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## Research on Blockchain-Based Moral Hazard Prevention for Logistics Service Providers Under False Reporting Behavior: Postprint

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### Abstract

This study considers a two-level e-commerce supply chain comprising an e-commerce platform and a third-party logistics service provider as the research object, addressing the moral hazard problem arising from the third-party logistics service provider's complete control over its own logistics service level, and analyzes strategies for adopting blockchain technology to mitigate such moral hazard. By leveraging a blockchain-based logistics service level monitoring system, and considering two scenarios—with and without blockchain technology adoption—we respectively establish Stackelberg game models between the e-commerce platform and the third-party logistics service provider under decentralized decision-making, investigate changes in supply chain profits before and after blockchain technology application and their correlation with technology cost investment, and finally verify the validity of conclusions through numerical analysis. The results demonstrate that when blockchain technology cost investment is controlled within a certain range, application of this technology can effectively reduce moral hazard in third-party logistics service providers, enhance overall supply chain profit while promoting effective improvement in profits for each supply chain node enterprise, thereby contributing to healthy and orderly supply chain development.

### Full Text

### Preamble

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## Research on Prevention of Moral Hazard in Logistics Service Providers Based on Blockchain Under Misreporting Behavior

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**Abstract:** This paper examines a two-level e-commerce supply chain comprising an e-commerce platform and a third-party logistics service provider. Addressing the moral hazard problem arising from the logistics provider's complete control over its service level, we analyze strategies for employing blockchain technology to mitigate such risks. By leveraging a blockchain-based logistics service level monitoring framework, we establish Stackelberg game models between the e-commerce platform and the third-party logistics provider under decentralized decision-making for two scenarios: with and without blockchain adoption. We investigate changes in supply chain profits before and after blockchain implementation and their relationship with technology cost investment, verifying our conclusions through numerical analysis. Results demonstrate that when blockchain technology costs are controlled within a certain range, the technology can effectively reduce moral hazard among third-party logistics providers, enhance overall supply chain profitability, and promote profit improvements at each node, thereby fostering healthy and orderly supply chain development.

**Keywords:** blockchain; logistics service level; moral hazard; Stackelberg game

**Classification:** F204; TP31

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## 0 Introduction

With the deepening development of China's third-party logistics industry, an increasing number of enterprises are outsourcing non-core logistics operations to third-party providers. However, these providers often conceal private information or manipulate behaviors to maximize their own profits, such as exaggerating service levels to the detriment of clients. Due to information asymmetry, principals cannot monitor the logistics process in real time, and delivery contracts cannot specify the effort levels required to maintain service standards. Consequently, third-party logistics providers may opportunistically reduce cost investments, creating moral hazard. While supervision and incentives are essential for governance, the associated costs are prohibitively high, allowing violations that harm principal interests to persist. Thus, innovative methods and technologies are urgently needed to address this issue.

Blockchain technology offers novel possibilities for preventing moral hazard in logistics services. Blockchain's consensus trust mechanisms, decentralized governance, and traceability features can effectively counteract such risks. Through standardized protocols and frameworks, blockchain enables real-time monitoring

and post-hoc tracking of provider activities based on immutable information and traceable records. By transforming traditional centralized systems into multi-center or decentralized architectures, blockchain facilitates power-sharing among different stakeholders, reducing the probability of opportunistic behavior. For instance, Quanliantong Co., Ltd. has proposed collaborative industrial supply chain applications, establishing blockchain-based corporate credit mechanisms centered on contract execution and quality assurance certification, thereby resolving trust issues in multi-party data sharing and enabling transparent supply chain management.

Current research on preventing moral hazard in third-party logistics primarily employs principal-agent theory, with limited focus on information technology applications. Key studies include: Zhu et al. [4] investigating how information asymmetry and moral hazard affect supplier quality prevention and buyer evaluation decisions; Chen [5] constructing incentive models for third-party logistics cooperation when both capability type and effort level are unobservable; Xu [6] extending outsourcing incentive models considering risk preferences and bilateral moral hazard; Xu et al. [7] examining bank incentive and supervision mechanisms for third-party logistics; Wang et al. [8] developing evolutionary game models for moral hazard between fresh e-commerce platforms and logistics providers; Huang et al. [9] proposing delivery-quality-based contracts to incentivize optimal effort; and Jiang et al. [10] designing incentive mechanisms that avoid moral hazard while improving service performance.

Blockchain integration holds significant potential for technological innovation and industrial transformation. Its core technologies—distributed ledgers, asymmetric encryption, consensus mechanisms, and smart contracts—can effectively connect upstream and downstream supply chain information, enabling real-time cargo tracking and ensuring transaction authenticity [11]. Current blockchain integration research includes: Zhang [12] exploring blockchain-based financing solutions to achieve supply chain management goals; Deng et al. [13] analyzing blockchain-factoring business coupling; Fan et al. [14] designing privacy protection systems for grain supply chains; You et al. [15] proposing digital asset transaction models; Minjae et al. [16] applying blockchain to price tracking for transparency; and Schmidt et al. [17] demonstrating how blockchain reduces transaction costs by limiting opportunistic behavior. However, existing moral hazard research focuses primarily on passive incentives, whereas blockchain integration enables proactive prevention, overcoming passive incentive limitations.

In summary, few studies have addressed blockchain-based prevention of third-party logistics moral hazard, despite blockchain's inherent suitability for this purpose. This paper constructs a two-level supply chain model to analyze moral hazard severity without blockchain and examines how technology cost investment and cost-sharing ratios affect optimal decisions with blockchain adoption. Through numerical experiments, we investigate the impacts of moral hazard, blockchain costs, freight cost elasticity, price elasticity, and service level elasticity on pricing, commission prices, freight volume, costs, and profits to determine

the viable cost range for moral hazard prevention and foster a healthy supply chain environment.

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## 1 Architecture of Blockchain-Based Logistics Service Level Monitoring System

We construct a blockchain-based logistics service level monitoring system architecture to establish a new supply chain logistics framework ensuring information transparency and controllable service levels. Beyond supply chain enterprises, this framework incorporates blockchain, smart contracts, and various IoT sensors. Blockchain provides distributed ledgers containing cargo quality and logistics service level information, smart contracts enable privacy protection and automation, while IoT sensors collect real-world data.

The framework is divided into four functional layers. As shown in [Figure 1: see original paper], the bottom layer is the IoT sensor layer. GPS tracks products during logistics, RFID records transaction information (with barcodes serving as cost-effective alternatives when precision requirements are moderate), and various sensors collect temperature, vibration, and humidity data [18,19] to assess delivery compliance. Additionally, interfaces are developed to extract information from diverse enterprise information systems [20].

The blockchain distributed database provides cargo quality and logistics service level data, with all supply chain participants—including e-commerce platforms, logistics providers, and customers—maintaining identical data copies. Asymmetric encryption protects node identities, timestamps ensure transaction sequencing, consensus mechanisms validate information legitimacy, and smart contracts enforce service level controls to enhance efficiency.

The contract layer emphasizes that data sharing alone is insufficient. Data collection across layers facilitates not only sharing but also service level control and supply chain efficiency. Privacy concerns arise in decentralized supply chains where independent decision-making requires confidentiality for competitive advantage. Therefore, digital identities control data access permissions, while smart contracts with real-time service level data enable automated logistics planning and efficient business contract execution, seamlessly transmitting customer demands from logistics providers to e-commerce platforms.

The business layer encompasses various operational activities. As the game principal, the e-commerce platform enables all nodes to control and manage logistics service levels through blockchain support. Based on smart contract recommendations, nodes can make procurement and commissioning decisions to achieve Stackelberg equilibrium.

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## 2.1 Problem Description

Consider a two-level supply chain comprising an e-commerce platform (R) and a third-party logistics service provider (L). The platform sells products to customers at unit price  $p$ , with delivery outsourced to the logistics provider at commission price  $w$  per order under agreed service level requirements. The provider then determines its unit freight cost investment  $c$ , but since service level is private information, the provider may shirk to reduce delivery effort—creating moral hazard.

Let  $\mu$  denote the moral hazard degree ( $0 \leq \mu < 1$ ), and  $\varphi(L(c))$  represent the actual service level under moral hazard, where  $\varphi(L(c)) = (1 - \mu)L(c)$ . The contractually agreed service level is  $L(c)$ . A blockchain-based monitoring framework enables the platform to accurately track logistics processes and verify service level compliance in real time, preventing moral hazard losses. While blockchain prevents moral hazard, it also incurs costs. We ignore upfront fixed investments and consider only the per-monitoring cost  $B_c$ . When both parties adopt blockchain, moral hazard is eliminated ( $\mu = 0$ ), and the provider must accurately upload all transportation parameters to the blockchain system. Blockchain's decentralization and immutability effectively suppress information tampering, significantly reducing moral hazard.

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## 2.2 Model Assumptions

- a) All supply chain nodes prioritize profit maximization, maintain complete rationality, and consider decision impacts comprehensively. The e-commerce platform serves as the Stackelberg leader.
- b) Market demand is influenced by both product price and logistics service level:  $Q = \kappa p^{-x} L(c)^y$  [21], where  $\kappa$  represents baseline market demand,  $x$  is the price elasticity coefficient, and  $y$  is the service level elasticity coefficient. Following Kaya et al. [22], logistics service level affects product demand.
- c) Service level correlates with freight cost investment:  $L(c) = \kappa c^\eta$  [23], where  $\eta$  is the service level elasticity coefficient.
- d) Blockchain costs are shared between the platform and provider. Let  $t$  denote the platform's cost-sharing proportion, with the provider bearing  $(1 - t)$ .

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## 2.3 Notation

Key symbols are defined in . We denote optimal solutions with “\*“, superscripts “N” for no blockchain and “B” for blockchain adoption, and subscripts “R” for

e-commerce platform, “L” for logistics provider, and “SC” for total supply chain.

### 3 Model Construction and Solution

Under decentralized decision-making, both parties independently maximize their own profits, with the logistics provider often engaging in profit-damaging behavior. We analyze two scenarios to identify blockchain adoption conditions for effective moral hazard prevention.

#### 3.1 Optimal Strategy Without Blockchain Technology

In traditional e-commerce supply chains [24-28], despite contractual service level agreements, the logistics provider may shirk by reducing freight costs to  $c$ , creating moral hazard that degrades actual service levels and destabilizes demand. Demand drops to  $Q = \kappa p^{-x}[(1 - \mu)L(c)]^y$ , while the platform, unaware of true delivery conditions, continues preparing inventory based on contracted levels, incurring 积压 losses of  $(Q_0 - Q)c$  where  $Q_0$  is the contracted volume.

The Stackelberg game model with the platform as leader is:

Platform’ s profit:  $\Pi_R(p, w) = (p - w - c)Q$

Provider’ s profit:  $\Pi_L(c) = (w - c)Q$

Using backward induction, we derive the provider’ s optimal freight cost and volume. The second-order condition  $\partial^2 \Pi_L / \partial c^2 < 0$  ensures a unique solution. Setting the first-order condition to zero yields:

$$c^* = \frac{yw}{y + 1}$$

Substituting into the platform’ s profit function and solving the first-order conditions for  $p$  and  $w$  gives optimal prices:

$$p^{N*} = \frac{2\eta + 1}{2\eta - 1} \cdot \frac{c}{x}$$

$$w^{N*} = \frac{2\eta + 1}{2\eta - 1} \cdot \frac{c}{y}$$

The corresponding optimal freight volume and cost are:

$$Q^{N*} = \kappa \left( \frac{2\eta - 1}{2\eta + 1} \right)^{x+y} \frac{c^{y/\eta}}{x^x y^y}$$

$$L(c)^{N^*} = \kappa \left( \frac{yw^{N^*}}{y+1} \right)^\eta$$

Maximum profits become:

$$\Pi_R^{N^*} = \frac{(2\eta+1)^2}{4\eta^2} \cdot \frac{\kappa c^{1-x-y/\eta}}{x^{x-1}y^y}$$

$$\Pi_L^{N^*} = \frac{(2\eta+1)}{2\eta} \cdot \frac{\kappa c^{1-x-y/\eta}}{x^x y^{y-1}}$$

$$\Pi_{SC}^{N^*} = \Pi_R^{N^*} + \Pi_L^{N^*}$$

**Proposition 1:** As the logistics provider's moral hazard degree  $\mu$  increases, the platform's profit  $\Pi_R^{N^*}$ , provider's profit  $\Pi_L^{N^*}$ , and total supply chain profit  $\Pi_{SC}^{N^*}$  all decrease.

*Proof:* The profit functions are explicitly dependent on  $\mu$ . Differentiating  $\Pi_R^{N^*}$  with respect to  $\mu$  yields  $\partial \Pi_R^{N^*} / \partial \mu < 0$ . Similar results hold for  $\Pi_L^{N^*}$  and  $\Pi_{SC}^{N^*}$ , confirming the proposition.

Proposition 1 demonstrates that high moral hazard damages profits across the supply chain. Providers prioritizing short-term gains over long-term development harm not only the principal and total supply chain but also themselves, necessitating technological solutions.

### 3.2 Optimal Strategy With Blockchain Technology

With blockchain-based monitoring, consensus mechanisms enable credit reconstruction and transparent communication. All nodes upload product and service information to the distributed ledger, eliminating intermediaries and enhancing accuracy. Blockchain's immutability and traceability enable effective supervision of service quality.

The Stackelberg game model becomes:

$$\text{Platform: } \max_{p,w} \Pi_R^B(p,w) = (p-w-c-tB_c)Q$$

$$\text{Provider: } \max_c \Pi_L^B(c) = (w-c-(1-t)B_c)Q$$

where  $Q = \kappa p^{-x} L(c)^y$  and  $L(c) = \kappa c^\eta$ .

Following similar solution procedures, we obtain:

**Proposition 2:** As blockchain technology cost  $B_c$  increases, platform profit  $\Pi_R^{B^*}$ , provider profit  $\Pi_L^{B^*}$ , and total profit  $\Pi_{SC}^{B^*}$  continuously decrease.

*Proof:* Differentiating the optimal profit functions with respect to  $B_c$  yields  $\partial \Pi_R^{B^*} / \partial B_c < 0$ ,  $\partial \Pi_L^{B^*} / \partial B_c < 0$ , and  $\partial \Pi_{SC}^{B^*} / \partial B_c < 0$ , establishing the result.

Proposition 2 indicates that blockchain costs reduce supply chain profits. However, the key consideration is whether these costs offset losses from traditional supply chain inefficiencies.

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## 4 Comparative Analysis

Blockchain cost investment critically influences adoption decisions. Rational cost investment should reduce moral hazard while creating additional value.

**Proposition 3:** When  $0 < B_c < \hat{B}_c$ , supply chain parties will adopt blockchain technology; when  $B_c > \hat{B}_c$ , they will not, where  $\hat{B}_c = \frac{(2\eta+1)^2}{4\eta^2} \cdot \frac{\mu}{(1-\mu)(x+y)}$ .

*Proof:* Adoption requires  $\Pi_{SC}^{B^*} > \Pi_{SC}^{N^*}$ . Substituting the profit expressions and simplifying yields the condition  $B_c < \hat{B}_c$ .

Proposition 3 establishes the cost constraint for blockchain adoption that both prevents moral hazard and increases total profits. Within this range, all node profits increase, motivating proactive adoption.

**Proposition 4:** When  $B_c > \frac{(1-\mu)w^{N^*}}{\mu}$ , the platform increases its selling price; otherwise, it decreases price, where the threshold is  $p^{B^*} > p^{N^*}$  if and only if  $B_c > \frac{(1-\mu)p^{N^*}}{\mu}$ .

*Proof:* Comparing prices with and without blockchain adoption yields the condition.

Proposition 4 shows that post-adoption selling prices rise with blockchain costs, as platforms seek to maintain margins through higher prices.

**Proposition 5:** When  $B_c > \frac{(1-\mu)w^{N^*}}{2\mu}$ , the platform increases the commission price to the provider; otherwise, it decreases the commission price.

*Proof:* Comparing commission prices  $w^{B^*}$  and  $w^{N^*}$  establishes the threshold.

Proposition 5 indicates that blockchain enables platforms to adjust commission prices upward to incentivize provider effort, leveraging enhanced monitoring capabilities.

**Proposition 6:** The provider's freight cost investment increases with blockchain cost when  $B_c > \frac{(1-\mu)c^{N^*}}{2\mu}$ ; otherwise, it decreases.

*Proof:* Comparing  $c^{B^*}$  and  $c^{N^*}$  yields the condition.

Proposition 6 shows that increased transparency compels providers to optimize service levels rather than compress costs, fostering stable cooperation.

**Proposition 7:** Freight volume increases with blockchain adoption when  $B_c < \frac{(1-\mu)Q^{N^*}}{2\mu}$ ; otherwise, volume decreases.

*Proof:* The volume increase condition  $Q^{B^*} > Q^{N^*}$  simplifies to the stated inequality.

Proposition 7 reveals the relationship between freight volume and blockchain costs, showing that controlled cost ranges boost volume while excessive costs reduce it.

## 5 Numerical Analysis

We validate theoretical findings using operational data from an e-commerce platform: baseline demand  $\kappa = 10,000$  units, unit cost  $c = 4$ , cost-sharing proportion  $t = 0.5$ , moral hazard  $\mu = 0.4$ , freight cost elasticity  $\eta = 2$ , price elasticity  $x = 0.5$ , service level elasticity  $y = 2$ , and blockchain cost  $B_c \in (0, 1]$ .

### 5.1 Impact of Blockchain Cost on Optimal Decisions

summarizes the effects of increasing blockchain costs on key decisions. Results show that selling prices, commission prices, and freight costs rise with  $B_c$ , while freight volume and all profits decline. This indicates divergent strategies: platforms raise prices to offset expenditures and use enhanced monitoring to adjust commission incentives, while providers abandon cost-cutting strategies in favor of service improvements to secure more freight volume.

**Figure 2** [Figure 2: see original paper] illustrates profit changes before and after blockchain adoption. Initial adoption boosts all profits compared to traditional models, but profits decline as costs increase. Effective moral hazard prevention and profit enhancement require  $B_c < 0.6$ , demonstrating that blockchain benefits are cost-dependent.

**Figure 3** [Figure 3: see original paper] shows commission price changes. Beyond a certain cost threshold, blockchain-enabled commission prices exceed traditional levels, reflecting the platform's ability to leverage traceability for active incentive management.

**Figure 4** [Figure 4: see original paper] depicts freight volume changes under different moral hazard levels ( $\mu = 0.4, 0.6$ ). With low moral hazard, blockchain adoption consistently increases volume. With high moral hazard, volume improvements require strict cost control, indicating that technology alone cannot offset severe opportunism.

### 5.2 Impact of $\mu$ , $t$ , $x$ , and $y$ on Optimal Decisions

**Figure 5** [Figure 5: see original paper] shows that without blockchain, all profits decrease as moral hazard increases, confirming that opportunistic behavior

undermines long-term supply chain development.

**Figure 6** [Figure 6: see original paper] reveals that at low cost-sharing proportions  $t$ , blockchain adoption leads to higher commission prices. As  $t$  increases, commission prices drop below traditional levels, highlighting the importance of balanced cost allocation for motivating adoption.

**Figure 7** [Figure 7: see original paper] demonstrates that profits decline with price elasticity  $x$ , indicating that excessive pricing harms profitability even with blockchain-enabled transparency.

**Figure 8** [Figure 8: see original paper] shows that provider profits increase with service level elasticity  $y$ , while platform and total profits first decrease then increase, confirming that high-quality logistics services benefit providers and that platform profits are sensitive to service quality.

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## 6 Conclusion

Moral hazard universally damages principal interests and threatens supply chain health. Blockchain's distributed ledger, consensus mechanism, timestamping, asymmetric encryption, and smart contracts offer significant potential for preventing third-party logistics moral hazard. Our Stackelberg game models reveal that: (a) without blockchain, all profits decrease with moral hazard severity; (b) when  $\mu = 0.4$  and  $B_c \in (0, 0.6)$ , blockchain adoption effectively prevents moral hazard while enhancing supply chain profits.

Future research should examine scenarios where the logistics provider leads the Stackelberg game or multiple providers compete, expanding blockchain application strategies.

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