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# Blockchain adoption decision analysis of fresh supply chain considering 3PL's misreporting behavior

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**Abstract**

In fresh supply chain, the third-party logistics service provider (3PL) has incentive to misreport its private information such as preservation service effort level and logistics transportation cost for the sake of gaining competitive advantage in the market. A tamper-proof and traceability system supported by blockchain technology (BCT) can prevent 3PL from misreporting. In this paper, we investigate the BCT adoption decision of a fresh supply chain consisting of a manufacturer, a retailer, and a 3PL when the 3PL misreports its private information. Specifically, we conduct four models: without BCT adoption and 3PL misreports its preservation service effort level (Model $NE$), without BCT adoption and 3PL misreports its logistics transportation cost (Model $NC$), without BCT adoption and 3PL misreports both preservation service effort level and logistics transportation cost (Model $ND$) and with BCT adoption and no misrepresentation (Model $AB$). By calculating the models, our study indicates that when the 3PL underreports its fresh-keeping service effort level and the degree of underreporting is high or when the 3PL overreports its logistics transportation cost and the degree of overreporting is high, all fresh supply chain members will reach an agreement on implementing BCT. However, when the 3PL misreports its fresh-keeping service effort and logistics transportation cost simultaneously, the BCT adoption decision is influenced not only by the misreporting coefficient of logistics transportation cost and preservation service effort, but also by logistics transportation cost. Finally, as logistics transportation cost increases, the manufacturer and retailer are reluctant to adopt BCT, while the 3PL is willing to adopt BCT.



*Keywords:* Misrepresentation behavior; Blockchain technology; Fresh supply chain; Third-party logistics

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## 1. Introduction

Many fresh retailers delegate the transportation tasks and preservation service to 3PLs in order to improve the freshness of products. However, 3PLs may misrepresent their private information for the sake of gaining competitive advantage in the market, which will damage the whole fresh supply chain. For example, the 3PL has information advantages of logistics service effort level and logistics transportation cost. It may overstate or understate the information to distort the decisions of other fresh supply chain members. As an emerging technology, BCT has the characteristics of traceability, transparency, decentralization and tamper-proof. When the fresh supply chain adopts BCT, information flows transparently through the fresh supply chain, it is not worth the loss to misreport for the 3PL. Therefore, it is meaningful and necessary to explore the 3PL's misreporting problem of the fresh supply chain and the adoption of BCT under different misreporting scenarios.

In the misreporting behavior of supply chain, Yan et al. (2016) consider a dual-channel supply chain consisting of two manufacturers and a retailer, and analyze the impact of the manufacturer's misreporting of cost information on the dual-channel supply chain's decisions[1]. Zhao et al. (2021) investigate outsourcing collecting strategy when the third-party remanufacturer misreports remanufacturing production cost[2]. Qu et al. (2022) consider the retailer's fairness concern and the manufacturer's misreport behavior and analyze their impacts on the optimal pricing and service level [3]. Chen et al. (2022) investigate the impact of cost misreporting on strategic inventories [4]. In the research of BCT adoption in supply chain, Zhong et al. (2023) explore the impacts of BCT on a dual-channel supply chain, and compare the optimal decisions and payoffs with government offering a quantity/innovation subsidy[5]. Considering the benefits of BCT for improving traceability and the negative impacts of reducing environmental sustainability, Biswas et al. (2023) explore the trade-offs between traceability and sustainability for BCT by establishing a game model[6].

There have been many studies on the misreporting problem and BCT adoption of supply chain, but most of them focus on traditional two-level supply chain and unilateral asymmetric cost information. However, there are few articles that consider 3PL's misreporting problem of the three-level fresh supply chain, and those that combine supply chain misreporting problem with BCT adoption are even rarer. In this paper, we investigate the roles of BCT adoption in the fresh supply chain when the 3PL misreports its private information. By constructing four Stackelberg models, we explore firms' optimal decisions as well as the impact of BCT adoption on the fresh supply chain' performances.

The remainder of this paper is organized as follows. Section 2 provides notations and problem descriptions. Section 3 presents four models of the 3PL misreports its private information and with BCT adoption. Section 4 compares the equilibrium decisions and payoffs of the fresh supply chain. Finally, the paper concludes in Section 5.

## 2. Notations and problem description

Consider a fresh supply chain consisting of a manufacturer, a retailer and a 3PL. The manufacturer produces fresh products, which are transported to the retailer through the 3PL, and finally sold to consumers. The 3PL not only provides transportation but also preservation service of products, and the logistics service fee will be paid by the retailer. Since improving the preservation service level, such as purchasing refrigerating equipment and upgrading technology, requires a certain cost, we assume that the fresh-keeping service cost is $C(e)=e^2/2$, which is widely used in previous literature[7,8]. In addition to the fresh-keeping service cost, the logistics transportation cost is $c$.

Due to the perishability of fresh products, consumers pay attention not only to the price but also to the freshness when purchasing fresh products. The freshness of products is directly related to 3PL's fresh-keeping service effort level, and the higher the fresh-keeping service effort level of the 3PL, the higher the freshness of products. Therefore, the demand function can be expressed by $q=1-p+\beta e$, where $\beta$ is the sensitivity coefficient of preservation service effort level and we assume $\beta=1$ to simplify the model.

When there is no BCT adoption, the 3PL has an incentive to misreport fresh-keeping service effort level and logistics transportation cost so as to gain profits. There are three scenarios of the 3PL's misreporting behavior that may occur (1) The 3PL lies about the fresh-keeping service effort level; (2) The 3PL lies about the logistics transportation cost; (3) The 3PL lies about the fresh-keeping service effort level and logistics transportation cost simultaneously. Notably, the misrepresentation factor of fresh-keeping service effort level is $\mu$ and the misrepresentation factor of logistics transportation cost is $\delta$, which are constants greater than $0$. To be specific, $0<\mu,\delta<1$ reflects that the 3PL understates its fresh-keeping service effort level and logistics transportation cost. On

the contrary, $\mu,\delta>1$ means that the 3PL overreports its fresh-keeping service effort level and logistics transportation cost. When the fresh supply chain implements BCT, due to the traceability, transparency, decentralization and tamper-proof characteristics of BCT, information flows transparently through the supply chain, the 3PL's misreporting behaviors can be inhibited. A summary of the model parameters and variables are illustrated in Table 1.

Table 1. Model Notations.

| Parameters | Explanation |
|---|---|
| $c$ | 3PL's logistics transportation cost |
| $\mu$ | 3PL's fresh-keeping service effort level misrepresentation factor |
| $\delta$ | 3PL's logistics transportation cost misrepresentation factor |
| **Decision variables** | **Explanation** |
| $w^i$ | Wholesale price, $i=NE,NC,ND,AB$ |
| $p^i$ | Retail price, $i=NE,NC,ND,AB$ |
| $e^i$ | Preservation service effort level, $i=NE,NC,ND,AB$ |
| $k^i$ | Unit product logistics service fee, $i=NE,NC,ND,AB$ |
| **Benefit variables** | **Explanation** |
| $\pi_M^i$ | Manufacturer's payoff, $i=NE,NC,ND,AB$ |
| $\pi_R^i$ | Retailer's payoff, $i=NE,NC,ND,AB$ |
| $\pi_T^i$ | 3PL's payoff, $i=NE,NC,ND,AB$ |
| $\pi_{SC}^i$ | Fresh supply chain's payoff, $i=NE,NC,ND,AB$ |

Where the superscript "$NE$" denotes without BCT and the 3PL lies about the preservation service effort level, "$NC$" denotes without BCT and the 3PL lies about the logistics transportation cost, "$ND$" denotes without BCT and the 3PL lies about the preservation service effort level and logistics transportation cost simultaneously, "$AB$" denotes the fresh supply chain adopts BCT and without misreporting behavior occurring.

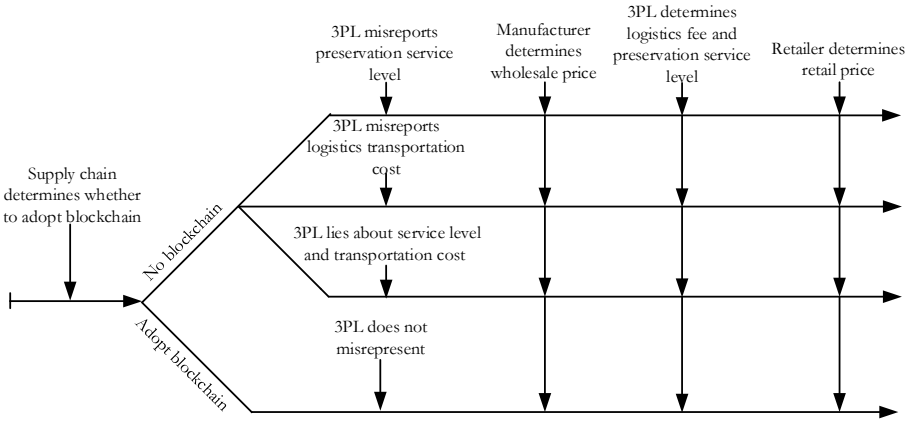



Fig. 1. The sequence of the game.

At the beginning of the game, the fresh supply chain participants determines whether to adopt BCT. If the answer is no, there will be three scenarios which are the 3PL lies about the fresh-keeping service effort level, the 3PL lies about the logistics transportation cost and the 3PL lies about the fresh-keeping service effort level and the logistics transportation cost simultaneously. If the supply chain firms unanimously agree to adopt BCT, the 3PL's misreporting behavior will be inhibited. After that, the manufacturer determines wholesale price, then the 3PL determines logistics service fee and preservation service effort level simultaneously. Finally, the retailer sets retail price. The sequence for this game is illustrated in Fig. 1.

## 3. Model development

### 3.1. The 3PL misreports the fresh-keeping service effort level (Model $NE$)

We begin with investigating the first scenario without BCT adoption in which the 3PL misreports the fresh-keeping service effort level. At this time, the fresh-keeping service level disclosed by the 3PL is $\mu e$ and the market demand is assumed as $q^{NE} = 1 - p + \mu e$. We first derive the retailer's optimal price decision in the last stage, who determines based on misrepresented market demand. Thus, the retailer's issue can be denoted by $\max \pi_R = (p - w - k)q^{NE}$ and the optimal retail price $p(w,e,k) = (1 + e + k + w)/2$. Substituting $p(w,e,k)$ into the 3PL's payoff function $\max \pi_T = (k - c)q^{NE} - e^2/2$ leads to its' optimal decisions are $k(w) = (2 + 2c - 2w - c\mu^2)/(4 - \mu^2)$ and $e(w) = (\mu - c\mu - w\mu)/(4 - \mu^2)$ respectively. Anticipating the retailer and the 3PL's response, the manufacturer sets wholesale price $w$ to maximize $\max \pi_M = wq^{NE}$ and obtains $w = (1 - c)/2$. The retailer can only sell the actual volume of products to consumers, but she has to pay for the purchase cost and preservation fee of products misreported. Thus, the retailer's actual profit is $\pi_R^{NE} = pq - (w + k)q^{NE}$.

**Proposition 1.** In Model $NE$, the optimal decisions and payoffs of the manufacturer, retailer and 3PL are

$$w^{NE} = \frac{1-c}{2},\ p^{NE} = \frac{-7 + \mu^2 + c(-1 + \mu^2)}{2(-4 + \mu^2)},\ k^{NE} = \frac{-1 + c(-3 + \mu^2)}{-4 + \mu^2},\ e^{NE} = \frac{(-1 + c)\mu}{2(-4 + \mu^2)}.$$

$$\pi_M^{NE} = -\frac{(-1 + c)^2}{4(-4 + \mu^2)},\ \pi_T^{NE} = -\frac{(-1 + c)^2}{8(-4 + \mu^2)},\ \pi_R^{NE} = \frac{1 + 7\mu - 7\mu^2 - \mu^3 + \mu^4 + c(6\mu^2 - 2 - 6\mu) + c^2(1 - \mu + \mu^2 + \mu^3 - \mu^4)}{4(\mu^2 - 4)^2}.$$

### 3.2. The 3PL misreports the logistics transportation cost (Model $NC$)

We now turn to scenario $NC$ in which without BCT adoption and the 3PL lies about the logistics transportation cost. At this time, the logistics transportation cost disclosed by the 3PL is $\delta c$ and the 3PL determines its logistics service fee and preservation service effort level based on $\max \pi_T = (k - \delta c)q - e^2/2$. However, the 3PL's actual payoff is $\pi_T^{NC} = (k - c)q - e^2/2$. In addition, the profit maximization objective function of the retailer and manufacturer are $\max \pi_R = (p - w - k)q$ and $\max \pi_M = wq$.

**Proposition 2.** In Model $NC$, the optimal decisions and payoffs of the manufacturer, retailer and 3PL are

$$w^{NC} = \frac{1}{2}(1 - c\delta),\ p^{NC} = 1,\ k^{NC} = \frac{1}{3}(1 + 2c\delta),\ e^{NC} = \frac{1}{6}(1 - c\delta).$$

$$\pi_M^{NC} = \frac{1}{12}(1 - c\delta)^2,\ \pi_R^{NC} = \frac{1}{36}(1 - c\delta)^2,\ \pi_T^{NC} = \frac{1}{24}(1 + 2c(\delta - 2) + c^2(4 - 3\delta)\delta).$$

### 3.3. The 3PL misreports the fresh-keeping service effort level and logistics transportation cost (Model $ND$)

In this scenario, there is no BCT adoption and the 3PL misreports the fresh-keeping service level and logistics transportation cost simultaneously. Therefore, the fresh-keeping service level disclosed by the 3PL is $\mu e$ and the market demand is assumed as $q^{ND} = 1 - p + \mu e$. The retailer determines price based on $\max \pi_R = (p - w - k)q^{ND}$. The logistics transportation cost disclosed by the 3PL is $\delta c$ and the 3PL makes its decisions based on $\max \pi_T = (k - \delta c)q^{ND} - e^2/2$. However, the actual payoffs of the retailer and 3PL are $\pi_R^{ND} = pq - (w + k)q^{ND}$ and $\pi_T^{ND} = (k - c)q^{ND} - e^2/2$. In addition, the profit maximization objective function of the manufacturer is $\max \pi_M = wq$.

**Proposition 3.** In Model $ND$, the optimal decisions and payoffs of the manufacturer, retailer and 3PL are

$$w^{ND} = \frac{1}{2}(1 - c\delta),\ p^{ND} = \frac{\mu^2 + c\delta(\mu^2 - 1) - 7}{2(\mu^2 - 4)},\ k^{ND} = \frac{c\delta(-3 + \mu^2) - 1}{\mu^2 - 4},\ e^{ND} = \frac{\mu - c\delta\mu}{8 - 2\mu^2}.$$

$$\pi_M^{ND} = \frac{(1 - c\delta)^2}{4(4 - \mu^2)},\ \pi_T^{ND} = \frac{c^2\delta(3\delta - 4) - 1 - 2c(\delta - 2)}{8(-4 + \mu^2)},\ \pi_R^{ND} = \frac{(1 + 7\mu - 7\mu^2 - \mu^3 + \mu^4 + 2c\delta(3\mu^2 - 1 - 3\mu) + c^2\delta^2(1 - \mu + \mu^2 + \mu^3 - \mu^4))}{4(\mu^2 - 4)^2}.$$

### 3.4. Adopting BCT (Model $AB$)

With BCT adoption, information flows transparently between supply chain members. Once one of participants misreports his(her) information, it will be detected by other supply chain members. The results of misrepresenting information may be the loss of reputation, or even the breakdown of the partnership, and further leading to withdrawal from the market. Therefore, it is unworthy misreporting information in the case of BCT adoption. In other words, the misreporting behaviors can be inhibited with BCT adopting. In Model $AB$, the retailer can receive true information of preservation service effort level and logistics transportation cost from the 3PL. Thus, the demand function is credible and denote by $q^{AB}=1-p+e$. The manufacturer, the retailer and the 3PL's problems can be given as follows:

$$\max \pi_M(w)=wq^{AB},\ \max \pi_R(p)=(p-w-k)q^{AB} \text{ and } \max \pi_T(k,e)=(k-c)q^{AB}-\frac{1}{2}e^2.$$

**Proposition 4.** In Model $AB$, the optimal decisions and payoffs of the manufacturer, retailer and 3PL are

$$w^{AB}=\frac{1-c}{2},\ p^{AB}=1,\ k^{AB}=\frac{1}{3}(1+2c),\ e^{AB}=\frac{1-c}{6},\ \pi_M^{AB}=\frac{1}{12}(-1+c)^2,\ \pi_R^{AB}=\frac{1}{36}(-1+c)^2,\ \pi_T^{AB}=\frac{1}{24}(-1+c)^2.$$

## 4. Comparison and analysis

In this section, we study the roles of BCT implementing on fresh supply chain and its participants' performances when different misrepresentation scenarios occur, including the wholesale price, retail price, preservation service effort level, logistics service fee and the payoffs of the firms.

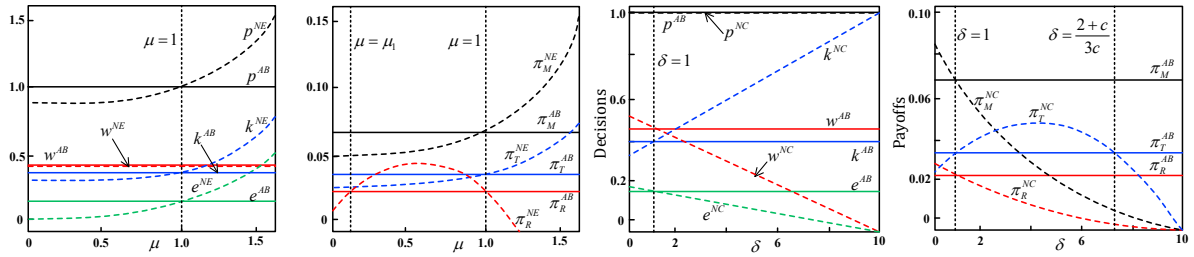
### 4.1. Comparison between Model $AB$ and Model $NE$.

In this subsection, by comparing and analyzing the equilibrium results of Model $AB$ and Model $NE$. we explore the roles of BCT adopting on fresh supply chain members' decisions and payoffs when the 3PL misreports the fresh-keeping service level. The results are characterized as follows.

**Proposition 5.** The comparison of the fresh supply chain participants' equilibrium decisions and optimal profits for Model $AB$ and Model $NE$ reveals that

(1) $w^{AB}=w^{NE}$; If $1<\mu<(1+\sqrt{5})/2$, then $p^{AB}<p^{NE}$, $e^{AB}<e^{NE}$ and $k^{AB}<k^{NE}$; otherwise, $p^{AB}>p^{NE}$, $e^{AB}>e^{NE}$ and $k^{AB}>k^{NE}$;

(2) If $0<\mu<1$, then $\pi_M^{AB}>\pi_M^{NE}$ and $\pi_T^{AB}>\pi_T^{NE}$; otherwise, $\pi_M^{AB}<\pi_M^{NE}$ and $\pi_T^{AB}<\pi_T^{NE}$. If $0<\mu<\mu_1$ or $1<\mu<(1+\sqrt{5})/2$, then $\pi_R^{AB}>\pi_R^{NE}$; otherwise, $\pi_R^{AB}<\pi_R^{NE}$.




(a) Impact of $\mu$ on decisions (b) Impact of $\mu$ on payoffs (c) Impact of $\delta$ on decisions (d) Impact of $\delta$ on payoffs

Fig. 2. The effect of BCT implementation on the firms' decisions and payoffs.

As shown in Fig. 2 (a), we observe that no matter the 3PL underreports or overreports its preservation service effort level, the adoption of BCT has no influence on the manufacturer's wholesale price. However, when the 3PL underreports its fresh-keeping service effort level (i.e., $0<\mu<1$), the BCT adoption will lead to a rise in the retailer's price, the 3PL's preservation service effort level and logistics service fee. The reason is that when the 3PL underreports (overreports) its fresh-keeping service level, the market demand under misrepresentation will be lower (higher), the BCT adoption can make all fresh supply chain members understand the real market demand and motivates the retailer and 3PL raise (lower) prices and fresh-keeping service level. We illustrate the impacts of BCT implementation on

firms' payoffs in Fig. 2 (b), which suggests that the roles of BCT adoption on the payoffs of the manufacturer and 3PL are the same as retail price, logistics service fee and preservation service effort level. However, the influences of BCT adoption on the retailer's payoff is unexpected. Only when the 3PL underreports its fresh-keeping service level and the degree of underreporting is low (i.e., $\mu_1 < \mu < 1$), the retailer's payoff will decline after adopting BCT, otherwise, the retailer's payoff will rise. In addition, when the 3PL underreports its fresh-keeping service level and the degree of underreporting is high (i.e., $0 < \mu < \mu_1$), fresh supply chain members' payoffs all rise after adopting BCT, that is, they reach an agreement on adopting BCT.

### *4.2. Comparison between Model AB and Model NC.*

In this part, by comparing the equilibrium results of Model $AB$ and Model $NC$, we investigate the effect of BCT implementation on fresh supply chain participants' decisions and performances when the 3PL misreports its logistics transportation cost. The results are shown as follows.

**Proposition 6.** The comparison of the supply chain participants' equilibrium decisions and optimal performances for Model $AB$ and Model $NC$ reveals that

(1) $p^{AB} = p^{NC}$; If $0 < \delta < 1$, then $w^{AB} < w^{NC}$, $e^{AB} < e^{NC}$ and $k^{AB} > k^{NC}$; otherwise, $w^{AB} > w^{NC}$, $e^{AB} > e^{NC}$ and $k^{AB} < k^{NC}$;

(2) If $1 < \delta < 1/c$, then $\pi_M^{AB} > \pi_M^{NC}$ and $\pi_R^{AB} > \pi_R^{NC}$; otherwise, $\pi_M^{AB} < \pi_M^{NC}$ and $\pi_R^{AB} < \pi_R^{NC}$; If $0 < \delta < 1$ or $(2+c)/3c < \delta < 1/c$, then $\pi_T^{AB} > \pi_T^{NC}$; otherwise, $\pi_T^{AB} < \pi_T^{NC}$.

As shown in Fig. 2 (c), we observe that no matter the 3PL underreports or overreports its logistics transportation cost, BCT adoption has no impact on the retail price. However, when the 3PL overreports its logistics transportation cost (i.e., $1 < \delta < 1/c$), the BCT adoption will lead to an increase in the manufacturer's wholesale price and the 3PL's preservation service effort level, and a decrease in the 3PL's logistics service fee. As shown in Fig. 2 (d), when the 3PL overreports its logistics transportation cost, BCT adoption will increase the payoffs of the manufacturer and the retailer. This is because BCT allows the manufacturer and the retailer to realize the true level of the 3PL's logistics transportation cost, the impact of rising wholesale price leads to higher profit for the manufacturer and the effect of decreasing logistics service fee leads to higher profit for the retailer. In addition, only when the 3PL overreports its logistics transportation cost and the degree of overreporting is low, the 3PL's payoff will decline after adopting BCT. As shown in Fig. 2 (d), when the 3PL overreports its logistics transportation cost and the degree of overreporting is high (i.e., $(2+c)/3c < \delta < 1/c$), fresh supply chain members can reach an agreement on adopting BCT.

### *4.3. Comparison between Model AB and Model ND.*

In this subsection, we will compare the equilibrium results of Model $AB$ and Model $ND$, exploring the roles of BCT implementing on fresh supply chain participants' payoffs when the 3PL misreports its fresh-keeping service level and logistics transportation cost simultaneously. The results are summarized as follows.

**Proposition 7.** The comparison of the firms' optimal payoffs for Model $AB$ and Model $ND$ reveals that

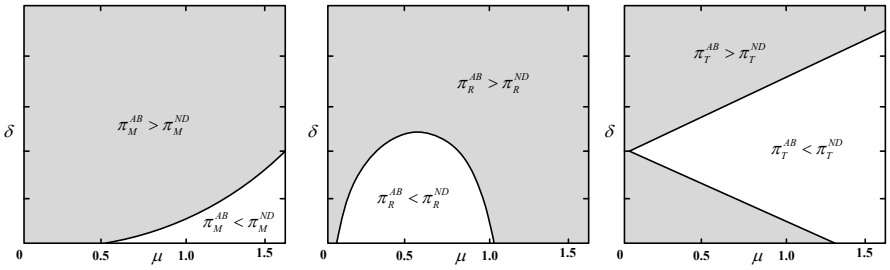
(1) If $0 < c < (2-\sqrt{3})/2$, $\mu_4 < \mu < (1+\sqrt{5})/2$ and $0 < \delta < \delta_3$ or $(2-\sqrt{3})/2 \le c < 1$, $0 < \mu < (1+\sqrt{5})/2$ and $0 < \delta < \delta_3$, then $\pi_M^{AB} < \pi_M^{ND}$; otherwise, $\pi_M^{AB} > \pi_M^{ND}$;

(2) If $0 < c < 1/4$, $\mu_5 \le \mu < \mu_6$ and $0 < \delta < \delta_4$ or $1/4 \le c < 1$, $0 < \mu < \mu_6$ and $0 < \delta < \delta_4$, then $\pi_R^{AB} < \pi_R^{ND}$; otherwise, $\pi_R^{AB} > \pi_R^{ND}$;

(3) If $0 < c < (\sqrt{5}-1)/(5+\sqrt{5})$, $0 < \mu \le \mu_7$ and $\delta_5 < \delta < \delta_6$ or $\mu_7 < \mu < (1+\sqrt{5})/2$ and $0 < \delta < \delta_6$ or $(\sqrt{5}-1)/(5+\sqrt{5}) < c < 1$, $0 < \mu < (1+\sqrt{5})/2$ and $\delta_5 < \delta < \delta_6$, then $\pi_T^{AB} < \pi_T^{ND}$; otherwise, $\pi_T^{AB} > \pi_T^{ND}$.

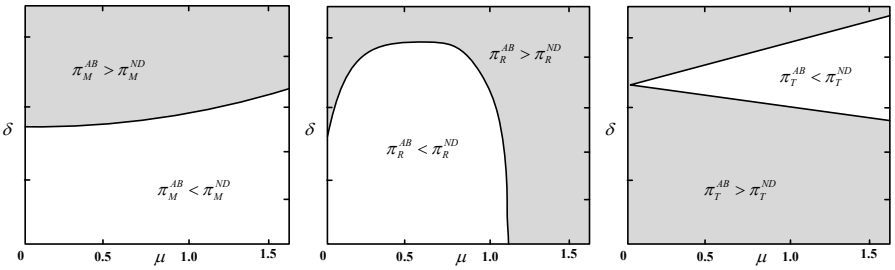
From Proposition 7, we observe that the explanation of the firms' payoffs can be divided into two cases about the logistics transportation cost, but the threshold is different for the manufacturer, retailer and 3PL. The similarity is when the 3PL underreports its logistics transportation cost and the underreporting degree is high, BCT adoption will reduce the payoffs of the manufacturer and retailer no matter what $c$ is. The reason is that underreporting logistics transportation cost is profitable to the manufacturer and retailer, but the adoption of BCT will erode this advantage. For the 3PL, when $c$ is low and $\mu$ is relatively high or $\mu$ is relatively high and $\delta$ is medium, or when $c$ is high and $\delta$ is medium, BCT adoption will reduce the 3PL's payoffs. Otherwise, implementing BCT is beneficial to the 3PL. From Fig. 3 and Fig. 4, we can observe that, as logistics transportation cost grows, the area in which the manufacturer and the retailer benefit from adopting BCT is shrinking, while the area in which the 3PL benefits from BCT adoption

is increasing, which indicates that the manufacturer and retailer are reluctant to adopt BCT, while the 3PL is willing to adopt BCT.




(a) Manufacturer's payoff (b) Retailer's payoff (c) 3PL's payoff

Fig. 3. Impact of BCT adoption on the firms' payoffs ($c = 0.1$).




(a) Manufacturer's payoff (b) Retailer's payoff (c) 3PL's payoff

Fig. 4. Impact of BCT adoption on the firms' payoffs ($c = 0.6$).

## 5. Conclusions

Many fresh retailers delegate the transportation and preservation service to the 3PL in order to control the deterioration rate and improve the freshness of products. However, the 3PL may misrepresent its private information for the sake of gaining competitive advantage in the market and distorting the decisions of other fresh supply chain members. There are three scenarios of the 3PL's misreporting behavior may occur: (1) The 3PL misreports the fresh-keeping service level; (2) The 3PL misreports the logistics transportation cost; (3) The 3PL misreports the fresh-keeping service effort level and logistics transportation cost simultaneously. Due to the traceability, transparency, decentralization and tamper-proof characteristics of BCT, when the fresh supply chain adopts BCT, information flows transparently through the fresh supply chain, the 3PL's misreporting behaviors can be inhibited. In this paper, we examine the BCT adoption decision of a fresh supply chain when the 3PL misreports its private information. By constructing four Stackelberg game models, we investigate firms' optimal decisions as well as the roles of BCT adoption on the fresh supply chain's performances.

Our results indicate that when the 3PL misreports its fresh-keeping service level, only when the 3PL underreports its preservation service effort level, the manufacturer and the 3PL will benefit from BCT adoption. However, when the 3PL underreports its fresh-keeping service effort level and the degree of underreporting is high, or the 3PL overreports its fresh-keeping service effort level, the retailer will benefit from BCT adoption. In addition, when the 3PL underreports its fresh-keeping service effort level and the degree of underreporting is high, fresh supply chain members will reach an agreement on adopting BCT.

This study also finds that when the 3PL misreports its logistics transportation cost, only when the 3PL overreports its logistics transportation cost, the manufacturer and the retailer will benefit from BCT adoption. However, when the 3PL underreports its logistics transportation cost, or the 3PL overreports its logistics transportation cost and the degree of overreporting is high, the 3PL will benefit from BCT adoption. In addition, when the 3PL overreports its logistics

transportation cost and the degree of overreporting is high, fresh supply chain members will reach an agreement on adopting BCT.

Finally, when the 3PL misreports its preservation service effort level and logistics transportation cost simultaneously, the impact of BCT adoption on the fresh supply chain is influenced by the combined effects of logistics transportation cost, logistics transportation cost misreporting coefficient and preservation service effort level misreporting coefficient. In addition, we can observe that, as logistics transportation cost grows, the manufacturer and retailer are reluctant to adopt BCT, while the 3PL is willing to adopt BCT.

Therefore, whether the fresh supply chain should adopt BCT needs to be judged by a variety of factors, including logistics transportation cost, preservation service effort misreporting level and logistics transportation cost misreporting level. What's more, analyzing the impacts of BCT adoption when different supply chain members misreport their private information would be an interesting direction for future research.

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## Appendix

The symbols involved in this paper are summarized as follows:

$\mu_1$ is the second solution of $7-7c-(56+16c)\mu+(c-1)\mu^2+(8+10c)\mu^3=0$, $\mu_2=\sqrt{(25-32c+16c^2-18c\delta+9c^2\delta^2)/(c-1)}/2-3(c\delta-1)/2(c-1)$, $\mu_3=\sqrt{(1+8c)/(1+2c)}$, $\mu_4=\sqrt{(1-8c+4c^2)/(1-c)^2}$, $\mu_5$ is the second solution of $7-32c+16c^2-63\mu+(55+16c-8c^2)\mu^2+9\mu^3+(c^2-8-2c)\mu^4=0$, $\mu_6$ is the third solution of $7-32c+16c^2-63\mu+(55+16c-8c^2)\mu^2+9\mu^3+(c^2-8-2c)\mu^4=0$, $\mu_7=(2c-1)/(c-1)$.

$\delta_1=(4\sqrt{5}+5c-\sqrt{5}c-2)/(3c+3\sqrt{5}c)$, $\delta_2=(\mu^2+2c\mu^2-1-8c)/(3c\mu^2-9c)$, $\delta_3=1/c-\sqrt{((4-8c+4c^2-\mu^2+2c\mu^2-c^2\mu^2)/c^2)/\sqrt{3}}$, $\delta_4=-\sqrt{(\mu^2-4)^2(1-2c(1-(\mu-1)^2\mu(1+\mu))-c^2((\mu-1)^2\mu(1+\mu)-1)+(\mu-1)^2\mu(8\mu-1))/(c^2(\mu-\mu^2-\mu^3+\mu^4-1)^2)}/3+(3\mu^2-1-3\mu)/c(\mu-\mu^2-\mu^3+\mu^4-1)$, $\delta_5=(1+2c-\mu+c\mu)/3c$, $\delta_6=(1+2c+\mu-c\mu)/3c$.

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