s\eta(1-e_r)p]}{e_s\eta(1-e_r)} ,$$

$$K'' = \frac{(1-p)[(1-e_s\eta)c_b - e_s e_r(\Delta - p\eta)]}{e_s\eta(1-e_r)}, \text{ and } K^N = (1-p)\left[\frac{1-e_s e_r}{e_s\eta(1-e_r)}\Delta - p\right].$$

Table A1 Optimal sourcing strategy and incentive for blockchain adoption

Variable cost for blockchain operations (c_b)	Marginal cost of sourcing from a safe supplier (Δ)	Penalty cost for detected infection (K)	Blockchain adoption	Optimal sourcing strategy
$0 < c_b < \frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_s e_r}$	$\frac{c_b}{1-e_s} \le \Delta < \eta p - \frac{c_b}{e_s(1-e_r)}$	-	√	(O,A)
	$\eta p - \frac{c_b}{e_s(1-e_r)} \le \Delta < \Delta^B$	$K > K'$	√	(O,A)
		$K \le K'$	×	(O,A)
	$\Delta^B \le \Delta < \hat{\Delta}$	$K \le K''$	×	(O,A)
		$K > K''$	√	(O,O)
$\frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_s e_r} < c_b < \frac{(1-e_s)\eta p}{1+(1-e_s)\eta}$	$\Delta^N \le \Delta < \frac{c_b}{1-e_s}$	$K > K^N$	×	(A,A)
		$K \le K^N$	×	(O,A)
	$\frac{c_b}{1-e_s} \le \Delta < \Delta^B$	$K \le K'$	×	(O,A)
		$K > K'$	√	(O,A)
	$\Delta^B \le \Delta < \hat{\Delta}$	$K > K''$	√	(O,O)
		$K \le K''$	×	(O,A)
$\frac{(1-e_s)\eta p}{1+(1-e_s)\eta} < c_b < \frac{(1-e_s)\eta p}{1-e_s\eta}$	$\Delta^N \le \Delta < e_s\eta(p-c_b)+c_b$	$K \le K^N$	×	(O,A)
		$K > K^N$	×	(A,A)
	$e_s\eta(p-c_b)+c_b \le \Delta < \hat{\Delta}$	$K \le K''$	×	(O,A)
		$K > K''$	√	(O,O)

Proof of Lemma A1

When retail price is given, the optimal sourcing strategy without/with blockchain and the incentive for blockchain adoption can be derived as follows.

As $\frac{\partial\pi_{O,O}^{R,B}}{\partial K} = -e_s\eta < 0$, we have a unique $\bar{K}' = \frac{p(1-p)(1-e_s\eta)}{e_s\eta}$ so that $\pi_{O,O}^{R,N} = 0$. And it requires $K > \bar{K}'$ in order to exclude Strategy (O,O) without blockchain. Also, $\frac{\partial\pi_{O,A}^{R,N}}{\partial K} = -e_s\eta(1-e_r) < 0$, so we get a unique

$\bar{K}'' = \frac{(1-p)\{p[1-e_s\eta(1-e_r)]-e_se_r\Delta\}}{e_s\eta(1-e_r)}$ by letting $\pi_{O,A}^{R,N} = 0$. Meanwhile, $\bar{K}'' - \bar{K}' = \frac{(1-p)(p-e_s\Delta)e_r}{e_s\eta(1-e_r)}$ is decreasing in Δ, so we know that $\bar{K}'' > \bar{K}'$ always holds when $\Delta < \frac{p}{e_s}$.

1. The optimal sourcing strategy without/with blockchain

When blockchain is not adopted, $\pi_{A,A}^{R,N} - \pi_{O,A}^{R,N} = (1-p)\left[e_s\eta(1-e_r) - (1-e_se_r)\Delta\right] + e_s\eta(1-e_r)K$, which is increasing in K, so we get the threshold $K^N = (1-p)\left\{(1-e_se_r)\Delta / \left[e_s\eta(1-e_r)\right] - p\right\}$ that solves $\pi_{A,A}^{R,N} = \pi_{O,A}^{R,N}$. And K^N is increasing in Δ, so $K^N < 0$, which means $\pi_{A,A}^{R,N} > \pi_{O,A}^{R,N}$, if $\Delta < \Delta^N = \eta p\left[1-(1-e_s)/(1-e_se_r)\right]$. Therefore, $\pi_{A,A}^{R,N} > \pi_{O,A}^{R,N}$, if $K > K^N$; but $\pi_{A,A}^{R,N} < \pi_{O,A}^{R,N}$, if $\Delta > \Delta^N$ and $K < K^N$.

When blockchain is adopted, it's clear that $\pi_{A,A}^{R,N} > \pi_{A,A}^{R,B}$ and $\pi_{O,A}^{R,B} > \pi_{A,A}^{R,B}$, then (A,A) is dominated by other strategies. $\pi_{O,O}^{R,B} - \pi_{O,A}^{R,B} = (1-p)e_s\left[\Delta - (p-c_b)\eta\right]$, which is increasing in Δ, so we obtain the threshold $\Delta^B = (p-c_b)\eta > 0$ that solves $\pi_{O,O}^{R,B} = \pi_{O,A}^{R,B}$. Then, $\pi_{O,O}^{R,B} > \pi_{O,A}^{R,B}$, if $\Delta > \Delta^B$, but $\pi_{O,O}^{R,B} < \pi_{O,A}^{R,B}$ otherwise.

Moreover, $\Delta^N - \Delta^B = \left[c_b - (1-e_s)p/(1-e_se_r)\right]\eta$, which is increasing in c_b, so $\Delta^N > \Delta^B$, if $c_b > (1-e_s)p/(1-e_se_r)$, but $\Delta^N < \Delta^B$ otherwise.

2. The incentive for blockchain adoption

From above analysis, the incentive for blockchain adoption is obtained by analyzing the following four cases.

Case 1: When $\Delta < \Delta^B$ and $K > K^N$, we compare the profits between (O,A) with blockchain and (A,A) without blockchain.

$\pi_{O,A}^{R,B} - \pi_{A,A}^{R,N} = (1-p)\left[(1-e_s)\Delta - c_b\right]$, which is increasing in Δ, so we know that $\pi_{O,A}^{R,B} > \pi_{A,A}^{R,N}$, if $\Delta > c_b/(1-e_s)$, but $\pi_{O,A}^{R,B} < \pi_{A,A}^{R,N}$ otherwise. Meanwhile, $\Delta^B - c_b/(1-e_s) = p\eta - \frac{1+(1-e_s)\eta}{1-e_s}c_b$, which is decreasing in c_b, so $\Delta^B > c_b/(1-e_s)$, if $c_b < (1-e_s)\eta p/\left[1+(1-e_s)\eta\right]$. $\Delta^N - c_b/(1-e_s) = p\eta\left[1-(1-e_s)/(1-e_se_r)\right] - c_b/(1-e_s)$, which is decreasing in c_b, so $\Delta^N > c_b/(1-e_s)$, if

$c_b < \frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_se_r}$, but $\Delta^N < c_b/(1-e_s)$ otherwise. And $\frac{1-e_s}{1-e_se_r}p > \frac{(1-e_s)\eta p}{1+(1-e_s)\eta} > \frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_se_r}$ always holds. In summary, $\pi_{O,A}^{R,B} > \pi_{A,A}^{R,N}$, if $c_b < \frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_se_r}$ and $\frac{c_b}{1-e_s} < \Delta < \Delta^N$ or $\frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_se_r} < c_b < \frac{(1-e_s)\eta p}{1+(1-e_s)\eta}$, $\Delta^N < \Delta < \Delta^B$ and $K > K^N$.

Case 2: When $\Delta > \Delta^B$ and $K > K^N$, we compare the profits between (O,O) with blockchain and (A,A) without blockchain.

$\pi_{O,O}^{R,B} - \pi_{A,A}^{R,N} = (1-p)\left\{\Delta - \left[e_s\eta(p-c_b)+c_b\right]\right\}$, which is increasing in Δ, so we know that $\pi_{O,O}^{R,B} > \pi_{A,A}^{R,N}$, if $\Delta > e_s\eta(p-c_b)+c_b$, but $\pi_{O,O}^{R,B} < \pi_{A,A}^{R,N}$ otherwise. Meanwhile, $e_s\eta(p-c_b)+c_b-\Delta^B = \left[1+(1-e_s)\eta\right]c_b - p\eta(1-e_s)$, which is increasing in c_b, so $e_s\eta(p-c_b)+c_b > \Delta^B$, if $c_b > \frac{(1-e_s)\eta p}{1+(1-e_s)\eta}$, but $e_s\eta(p-c_b)+c_b < \Delta^B$ otherwise. In summary, $\pi_{O,O}^{R,B} > \pi_{A,A}^{R,N}$, if $c_b < \frac{(1-e_s)\eta p}{1+(1-e_s)\eta}$ and $\Delta > \Delta^B$ or $c_b > \frac{(1-e_s)\eta p}{1+(1-e_s)\eta}$ and $\Delta > e_s\eta(p-c_b)+c_b$.

Case 3: When $c_b < \frac{1-e_s}{1-e_se_r}p$, $\Delta^N < \Delta < \Delta^B$, and $K < K^N$, we compare the profits between (O,A) with blockchain and (O,A) without blockchain.

$\pi_{O,A}^{R,B} - \pi_{O,A}^{R,N} = (1-p)\left[e_s\eta(1-e_r)-c_b-e_s(1-e_r)\Delta\right]+e_s\eta(1-e_r)K$, which is increasing in K, so we have the threshold $K' = \frac{(1-p)[e_s(1-e_r)\Delta+c_b-e_s\eta(1-e_r)p]}{e_s\eta(1-e_r)}$ by letting $\pi_{O,A}^{R,B} - \pi_{O,A}^{R,N} = 0$. And $K' < 0$, if $\Delta < \eta p - \frac{c_b}{e_s(1-e_r)} < \Delta^B$. In addition, $K^N - K' = \frac{(1-p)[(1-e_s)\Delta - c_b]}{e_s\eta(1-e_r)}$, which is increasing in Δ, so when $\Delta > c_b/(1-e_s)$, then $K^N > K'$, but $K^N < K'$ otherwise. Meanwhile, $\eta p - \frac{c_b}{e_s(1-e_r)} - \frac{c_b}{1-e_s} = \eta p - \frac{(1-e_se_r)c_b}{e_s(1-e_s)(1-e_r)}$, which is decreasing in c_b, so $\eta p - \frac{c_b}{e_s(1-e_r)} > c_b/(1-e_s)$, if $c_b < \frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_se_r}$. In summary, $\pi_{O,A}^{R,B} > \pi_{O,A}^{R,N}$, if $c_b < \frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_se_r}$, $\Delta^N < \Delta < \eta p - \frac{c_b}{e_s(1-e_r)}$ or if $\eta p - \frac{c_b}{e_s(1-e_r)} < \Delta < \Delta^B$ and $K > K'$ or if $\frac{e_s\eta(1-e_r)(1-e_s)p}{1-e_se_r} < c_b < \frac{(1-e_s)\eta p}{1+(1-e_s)\eta}$, $c_b/(1-e_s) < \Delta < \Delta^B$ and $K > K'$.

Case 4: When $\Delta > max\left\{\Delta^B, \Delta^N\right\}$ and $K < K^N$, we compare the profits between (O,O) with blockchain and (O,A) without blockchain.

$\pi_{O,O}^{R,B} - \pi_{O,A}^{R,N} = (1-p)\left[e_s e_r(\Delta - p\eta) - (1-e_s\eta)c_b\right] + e_s\eta(1-e_r)K$, which is increasing in K, so we have the threshold $K'' = \frac{(1-p)[(1-e_s\eta)c_b - e_s e_r(\Delta - p\eta)]}{e_s\eta(1-e_r)}$ by letting $\pi_{O,O}^{R,B} - \pi_{O,A}^{R,N} = 0$. And $K'' < 0$, if $\Delta > \hat{\Delta} = \eta p + \frac{1-e_s\eta}{e_s e_r}c_b > \Delta^B$. In addition, $K^N - K'' = \frac{(1-p)[\Delta - e_s\eta(p-c_b) - c_b]}{e_s\eta(1-e_r)}$, which is increasing in Δ, so when $\Delta > e_s\eta(p-c_b) + c_b > \Delta^N$, then $K^N > K''$, but $K^N < K''$ otherwise. Meanwhile, $\hat{\Delta} - \left[e_s\eta(p-c_b) + c_b\right] = \eta p(1-e_s) + \frac{(1-e_s e_r)(1-e_s\eta)c_b}{e_s e_r} > 0$, so $\hat{\Delta} > e_s\eta(p-c_b) + c_b$ always holds. In summary, $\pi_{O,O}^{R,B} > \pi_{O,A}^{R,N}$, if $\Delta > \hat{\Delta}$ or if $c_b < \frac{(1-e_s)\eta p}{1+(1-e_s)\eta}$, $\Delta^B < \Delta < \hat{\Delta}$ and $K > K''$ or if $c_b > \frac{(1-e_s)\eta p}{1+(1-e_s)\eta}$, $e_s\eta(p-c_b) + c_b < \Delta < \hat{\Delta}$ and $K > K''$. (Q.E.D)

Proof of Proposition 3

The optimal strategy and incentive for blockchain adoption with endogenous retailer price are similar to that with exogenous price shown in Lemma A1.

1. Comparison of Strategies (O,A) with blockchain, (O,O) with blockchain and (A,A) without blockchain.

Comparing the profits between (O,A) with blockchain and (A,A) without blockchain, which requires $\Delta < \Delta_1$ based on Proposition 2, we obtain $\Delta = c_b/(1-e_s)$ by letting $\pi_{O,A}^{R,B} - \pi_{A,A}^{R,N} = \frac{1}{4}\left[-(1-e_s^2)\Delta^2 + 2(1-e_s+e_s c_b)\Delta + (1-c_b)^2 - 1\right] = 0$, which has a unique feasible solution owing the constraint of nonnegative demand. Then, if $\Delta > c_b/(1-e_s)$, $\pi_{O,A}^{R,B} > \pi_{A,A}^{R,N}$, but $\pi_{O,A}^{R,B} > \pi_{A,A}^{R,N}$ otherwise. And when $c_b < \frac{(1-e_s)\left(1-\sqrt{1-e_s\eta}\right)}{e_s + (1-e_s)\left(1-\sqrt{1-e_s\eta}\right)}$, $\Delta_1 - c_b/(1-e_s) > 0$ always holds. Therefore, when $c_b < \frac{(1-e_s)\left(1-\sqrt{1-e_s\eta}\right)}{e_s + (1-e_s)\left(1-\sqrt{1-e_s\eta}\right)}$ and $c_b/(1-e_s) < \Delta < \Delta_1$, $\pi_{O,A}^{R,B} > \pi_{A,A}^{R,N}$, while $\pi_{O,A}^{R,B} < \pi_{A,A}^{R,N}$ otherwise.

Then, we compare the profits between (O,O) with blockchain and (A,A) without blockchain and it requires $\Delta > \Delta_1$ from Proposition 2. As $\pi_{A,A}^{R,N}$ decreases in Δ while $\pi_{O,O}^{R,B}$ is not affected by Δ, we obtain the threshold $\Delta_2 = 1 - \sqrt{1-e_s\eta}(1-c_b)$ that solves $\pi_{O,O}^{R,B} = \pi_{A,A}^{R,N}$ and $\Delta_2 > \Delta_1$ if

$c_b > \frac{(1-e_s)\left(1-\sqrt{1-e_s\eta}\right)}{e_s+(1-e_s)\left(1-\sqrt{1-e_s\eta}\right)}$, but $\Delta_2 < \Delta_1$ otherwise. Then, $\pi_{O,O}^{R,B} > \pi_{A,A}^{R,N}$, if $\Delta > \Delta_2$; but $\pi_{O,O}^{R,B} < \pi_{A,A}^{R,N}$, otherwise.

2. Comparison with Strategy (O,A) without blockchain

When $\Delta < \min\{c_b/(1-e_s), \Delta_2\}$, the proofs of comparing profits between (O,A) without blockchain and (A,A) without blockchain are identical with Proposition 1. For other conditions, we derive the general results by neglecting the constraint of $K > \bar{K}$. And if the constraint is considered, the results is that some cases that (O,A) without blockchain is the optimal strategy will be replaced by (O,A) with blockchain or (O,O) with blockchain.

(1) $c_b < \frac{(1-e_s)\left(1-\sqrt{1-e_s\eta}\right)}{e_s+(1-e_s)\left(1-\sqrt{1-e_s\eta}\right)}$ and $c_b/(1-e_s) \le \Delta < \Delta_1$. ($(O,A)$ with blockchain vs. (O,A) without blockchain)

$\pi_{O,A}^{R,B} - \pi_{O,A}^{R,N} = \frac{1}{4}\left[(1-c_b-e_s\Delta)^2 - \frac{[1-e_s\eta(1-e_r)-e_se_r\Delta]^2}{[1-e_s\eta(1-e_r)]}\right] + e_s\eta(1-e_r)K$, which is increasing in K, so the threshold $K_1 = \frac{1-(1-c_b)^2+2(1-c_b-e_r)e_s\Delta-\left(1-\frac{e_r^2}{1-e_s\eta(1-e_r)}\right)e_s^2\Delta^2}{4e_s\eta(1-e_r)} - \frac{1}{4}$ can be obtained. Especially, we obtain $\underline{\Delta} = \frac{\sqrt{1-e_s\eta(1-e_r)}\left(1-\sqrt{1-e_s\eta(1-e_r)}-c_b\right)}{e_s\left[\sqrt{1-e_s\eta(1-e_r)}-e_r\right]}$ such that $K_1 = 0$, which has a unique feasible solution owing the constraint of nonnegative demand. Then, $K_1 > 0$ if $\Delta > \underline{\Delta}$, but $K_1 < 0$ otherwise. Meanwhile, $K_0 - K_1 = \frac{(1-c_b-e_s\Delta)^2-(1-\Delta)^2}{4e_s\eta(1-e_r)}$, so if $\Delta > \frac{c_b}{1-e_s}$, then $K_0 > K_1$. Therefore, under this condition, when $K > K_1$, $\pi_{O,A}^{R,B} > \pi_{O,A}^{R,N}$, while $\pi_{O,A}^{R,B} < \pi_{O,A}^{R,N}$ if $\Delta > \underline{\Delta}$ and $K < K_1$.

(2) $\Delta > max\{\Delta_1, \Delta_2\}$ ((O,O) with blockchain vs. (O,A) without blockchain)

$\pi_{O,O}^{R,B} - \pi_{O,A}^{R,N} = \frac{1}{4}\left[(1-c_b)^2(1-e_s\eta) - \frac{[1-e_s\eta(1-e_r)-e_se_r\Delta]^2}{[1-e_s\eta(1-e_r)]}\right] + e_s\eta(1-e_r)K$, which is increasing in K, so the threshold $K_2 = \frac{1-(1-c_b)^2(1-e_s\eta)-2e_se_r\Delta+\frac{e_s^2e_r^2}{1-e_s\eta(1-e_r)}\Delta^2}{4e_s\eta(1-e_r)} - \frac{1}{4}$ can be obtained. And

$\frac{\partial K_2}{\partial \Delta} = \frac{e_r \left\{ e_s e_r \Delta / \left[1 - e_s \eta (1 - e_r)\right] - 1 \right\}}{2\eta (1 - e_r)} < 0$, which means K_2 is decreasing in Δ, so we have the threshold $\overline{\Delta} = \frac{1 - e_s \eta (1 - e_r) - (1 - c_b)\sqrt{\left[1 - e_s \eta (1 - e_r)\right](1 - e_s \eta)}}{e_s e_r}$ by letting $K_2 = 0$. Then, we have $K_2 < 0$ if $\Delta > \overline{\Delta} = \frac{1 - e_s \eta (1 - e_r) - (1 - c_b)\sqrt{\left[1 - e_s \eta (1 - e_r)\right](1 - e_s \eta)}}{e_s e_r}$, but $K_2 > 0$ otherwise. Meanwhile, $K_0 - K_2 = \frac{(1 - c_b)^2 (1 - e_s \eta) - (1 - \Delta)^2}{4 e_s \eta (1 - e_r)}$, so when $\Delta > \Delta_2$, then $K_0 > K_2$. Therefore, under this condition, when $K > K_2$, $\pi_{O,O}^{R,B} > \pi_{O,A}^{R,N}$, while $\pi_{O,O}^{R,B} < \pi_{O,A}^{R,N}$ if $\Delta < \overline{\Delta}$ and $K < K_2$. (Q.E.D.)

Proof of Proposition 4

After solving $CS_j^i = \int_{p_j^i}^{1} (v - p) f(v)\, dv$, we have $CS_j^i = \frac{1}{2}\left(1 - p_j^i\right)^2$. Replacing p_j^i with the optimal prices in Table 2, the optimal consumer surplus can be derived and they are summarized in Table 4 in the main text. Further, by comparing the value of CS_j^i obtained above, it's clear that $CS_{O,O}^B > CS_{O,A}^B$, $CS_{O,A}^N > CS_{A,A}^N$ and $CS_{O,A}^N > CS_{O,A}^B$. And $CS_{O,A}^N$ decreases in Δ while $CS_{O,O}^B$ is not affected by Δ, so we obtain the threshold $\Delta_{CS} = \frac{\left[1 - e_s \eta (1 - e_r)\right] c_b}{e_s e_r}$ that solves $CS_{O,O}^B = CS_{O,A}^N$. Then, we have the condition of $CS_{O,O}^B > \max\left\{CS_{O,A}^N, CS_{A,A}^N, CS_{O,A}^B\right\}$ by letting $CS_{O,O}^B \geq CS_{O,A}^N$, that is $\Delta \geq \Delta_{CS}$, and $CS_{O,A}^N > \max\left\{CS_{O,O}^B, CS_{A,A}^N, CS_{O,A}^B\right\}$ otherwise. (Q.E.D)

Proof of Proposition 5

Follows from Propositions 3 and 4.

Proof of Lemma 2

Following the proof of Lemma 1, we get $\tilde{p}_j^B$ and $\widetilde{\Pi}_j^B$, and by comparing the values of $\tilde{p}_j^B$ and p_j^B, we can easily obtain the results.

Proof of Proposition 6

Following the proofs of Propositions 1 to 3, we have the optimal sourcing strategies under different conditions, which are shown in Table 6 in the main text.

Proof of Proposition 7

We have $\widetilde{CS}_j^B = \frac{1}{2}\int_{p_j^i-\theta}^{1}(v-p+\theta)f(v)dv + \frac{1}{2}\int_{p_j^i}^{1}(v-p)f(v)dv$, which can be solved as $\widetilde{CS}_j^B = \frac{1}{2}\left(1-p+\frac{\theta}{2}\right)^2 + \frac{1}{8}\theta^2$ and are derived by substituting $\tilde{p}_j^B$ from Table 5 in the main text into $\widetilde{CS}_j^B$. It's obvious that $\widetilde{CS}_{O,O}^B > CS_{O,O}^B$, $\widetilde{CS}_{O,A}^B > CS_{O,A}^B$, and $\widetilde{CS}_{O,O}^B > \widetilde{CS}_{O,A}^B$. Then, following the proof of Proposition 4, we have $\widetilde{\Delta}_{CS} = \frac{1}{e_s e_r}[1-e_s\eta(1-e_r)]\left[1-\sqrt{(1+\theta/2-c_b)^2+\theta^2}\right]$, and when $c_b > 1+\frac{\theta}{2}-\sqrt{1-\theta^2}$, then $\widetilde{\Delta}_{CS} > 0$, but $\widetilde{\Delta}_{CS} < 0$ otherwise. To sum up, when $\Delta \geq \widetilde{\Delta}_{CS}$, then $\widetilde{CS}_{O,O}^B > \max\left\{CS_{O,A}^N, \widetilde{CS}_{O,A}^B, CS_{A,A}^N\right\}$, but $CS_{O,A}^N > \max\left\{\widetilde{CS}_{O,O}^B, \widetilde{CS}_{O,A}^B, CS_{A,A}^N\right\}$ holds when $\Delta < \min\left\{\widetilde{\Delta}_{CS}, 0\right\}$. In addition, $\widetilde{\Delta}_{CS} - \Delta_{CS} = \frac{1}{e_s e_r}[1-e_s\eta(1-e_r)]\left[1-c_b-\sqrt{(1-c_b+\theta/2)^2+\theta^2}\right] < 0$. (Q.E.D)

Proof of Proposition 8

Combining with the previous analysis, we know $\widetilde{K}_2 < K_2$, $\widetilde{\Delta}_1 > \Delta_1$, $\widetilde{\Delta}_2 < \Delta_2$ and $\widetilde{\Delta}_{CS} < \Delta_{CS}$, so $\tilde{b} = \left(K-\widetilde{K}_2\right)^+ < \bar{b}$, when $c_b < \frac{\theta}{2} + (1-e_s)\left(1-\sqrt{1-e_s\eta}\right)\Big/\left[e_s + (1-e_s)\left(1-\sqrt{1-e_s\eta}\right)\right]$,

$$\tilde{s} = \left(\max\left\{\widetilde{\Delta}_1, \widetilde{\Delta}_{CS}\right\} - \Delta\right)^+ = \begin{cases} \left(\widetilde{\Delta}_1 - \Delta\right)^+ > \bar{s}, if\, \widetilde{\Delta}_1 > \widetilde{\Delta}_{CS} \\ \left(\widetilde{\Delta}_{CS} - \Delta\right)^+ < \bar{s}, if\, \widetilde{\Delta}_{CS} > \widetilde{\Delta}_1 \end{cases},$$

and when $c_b > \frac{\theta}{2} + (1-e_s)\left(1-\sqrt{1-e_s\eta}\right)\Big/\left[e_s + (1-e_s)\left(1-\sqrt{1-e_s\eta}\right)\right]$,

$$\tilde{s} = \left(\max\left\{\widetilde{\Delta}_2, \widetilde{\Delta}_{CS}\right\} - \Delta\right)^+ = \begin{cases} \left(\widetilde{\Delta}_2 - \Delta\right)^+ < \bar{s}, if\, \widetilde{\Delta}_2 > \widetilde{\Delta}_{CS} \\ \left(\widetilde{\Delta}_{CS} - \Delta\right)^+ < \bar{s}, if\, \widetilde{\Delta}_{CS} > \widetilde{\Delta}_2 \end{cases}. \qquad \text{(Q.E.D)}$$

Appendix B. General case with Strategy (*O*, *O*) without blockchain

We show the results of the retailer's optimal decisions in the scenario where Strategy (O,O) without blockchain can be adopted by him by relaxing the assumption $K > \bar{K}$. Given the retail price, the main results are given as follows. Firstly, the optimal sourcing strategies without blockchain adoption are shown in Table B1.

Table B1 Retailer's optimal sourcing strategy without blockchain

Marginal cost of sourcing from a safe supplier (Δ)	Penalty cost for infection (K)	Optimal sourcing strategy without blockchain
$\Delta \le \Delta_1^N$	-	(A,A)
$\Delta_1^N < \Delta \le \Delta_2^N$	$K < K_2^N$	(O,A)
	$K \ge K_2^N$	(A,A)
$\Delta > \Delta_2^N$	$K < K_2^N$	(O,O)
	$K_1^N < K \le K_2^N$	(O,A)
	$K > K_2^N$	(A,A)

For the thresholds, we have $\Delta_1^N = p\eta\left[1-(1-e_s)/(1-e_s e_r)\right]$, $\Delta_2^N = p$, $K_1^N = (1-p)(\Delta/\eta - p)$ and $K_2^N = (1-p)\left\{(1-e_s e_r)\Delta/\left[e_s\eta(1-e_r)\right]-p\right\}$. Meanwhile, $\pi_{O,A}^{R,B} > \pi_{O,O}^{R,B}$ if $\Delta < \Delta^B = (p-c_b)\eta$, but $\pi_{O,A}^{R,B} < \pi_{O,O}^{R,B}$ if $\Delta > \Delta^B$.

Next, the results of comparing the profits between with and without blockchain adoption are as follows.

(1) $\Delta < \min\left\{c_b/(1-e_s), e_s\eta(p-c_b)+c_b\right\}$: Under this condition, $\Pi_j^N > \Pi_j^B$, where $j \in \left\{(O,O),(A,A),(O,A)\right\}$, so the optimal sourcing strategies are identical with Table B1;

(2) $\min\left\{c_b/(1-e_s), e_s\eta(p-c_b)+c_b\right\} < \Delta < \Delta_2^N$.

Table B2 Optimal decisions when $\min\left\{c_b/(1-e_s), e_s\eta(p-c_b)+c_b\right\} < \Delta < \Delta_2^N$

Variable cost for blockchain operations (c_b)	Marginal cost of sourcing from a safe supplier (Δ)	Penalty cost for detected infection (K)	Blockchain adoption	Optimal sourcing strategy
$0 < c_b < \dfrac{e_s\eta(1-e_r)(1-e_s)p}{1-e_s e_r}$	$\dfrac{c_b}{1-e_s} \le \Delta < \eta p - \dfrac{c_b}{e_s(1-e_r)}$	-	√	(O,A)
	$\eta p - \dfrac{c_b}{e_s(1-e_r)} \le \Delta < \Delta^B$	$K > K'$	√	(O,A)
		$K \le K'$	×	(O,A)
	$\Delta^B \le \Delta < \Delta_2^N$	$K \le K''$	×	(O,A)
		$K > K''$	√	(O,O)
$\dfrac{e_s\eta(1-e_r)(1-e_s)p}{1-e_s e_r} < c_b < \dfrac{(1-e_s)\eta p}{1+(1-e_s)\eta}$	$\dfrac{c_b}{1-e_s} \le \Delta < \Delta^B$	$K > K'$	√	(O,A)
		$K \le K'$	×	(O,A)
	$\Delta^B \le \Delta < \Delta_2^N$	$K \le K''$	×	(O,A)
		$K > K''$	√	(O,O)
$\dfrac{(1-e_s)\eta p}{1+(1-e_s)\eta} < c_b < \dfrac{(1-e_s)\eta p}{1-e_s\eta}$	$e_s\eta(p-c_b)+c_b \le \Delta < \Delta_2^N$	$K > K''$	√	(O,O)
		$K \le K''$	×	(O,A)

For the thresholds, we have $\overline{\Delta} = \eta p + \frac{1 - e_s \eta}{e_s} c_b$, $K' = \frac{(1-p)[e_s(1-e_r)\Delta + c_b - e_s \eta (1-e_r) p]}{e_s \eta (1-e_r)}$ and $K'' = \frac{(1-p)[(1-e_s \eta) c_b - e_s e_r (\Delta - p\eta)]}{e_s \eta (1-e_r)}$.

(3) $\Delta > \Delta_2^N$

Table B3 The optimal decisions when $\Delta > \Delta_2^N$

Variable cost for blockchain operations (c_b)	Marginal cost of sourcing from a safe supplier (Δ)	Penalty cost for detected infection (K)	Blockchain adoption	Optimal sourcing strategy
$c_b < \frac{(1-e_s)\eta p}{1-e_s \eta}$	$\Delta_2^N \le \Delta < \overline{\Delta}$	$K > K''$	√	(O,O)
		$K_1^N < K \le K''$	×	(O,A)
		$K \le K_1^N$	×	(O,O)
	$\Delta > \overline{\Delta}$	$K \le K'''$	×	(O,O)
		$K > K'''$	√	(O,O)
$c_b > \frac{(1-e_s)\eta p}{1-e_s \eta}$	$e_s \eta (p - c_b) + c_b \le \Delta < \overline{\Delta}$	$K > K''$	√	(O,O)
		$K_1^N < K \le K''$	×	(O,A)
		$K \le K_1^N$	×	(O,O)
	$\Delta > \overline{\Delta}$	$K \le K'''$	×	(O,O)
		$K > K'''$	√	(O,O)

Note that $K''' = \frac{(1-p)(1-e_s \eta) c_b}{e_s \eta}$.